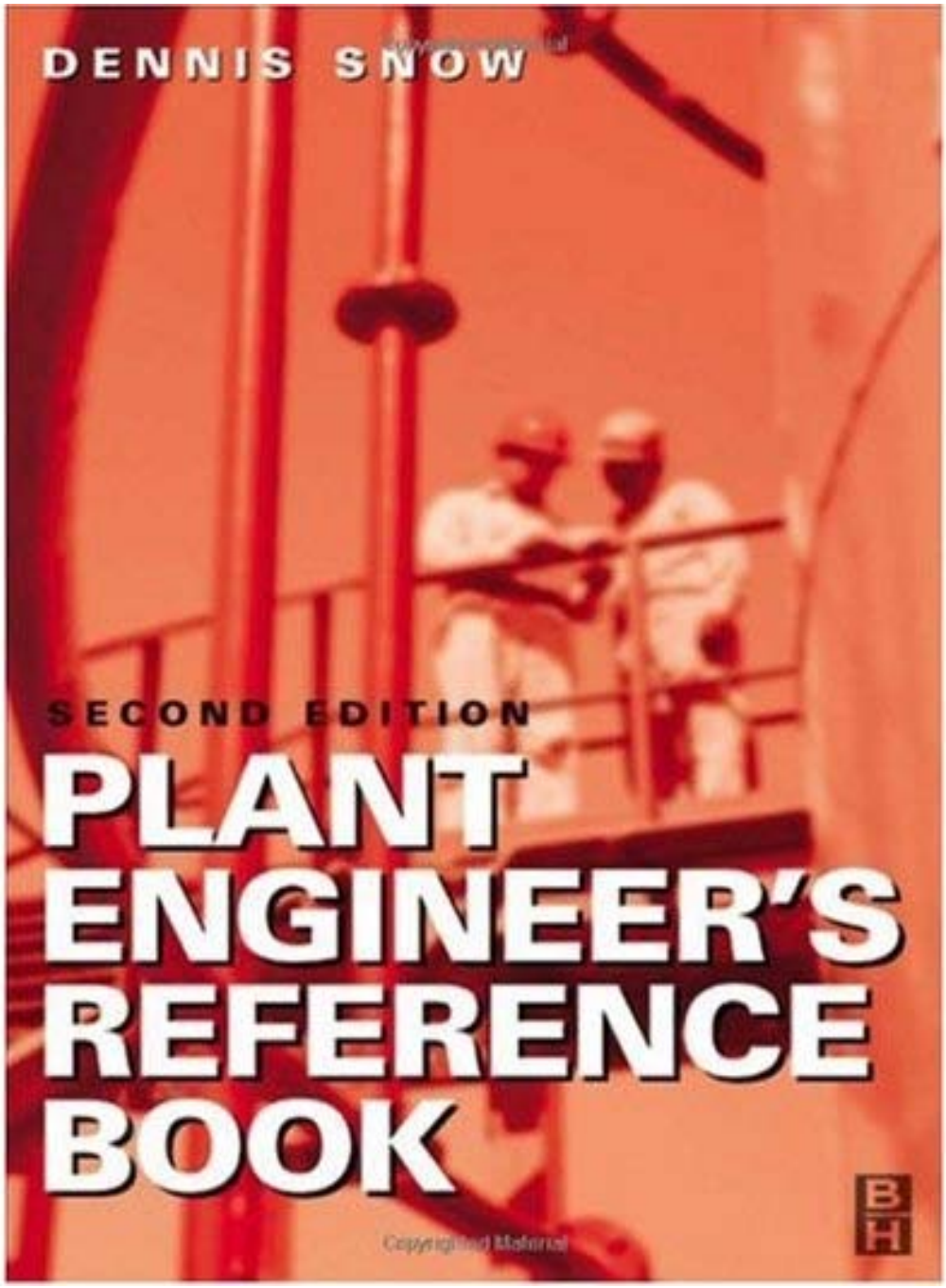

DENNIS SNOW
SECOND EDITION
PLANT ENGINEER'S REFERENCE BOOK
BH

Plant Engineer's Reference Book

Second edition

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PLANT A TREE

FOR EVERY TITLE THAT WE PUBLISH, BUTTERWORTH-HEINEMANN WILL PAY FOR BTCV TO PLANT AND CARE FOR A TREE.

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Forewords

A quick glance at the contents of this reference book, immediately gives the reader an idea as to how much thought has been put into the structuring of this publication.

This work has been brought together by a very widely experienced engineer who has 'been there' and experienced so many of the problems and difficulties that a plant or operations engineer is likely to encounter during his day to day activities.

This thought process has been directed meticulously through to all the contributors, and is detectable in the structure of each chapter.

Although based on the setting up of a new static installation, the thought processes are similar and applicable to the efficient running, profitability and care of both mobile and existing installations.

This book follows a successful decade of the first edition, and has, where possible, incorporated the many ongoing updates, brought about by the changing times that we are now living in, and having to comply with.

This book has been a large part of Dennis' life over the last few years. His efforts will enable future generations of Plant and Operations Engineers to benefit from his own wealth of experience and that of his many contributing colleagues. Well done Dennis, you have given us all a valuable legacy!

Eur Ing Mark Hansford BSc(Eng), CEng, HonFSOE, HonFIPlantE
President Emeritus: Society of Operations Engineers
Past President: Institution of Plant Engineers

Recently the formation of the Society of Operations Engineers, which incorporates the Institution of Plant Engineers as one of the founder Professional Sectors, is an indication of how the industrial roles of the engineering professions are changing.

The plant engineering profession, in itself, has not changed, nor has the responsibilities or importance: but what has changed is the management terminology. You will now find terms like asset management, facilities management and others coming to the fore, and these find a focus in the generic description of 'Operations Engineering.' It is this description which is now attributed to those with responsibility for many and varied areas of engineering and is included in the title of our new body.

It is encouraging to see that the editor, and his very experienced colleagues, have continued the theme of the first edition, in guiding the engineer through the labour pains of bringing the eventual goal, a total project, to fruition. Obviously, changes have taken place since the first edition, with tracks of legislation and many new 'Codes of Practice' introduced, through the European Community, which have been dealt with as appropriate.

Dennis Snow has been involved in many successful industrial operations on both sides of the Atlantic. It is with this experience, coupled to his personal knowledge of so many of the authors who have helped him to put this reference book together, that should make the second edition even more successful than the first.

David Cox JP
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First President: Society of Operations Engineers

Preface to the second edition

As with the first edition of this reference book, it would not have been possible, without the total co-operation of so many experienced individual authors and their colleagues, coupled with the backing of many well-known companies. What a wealth of professional knowledge and expertise. An acknowledgement such as this can only scratch the surface and cannot convey my very grateful thanks that are due to those people who have spent many hours of their valuable time putting together so many pages of knowledge, for the benefit of others. Those who will be seeking assistance in tackling their day-to-day problems and seeking advice, and in particular the budding plant engineering students starting out on a multidisciplinary career, will be extremely grateful.

Over the years I have put together many processing plants and it was this in mind that I have structured this book. I was very fortunate to have been in at the beginning of so many projects, from the basic decision stage, the budgeting, planning, design, specification, tendering, installation, commissioning to the eventual efficient running and the maintenance.

Plant engineering is such a broad subject incorporating a multitude of disciplines, many problems, and a wide variety of solutions to many situations, unlike some disciplines that have clear cut methods. I have spent many hours trying to obtain information to assist me in my work and hence the theory behind the structuring of this reference book.

As a long standing active member of the Institution of Plant Engineers, I have been to many local branch meetings, attended conferences and had the opportunity of discussing problems and new techniques with colleagues. In turn I hope that I have been able to be of assistance to them with their problems.

Plant engineering sees no boundary and has brought together many engineers from competitive companies, all of who are interested in safety and the development of new techniques leading to improving efficiency and the working environment.

I would therefore like to take this opportunity to thank those members of the Institution for their patience and assistance in helping me to structure this publication, many who have contributed.

My wife Betty suffered considerably whilst the first edition was being put together and did not deserve to have a second edition thrust upon her. She has been more than tolerant again, for which she deserves more than my thanks and appreciation.

Dennis A Snow

Preface to the first edition

The preparation of a reference book such as this could not possibly be acheived without the total cooperation of so many individual authors and the backing of their various employers, especially where company contributions have been made, bringing together a wealth of professional knowledge and experience.

An acknowledgement such as this can only scratch the surface and cannot really portray the grateful thanks I wish to acknowledge to all these people and concerns who have devoted so much time and effort to place their ideas and contributions on paper.

Plant Engineering is such a broad subject incorporating a multitude of disciplines and a wide variety of solutions to virtually every problem or situation, unlike some subjects that have clear cut methods.

In compiling the initial suggested guidelines for each of the contributions, I posed the questions to myself for what information and assistance had I found difficult to locate during over 30 years in industry as a Plant Engineer responsible for plant in the UK and abroad and how could it be best presented to assist others in their profession.

As an active member of the Institution of Plant Engineers for many years I have been able to seek the knowledge of my colleagues when problems have occurred and I hope that I have been able to help them on occasions.

I would therefore like to take this opportunity to thank those members of the Institution for their patience and assistance in helping me to structure this publication, and in particular, members of the Publication Committee, together with the following companies:

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I would also like to include my wife Betty, who has been extremely tolerant whilst I have spent many hours word processing.

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1 Physical considerations in site selection

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1.1 Environmental considerations of valley or hillside sites

1.1.1 The effect of topography on prevailing winds and strengths

Apart from the obvious influence of topography in producing shelter or the enhanced exposure to wind (discussed later), the influence of large topographic features can be sufficient to generate small-scale weather systems which are capable of producing significant winds. Three types of wind are associated with topography:

Diurnal winds
Gravity winds
Lee waves

1.1.1.1 Diurnal winds

Under clear skies in daytime the slopes of hills and mountains facing the sun will receive greater solar heating than the flat ground in valley bottoms. Convection then causes an upslope flow, called anabatic wind, which is generally light and variable but which can often initiate thunderstorms. At night, the upper slopes lose heat by radiation faster than the lower slopes and the reverse effect happens, producing downslope katabatic winds. However, the denser cold air falling into the warmer valley can produce strong winds in a layer near the ground. The higher the mountains, the stronger is the effect. As the mountains in the UK are not very high, it is not surprising that the speeds of katabatic winds do not approach those of large depressions.

1.1.1.2 Gravity winds

The effect of katabatic winds can be much enhanced if greater differences in air temperature can be obtained from external sources. A continuous range of mountains can act as a barrier to the passage of a dense mass of cold air as it attempts to displace a warmer air mass. Cold air accumulates behind the mountain range until it is able to pour over the top, accelerating under gravity to give strong winds down the lee slope. The mountains of the UK are not high enough to produce gravity winds of speeds sufficient to damage buildings.

1.1.1.3 Lee waves

Under certain conditions of atmospheric stability, standing waves may form in the lee of mountains. This wave motion is an oscillating exchange of kinetic and potential energy, excited by normal winds flowing over the mountain range, which produces alternately accelerated and retarded flow near the ground. Sustained lee waves at the maximum amplitude are obtained when the shape of the mountain matches their wavelength, or when a second range occurs at one wavelength downstream. The existence of lee waves is often indicated by clouds which are unusual in that they remain stationary with respect to the ground instead of moving with the wind. These clouds are continuously forming at their upwind edge as the air rises above the condensation level in the wave and dissipating at the downward edge as the air falls again.

Conditions are frequently suitable for the formation of lee waves over the UK, an effect that is routinely exploited by glider pilots to obtain exceptionally high altitudes. The combination of lee waves with strong wind, sufficient to produce damage to structures in the bands of accelerated flow, is fortunately rare, but an analysis of the Sheffield gale of 16 February 1962 by the UK Meteorological Office showed that this was a case where strong winds were further enhanced by lee waves.

1.1.1.4 Other factors

Other factors to account for topography with regard to valley or hillside sites should include possible inversion and failure to disperse pollutants. Temperature inversion occurs when the temperature at a certain layer of the atmosphere stays constant, or even increases with height, as opposed to decreasing with height, which is the norm for the lower atmosphere. Inversions may occur on still, clear nights when the earth and adjacent air cool more rapidly than the free atmosphere, or when throughout a layer high turbulence causes rapid vertical convection so that the top of the turbulent layer may be cooler than the next layer above it at the interface.

The running of a cool air flow under a warm wind is another cause of temperature inversion. As a rule, the presence of an inversion implies a highly stable atmosphere: one in which vertical air movements are rapidly damped out. In such a situation, fog and airborne pollutants collect, being unable to move freely or be dissipated by convection.

Additional dispersal problems may occur when the prevailing wind occurs perpendicular (or nearly so) to the valley or hill ridge line. This may lead to speed up and turbulence over the valley or it may simply reduce the effect of airflow carrying away airborne pollutants.

It is possible to obtain wind data for almost any location in the world, although these frequently require modification and interpretation before they can be used. Addresses of advisory offices for the UK are listed below.

1.1.1.5 Advisory offices of the Meteorological Office

For England and Wales:
Meteorological Office
London Road
Bracknell
Berkshire RG12 2SZ

For Scotland:
Meteorological Office
231 Corstorphine Road
Edinburgh EH12 7BB

For Northern Ireland:
Meteorological Office
Progressive House

1 College Square East
Belfast BT1 6BQ

1.1.1.6 Advisory service of the Building Research Establishment

The Advisory Service
Building Research Station
Bucknalls Lane
Garston
Watford WD2 7JR

1.1.2 Design for wind

A structure may be designed to comply with any of the following information:

1. No specific details available.
2. Specified basic wind speed and relevant site data.
3. Specified design wind speed, with or without FOS.
4. Specified survival wind speed, with or without FOS.

When details are given they should be checked, if only by comparison with equivalent wind speeds derived from first principles, to ensure that they are reasonable.

Depending on the specified requirements the wind speeds may or may not utilize gust wind speeds as in CP3 (3) or mean hourly wind speeds, v, with applied gust factors.

1.1.3 The factored basic wind speed approach

The current British Standard Code of Practice (CP3: Chapter V: Part 2: 1972) uses a basic gust wind speed, V, multiplied by a series of S factors which adjust the basic values to design values for the particular situation. CP3 uses up to four S factors:

S_1: Topography factors
S_2: Ground roughness, building size and height above ground factors
S_3: Statistical factor
S_4: Directional factor

1.1.3.1 S_1 – Topography factors

The effect of local topography is to accelerate the wind near summits or crests of hills, escarpments or ridges and decelerate it in valleys or near the foot of steep escarpments or ridges. The extent of this effect on gust wind speeds is generally confined to the region 1.0–1.36. Local topography is considered significant when the gradient of the upwind slope is greater than 5 per cent.

The shape of the upwind slope affects the degree of shelter expected near the foot of the slope when the slope is shallow and the flow remains attached. When the changes in slope are sudden, so that upwind slope can be approximated by a single straight line for more than two-thirds of its length, then the shape is 'sharp'. Otherwise the changes of slope are gradual and the shape is 'smooth'. This distribution is relevant for sites close to the foot of the upwind slope, where 'sharp' topography offers a greater degree of shelter.

1.1.3.2 S_2 – Ground roughness, building size and height above ground factors

The factor S_2 takes account of the combined effect of ground roughness, the variation of wind speed with height above ground and the size of the building or component part under consideration. In conditions of strong wind the wind speed usually increases with height above ground. The rate of increase depends on ground roughness and also on whether short gusts or mean wind speeds are being considered. This is related to building size to take account of the fact that small buildings and elements of a building are more affected by short gusts than are larger buildings, for which a longer and averaging period is more appropriate.

1.1.3.3 S_3 – Statistical factor

Factor S_3 is based on statistical concepts and can be varied from 1.0 to account for structures whose probable lives are shorter (or longer) than is reasonable for the application of a 50-year return-period wind.

1.1.3.4 S_4 – Directional factor

In the latitudes occupied by the UK (50–60°N) the climate is dominated by westerly winds and a band of low pressure between Scotland and Iceland. The basic wind speed may be adjusted to ensure that the risk of it being exceeded is the same for all directions. This is achieved by the wind speed factor S_4.

When applying S_4, topography factor S_1 and the terrain roughness, building size and height above ground factor S_2 should be appropriately assessed for that direction.

1.2 Road, rail, sea and air access to industrial sites

1.2.1 Introduction

Many industrial processes and factories require specific accessibility for one particular form of transport. Examples of the above include distribution warehousing, transport operations (particularly intermodal such as through seaports) and those industries dealing with bulk commodities (e.g. oil refineries). For other industries access to strategic modal networks is important in order to be competitive where cost of transport and time savings are a significant factor. Examples of these operations include air freighting and fresh-food deliveries. A third category would include those establishments which would require high-visibility sites to enhance their reputation in the marketplace.

1.2.2 Design considerations

It is difficult to give specific advice on this subject as there is a very large range of industrial undertakings. The awareness for, and acceptability of, access is dependent

on the types of goods to be moved and the frequency and method of movement. In some undertakings there is a major movement between different transport modes which is concentrated either at ports or at major road/rail interchanges.

In addition to the amount of commercial traffic it is vital to consider the movement associated with employees and visitors, which themselves can generate large numbers of vehicular and pedestrian movements. For very large manufacturing sites there will also be the need for accessibility for public transport, which, for a large workforce, may need to be supplemented by investment in subsidized travel.

Site access will reflect the nature of the existing local transport system and will need to be designed to cater for the anticipated future traffic flows associated with on-site development. At the extreme of the range this could include a significant on-site infrastructure, potentially involving small bus stations for staff or private rail sidings for goods heavily committed to using the rail network. Special consideration might also need to be given to customs facilities, where operations include cross-border movements with or without bonding operations.

1.2.3 Forms of site access

Access to the road network can range from a simple factory gate or location on a business park to a major industrial complex requiring its own major grade separated interchange due to the high traffic volumes on the strategic road network. New site developments will need to cater for future traffic growth and must be adequate to deal with a design life over the foreseeable future.

Access to the rail system must be negotiated with British Rail and may involve the use of a Section 8 Grant, where it can be demonstrated that the use of the rail network minimizes lorry traffic on the road system. It will be necessary to incorporate security arrangements to prevent trespass on the rail line and some form of signalling arrangement will be necessary for the junction and sidings. Major complexes may run their own railway network, including a private shunting engine.

Access to a seaport will be limited by the ability of total traffic generated by the docks and the incorporation of these traffic movements into the local road system.

Air traffic access may be constrained by the operational aspects of the airport. Otherwise, the road-related traffic will be dealt with in a manner similar to that of seaports, except that the vehicles are likely to be smaller in size and of lower traffic volumes, reflecting the higher-value goods being transported by air.

1.2.4 Providing access to the road system

Before access is obtained to any road it is necessary to obtain the consent of the relevant highway authority. In England the Department of Transport is the highway authority for all motorways and trunk roads. Direct access to motorways is generally prohibited and the policy regarding access to trunk roads is to minimize the number of accesses and to encourage the free flow of traffic on the major road. Therefore careful consideration needs to be given to the ability of the proposed access to cover traffic capacity and road safety adequately.

The local county council is the highway authority, in non-metropolitan areas, for all other roads, although, in many instances the local authority (generally, city or district) may have agency powers for the roads within its area.

It will be necessary to forecast the amount of traffic to be generated by the development within the site and to propose a form of junction which not only deals with the site's traffic but also adequately caters for the existing traffic on the road. Tests for capacity are required and attention should also be given to the safety of operation of the proposed access.

Various types of junctions are available and include simple priority T-junctions, traffic signals and roundabouts. In proposing any junction improvements or new junction it is necessary to be aware of land ownership in order to ensure that all improvement works can be carried out within highway land or land within the proposed development site.

As part of the planning approvals it is increasingly common to provide road-improvement schemes which are sometimes off-site and are necessary to deal with site-generated traffic, which has detrimental effects on the local road network. These off-site improvement schemes can be obtained within legal agreements referred to as Section 106 Agreements. These are undertaken with the local planning authority or with Section 278 Agreements, undertaken directly with the highway authority. Generally, these Agreements require the applicant of the proposed site to carry out specified highway improvement schemes to an agreed timetable relevant to the planning application.

In the above examples the location of the site adjacent to a strategic route network is an important consideration.

1.2.5 Selection of sites

Suitable sites are normally limited to those areas designed in Development Plans as being for industrial or commercial uses. Such land should be capable of being accessed directly from the primary or secondary distributor roads in the area. Segregation of lorries and lorry access from residential areas should be achieved where possible.

The utilization of existing or the provision of new rail heads will also be a determining factor for some operators, and frequently the rail sidings do not have good road access. In these cases extensive improvement measures may be necessary to provide adequate space and geometrical requirements.

1.2.6 Checklist

The following list, while not exhaustive, identifies many of the issues which will need careful consideration. In many instances it might be necessary to seek the advice of a specialist traffic consultant, either in the design of a scheme or in access, or to negotiate with the highway authority the impact of a proposed development and any attendant road-improvement schemes.

1. *Types of operation to be carried out*
   - Number of lorries
   - Staff cars
   - Visitors' cars
   - Rail/water/air access
   - Public transport provision
   - Cyclists
   - Pedestrians

2. *Types of site*
   - Large single site
   - Industrial estate
   - Segregation of access for lorries and cars
   - Capacity of access and need for improvement
   - Ensure no queueing back onto highway
   - Ensure sufficient on-site space for all vehicles to enter highway in forward gear
   - Ensure off-highway loading/unloading
   - Access for emergency vehicles

3. *Access arrangements*
   - Junction types – priority
     – roundabout
     – signals
   - Access width should be a minimum of 6.1 m to allow lorries to pass each other (7.3 m ideal)
   - Single access could cope with up to 250 lorry movements per day
   - Any gate or security barrier to be set in at least 20 m from public highway to avoid blockage or interference to pedestrians
   - Minimum centre line radius to be 12 m
   - Minimum entire live radius to access road to be 60 m. Widening on bends may be required

4. *Manoeuvring space*
   - Turning circle for articulated vehicles to be 26 m diameter minimum
   - For draw-bar vehicles this can be reduced to 21 m
   - Turning head for rigid lorries only needs to be 35 m long
   - Turning head for articulated vehicles should be 53 m long. Kerb radii need to be 9 m
   - Loading bays at 90° to road should be 31 m deep including the road width. Bay should be 3.5 m wide
   - Strong site management is required to ensure manoeuvring space is kept clear of storage/goods/debris at all times
   - Headroom clearance should be a minimum of 4.65 m with careful consideration to ensure all pipework, etc. is above that level. Approach gradients to flat areas will reduce the effective height.

It is emphasized that the above checklist is not exhaustive. Any reductions in the standards identified above will lead to difficulty of operation, tyre scrub, potential damage to vehicles and buildings, and general inefficiency. Cost effectiveness could also be hindered due to loss of time caused by blocked-in vehicles. Safety is also a highly important factor which should be prominent in any decision making.

1.3 Discharge of effluent and general site drainage

1.3.1 Effluent

1.3.1.1 Introduction

The control of drainage and sewerage systems and of sewage disposal is governed entirely by Parliamentary Acts and statutory regulation. The Building Regulations 1985 and Public Health Acts 1936 and 1961 cover sewerage, sewage disposal, drainage and sanitation for buildings and other public health matters. The Public Health Act 1937 (Drainage of Trade Premises) and the Control of Pollution Act 1974 deals, among other things, with the disposal of trade and industrial effluent.

1.3.1.2 Methods of treatment

Two methods of treatment can be considered:

1. On-site treatment and disposal; and
2. Off-site treatment and disposal.

Where on-site treatment is to be undertaken consideration should be given to the following:

1. Where large volumes of effluents are produced and/or different types of contaminants, large equipment areas may be required. Sufficient space must also be allowed for maintenance and inspection of such equipment.
2. Settlement/storage areas for effluent need to be sized not just for average flow but also for peak periods. Where production is based on a shift system, peak flows created during holiday periods (shutdown, major maintenance, etc.) should be considered.
3. Where effluents require primary, secondary and possibly additional tertiary treatment, attention should be paid to the various treatment processes with regard to personnel safety and public sensitivity to on-site treatment.
4. Where concentrated alkali and/or acids are stored and used on-site as part of the treatment process, care should be exercised to prevent misuse, fire, and security and health hazards. The provision of emergency showers, eye-wash stations, etc. needs careful consideration.
5. If equipment malfunctions during the treatment process, adequate precautions should be taken to prevent the discharge of untreated effluent. Such precautions should be the provision of emergency collection tasks or the use of approved, licensed, effluent-disposal traders.
6. Where accidental discharge of untreated effluent does occur the water authority and/or environmental health officer should be advised immediately. All steps should be taken to limit the extent and intensity of any potential contamination.
7. Where small and/or single contaminant effluents are encountered, packaged treatment plants may be acceptable. Consideration should, however, be given

to capital cost, payback period, reliability of equipment, maintenance, plant-life expectancy and contaminant-removal efficiencies.
8. Pipework material for conveying effluent to treatment plants should exhibit resilience to corrosive attack by the effluent as well as scouring and erosion created by the material content of the effluent.
9. Consideration should be given to plant operation in a shift system and any requirements for an analyst to be present during operational/non-operational periods.
10. Precautions must be taken against freezing for external pipework, tanks, meters, gauges, and monitoring equipment.
11. Assessments should be made for electrically operated process equipment which may require an essential power supply in the event of a mains failure.
12. The quality of the effluent discharge must be regularly checked. Depending on the quantity and type of discharge, this may require an in-house laboratory and analysis room.
13. The quantity of final treated effluent may be limited by the water authority, and monitoring of the final outfall may have to be considered in conjunction with a holding tank.
14. Large or small on-site treatment plants will create sludge concentrates which require disposal. Where large quantities of sludge occur, on-site de-watering filters may be considered with dry sludge cakes properly removed from site by licensed contractors. Alternatively, small quantities of wet sludge concentrates may be removed and disposed of by similar contractors.

Where off-site treatment is undertaken the following should be considered:

1. Cost comparison with on-site treatment.
2. Availability of approved, licensed contractors to handle the type of effluents being considered.
3. Reliability of licensed contractors during emergency, weekend and holiday periods.
4. Space requirements for holding untreated effluent prior to removal from site.
5. Accessibility, safety and security associated with the holding vessels by the vehicles of the licensed contractors.
6. Suitable pumps may be required to pump from holding tanks into licensed contractor vehicles.

1.3.2 Site drainage

The discharge of surface water from a site may originate from three potential sources:

Rainwater from building(s)
Surface-water runoff from paved/hard standing areas
Subsoil drainage (groundwater)

1. The rainwater runoff from buildings is dependent on the geographical location and storm-return period specified. (Reference should be made to BS 6367.) Rainwater runoff from a roof is relatively clean and can discharge directly to a watercourse, lake, etc. without passing through an interceptor.
2. The surface water runoff from paved/hard standing areas is also dependent on rainfall intensity calculated from the geographical locations of the site and storm-return period. However, the return period for a site will be far higher than for a building in order to ensure prevention of persistent flooding of the site. In many instances the local authority may specify the storm-return period as the design criterion. The water authority and/or National Rivers Authority will determine the maximum quantity of surface water that may discharge to a watercourse or river. Where development of a greenfield site or an extension to an existing building takes place, the rate of stormwater runoff may necessitate the provision of a balancing pond or reservoir.

   While the drainage design may be able to cater for minimal surcharging, any substantial rise in floodwater can be contained by the balancing pond and minimize flooding to the site and damage to plant ecology. Lining of a balance pond must be considered to prevent water seepage. Suitable linings are clay or butyl rubber sheeting.

   Where potential flooding to the site is minimal an alternative to the balance pond could be an open-trench system which could provide on-site storage and added security to watercourses.

   The open-trench system provides easy maintenance and may obviate the need for highway kerbs and gulleys, but requires adequate security to prevent vehicle collision.

   Surface water from hard standing areas subject to petrol and oil contamination (e.g. car parks) must pass through an interceptor prior to discharge to a watercourse, surface-water drain, etc. The sizing of petrol/oil interceptors varies between local authorities/District Council areas. Many agree that the first 5 minutes of surface-water runoff is the most contaminated, and accept a reduced interceptor size, while allowing a higher flow rate, caused by increased storm intensity, to bypass the interceptor chamber (see Figures 1.1 and 1.2).
3. Subsoil drainage may be required for the following reasons:
   (a) Seasonal fluctuations in water-table level may cause isolated flooding. Subsoil drainage may be considered to keep the water-table level relatively constant.
   (b) Where underground springs occur, laying of subsoil drainage may be considered to maintain water-level equilibrium within the subsoil to permit building construction or similar activities.
   (c) Draining of permanently flood land such as marsh or bogland.

1.3.2.1 Gravity or pumped discharge

Wherever practical, surface-water runoff should be designed for gravity discharge, preferably located at the lowest part of the site. However, where a gravity system is

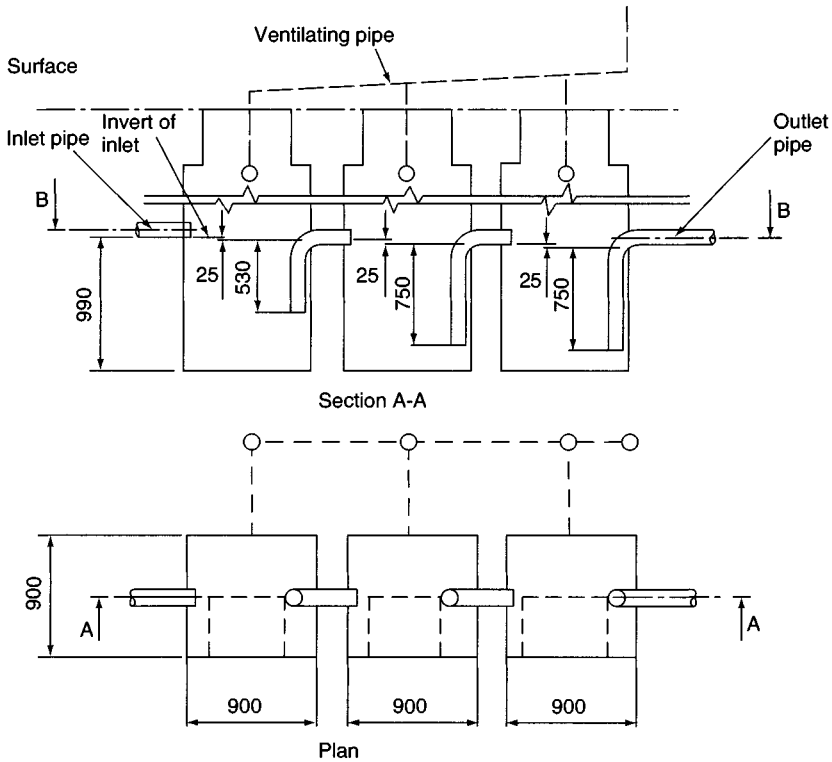


Figure 1.1 A traditional three-chamber petrol interceptor. (Dimensions are in millimetres.) All pipes within the chambers through which liquid passes should be of iron or another equally robust petrol-resistant material

impractical or impossible a pumped discharge must be considered.

When sizing a pumped discharge the following should be evaluated:

1. Pumps, valve controls, etc. to be in duplicate;
2. Maximum discharge permitted into watercourse by water authority;
3. Discharge duty to be twice dry weather flow subject to (2) above;
4. Will essential power supply be required to both pumps?
5. Space requirements for pumps, including installation, maintenance and inspection.

Figures 1.3–1.7 show edge and bank details for storm-retention reservoirs and Figure 1.8 and Table. 1.1 relate rainfall intensity, duration and return period.

1.4 Natural water supplies, water authority supplies and the appropriate negotiating methods and contracts

There are three major sources of water supply:

Borehole
Rivers
Service reservoir

The majority of water supplies are provided from a combination of all three.

A wide variety of Acts of Parliament govern the supply of water to domestic and industrial premises. Within these Acts the statutory undertakings for preventing waste, undue consumption, misuse and contamination of water supplied by the various authorities.

Having established the respective local regional water authority and water company, the following is a list of information that the water authority will require to assess a consumer's needs:

1. Project name
2. Site address
3. Building size (m^2)
4. Number of occupants and anticipated multiple use/tenancy
5. Building usage
6. Point of supply connection - height above ground
7. Anticipated flow rated for the following uses:
   (a) Domestic
   (b) Industrial
   (c) Fire
   (*Note*: Flow rates should include average and maximum demands and the periods throughout the year during which supplies are required.)
8. Cold water storage volume
   (a) Domestic
   (b) Industrial
   (c) Fire

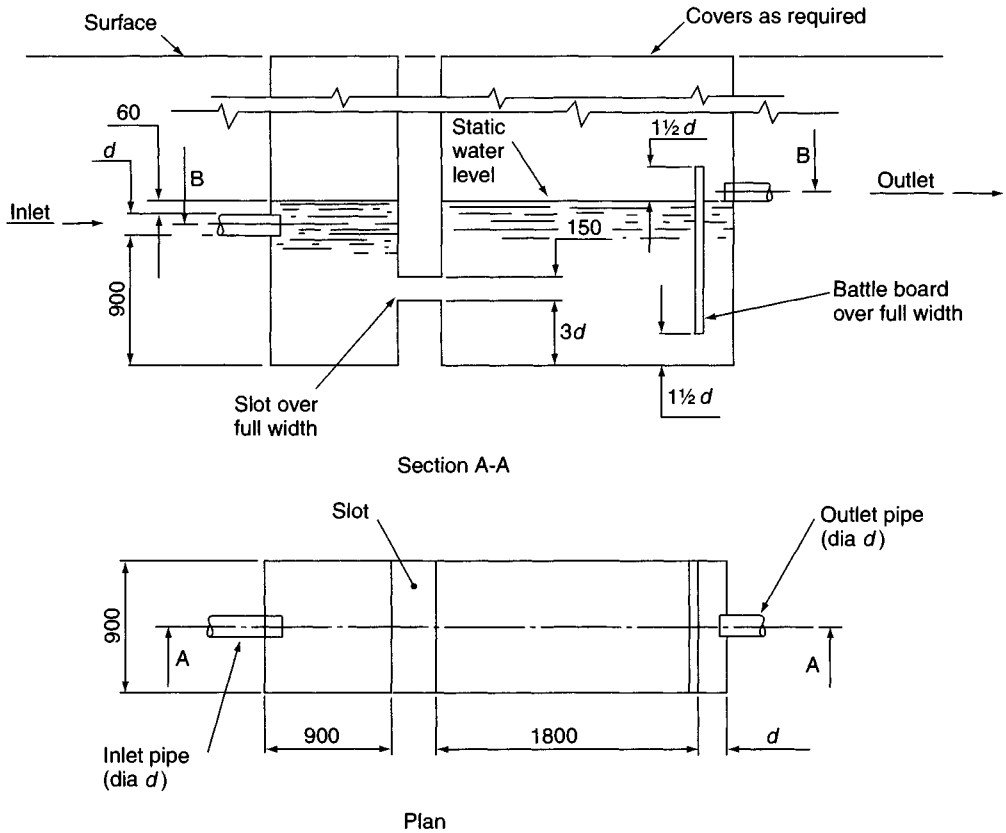


Figure 1.2 An alternative two-chamber petrol interceptor. (Ventilation not shown: dimensions are in millimetres)

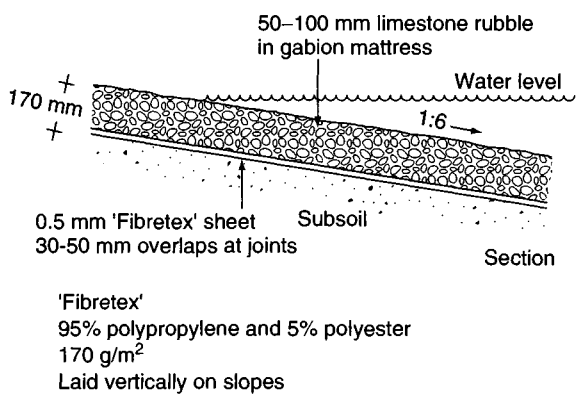


Figure 1.3 Rip-rap bank ('Fibretex'/stone)

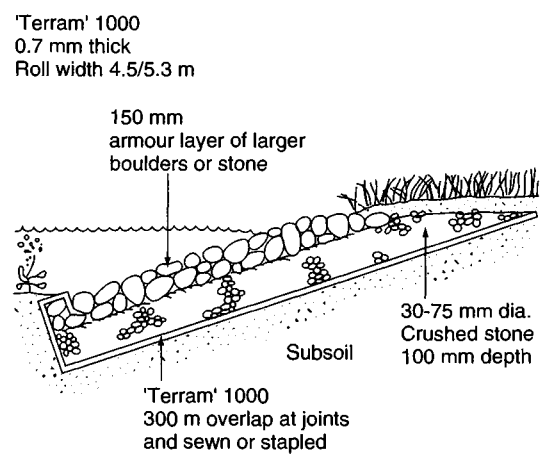


Figure 1.4 Rip-rap bank ('Terram'/stone)

Once the water authority has established that a water supply is available, the following information should be obtained by the consumer:

1. Copy of water authority bye-laws.
2. Marked-up layout drawing indicating location, size, depth and maximum and minimum pressure of the main in the vicinity of the site.
3. An indication of which mains may be considered for:
   (a) Domestic use
   (b) Industrial use
   (c) Fire use
4. Confirmation as to whether the water main passes through any adjacent property which may involve easements to gain access for maintenance, etc.

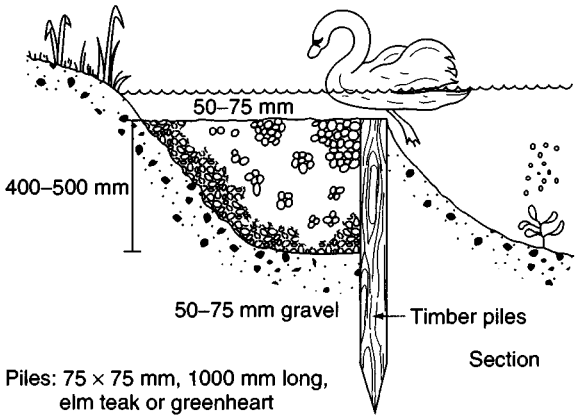


Figure 1.5 Piling margin

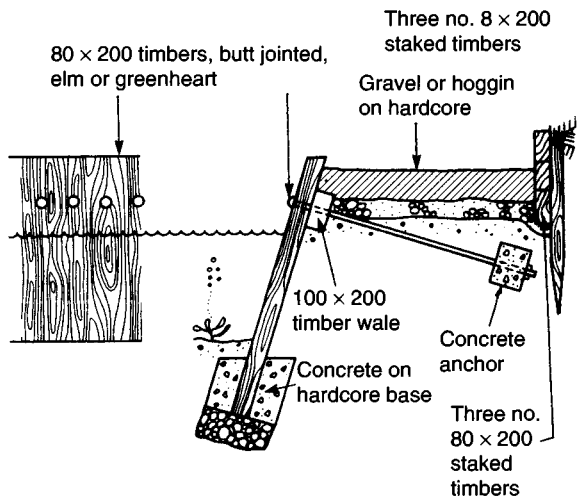


Figure 1.7 Board wall/path

5. Confirmation as to whether the water flow and pressure will be affected by usage from adjacent buildings.
6. Confirmation as to whether a guarantee of security of supply can be provided throughout the year, including any anticipated periods of drought.
7. Confirmation of the source(s) of water supply and provision of a current water analysis.
8. Confirmation that the authority will supply the water meter and housing.
9. Confirmation of the authority's preferred pipe material for incoming mains and any materials not recommended due to aggressive soil.
10. Confirmation that direct mains boosting is allowed.
11. Provision of rates of charges (depending on annual consumption), including any proposed EC levy.
12. Confirmation of costs of maintenance and metering charges.
13. Provision of details relating to any future authority plans which may affect supplies to the site.
14. Confirmation of total capital cost of supplying a water supply.
15. Provision of a fixed time-frame installation programme.

While the above list is not exhaustive, it provides an indication of the necessary negotiated issues to be resolved between a consumer (or their representative) and the water authority.

1.5 Water storage, settling wells and draw-off regulations

1.5.1 Water storage

The Water Supply Byelaws Guide (1989) gives detailed information on the systems and devices necessary to prevent waste, undue consumption and contamination of water. Care must be taken when assessing water storage, as some water authorities have special powers to restrict total water storage retained for a given building and/or

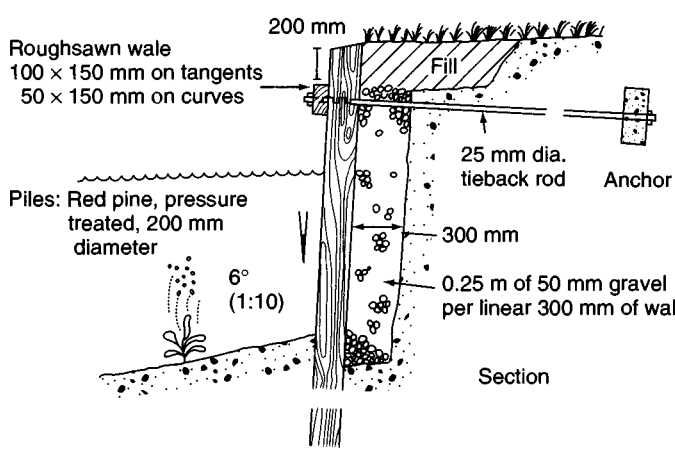


Figure 1.6 Piling edge

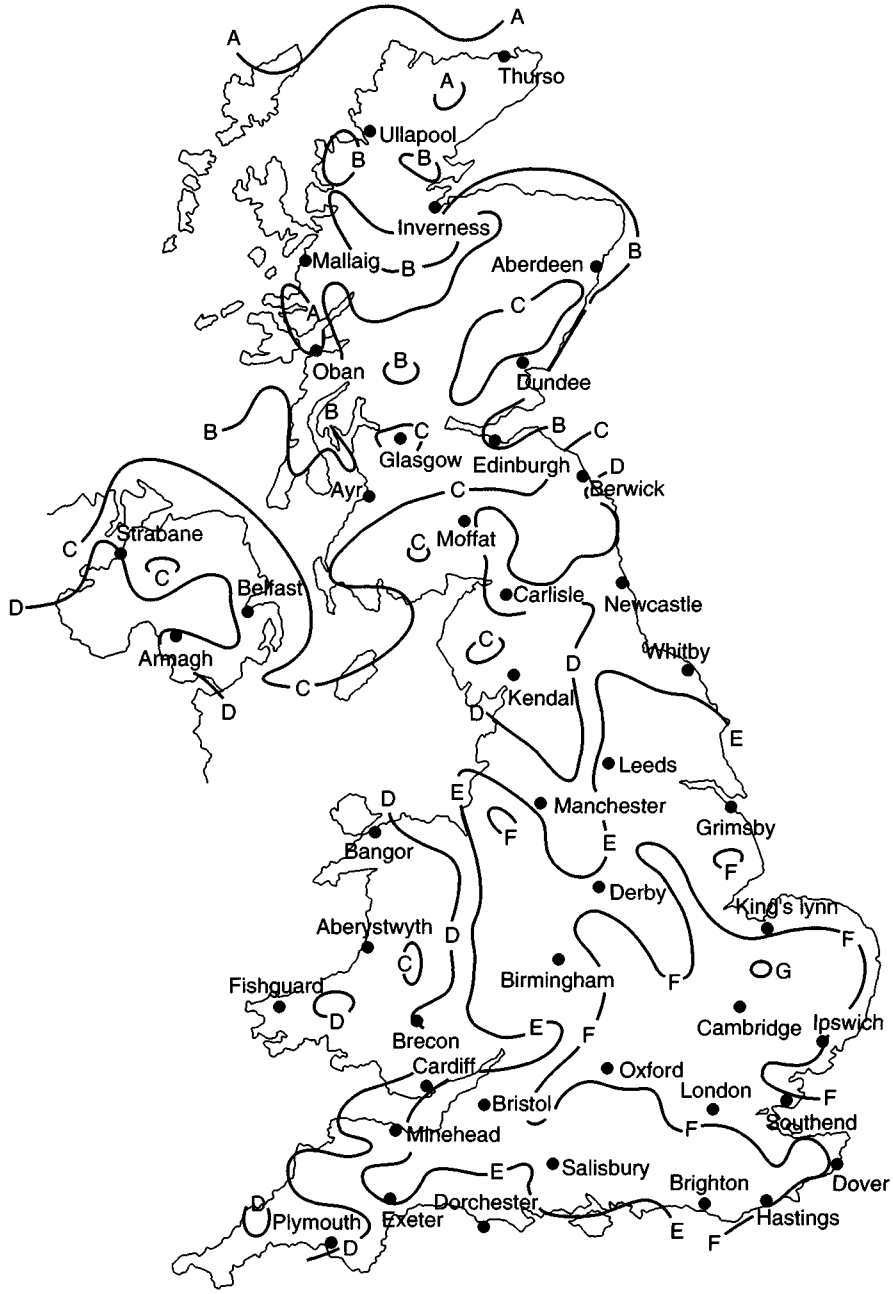


Figure 1.8 Key to rainfall tables (to be read with Table. 1.1)

site. Early consultation with the water authority is also recommended when large volumes of water storage/usage are anticipated, especially if heavy demand is required for industrial purposes.

The necessity of water storage may be outlined as follows:

1. To protect against interruption of the supply caused by burst main or repair to mains, etc.;
2. To reduce the maximum of demand on the mains;
3. To limit the pressure on the distribution system, so reducing noise and waste of water due to high-pressure mains and enabling higher-gauge and cheaper material to be used;
4. To provide a reserve of water for firefighting purposes;
5. Additional protection of the mains from contamination, i.e. prevention against back siphonage.

In designing the water storage capacity, account should be taken of the pattern of water usage for the premises

Table 1.1 Series of tables relating rainfall intensity, duration and return period

Rainfall amount 1.5 mm in 2 minutes, occurring on average once in 5 years (2 min M5)

Duration (mins)	*Intensity (mm/hr)*				
	50 mm	*75 mm*	*100 mm*	*150 mm*	*225 mm*
1	4.5	35	185	1800	–
2	5.5	55	300	3500	–
3	10	175	800	–	–
4	20	210	–	–	–
5	40	400	2000	–	–
10	300	300	–	–	–
	Return periods (years)				

Rainfall amount 2 mm in 2 minutes, occurring on average once in 5 years (2 min M5)

Duration (mins)	*Intensity (mm/hr)*				
	50 mm	*75 mm*	*100 mm*	*150 mm*	*225 mm*
1	1.75	7	35	325	4000
2	2	18	60	850	–
3	4.5	35	175	1800	–
4	7	45	350	3000	–
5	8	60	750	4000	–
10	45	450	2500	–	–
	Return period (years)				

Rainfall amount 2.5 mm in 2 minutes, occurring on average once in 5 years (2 min M5)

Duration (mins)	*Intensity (mm/hr)*				
	50 mm	*75 mm*	*100 mm*	*150 mm*	*225 mm*
1	7 mths	3	8	90	1000
2	1.5	5	20	300	2500
3	2	7.5	40	500	–
4	3	15	60	800	–
5	4	20	100	1000	–
10	15	150	700	–	–
	Return period (months/years)				

Rainfall amount 3.0 mm in 2 minutes, occurring on average once in 5 years (2 min M5)

Duration (mins)	*Intensity (mm/hr)*				
	50 mm	*75 mm*	*100 mm*	*150 mm*	*225 mm*
1	6 mths	1.75	4.5	35	400
2	7 mths	2.5	10	60	750
3	8 mths	4.5	18	190	2000
4	9 mths	7	20	350	3000
5	2 yrs	11	40	–	–
10	7 yrs	40	300	–	–
	Return period (months/years)				

Table 1.1 (*continued*)

Rainfall amount 3.5 mm in 2 minutes, occurring on average once in 5 years (2 min M5)

Duration (mins)	*Intensity (mm/hr)*				
	50 mm	*75 mm*	*100 mm*	*150 mm*	*225 mm*
1	5 mths	1	2	20	180
2	6 mths	1.75	4.5	35	320
3	7 mths	2	19	60	700
4	9 mths	4	12	100	800
5	10 mths	4.5	18	185	1800
10	4 yrs	20	95	750	–
	Return period (months/years)				

Rainfall amount 4 mm in 2 minutes, occurring on average once in 5 years (2 min M5)

Duration (mins)	*Intensity (mm/hr)*					
	50 mm	*75 mm*	*100 mm*	*150 mm*	*225 mm*	*275 mm*
1	4 mths	7 mths	1.5	7	50	180
2	5 mths	8 mths	2	18	110	450
3	5 mths	1.75	4	35	250	700
4	6 mths	1.75	6	40	350	1000
5	7 mths	2	7.5	50	650	–
10	2 yrs	7.5	40	300	3500	–
	Return period (months/years)					

Rainfall amount 4.5 mm in 2 minutes, occurring on average once in 5 years (2 min M5)

Duration (mins)	*Intensity (mm/hr)*						
	50 mm	*75 mm*	*100 mm*	*150 mm*	*225 mm*	*275 mm*	*300 mm*
1	3 mths	5 mths	9 mths	4.5	40	75	350
2	3 mths	6 mths	2	7	55	190	750
3	4 mths	1	3	18	120	350	1100
4	6 mths	1.5	4.5	20	200	450	1600
5	6 mths	2	5	38	250	650	–
10	1 yr	6	50	200	1800	1900	–
	Return period (months/years)						

Notes: For intensities of 225 mm per hour and above, alternative means of protecting the building other than increasing the size of rainwater pipes etc. should be considered, such as the provision of overflows or additional freeboard.
The average roof should have a duration/runoff time not exceeding two minutes. Periods of greater duration shown for information and completeness only.

and, where possible, to assess the likely frequency and duration of breakdown from the water authority mains. When dealing with domestic water storage this is usually provided to meet a 24-hour demand and, when considering health care premises, Hospital Technical Memorandum 27 outlines minimum recommended water-storage capacities for differing types of hospital wards.

However, to apply the same philosophy to industrial buildings would be incorrect, and due consideration must

be given to the effect of loss of water supply to the process/manufacturing production.

When assessing water storage the following should be considered:

1. Where there is a requirement for large volumes of water, storage may be sized on quantity of usage per shift;
2. Frequency of interruption to mains supply;
3. Space requirements;
4. Cost of water storage tank and associated supports;
5. Protection against frost;
6. Type of industrial usage and effect of loss of water supply to production;
7. Minimizing the risk of Legionnaires' Disease.

1.5.2 Draw-offs

In the UK, maximum draw-off from water mains differs throughout the various water authorities. What may be acceptable in one area may not be acceptable in another. Water mains may generally be able to supply direct to domestic buildings but not to industrial premises, where constant flow and negligible fluctuation in pressure is required. Contamination of water supply by back siphonage is of major concern to water authorities.

Water consumption for commercial and industrial premises are metered and costed on a per cubic metre of usage basis, with additional costs for reading and maintenance of the meter station(s). It is important that assessment of water usage is as accurate as possible, as water charges are based on a sliding scale, i.e. as volume of water usage increases, cost per unit decreases.

Where production in new premises is to be phased with peak usage only being attained after a period of years it is important to consider this during initial discussions with the relevant water authority when negotiating unit rate costs.

See Figures 1.9–1.17.

1.6 Problem areas associated with on-site sewage treatment for isolated areas

The outfall of a foul-water drainage system should discharge into a foul-water or combined drainage system (foul and surface water). Where such a drainage system is not conveniently available and cannot economically be extended to a site, other methods of foul-water disposal will be necessary, either a cesspool or a septic tank.

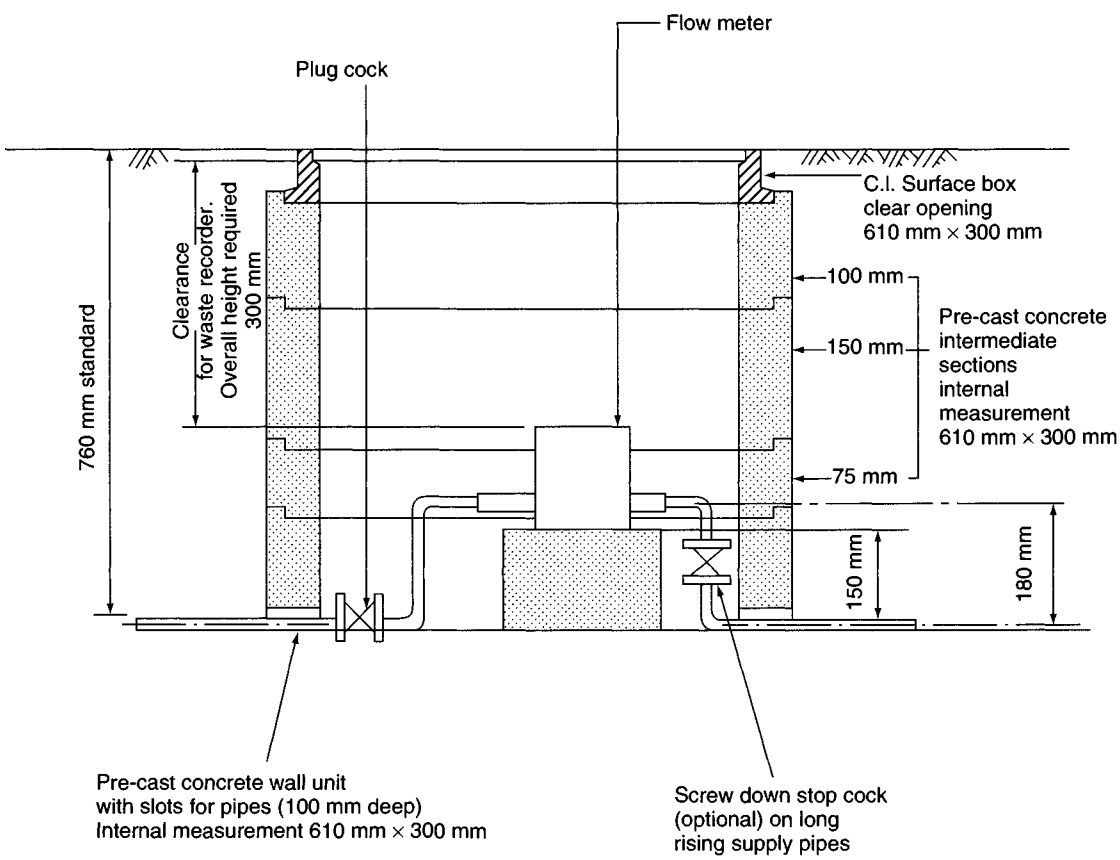


Figure 1.9 Standard pipe installations for water flow meter and frost cock

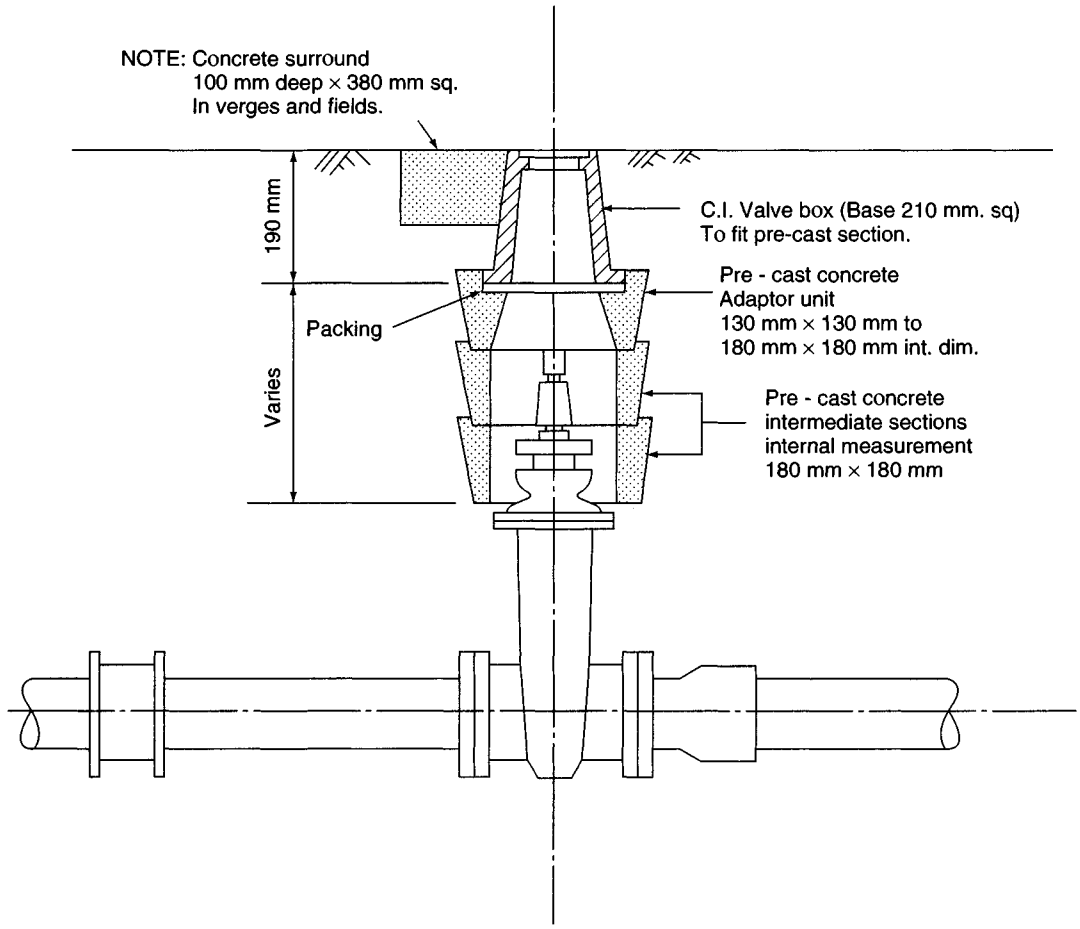


Figure 1.10 Standard pipe installations for water sluice valve up to 250 mm diameter. *Notes:* (1) If a valve extension spindle is required, a galvanized centering support must be provided. (2) Flanged valves with appropriate adaptors must be used. (3) Unless otherwise directed, pre-cast concrete units shall be bedded on well-compacted granular material Type A brought up from the base of the trench

1.6.1 Cesspools

A cesspool is a tank normally located underground which is designed to store the entire foul drainage discharge from premises between disposals by tank vehicles(s). The following points should be noted when considering the use of a cesspool:

1. Minimum capacity of 18 m^3 measured below the level of the inlet (or as equivalent to approximately 45 days' capacity);
2. It must be covered and impervious to rainwater, groundwater and leakage;
3. It must be ventilated;
4. It must be positioned such as not to pollute any water sources or cause a public nuisance;
5. It must be sited so that the contents may be removed other than through a building, with reasonable access for tanker vehicles where required;
6. Its position should also be considered relative to future sewerage systems.

Cesspools should only be utilized in extremely remote areas and after consideration of all other forms of effluent disposal has been undertaken.

1.6.2 Septic tanks

A septic tank is a purification installation designed to accept the whole sewage/trade discharge from premises. Its construction is such that it allows the settling out of the sludge content of the incoming effluent and renders the final effluent acceptable, by prior agreement with the water authority, for discharge to a watercourse or soakaway. The sludge within the septic tank decreases in volume by the action of microorganisms changing the sludge from aerobic to anaerobic.

The following points should be noted when considering the use of a septic tank:

1. It should be impervious to rainwater, groundwater and leakage;
2. It must be positioned such that the contents may be periodically removed by a tanker vehicle;

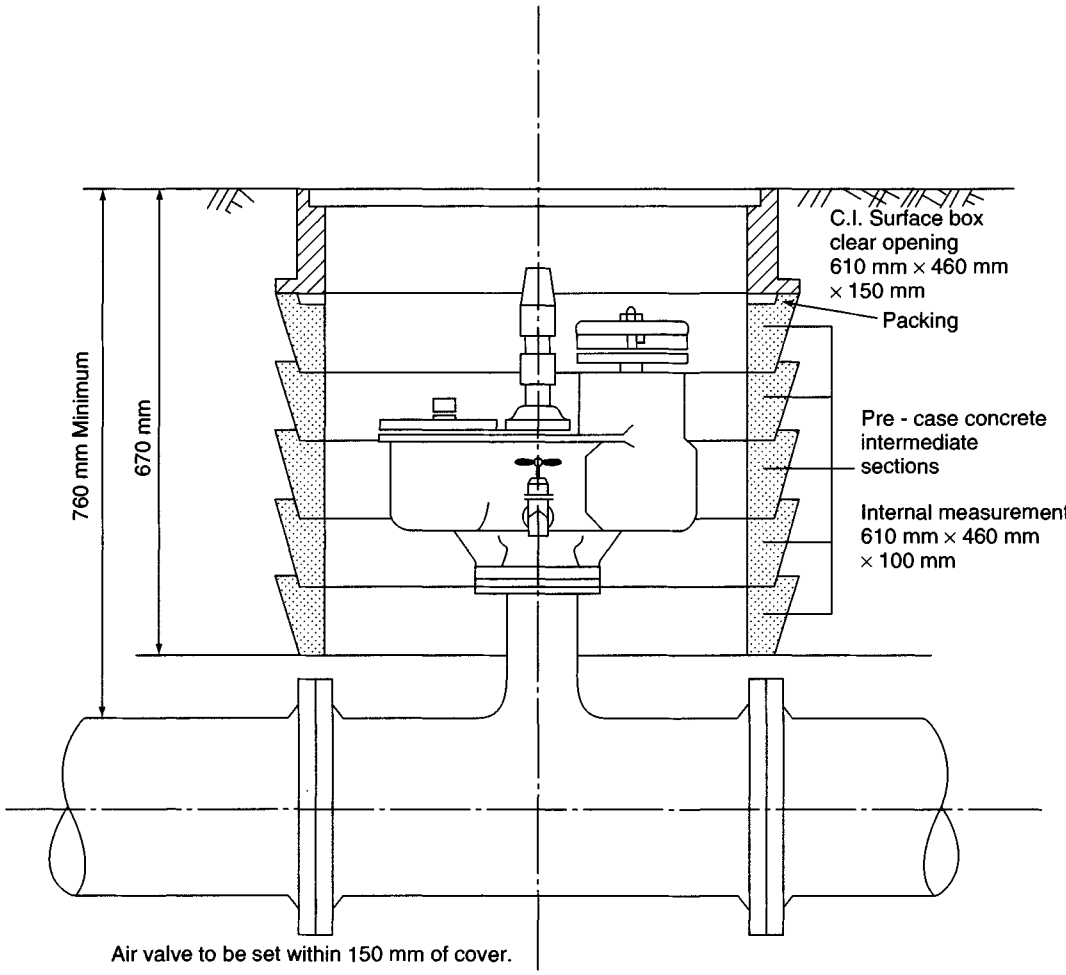


Figure 1.11 Standard pipe installations for a double air valve. *Note:* Unless otherwise directed, pre-cast concrete units shall be bedded on well-compacted granular material Type A brought up from the base of the trench

3. A percolation filter and/or sub-surface irrigation may be required to provide aeration and final purification;
4. The change of bacterial action from aerobic to anaerobic produces methane gas which must be ventilated to atmosphere;
5. Its position should also be considered relative to future sewerage systems;
6. Minimum capacity of 27001 to be provided. Subject to local authority approval, the effluent outfall from a septic tank may be connected to an adopted sewer subject to quality of outfall and size and location of drainage.

1.7 Landscaping on industrial and reclaimed land

1.7.1 General

In the context of overall landscaping, here we will concentrate on what is normally recognized as soft landscaping, i.e. that area which includes waterbodies and growing plants. The primary problems which have to be solved in any scheme for creating a new growing, living landscape out of a reclaimed land are:

1. Contamination in the ground. (There may be contamination in the air, but this is beyond the scope of this chapter.)
2. Soil structure and land drainage within the reclaimed ground.

1.7.2 Contaminated land

It is not unusual for industrial land or land formed from tipped waste to be contaminated to some degree. Heavy contamination will have to be dealt with as a particular engineering problem: i.e. to seal, bury or remove any highly contaminated material. Moderate contamination can normally be dealt with *in situ* by dilution of the concentrated contaminant. Whatever treatment is utilized, steps must be taken to prevent the leaching of any contaminants through the soil.

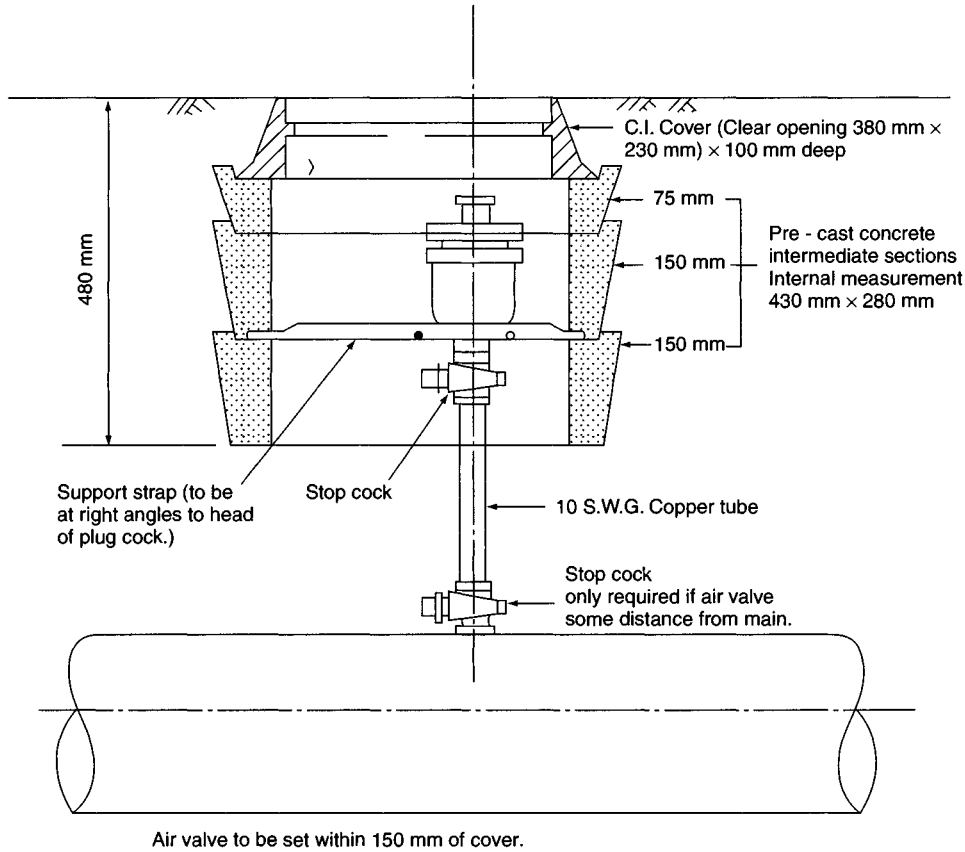


Figure 1.12 Standard pipe installations for a single air valve. *Note:* Unless otherwize directed, pre-cast concrete units shall be bedded on well-compacted granular material Type A brought up from the base of the trench

As far as the effects of contamination are concerned, the main problems associated with harm to plant growth are the presence of particular heavy metals which are poisonous to plant life and/or lack of oxygen in the soil growing medium due to the presence of gases produced by the contaminated ground (for example, methane). Lack of oxygen can also be the result of a poor soil structure, over-compaction (no air voids), etc.

The Department of the Environment sets guidelines for safe limits to heavy metals content in the soil for reasons of both public and plant health. Before planting regimes are implemented in any reclaimed ground these heavy metal levels must be assessed and, if high, reduced. One acidic or alkaline soil also will need neutralizing and the type of proposed planting chosen for the soil type.

As indicated earlier, heavy contamination can be buried, sealed or removed. Burying of the material should be well below the root growth zone, and this is normally taken as 3.0 m below the final ground-surface level. Sealing for heavy contamination to prevent vertical or lateral leaching through groundwater flow can be with compacted clay or proprietary plastic membranes. Removal from site of the contaminants is normally only contemplated in a landscaped scheme where the material, even at depth, could be a hazard to public health directly or phytotoxic to plant life.

Where there is a landfill gas-generation problem, active (i.e. pumped) or passive venting, by way of stone-filled trenches at least 1.0 m deep, may be needed. Where active venting is appropriate, the commercial use of the gas extracted can be considered.

Contaminated groundwater (leachate) should be kept below the root growth zone. Only rainwater or clean irrigation water should meet the needs of plants.

Any waterbodies constructed on the contaminated land which are to support aquatic life will need to be completely sealed against the underlying ground and inlet and outlet water provisions designed so that they are sealed against any flow of contaminated water into the waterbody.

As a general rule, young, immature plants should be chosen for any landscape planting scheme on reclaimed, previously contaminated, land. This allows the plants to adapt gradually to such an environment. It is not normally appropriate to plant mature shrubs and trees to create an instant 'mature' landscape in such an environment.

1.7.3 Non-contaminated land

For land that is reclaimed with 'inert'/non-contaminated materials the main problem in creating a good growing medium tends to be in producing a soil structure profile within a limited period of time. It its normal natural state

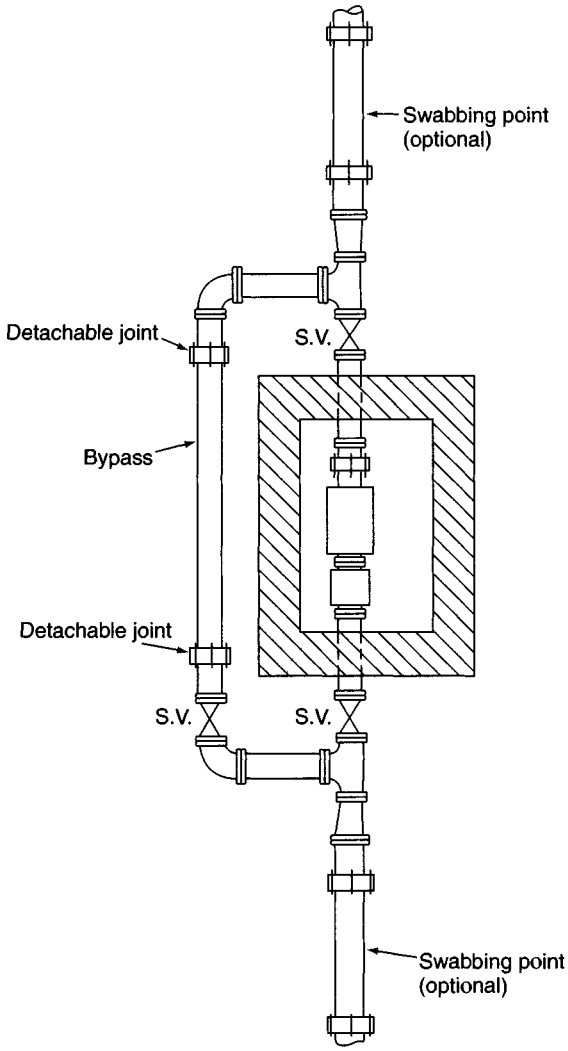


Figure 1.13 Standard bulk meter layout for a brick-built chamber (230 mm brickwork on a concrete base). *Notes*: (1) The meter should be either on straight or bypass to suit site (i.e. to keep meter off road). (2) Chamber cover should be approximately 685 mm × 510 mm

such a profile would take many many years to develop. A good profile will provide an oxygen- and nutrient-rich soil, not too acid or alkaline, which is well drained. Any reclamation project should aim to supply this ideal environment as soon as possible. To do this, a clear and firm specification for the reclamation material and how it is to be placed will be needed at the beginning. Extensive drainage with both the land form and the subsoil will also be required.

Imported topsoil or topsoil manufactured from imported nutrients mixed into existing soil will normally be required. Topsoil depths will vary in accordance with the planting, from 400 mm for grassed areas to 1.5 m for major trees. Under these conditions instant, mature landscapes can be constructed immediately.

In any scheme for creating a landscape on reclaimed land the ultimate aim will be not only to create a green landscape but also to provide an environment in which the ecosystem will develop quickly. Some important factors which must be taken into account here are:

1. Early structural planting to provide windbreaks and shelter for younger plants and wildlife to develop.
2. A balanced landscape needs waterbodies. These should be designed to have shallow margins to provide the appropriate conditions for wetland planting which, in turn, provide the balanced habitats for a rich wetland ecosystem.
3. A properly designed planting regime away from the water bodies will provide cover, space and the natural habitats for a wider wildlife system.
4. It is not normally necessary to seed waterbodies with fish. Fish will be introduced by natural means (e.g. by aquatic bird life).

Finally, in any projected landscape due consideration should be given to the future maintenance of the completed scheme. Unlike a normal building development, a landscape progressively develops with time. In order to maintain the original design concept a clear maintenance regime and organization should be established early in the project development process to start as soon as the landscape has been initially established.

1.8 Legislation on contaminated land of concern to the plant engineer

1.8.1 The UK, EU and world context

The notes below apply specifically to the United Kingdom context; while the law applying to Scotland and Northern Ireland is generally very similar in its effect, there are some variations.

In most cases the same issues will be addressed by legislation world-wide and, in that sense, this section can be treated as a "checklist". However, readers outside the United Kingdom or the EU are urged to check the precise requirements of relevant legislation in the State concerned.

EU Directives are binding on member states, including the United Kingdom. This means that their main requirements must find expression in each member state's legislation although the details of how this is done will depend on national legislative tradition. Much of the more recent UK legislation will therefore have parallelism with that of other EU countries and this will be extended in coming years.

1.8.2 Planning Controls

Contaminated land often becomes an issue when redevelopment is considered: In the UK, development of land is subject to approval from the Planning Authority, i.e. the Local Authority ("Planning Consent"). *(Town and Country Planning Act 1990*, and various Orders and Regulations made thereunder). The development of land known to be

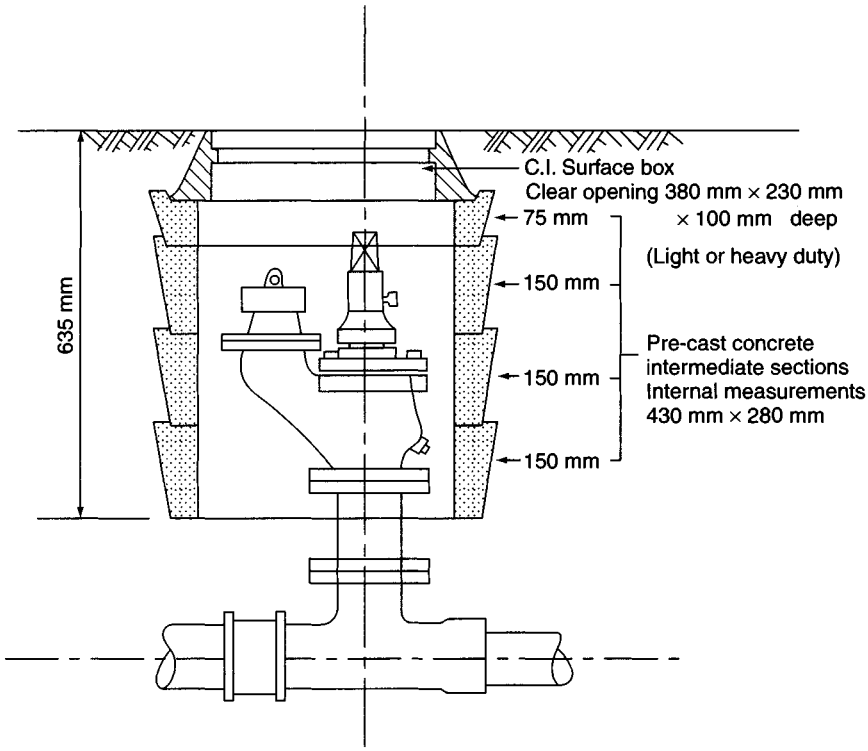


Figure 1.14 Standard pipe installations for a fire hydrant. *Notes:* (1) Hydrant Tee must be appropriate to type of main installed. (2) Depth of hydrant outlet must not exceed 300 mm below finished ground level. (3) Unless otherwise directed, pre-cast concrete units shall be bedded on well-compacted granular material Type A brought up from the base of the trench

contaminated or likely to be affected by nearby contamination will be subject to appropriate conditions. These will typically fall into two parts:

Firstly, the developer will be required to submit and execute a scheme for the investigation of the land, to the satisfaction of the Local Authority. This will normally be entrusted to a specialist contractor and will identify the nature and distribution of the contamination. A risk assessment will be carried out and appropriate precautions designed into the development. Potential hazards include:

- Toxic substances in the soil, e.g. arsenic, heavy metals, organic compounds.
- Evolution of gases by landfilled refuse and other materials. The principal hazard here is from migration of methane into confined spaces such as buildings and service ducts/chambers, giving rise to a fire/explosion hazard. Other gases arising in landfill materials especially carbon dioxide, can act asphyxiants in confined spaces.

Under the terms of the *General Development Order, 1988*, made under the Town and Country Planning Acts, Local Authorities must keep a map of known, gassing landfill sites in their area. Any Application for Planning Consent for land within 250 metres of such a site will receive special scrutiny to ensure that no hazard is posed to the development or that appropriate measures are taken.

Investigation will start with a desk study of available records and evidence about the history of the land. On site, it will usually include sinking trial pits or boreholes and submitting samples of substrate and ground water for analysis. Where flammable methane or other gases are a problem, gas measurements may be taken for a period of months in specially constructed boreholes. This is because the gas regime will vary with barometric pressure and rainfall and shorter-term measurements may not give the full picture. The density of the grid of boreholes or sampling points will be designed to give statistically robust data.

Secondly, the Consent will require the developer to submit a scheme, based on the outcome of the investigation, of constructional and other precautions which will eliminate any hazard from the contamination. There may also, of course, be separate issues of structural design with made-up ground.

It should be noted that, in UK practice, land does not have to be "completely" free from contamination; in practice, this would be impossible to define or enforce because traces of contaminants are present in all ground; indeed, many occur naturally. Land being redeveloped, however, must be *fit for the use to which it is put.*

For example, a proposal to construct a factory and associated hard standings on a site moderately contaminated with heavy metals would not cause much concern because the soil is inaccessible, being covered with concrete. On

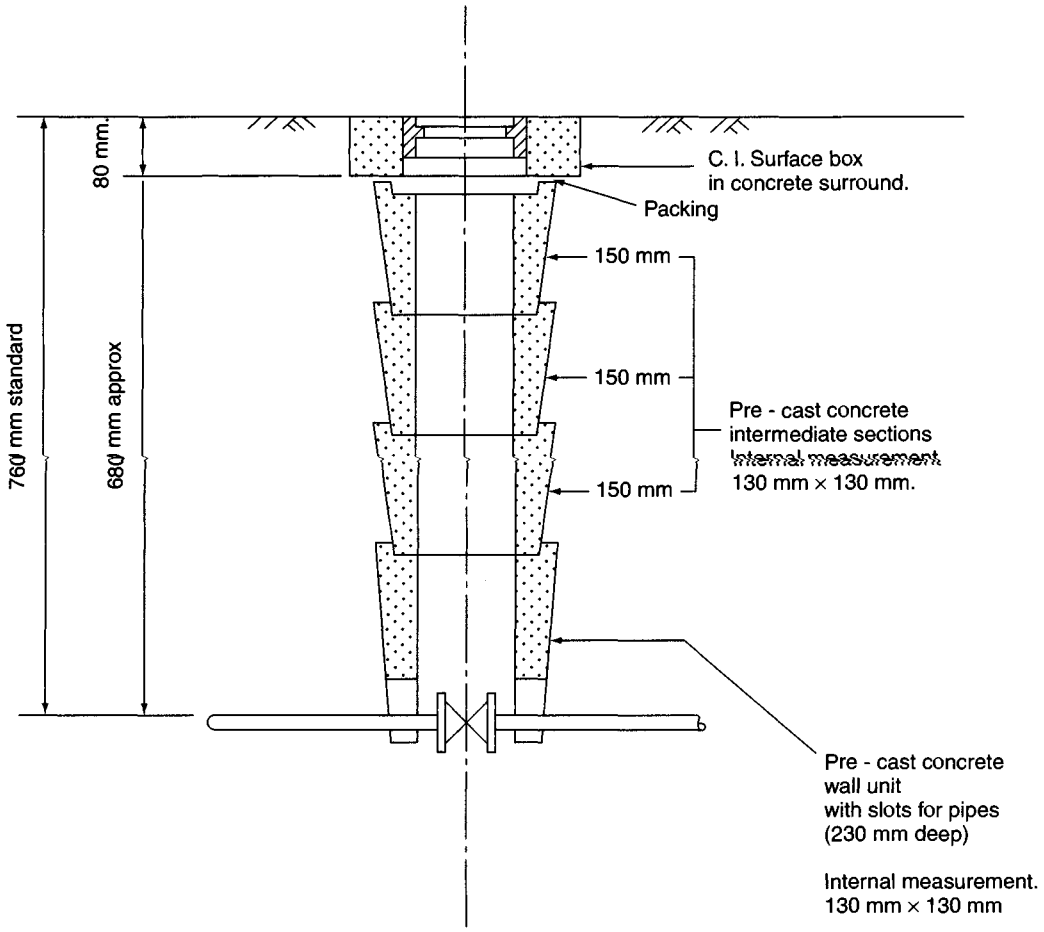


Figure 1.15 Standard pipe installations for a communication pipe stopcock. (It may be necessary to provide a base unit where polythene is being used)

the other hand, a scheme to build houses on the same site with large gardens, in which young children will play and vegetables be grown, would require more careful consideration.

Precautions on development sites can be divided into remediation of the site itself (or adjoining land) and constructional design.

Examples of site remediation:

- Removal and disposal of the contaminated top layer.
- Covering contaminated soil with clean soil from elsewhere.
- Installation of impermeable membranes and barriers to prevent the migration of gas into sensitive areas. These are usually supplemented by ground venting arrangements on the gassing side of the barrier.
- Site venting arrangements: These are usually passive, where gas flows under its own pressure via a gas drainage system into simple vent stacks. Alternatively, where large flows of gas have to be dealt with, mechanical ventilation may be used. Very large flows of gas may be led to a flare-stack, although this would be unusual on a site which was actually under development.
- Ground water drainage arrangements: Fluctuations in the water table in a landfill site may affect the gas regime. It may therefore be necessary to make positive arrangements for improved site drainage. If the leachate collected is strongly contaminated, it will be necessary to obtain appropriate consents from the utility company and/or the Environment Agency for its discharge to sewer or watercourse.
- Monitoring arrangements: Ongoing monitoring of gas concentrations may be required and boreholes may be sunk at strategic points on the site for this purpose. Gas monitoring may be done manually with portable instruments or sophisticated remote automatic systems installed, where appropriate.

Examples of constructional precautions:

- Positioning and layout of buildings.
- Selection of building type, e.g. apartments surrounded by public spaces rather than houses with individual gardens.
- Careful structural design of foundation rafts to avoid differential settlement and cracking.

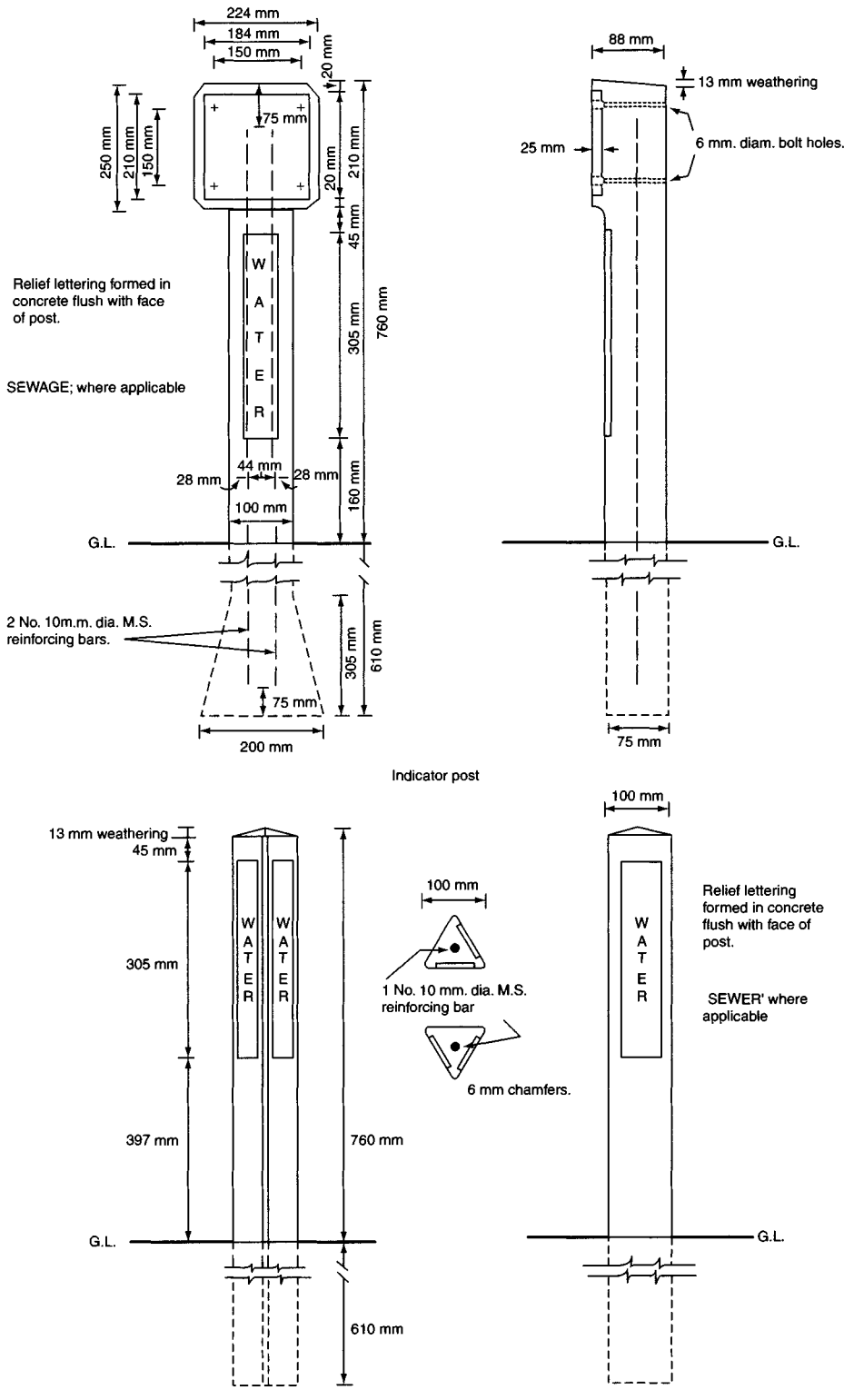


Figure 1.16 Pre-cast concrete indicator and marker posts

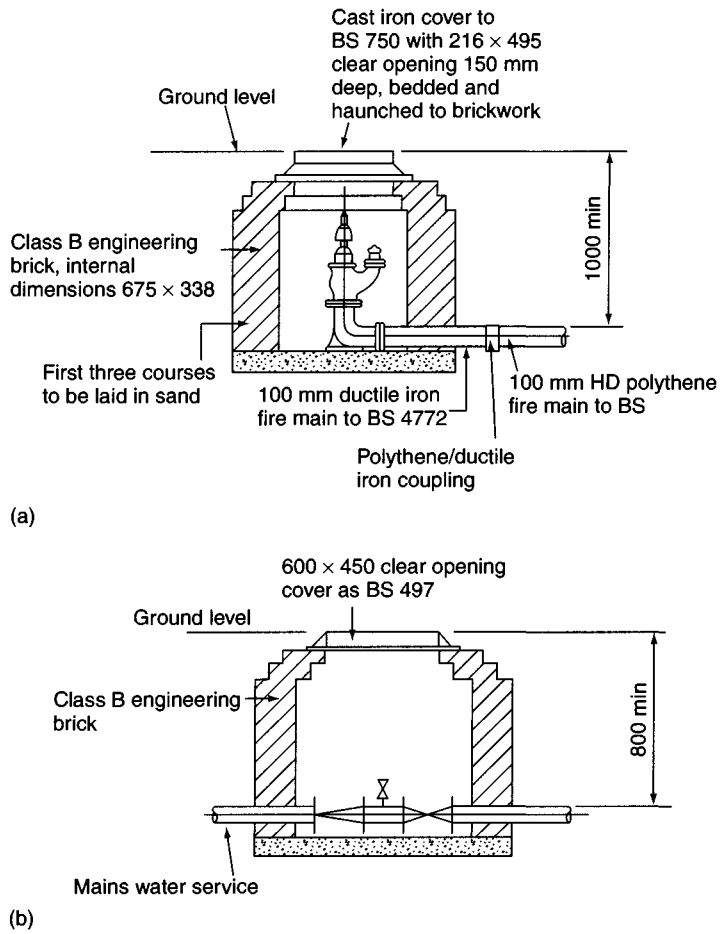


Figure 1.17 (a) Fire hydrant pit; (b) stopvalve pit. *Note*: To each fire hydrant an indicator plate with post to BS 3251 must be provided and installed

- Incorporation of purpose-made impermeable membranes into foundation rafts.
- Careful detailing of key structural features such as wall/floor junctions to ensure continuity of the impermeable layer.
- Attention to entry points of services into buildings to eliminate gas migration routes.
- Passive or mechanical venting of sub-floor voids and other spaces.
- Passive, gravel-filled vent trenches around building foundations, giving gas a preferential escape route.
- Fitting of automatic methane alarms in buildings.
- Planning conditions and/or restrictive covenants to control the construction of sheds, conservatories and the like in gardens.

In some cases, management companies supported by financial trusts have to be set up by developers to ensure the continuing maintenance of protective arrangements over a long period into the future.

Readers requiring more detail on the above topics are recommended to consult the extensive literature published by the:

Construction Industry Research and Information Association (CIRIA),
6, Storeys Gate,
Westminster,
London SW1P 3AU.

1.8.2.1 Standards for ground contamination

Detailed concentration limits for soil contaminants can be found in the following reference documents:-

- The list published by the UK *Interdepartmental Committee on Contaminated Land (ICRCL): ICRCL 59/83.*
- *Proceedings of the Conference on Reclamation of Contaminated Land: Site Investigation and Materials Problems, Eastbourne, UK, October 1979. (Society of the Chemical Industry, London, 1980).* (The "Kelly Indices" (former GLC), Guidelines for contaminated soils, specifically developed for gasworks sites in London).
- *The Dutch Soil Clean-up Guideline, Dutch Ministry of Public Housing, Physical Planning and the Environment.*

For a terrace housing development in the Midlands raft construction was proposed. The ground conditions comprised deep structural fill (foundry sand) overlying coal measures strata. Gas was detected in the fill at concentrations up to 1% and 5% methane and carbon dioxide by volume in air respectively. A cross-section of the raft is shown below.

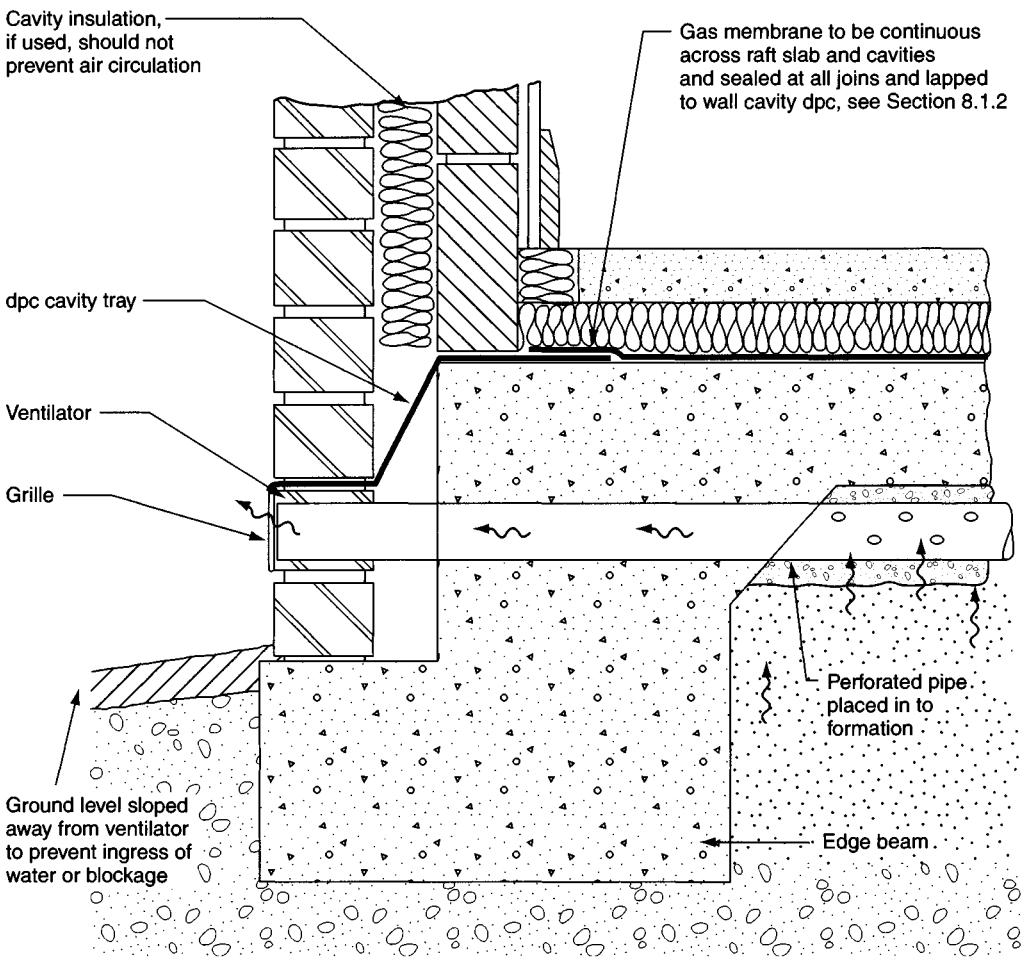


Figure 1.18 Example of raft construction on gassing ground

In addition, at the time of writing, rapid advances are being made with computer models which will generate risk assessments from health data on individual contaminant species and site parameters.

1.8.3 Statutory liabilities for former contaminative activities: Environmental Protection Act 1990, Part IIA

Part IIA of the *Environmental Protection Act 1990* (enacted by Part II of the *Environment Act 1995*) created in the UK a new regime for assessing and securing the remediation of sites subjected in the past to contaminative activities. (i.e. it does *not* apply to sites where contaminative activities are still in progress). This regime came into effect in 2000. Enforcement is divided between Local Authorities and (in England and Wales) the Environment Agency.

Contaminated land is land which:-

"... appears to the Local Authority to be in such a condition, by virtue of substances in, on or under the land, that significant harm is being caused, or there is a significant possibility of such harm being caused, or that pollution of controlled waters [rivers, lakes, aquifers etc. for which the Environment Agency is responsible] *is being, or is likely to be, caused".*

To establish that land is contaminated, it is necessary to establish the simultaneous existence of:

- A source of contaminant.
- A "target" which can be harmed by the contaminant.
- A means by which the contaminant can travel from one to the other.

This test is known as the *Source-Pathway-Receiver Linkage.*

The role of the Local Authorities is to:

- Devise and publish a strategy for identifying, assessing and remedying contaminated land in their areas.
- Cause their areas to be inspected to identify contaminated land.
- To act as enforcing authority for all contaminated land which are not *Special Sites*. These are sites where there are especially hazardous contaminants present or where there are other complications such as the risk of contaminating an aquifer.

The Local Authorities have four main tasks:

- To establish who is responsible for the remediation of the contaminated land. *(The "Polluter Pays").*
- To decide, after consultation with the landowner, the Environment Agency and the person(s) who caused the contamination, what remediation is required. (The land need only be *fit for the use to which it is to be put,* when remediation is complete).
- To ensure that the remediation is carried out by the person responsible, either by agreement with them or by serving on them a *Remediation Notice,* which requires them to carry it out.
- In circumstances where no other course of action is possible, e.g. because the person causing the contamination no longer exists, to carry out the remediation themselves.
- To determine who should be liable, and in what proportions, for the cost of the remediation work.
- To record prescribed information about contaminated land and their actions in relation to it in a Register, which is available for public inspection.

As well as being responsible for Special Sites, the *Environment Agency* provides consultation and guidance to Local Authorities and collates and publishes information about contaminated land in the UK.

Persons involved in action by the Local Authority have extensive rights of appeal to the Secretary of State for the Environment.

Persons who are carrying on, or considering carrying on, contaminating activities should therefore give careful consideration to potential future liabilities which they may have to bear.

Further reading

BS 6297, Code of Practice for the design and installation of small sewage treatment works and cesspools
BS 6700, Design of water services
The Building Regulations 1985
Chartered Institute of Building Services Engineers (CIBSE) Guides
Code of Practice on Legionnaires' Disease for health care premises
DHSS and Welsh Office Health Technical Memorandum 27
Institute of Plumbing Data Book
Institution of Water and Environmental Management
Minimising the risk of Legionnaires' Disease, Technical Memorandum CIBSE 13

2 Plant location

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2.1 Selecting the location

Location is a strategic issue, and the decision where to locate cannot be taken lightly. It is the first decision in the implementation of a project (that is, once it has been agreed to go ahead). Upon taking this decision, an investment is made which is irreversible. That investment in 'bricks and mortar' cannot physically be transferred to another location if the decision turns out to be wrong. In time, the assets may be realized but probably at much lower values than paid.

Traditionally, companies have sought to acquire competitive advantage over their rivals through their choice of location. In a historical context, firms tended to establish their factories for reasons of economic geography, e.g.:

- Proximity to raw material source
- Proximity to relatively cheap and abundant energy
- Availability of relatively inexpensive manpower or specialist skills
- Good transport links with materials suppliers and markets.

In more recent times the location decision has been influenced by government intervention, e.g.:

- High tariff duties imposed on imports which encourage exporters to that country to consider setting up local operations
- Investment incentives in the form of tax relief and grants
- The provision of infrastructure, especially improved transport communication

In today's world the decision is more complex. Markets are more sophisticated, skills can be in short supply, technological change can soon outdate newly installed processes, and there has been a phenomenal revolution in communications, both in terms of the physical movement of goods and people and of information around the world. As a consequence, companies often have to consider a wide number of options, and the eventual decision is based on optimizing the perceived net benefits.

The following are the key factors in selecting a location, and these are discussed in more detail below:

- Factor costs
- Protected markets and economies of scale
- Government influences
- Corporate matters
- People matters

2.1.1 Factor costs

All other things being equal, the company will site its plant where it is cheapest to manufacture. This is determined by the nature of the product and of the manufacturing process. For instance:

- Where the process requires significant quantities of raw material (especially if it is bulky) or generates significant volumes of finished product the economics favour locations close to sources of the raw material or close to the points of sale (for example, sugar milling, cotton ginning, the winning of metals, the beneficiation of non-precious minerals).
- Where considerable quantities of energy are used in the process, relatively cheap and abundant sources of energy need to be available (for example, alumina and aluminium smelting, steel making).
- Where the process is labour intensive, low-cost workers are required in numbers (for example, textiles and clothing). The cost of capital has little effect on the choice of location as sourcing of capital can be from anywhere. The ability, however, to repatriate profits and the proceeds from the sales of assets and exposure to foreign exchange risk are important if the location options are abroad. This factor becomes more relevant, the greater the capital intensity of the project.

Associated with factor costs are linkages with material suppliers, subcontractors and support services (e.g. temporary staffing agencies, travel agents, reference libraries, office-maintenance services, security). The availability and cost of these need to be considered.

2.1.2 Protected markets and economies of scale

All markets are protected to some extent. Domestic suppliers have, at times, the natural protection of lower transportation costs, a greater understanding of the local marketplace through its experience and knowledge of social customs and culture, and an easier ability to respond to domestic customer requirements. Added to this, tariff duties may have to be paid on imports.

Where products are demanded in volume, process technologies have been developed to minimize unit costs. The concept of the 'minimum economic scale' of plant (MES: sometimes referred to as 'minimum efficient size') is the point beyond which increases in scale do not significantly reduce unit costs.

Where domestic markets are large enough, companies can establish MES plants or larger. When they are not, several alternatives need to be assessed, namely:

- Setting up a plant of sub-optimal size to serve the local market based on the premise that the higher unit costs can be offset against factor cost advantages and the protection that the market affords the local producer.
- Establishing a MES plant and seeking export opportunities.
- Supplying, or continuing to supply, the local market from a MES plant established abroad.

2.1.3 Government influences

As already indicated, governments (regional and national) try to attract inward manufacturing investment in various ways. For example, in the 1950s, 1960s and 1970s, this was largely developed behind high tariff duties on imports. Infant-industry arguments are used by countries to adopt protectionist policies, but companies must expect eventual pressures 'to grow up' and face open market competition. With trends for countries to join economic

unions such as the European Union, the advantages of tariff protection cannot always be guaranteed.

Local and regional governments are frequently involved in the promotion of their areas. In some places, particularly in Western developed countries, they are able (and often keen) to provide useful information on their locality, covering available sites, rents, land prices and details on transport communications. These bodies can be very effective in helping to finalize choice. For example the roles of the Welsh Development Agency and Scottish Development Agency, to encourage the semiconductor and electronic industries into their regions during the 1990s.

Governments often offer monetary incentives to prospective manufacturing investors. The types of inducements offered are:

- Tax-free holidays; periods of possibly 3–15 years of no tax liability on profits (this also can apply to local, property or any other tax normally imposed on a firm);
- Deferred tax allowances; where capital and operating costs in early loss-making years can be offset against profits later;
- Liberation from payment of import duties on capital plant and equipment, and on materials;
- Capital grants and/or low-cost loans for the purchase of plant and equipment;
- Liberal depreciation allowances;
- Training grants and/or facilities; to assist towards the cost of acquiring a suitably skilled workforce;
- The provision of land and services at zero or nominal prices (these sometimes extend to factory units and accommodation for senior management staff);
- The provision of 'free zones', usually in port locations, where goods can be imported duty free, processed and the bulk (if not all) exported.

Although many of these incentives are generally limited to the poorest regions of the European Union (EU), where natural economic advantages to meet present-day opportunities are few, they are also widespread in developing countries.

Investment is more easily attracted to areas with adequate infrastructure. Governments encourage inward investment through the provision of industrial estates, sometimes with standard factory units ready for occupation; energy and water supply; roads suitable to withstand heavy vehicle traffic; other means of transport, airports, seaports, railways; and waste-disposal facilities. Progressive government departments concerned with industrial development make available a wide range of information about their areas, including local services, amenities, housing and education.

When locating in a foreign country the national government may insist on a certain level of 'local content' being achieved in a given period of time. This requirement, which is often subject to negotiation, can involve the company in a significant amount of administrative work in order to demonstrate that the conditions are being fulfilled. In addition, local content schemes invariably mean higher costs of production.

2.1.4 Corporate matters

The opportunity cost of senior management time is high, and new projects usually take up a disproportionate amount of senior management time. This may be the critical factor in choosing between the best candidates in the 'last round' of selection.

Another critical factor could be 'image'. High-technology companies like to reinforce their image by having addresses that are synonymous with education and science (e.g. Cambridge). Others may want to associate themselves with an area traditional for high-quality manufacturing (e.g. Sheffield) or research and development such as in the pharmaceutical industry, which is concentrated in Switzerland.

2.1.5 People matters

A prospective location may appear to be right in all other respects but fails because of the manpower resource. This refers to not only the economic aspects such as the availability of labour and skills but also to the qualitative ones of being able to understand the local culture and customs, appreciation of people's attitudes and values and confidence in the ability to blend these with the culture and aspirations of the company to form a cohesive production unit that will work. A successful processing concept in one cultural environment may not be a success in another.

Japanese investors in overseas manufacturing operations have been careful in their approach as well as in their choice of location. It is notable that the UK has received more than its share of Japanese investment in Europe in terms of population. An important factor here is language, as English is the most commonly spoken foreign language in Japan.

Stability of labour relations is an important criterion for location selection. The Japanese have negotiated single-union plants and 'no-strike' deals with trade unions to try to ensure such stability.

Probably the ultimate factor behind the choice of location is the influence key personnel can bring to bear on the decision. Project success largely depends on people, especially those at the top. With limited options on the person and/or team to lead the project's implementation, their location preference could be final.

2.2 Services

2.2.1 Availability of water

A water supply is an essential service for all manufacturing and process industries for domestic, cooling or process use. In 1996 nearly 3,670 million m^3 of water was supplied to the industries of England and Wales, including fisheries and agriculture, with a further 11,400 million m^3 used in the electricity supply industry. Another 6,630 million m^3 was pumped into the public potable water supply systems. Almost all of the electricity supply water was used for cooling purposes was taken from surface waters with nearly 70% originating from tidal sources.

The significance of a water resource on the location of an industrial plant is essentially cost and security of supply. Certain industries (e.g. beer and mineral water production) may consider a water supply with particular chemical characteristics as essential to their location. Water supply costs are related directly to quantity but can rise almost exponentially in relation to quality. Therefore, subject to other commercial considerations, there is an advantage to industries who use large volumes of relatively low-quality water for process or cooling (e.g. paper and pulp, textiles, chemicals and steel) to locate in areas where surface or groundwater may be exploited. Their need for higher-quality water is met from the public metered supply or from on-site treatment facilities. For the majority of industries, however, water supply is not a prime consideration in plant location. Traditionally, their demand for water is met from the public metered supply supplemented, where appropriate to availability and quality for use, by surface or groundwaters. Nevertheless, the cost of water provided by the ten water PLCs in England and Wales varies significantly. The current average metered cost for the ten companies is 59 p/m^3 in the range 41.51–76.19 p/m^3, i.e. a 83½% cost difference. Many of the water PLCs offer different tariff systems, depending on the volumes consumed. Recent legislation and regulations will undoubtedly increase substantially the cost of public water supplies and also the cost differences between the water companies.

In addition to varying in costs, the chemical composition of the water provided from the mains supply also varies between the water companies, as may that between independent supplies within each company's area. The current criterion on potable water quality requires it to be 'wholesome', i.e. it should not create a health hazard, with relatively wide limits on particular constituents. The cost of removing these constituents (e.g calcium, magnesium, chlorides, iron and silica) increases with concentration and variability. This imposes a cost burden on, for example, the semiconductor and electronic component industries and on the operation of high-pressure boilers. Therefore both the potential cost of metered water supply and the chemical composition of the supply waters may influence future decisions on the water company's area in which an industry may wish to locate.

Security of supply in relation to quantity is governed for surface and groundwaters by the granting of an abstraction licence by the Environment Agency (EA). The licence limits the total daily quantity and the rate at which the waters may be abstracted, taking account of the natural resource and the needs of other abstractors. Metered water supply is subject to contract with the water companies, who may impose quantity and draw-off rate limitations. The limitations imposed by the licence or contract may influence plant location.

With regard to surface-water abstraction the following additional points are worth noting:

- The character of surface waters can change significantly and rapidly throughout the year, and any process or cooling-water system should be designed accordingly.
- The higher the quality of the surface waters providing the supply, the more stringent will be the treated wastewater discharge consent standards imposed by the EA on effluents returned to the surface waters.

2.2.2 Trade effluent disposal

It will be seen from Section 2.2.1 above that industry is an intensive user of water. Almost all of this water produces a wastewater, requiring to be disposed as either domestic waste or trade effluent. Domestic wastewater is invariably discharged to the municipal sewers for treatment at the municipal sewage-treatment facilities by the water companies. The cost of this service is generally recovered by the water PLCs via metered charges or an allowance calculated upon the number of employees and losses from the aquatic environment.

Trade effluents may be discharged to the municipal sewers, to surface waters or on or into the land. Discharges to surface waters, including estuaries and coastal waters, or into the land are controlled by means of Consents to Discharge with the EA and Agreements with the water companies. Discharges to controlled landfill sites are by agreement with the EA. In all cases the Consents and Agreements will impose conditions on the quantity, rate of discharge and chemical composition of the trade effluents acceptable for discharge.

The quantity, rate of discharge and chemical constituent limits incorporated into the Consents and Agreements for surface-water discharges are set by the EA to prevent pollution and to meet the river quality objectives (RQOs) of the receiving waters. Limits on land discharges are set to protect groundwater aquifers. Currently, limits are imposed on organics, suspended solids, ammonia, toxic metals, pH and temperature in the trade effluent discharges. The actual limits on each of these constituents take account of available dilution, the surface or groundwater use and the impact of other dischargers. The limits can therefore vary significantly between discharge locations. Nevertheless, the constraints imposed by the EA on discharges to surface waters and to land are generally considerably more stringent than those imposed by the water companies on sewer discharges. Impending and future EU directives on environmental protection and drinking-water standards may not only reduce the constituent acceptance limits but also extend the list of constituents constrained.

Disposal of industrial effluents to controlled landfill sites is generally confined to slurries and sludges. The quantity and composition of the wastes acceptable for disposal is controlled by licences issued by the EA.

The quantity, rate of discharge and chemical constituent limits incorporated into the Consents and Agreements for discharges to the sewerage systems are set by the water PLCs to protect the health of sewer and treatment plant personnel, the fabric of the sewers and the operation of sewage-treatment processes. The constraints take account of the hydraulic capacity of the sewers and the treatment works, the organic and solids-handling capacity of the treatment works, the ultimate disposal route for sewage sludge and the needs of other trade effluent dischargers. In addition to limiting the concentration of specific constituents, including those mentioned for surface-water discharges, materials which could be dangerous to the

health of sewer workers are prohibited from discharges. Also, the water companies are obligated to inform the EA of the presence of any chemical included in a 'Red List' of some 30 chemical constituents in a trade effluent before the effluent can be granted a Consent to Discharge. The EA have the powers to prohibit or limit the concentration of any of these chemicals in effluents discharged to municipal sewers.

Municipal sewage-treatment effluents discharge to surface waters and are subject to the same EA control on quality and quantity as independent industrial surface-water discharges. Any tightening of EA Consent standards may therefore result in more stringent controls on industrial effluents discharged to sewers.

The significance of these industrial effluent disposal options on the location of an industrial plant is essentially cost. All the water PLCs levy charges on industry for the reception, conveyance and treatment of the industrial effluents. The EA often sets a charge for the consent that is normally volume related, which covers administration and monitoring/analysis costs. However, the cost of installing and operating treatment facilities, including sludge removal, to achieve and maintain the Consent standards can be considerable. The cost of treatment escalates significantly with increasingly stringent treated effluent standards. The actual cost of this disposal route will, of course, depend on the quantity and character of wastewaters generated by a particular industry in addition to the treated effluent standards to be met. The conditions imposed in the Consents to Discharge could therefore influence the location of an industrial plant adopting a surface-water or land-disposal route for its effluents.

In addition to the treatment costs, it should be remembered that provision of treatment plant occupies site space which may be more profitably used and that the penalties for infringements of the consent standards are increasing.

The cost of depositing waste on controlled landfill sites was relatively cheap but is getting more expensive. However, the expense of road transport to suitable sites generally limits this disposal route to relatively low-volume applications.

The cost of industrial effluent disposal to the municipal sewers is based on a 'Polluter Pays' policy, which takes account of the quantity and pollution loads in the discharge. All the water PLCs calculate their trade waste charges in accordance with various modifications of the Mogden formula given below:

$$C = R + V + \frac{(O_t)B}{O_s} + \frac{(S_t)S}{S_s}$$

where

C = total charge for trade effluent treatment (p/m^3),
R = reception and conveyance charge (p/m^3),
V = volumetric and primary treatment cost (p/m^3),
O_t = the chemical oxidation demand (COD) of trade effluent after one hour settlement at pH 7 (mg/1),
O_s = COD of crude sewage after one hour settlement (mg/l),
B = biological oxidation cost (p/m^3) of settled sewage,
S_t = total suspended solids of trade effluent at pH 7 (mg/l),
S_s = the total suspended solids of crude sewage (mg/l),
S = treatment and disposal of primary sludges generated by the trade waste (p/m^3).

However, all of the functions in the formula, excluding the trade effluent functions O_t and S_t, are different for each of the water companies and are reviewed annually. Therefore the unit costs of charges vary between the companies. Currently the unit costs for treating a trade waste equivalent to domestic-strength sewage range from 35.63 – 84.19 p/m^3 As with the water supply there are different tariffs for trade effluent charges. Subject to other commercial considerations, the cost of trade waste charges could influence the water company area in which to locate an industrial plant. The conditions imposed in the Consent to Discharge could influence the location within an area most beneficial to plant location.

2.2.3 Electricity

Previous considerations concerning the purpose engineering of the facility will have established the size and characteristics of the electrical load in terms of consumption and maximum demand. These will be essential data with which to enquire of the electricity authority as to the availability of an electrical supply.

Generally, there will be no insurmountable difficulty in obtaining an electrical power supply, the principal factors being the cost of providing it and the time delay in making it available. The scale and nature of the project will dictate the amount of power required, the load characteristics and the most suitable voltage for its supply. The state of the public supply network in the area of the proposed development will then constrain the supply authority in its ability to quote for a suitable supply in the short, medium or long term.

A relatively small power demand at low or medium voltage in a built-up area might be provided in the short term by teeing from an existing main feeder in the locality, or providing a radial feed from an existing substation. If the load is large or remote from the existing supply network, or if the local network is fully loaded, then a new incoming supply brought from a distance might be a medium- to long-term project, with time and cost dictated by legal wayleave considerations as well as the technical aspects involved. It is therefore necessary to make the earliest possible approach to the relevant electricity supply authority to establish the availability and cost-environment situation, as this may influence the initial engineering and planning factors to be accounted.

Two other areas that need more consideration are computer installations and harmonics. Because of their application to process plant control systems, computer installations often require un-interruptible power supplies, which will safeguard the control of process parameters and product quality and safety should the power supply fail. The increasing application of variable speed drives to mechanical plant, requires that consideration is given to the production of harmonics and their influence on the

power supply and other electrical equipment within the plant.

2.3 Ecology and pollution

2.3.1 Introduction

Urban, rural and industrial developments may have profound effects on the surrounding environment. Such effects can defeat the object of development, in that the disbenefits may outweigh the benefits. In the case of natural resources, inappropriate development may even destroy the resource base. However, if environmental matters are accorded adequate consideration during the planning and management of development programmes and projects it is possible for pollutants to be assimilated, and the whole development to be accommodated by the environment in such a way that adverse effects are minimized and the economic and social benefits of development are maximized.

2.3.2 Baseline studies and modelling

The basic requirement of any precommissioning environmental study is information on the existing state of the environment prior to any new development. Where such data are not already available, baseline studies must be carried out. Essentially, such studies are designed to provide baseline data from which the physico-chemical and ecological effects of development may be assessed and against which changes due to development may be measured after commissioning of the project.

Many computer programs are available that are often used to develop these studies and to prove to the enforcement agencies the predictions for current and future pollutant dispersions and loadings. There are a number of proprietary stack discharge programs (e.g. AERMOD) that can calculate the ground-level concentration of pollutants at various distances from the stack and plant. The same can be applied to the liquid environment where programs (e.g. ISIS, MIKE) can be utilised to predict thermal, physico-chemical behaviour in the receiving water systems, i.e. rivers and estuaries. It is very important that the most appropriate program is used and experienced operators use the application. By use of these modelling tools, emission control equipment and waste-treatment plant can then be designed to meet any local or in-house and corporate standards for ambient air and water quality.

2.3.3 Environmental standards

In some parts of the world the need to exploit natural resources is so urgent that it has preceded the formulation of adequate environmental controls. The pace of natural resource exploitation and the growth of associated industries has overtaken the evolution of institutions which would have the authority to exert such controls.

The problem has been recognized by many of the developers concerned, who have consequently themselves adopted the environmental standards of other industrialized nations. In the absence of national controls this is a responsible and laudable approach. However, the piecemeal adoption of standards taken from elsewhere does not take account of local conditions. These conditions may either enhance or limit the ability of the environment to disperse and attenuate/assimilate pollutants (e.g. the occurrence of temperature inversions will limit the dispersion of air pollutants). Similarly, the use to which local resources are put may demand particularly high standards of environmental quality (e.g. the use of sea water or river water as the basis of potable water supply). The choice of standards must also take into account local practices and existing local administration.

At the plant level, in-plant monitoring of unique compounds and the modelling of plant conditions to develop appropriate working practices and internal environmental quality standards may be needed.

2.3.4 Environmental assessment

In the case of a large-scale development it may be desirable to combine several environmental services for a full environmental impact assessment (EIA). This is the process of examining, in a comprehensive, detailed and systematic manner, the existing environment (natural, built and social) and the development which it is proposed to place within it. By integrating the two, an objective estimate can then be made of the likely effects of the development upon the environment, including benefits and disbenefits. Special techniques may be employed to help identify or quantify these impacts (e.g. the use of interaction matrices, overlays, screening tests, checklists, etc.).

An EIA can be particularly useful in distinguishing the relative environmental impact of alternative sites, processes and strategies for industrial, rural or urban development. This essential environmental information, together with financial and political considerations, can then be used by decision makers to choose the alternatives which will provide maximum economic and social benefits with the minimum of environmental disturbance. Guidelines for assessing industrial environmental impact and environmental criteria for the siting of industry have been prepared for the United Nations Environment Programme.

2.3.5 Resource planning

Ecology studies employ information from all the other environmental sciences to draw conclusions about environmental change which will result from development. However, when the exploitation of natural resources is being planned, the nature of the ecosystem and its response to change are themselves the most important elements to be considered. Industrial developments need to be assessed in the context of their ecological setting to ensure that the proposed development, first, will be feasible within local constraints and, second, will not bring about irreversible and unacceptable changes to other essential parts of the ecosystem.

The activity of ecologists in resource planning has three forms: preservation, integration and conservation.

2.3.5.1 Preservation

In this case, individual new developments are designed in such a way as to preserve discrete ecological systems

which have been identified as of importance as 'life-support systems', as regionally/internationally important wildlife habitats or as sources of rare natural materials, etc.

2.3.5.2 Integration

In the case of development projects which are on a large scale (e.g. mining or dam construction) or which cover a considerable area, ecological planning attempts to achieve integration between the project and the ecosystem. The object is to ensure not only the continued functioning of the ecosystem as a whole but also those elements of the ecosystem which provide the development project with 'goods and services' (e.g. fuel, raw materials and the assimilation of waste).

Ecological planning in this context will help to avoid ecological disasters (e.g. excessive weed growth in stored water) and maximize the lifespan of the benefits derived from the development. It will be clear that this holistic approach to development has economic as well as ecological advantages.

2.3.5.3 Conservation

Where regional development is to be undertaken it is reasonable to adopt a positive ecological approach. This can begin with the formulation of a conservation policy with specific goals. These may include the conservation of individual animal/plant species or habitat types which are threatened by development. The goals will be met by a programme of conservation projects (e.g. the setting up of national parks, country parks or natural reserves). This positive approach to the ecosystem will not only benefit wildlife but will also create the opportunities for tourism and leisure, which are a vital adjunct to most development projects.

2.3.6 Environmental management

Once commissioned, even the best-planned industrial development requires monitoring and management to ensure that its operation continues to be environmentally acceptable. This applies equally to established industries. When unexpected environmental problems arise a rapid response is required to assess the cause and magnitude of the problem and to devise remedial measures.

2.3.6.1 Air pollution

Dusts produced by quarrying and fluorides emanating from oil refineries are typical pollutants which need regular monitoring. A range of portable equipment for the identification and quantification of toxic and other gases can be used on an *ad hoc* basis.

When unpleasant odours resulting from manufacturing processes or waste-disposal operations give rise to public complaints they should be identified and quantified prior to deriving methods of abatement. Such work is often innovative, requiring the design and fabrication of new equipment for the sampling and analysis of pollutants.

2.3.6.2 Water pollution

Consultants are equipped to monitor the quality of freshwater, estuarine and marine environments and can make field measurements of a variety of water-quality parameters in response to pollution incidents. For example, reasons for the mortality of marine shellfish and farmed freshwater fish have been determined using portable water-analysis equipment. Various items of field equipment are, of course, also employed in baseline studies and monitoring, respectively, before and after the introduction of new effluent-disposal schemes.

Where extreme accuracy is required in the identification of pollutants or in the quantification of compounds which are highly toxic or conservative, laboratory analysis of samples is conducted. Highly sophisticated techniques have, for example, been employed in the isolation of taints in drinking-water supplies.

2.3.6.3 Land pollution

As development proceeds, land is coming under increasing pressure as a resource, not only for the production of food and the construction of new buildings but also for disposal of the growing volume of industrial and domestic waste. The design and management of sanitary landfill and other waste-disposal operations requires an input from most of the environmental sciences, including geologists and geotechnicians, chemists and physicists, biologists and ecologists. Such a team can deal with the control and treatment of leachate, the quantification and control of gas generation, and the placement of toxic and hazardous wastes. This may be needed in designs for the treatment of industrially contaminated land prior to its redevelopment.

2.3.6.4 Ecological studies

The acceptability of some industrial and ephemeral development projects such as landfill or mineral extraction may depend upon an ability to restore the landscape after exploitation has been completed. As more rural development projects come to fruition, ecologists will become increasingly involved in resource management to ensure that yields are sustained and to avert the undesirable consequences of development. Some industrial developments and rearranged plant layout schemes will not be complicated, but when ecology studies are needed the employment of specialist consultants is recommended.

3 Industrial buildings

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3.1 Introduction

Industrial activity encompasses an enormous variety of operations, and industrial buildings provide the required protection from the external environment. Of necessity, therefore, they take many shapes and structural forms and may be composed of a variety of materials.

3.1.1 Procurement

Industrial buildings can be procured in one of three basic forms:

1. Specific design
2. 'Off the shelf'
3. Speculative.

3.1.1.1 Specifically designed industrial buildings

Many industrial operations will require buildings with a large number of specific attributes. Such requirements will include many of the following:

Location
Plan dimensions
Height to eaves
Column layout
Services provision
Drainage provision
Provision of cranes
Superstructure-imposed load capacity
Floor loading capacity (point load, uniformly distributed load, line load)
Floor flatness
Floor abrasion/impact/chemical/slip resistance
Access facilities
Loading/unloading facilities
Floor pits
Intermediate platform arrangements
Suitability for automatic guided vehicles
Suitability of environmental controls
Ease of cleaning
Corrosion resistance
Machine base availability
Sound insulation
Provision for future expansion.

Any one of the above may require a specific building to be designed and constructed due to the unsuitability of available facilities falling into the option (1) and (2) categories.

Apart from performance criteria, an industrial building might also be required to project a 'corporate identity' by a striking appearance. This generally requires a specifically designed facility.

3.1.1.2 'Off the shelf' industrial buildings

'Off the shelf' buildings are generally of set modular form designed to a standard set of criteria. The available degree of variation may be limited, but they are perfectly suitable for several industrial uses.

3.1.1.3 Speculative industrial buildings

These are often developed on new industrial estates with no particular tenant in mind. They may be quite adequate for general light engineering/warehousing/retail units. However, prospective industrial occupiers with any but the most basic general requirements are likely to have to spend considerable sums adapting the building to their needs, if indeed this is physically and economically viable.

3.1.2 Structural materials

The majority of industrial building superstructures are framed in structural steel, although a small percentage are in precast concrete. Steel is used primarily for its large strength-to-weight ratio, enabling it to span large distances economically. Steelwork is easily modified, which provides for a degree of adaptability not always available from concrete structures.

Ground slab and foundations are invariably reinforced concrete, though some ground bearing slabs are constructed with no reinforcement. Industrial buildings for containment of toxic of other processes may require construction primarily from reinforced concrete.

A dwarf wall of concrete, blockwork or brickwork is often constructed around the building perimeter to minimize cladding damage from forklift trucks, etc.

3.1.3 Structural form

3.1.3.1 Stability

Building stability can be provided by:

1. Framing action from rigid connections between columns and roof members;
2. Vertical cross-bracing or shear walls;
3. Columns cantilevering from foundations; or
4. A combination of these techniques.

Roof bracing may be required for rafter and purlin stability or load transfer to vertical bracing.

A roof diaphragm can also be provided by a composite concrete slab or a stressed-skin system, but the latter may severely restrict the provision of subsequent roof penetrations. Concrete roof slabs are unusual, due to the greatly increased mass over the more normal metal decking/insulation/waterproof membrane or insulated metal decking options.

3.1.3.2 Column layout

It is self-evident that fewer permanent obstructions within the perimeter provide a greater potential flexibility of operations. However, larger spans are bought only at the expense of structure.

Columns may also perform other functions, apart from roof support:

1. Support of intermediate-level platforms;
2. Restraint to partition walls;
3. Support for cranes/jibs;
4. Services (pipework, ductwork, etc.) support.

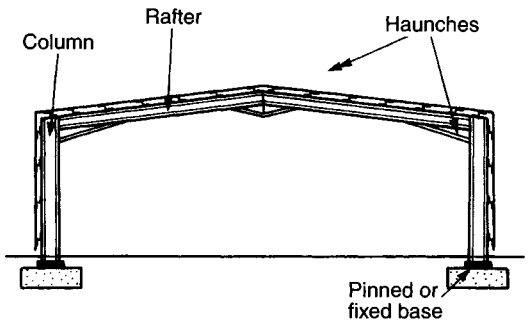


Figure 3.1 A typical portal frame

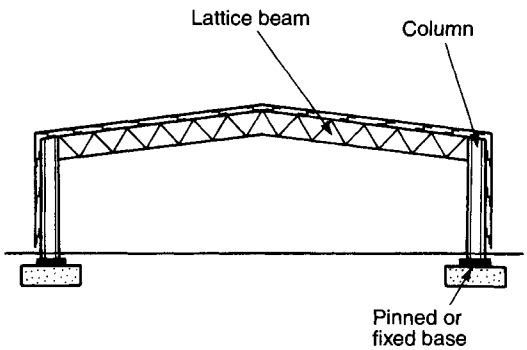


Figure 3.2 A typical lattice girder frame

3.1.3.3 Roof shape

Flat roofs Flat roofs are popular with architects due to their reduced visual impact. However, they generally require a much higher standard of waterproofing, and may be susceptible to ponding, moss growth and dirt/debris entrapment. Inevitably they also require internal downpipes for rainwater disposal.

Falls to gully positions may be provided by the natural deflections of the roof structure or small slopes to the roof steelwork (e.g. 1:40–1:60).

Pitched roofs Pitched roofs are typically sloped at a minimum of 6° to ensure the weather resistance of lapped sheeting without sophisticated seals or a waterproof membrane. Portal frames are also more liable to 'snap through buckling' at very shallow pitches. A pitched roof means a greater 'dead' volume to heat, although there is additional space for high-level services distribution.

3.1.3.4 Roof construction

1. *Flat roofs*
Typically, framing is achieved with:

(a) Universal beams (span < 15 m);
(b) Castellated beams (20 m > span > 15 m);
(c) Lattice girders (span > 20 m).

A recent development has been the practice of using site butt-welded, closely spaced, continuous secondary beams spanning over continuous primary beams and replacing the traditional purlins. Secondary spans of 20 m have been achieved with this method.

Other considerations include:

(a) Castellated beams may require reinforcement at high shear regions;
(b) Castellated and lattice beams provide a services zone within the structural depth;
(c) Lattice girders may be formed into V beams of triangular cross section.

2. *Pitched roofs*
Typically, framing is achieved with:

(a) Portal frames (Figure 3.1);
(b) Pitched lattice girders (Figure 3.2);
(c) Trusses (Figure 3.3);

Portal frames may be single-bay, multi-bay (Figure 3.4), propped, tied, or mansard with pinned or fixed foot. They may be composed of universal beams or tapered plate girders.

Trusses may be the best solution for very high imposed loads. Frame action with columns is not possible with trusses. Although trusses are generally the lightest form

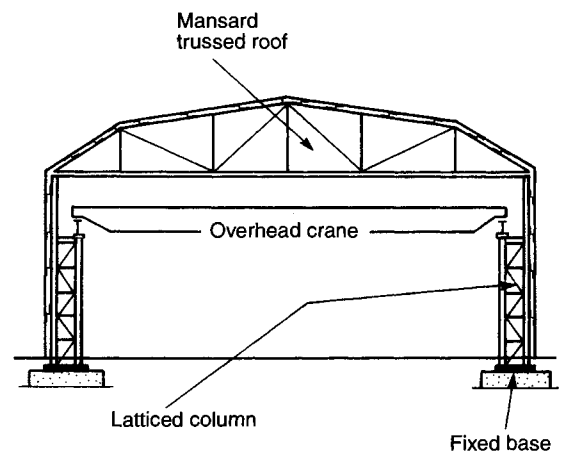


Figure 3.3 A typical trussed roof

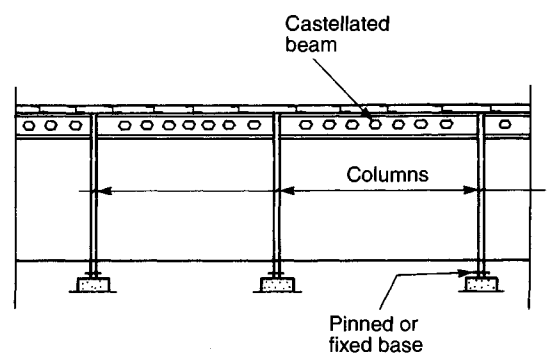


Figure 3.4 A typical multi-bay beam and post construction

of roof construction, they may be the most expensive due to high fabrication cost. A combination of lattices or lattice and truss may form a sawtooth roof profile for incorporation of northlights.

3. *Space trusses*
Substantial two-directional spans can be achieved by three-dimensional space trusses utilizing proprietary nodal joints. Typically, they are too expensive for normal industrial buildings.

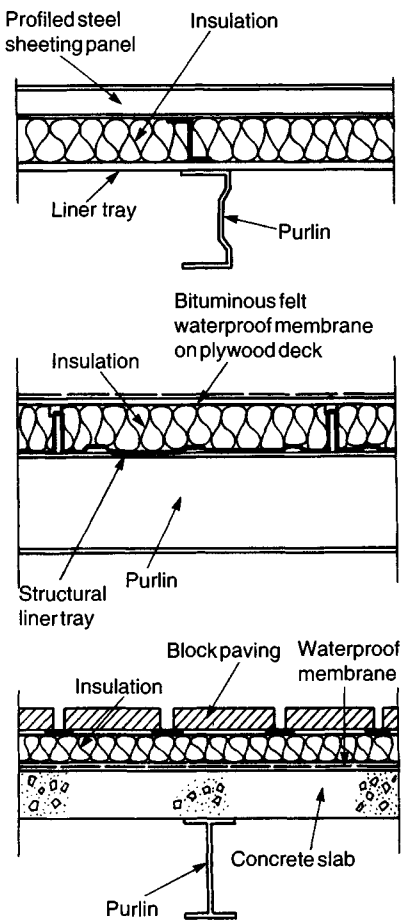


Figure 3.5 Typical roof constructions

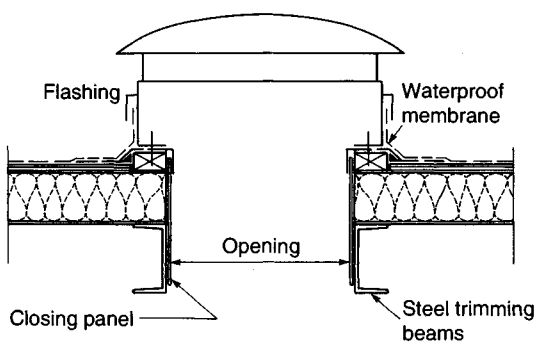


Figure 3.6 Typical roof penetration

3.2 Specifying an industrial building

Many industrial buildings, and industrial projects in the broader sense, are completed entirely to the owner's satisfaction in terms of the key criteria of time, cost and quality. It is also true that many are not. There can be various reasons for this, some related to the nature of the construction industry in general, some to the performance of professional teams and others related to the manner in which the project was initially set up. The most common cause of problems with the finished product is the way in which the owner's requirements were specified, and this extends to include the selection of the project team.

These problems cannot always be attributed to the owner. An industrial client is not usually a regular developer of buildings, which are, in most cases, secondary to whatever process or production facility he wishes to construct. He is, after all, not engaged in the construction industry on a day-to-day basis. He should be entitled to expect good advice from the team he appoints, and to expect them to 'ask the right questions'. But whatever the project, and however limited the owner's resources, it is vital that he is able to provide the necessary input to ensure that he gets what he wants.

We are not concerned here with contractual issues, nor with questions of responsibility. What follows is a set of practical guidelines which seek to address the main areas where problems can arise.

3.2.1 Procurement

From the time when the owner decides that a project is desirable there are many approaches to the procurement strategy, ranging from a conventional set-up with consultants/contractors right through to a complete 'turnkey' arrangement. There is no right or wrong way of proceeding, and it is difficult to generalize, but it is true to say that the turnkey (or design and build) approach is most likely to succeed where:

1. The owner's requirements are clear, simple, and unlikely to change;
2. The owner is unable to allocate much time to the project;
3. The owner does not require direct control over all the participants in the design and construction process.

In other cases, where perhaps the requirements are ill defined, or there is concern over some particular aspect of the project, it may well be more appropriate to have the project designed and/or managed by independent professionals. For example, most industrial building projects are best suited to an engineer-led approach. If, however, the owner is particularly concerned about the architectural aspects of the scheme, he may prefer to make his own selection and appointment of an architect.

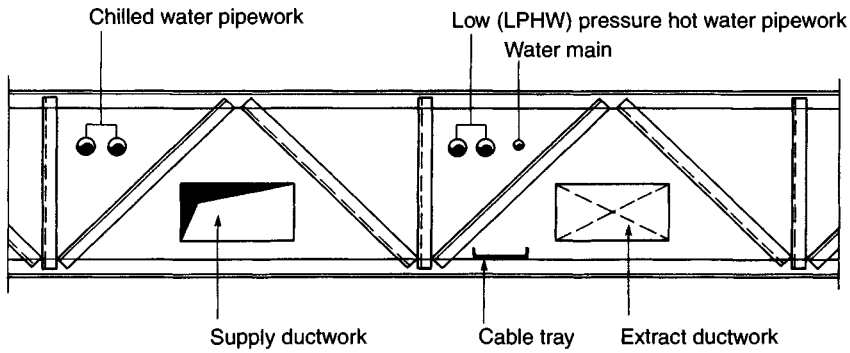


Figure 3.7 Typical services coordination through a lattice girder

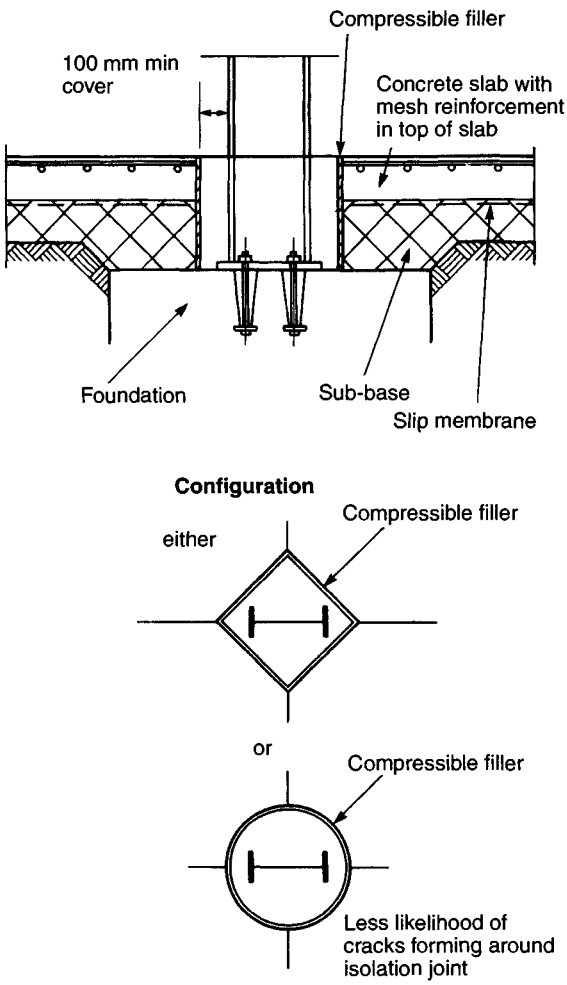


Figure 3.8 Isolation joint at foundation

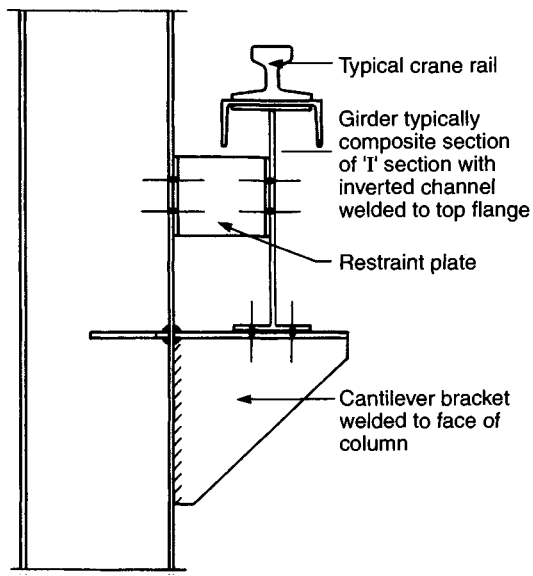


Figure 3.9 Crane gantry girder

Whichever approach is adopted, the owner must be sure that he has considered those issues most important to him and has set up the project in a way that gives him the level of control he wishes to exercise. He should also take care to ensure that the team involved has adequate experience, not only of the type of project under consideration but also of the approach being adopted.

3.2.2 Budgets

The construction industry has a poor reputation in terms of cost control, and tales of budget overspends are legion. This is often attributed to deficiencies in the industry and among the professionals who work within it.

Whoever is to blame at the end of the day, the problem can often be traced to the fact that the initial budget was unrealistic at the outset. To set an inadequate budget, watch it overrun, and then look for a scapegoat may have become common practice but it achieves nothing.

It is therefore absolutely vital that a sensible cost plan be prepared and agreed at the earliest possible stage. Obviously, an owner will prepare rough budgets when considering basic project viability, but as soon as

he is able he should obtain advice from his selected team.

Good professionals will not simply agree with the rough budget already prepared. They will give objective advice, including the level of confidence in the estimate and an assessment of the likely effects of changes to the specification, so that a realistic view can be taken by the owner. It is better to recognize the problem immediately, and modify the scope or specification to suit, than to be forced into late changes or even omissions which reduce the effectiveness of the finished project.

3.2.3 Specification

The level of briefing which an owner can give is variable, depending on his resources and his detailed knowledge of building or facilities requirements. The most important point here, however, is clarity. The brief may have to be simple, but it must be clear – and it must also be clear who has the responsibility for developing it.

The best way to ensure controlled development of the brief, and of the cost plans which necessarily accompany it, is to set up a system of data sheets which define, in increasing detail as the project develops, the spatial, functional and servicing requirements of each component part of the project. A well-resourced technical client may wish to do this himself. More commonly, it is a task which should be entrusted to the design team. Whoever does it, regular joint review of this information will help to ensure satisfaction with the finished product.

3.2.4 Schedules

Much of what has been said about budgets applies equally to the project programme. It should be realistic from the outset – again independent professional advice should be sought.

Modern 'fast-track' techniques of design and procurement have taken all the slack out of the traditional methods, and this is generally to the benefit of all concerned. There is a price to pay, however, in terms of flexibility. The owner, and his design and construction team, have to work within a discipline in respect of changes; programmes and budgets are very vulnerable to changes in this environment. This relates very closely to the earlier comments on clarity of briefing and information flow.

3.2.5 Procedures

Having decided on the appropriate way to proceed with the project, the owner needs to satisfy himself that adequate systems and procedures have been put in place to give him the necessary control and confidence in the project. These will, of course, vary considerably from owner to owner and project to project, but certain key points are worth remembering.

There is a clear need for the owner to appoint a single project officer. He may well be part-time as far as this activity is concerned, and will often need to draw on the expertise of others in his own organization. However, a single point of contact between the owner and his project team has been shown to be a vital ingredient in successful projects. Of equal importance is the need for regular reviews to ensure that things are going to plan. It is also necessary to have an agreed mechanism for change control, since once a project is under way, particularly if, as is usual, it is being run to a tight programme, any changes are likely to have an impact on both programme and budget.

The theme running through the above is that the key ingredient is clarity, both in specification and organizational terms. This does not need to mean a major effort or input on the part of the owner, but rather careful consideration, at an early stage, of what is actually required.

If what is required is unclear at the outset, then it is wise to say so, and allow for that fact in the development of budgets and programmes, rather than to pretend that the project is fully specified and suffer the consequences later. An industrial client, like any other, will get what he pays for; but he also needs to ensure that he gets what he needs.

3.3 Security

3.3.1 Objectives

The object of all security systems is to guard the company against loss. The principal risks that are faced include:

1. *Criminal action:* This may include robbery, vandalism, fraud and industrial espionage.
2. *Direct damage to assets:* This may be caused by explosion, rainwater ingress and fire. The level of security is dependent upon good building details and the fire-suppression system used.

3.3.2 Criminal action

This section will consider the options available to deal with criminal action. There are several levels of security. The higher the level of security, the greater the cost. This expenditure will relate not only to the capital cost of the security system but also the restriction that is placed upon the efficiency of the employees. In planning a security system it should be recognized that no system can guarantee detection of, or immunity from, intruders. The purpose of a system is to confer on the property or persons at risk a level of security that, through careful planning, is in balance with the degree of determination and expertise of the intruder. In making this evaluation, all physical circumstances of the risk need to be assessed. However, the degree of security decided upon has to be consistent with a system which is, in every sense, practical and reliable and which cannot become an unacceptable burden to the general public or police.

Furthermore, the cost of the security system must bear a relationship to the risk, particularly since an increase in the cost of a system does not necessarily cause an increase in the level of security. Cost effectiveness should be of prime consideration.

In planning a security system its requirements should be ascertained as accurately as possible by consultation between appropriate interested parties, which may include one or more of the following:

1. The insurers
2. The local police authority
3. The Health and Safety Executive
4. The local public authority
5. The customer
6. Any statutory regulations
7. Consultants
8. Security companies

In assessing how to apply the requirements of a security system the following items should be considered both individually and collectively:

1. Physical barriers and deterrents
2. Electronic detection systems
3. Security patrol and guarding
4. Controlling entry and egress
5. Employee awareness, procedures and training
6. Local, remote and delayed alarms.

All parts of the security system should interact with each other to form an integrated whole.

3.3.3 Layers of protection

The security system can be considered as layers of protection. Physical barriers and deterrents constitute not only the building structure itself, made up of walls, doors, windows, floor and a roof, but the yard around the building and probably a perimeter fence or wall.

Electronic detection systems may range from simple intruder-detection devices monitored by basic control units to a variety of complex systems monitored by sophisticated computer-operated controls linked to 24-hour manned stations. Intruder-detection devices can be arranged into the following groups:

1. Static detection devices
2. Movement-detection devices
3. Trap and object devices

Static detection devices would include the following:

1. Tube and wire frames are used to protect windows, skylights and similar glass areas and constitute a high level of security but may be aesthetically unacceptable.
2. Aluminium foil is used to protect windows and glass doors. Although usually acceptable, this is subject to tampering if accessible to the public.
3. Break-glass detectors detect the high frequencies produced when glass is broken or cut with a glass cutter. These are the most cost-effective methods of glass protection in most cases and are especially suited to areas accessible to the public.
4. Vibration sensors are similar to break-glass detectors but are fixed to walls and doors against violent attack. The structure to which they are fitted must not be subject to vibration from external sources, otherwise false alarms may result.
5. Closed-circuit wiring comprises plastic-covered single-strand wire strung at regular intervals across doors, walls and ceilings. This is prone to failure in damp conditions and is mainly used in high-security buildings.
6. A pressure pad, also used as a form of trap protection, is a flat rectangular, plastic-covered contact placed at strategic points underneath a carpet.
7. Magnetic reed contacts are glass-encapsulated magnetically operated reed switches used on doors and windows. The contacts can be overcome by cutting the door, leaving the magnet undisturbed.

Movement-detection devices are designed to detect the movement of an intruder in the interior of the building:

1. Beams of invisible infrared light shone across an opening will detect movement that breaks the beam. Although relatively cheap, beam devices are easily recognized and avoided, and therefore constitute low security.
2. Microwave movement detectors utilize the principle of the Doppler effect on high-frequency low-power radio waves. These units are moderate in cost and suitable for large-volume coverage. Microwaves, however, penetrate certain materials easily, such as plasterboard, and careful siting is required to avoid false alarms.
3. Ultrasonic movement detectors utilize the principle of the Doppler effect on high-frequency sound waves. Ultrasonic movement detectors do not penetrate solid objects, but have smaller volume of coverage than microwave movement detectors. These units may also be affected by moving hot or cold air pockets in a room.
4. Passive movement detection senses radiated heat, such as that from a human body. These units are also sensitive to heat emitted by radiator, convection heaters and direct sunlight, so that careful siting is required.
5. Dual-technology detectors combine two of the techniques described above, except for beams, and provide good rejection of unwanted alarms.

Trap- and object-protection devices provide protection to an area and object within a building and should never be used on their own:

1. A contact on a safe will recognize attack by drilling, sawing, filing, explosions and oxyacetylene or thermic lance.
2. CCTV cameras are very expensive and require a manned station, but with careful siting and the latest technology, they can see in moonlight and can set off alarms when picking up motion.

Security patrol and guarding is only satisfactory if properly managed and controlled with trained guards and complemented by electronic detection and monitoring equipment. The guards would generally be available to react to the unexpected, and should be well briefed as to responsibility and how to obtain help as well as how to deal with any type of unexpected situation.

Controlling entry and egress can be very useful for ensuring that only authorized people have entered the secured area as well as identifying who is actually in the building in an emergency situation such as a fire. There are several methods of controlling entry and egress, some of which are listed below:

1. *Guards:* These are probably the least efficient, primarily because of the human element. However, there are obvious psychological strengths to human presence.
2. *Mechanical key system:* This provides a basic level of security for heavily used areas. Although complicated mechanisms can be designed, their operation is slow, and hence are suitable only for limited access.
3. *Magnetic card systems:* These are very good for busy areas and can be made very difficult to forge. The level of security can be increased, at the expense of efficiency in busy areas, by incorporating the necessity for a PIN number.
4. *Automatic systems:* These require no direct contact between the user and the device reading the code. They provide a high degree of convenience in use.

For high-security buildings it is imperative that employees are made aware not only of the need for security but also what procedures have to be followed and instructed on basic security awareness.

The type of alarm system used is dependent on the expected type of security breach and the method employed in responding to one. In unguarded premises, requiring only a low level of security, an alarm which operates immediately a device detects a security breach may be sufficient to ward off vandals, burglars and crimes of opportunity. On the other hand, where breaches of security may involve more determined criminals, such as fraud or industrial espionage, delayed alarms on the premises may give time for security personnel and/or police to apprehend the criminal in the process of committing the crime.

3.3.4 Reliability

No alarm system, however well planned and installed, can be completely reliable or tamperproof. The successful operation of a security system requires the active co-operation of those involved in carrying out the necessary procedures carefully and thoroughly. The usefulness of the whole system can be jeopardized by lack of care or inadequate attention to routine procedures in maintenance and servicing. This care has to be extended to the security of keys and of information regarding the system, its installation and method of operation.

3.4 Leases

3.4.1 Relationships

The relationship of landlord and tenant is created by a lease, whereby the landlord grants a portion of his interest in the land and allows the tenant to occupy and enjoy that land for a period or term usually in return for a monetary payment called rent. The relationship is governed by the law of landlord and tenant, which is covered by common law dating from feudal times and beyond, and, more importantly, statute law. The statute law is updated and revised by successive governments and legal advice should be sought when drafting or entering into leases.

3.4.2 The preparation of a lease

A lease or contract of tenancy can be verbal but is usually in writing, as there is the possibility of misunderstandings and thus disputes. In some cases this is overcome by a deed which sets out the conditions of the letting. This is a contractual document which is made by indenture, i.e. in two parts. One part, called 'the lease', is signed and sealed and delivered by the landlord to the tenant while the other, called 'the counterpart', is signed, sealed and delivered by the tenant and handed to the landlord. The two are identical and, being legal documents, use formal words such as 'lessor', 'lessee', etc. and generally commence with the words 'This lease' or 'This indenture'.

The lease by deed sets out the conditions of the letting in a formal manner and should include:

1. Generally, the description of the property;
2. The names of the parties;
3. When it is to commence and how long it will last;
4. The covenants which consist of promises and agreements by the landlord and tenant to do or not to do certain things;
5. The rent that is to be paid;
6. Any exceptions and reservations which the landlord wishes to retain;
7. The conditions showing how the term may be ended, extended or created (which may include implied conditions);
8. The provisos, which are any express conditions.

The deed is dated, signed, sealed, witnessed and delivered and operates by the devise of the landlord's interest in the property to the tenant.

The understanding of these constituent parts of the lease is very important, and they should be read very carefully. Expert advice should be sought for a thorough understanding of them.

3.4.3 Covenants

Covenants may be express or implied, i.e. those expressly written into the lease in a deed and those not expressed but implied in a deed by law in order to give effect to the intention of the parties or to remedy an obvious omission. Express covenants could be:

1. To pay rent;
2. To pay rates and taxes;
3. To repair and keep in repair;
4. To paint/decorate within certain times;
5. To insure and produce receipt of insurance;
6. To permit the lessor and his agents to enter and view;
7. Not to alter the structure;

8. Not to assign or sub-let;
9. To yield up at the end of the term.

Implied covenants could be implied into a lease by common law or by statute, and in the case of the latter cannot easily be varied or excluded by agreement between the parties. Some examples of covenants by the landlord are:

1. That the landlord has good title and therefore to give possession of the date fixed for commencement of the term;
2. To give the tenant quiet enjoyment during the tenancy;
3. In the case of furnished premises to ensure at the commencement of the tenancy that the premises are fit for human habitation.

3.4.4 Rent

Land is granted by a landlord to a tenant for a variety of purposes, and several names are given to the 'rent' due from the tenant to the landlord. Premises for occupation are generally let at a 'rack rent' which is assessed upon the full annual value of the property, including land and buildings, the 'best rent' being the highest rack rent that can reasonably be obtained for the whole lease.

Sometimes land and buildings are let on a long lease to a tenant who proposes to sub-let on short terms such as weekly or monthly tenancies. In this case, the rent paid on lease is less than the rack rent, and is called a head rent.

When land is let for construction it is usual for a 'peppercorn rent' of no actual value to be agreed while the houses, etc. are built. Although cases do occur where a peppercorn rent is received throughout a long lease it is more usual for a 'ground rent' to be charged. This is less than the rack rent, usually because a premium has been paid at the start of the lease. Ground rents are much higher than peppercorn rents and may include increases during the lease.

Rent is due on the days appointed for its payment in the lease, and unless the lease expressly provides for rent to be paid in advance it will be payable in arrears.

3.4.5 Reviews

Many leases, especially business leases, contain rent-review clauses which provide for regular reviews at, for example, three-, five- or (more usually) seven-yearly intervals. A clause will define rent-review periods and set out the formula and machinery for assessing the rent in each period.

3.4.6 Assigning and sub-letting

Any tenant who has not contracted to the contrary may sub-let his land (or part of his land) for any term less than that which he holds. A sub-letting is therefore distinguished from an assignment in that a tenant who assigns, disposes of the whole of his interest under the lease (and thereby puts the assignee into his place), whereas a tenant who sub-lets does not.

3.5 Obtaining approval to build

When contemplating the construction of a new industrial building or alterations to an existing one the statutory requirements and the powers available to the authority responsible for issuing approval should be taken into account. The exact procedures will, necessarily, be dependent upon the location (i.e. district and/or country) and the type of industrial building proposed. The approval process in the UK can, however, be divided into two stages. These are to obtain:

Planning approval
Building control approval.

We shall consider each stage in the context of general requirements. The standard and detail needed to obtain approval is contained within statutory documents that can be obtained from the relevant authority.

3.5.1 Planning approval

Obtaining planning approval provides permission to build and, more importantly, justification to pursue the preparation of detailed plans and documentation necessary for building control approval. Planning permission prior to detailed design of the building is not a requirement, but rejection of planning submission would probably render the design useless.

The authority granting permission to build will depend upon the type and size of building. Major projects, such as nuclear power stations or large industrial complexes, may involve a public enquiry and the need to produce a study into the environmental impact. Generally speaking, though, the planning submission will be considered by a committee nominated by the local authority.

The following is a list of items that could (and would usually) form the basis for a planning submission:

1. Site location
2. Building footprint
3. Height
4. Use of building
5. Aesthetic appearance
6. Utility requirements (e.g. gas, electricity, etc.)
7. Employment requirements
8. Traffic/highways implications.

An awareness of the Structure Plan and Local Plan policies (10 year plans to guide development at regional/local levels) and national planning guidance are essential at this stage of the project.

3.5.2 Building control approval

The majority of new build, alteration and extension projects will have to comply with statutory requirements relating to the health and safety of building users, conservation of energy and access and facilities for disabled people. Detailed documents have to be produced which demonstrate how the proposals achieve a number of functional requirements and any local legislation specific to a particular building use.

In the UK, the Building Regulations are the primary means of controlling building work. Plans can be assessed and the work inspected either by the Local Authority or a private Approved Inspector. The requirements cover the following areas:

Structure
Fire safety
Resistance to weather/groundwater
Ventilation
Sanitary accommodation
Drainage
Heat producing appliances
Stairs, ramps and guarding
Conservation of fuel & power
Access & facilities for disabled people
Glazing safety

Each functional requirement related to the above is accompanied by an 'approved document' which describes ways of achieving the minimum necessary standards, together with alternative approaches, which are usually by following British Standards and their international equivalents.

It should be noted that the building owner is ultimately responsible for the work complying with the appropriate regulations and failure to achieve this, or to notify the inspector of certain stages of work, is a criminal offence.

3.6 Extending existing buildings

3.6.1 Viability

The extension of existing facilities can often present an attractive alternative to relocation, with all its attendant disruption and potential impacts on production, industrial relations and morale. However, the viability of extension is predicated on the consideration of various strategic and tactical issues:

1. Land availability and location in relation to existing buildings;
2. Nature of activities proposed in extension (e.g. linear, cellular, storage, bulk process, administrative, etc.);
3. Topographical and geotechnical conditions;
4. Existing structures (their condition, type of construction, etc.);
5. Infrastructure and services such as roads, telecommunications, water, foul and storm drainage, gas, power, etc., location, routing, capacity (used and spare), state of repair, etc.;
6. Local and statutory authority issues (e.g. planning, building control, service tariffs);
7. Environmental concerns (effluent treatment, noise, etc.).

3.6.2 Facility brief

Once the primary considerations of size, height, conceptual layout, structural loads, servicing (mechanical, electrical, communications, public health, statutory services) requirements, access, material and personnel traffic, etc. have been addressed, a facility brief can be produced to allow collation of the basic project planning information:

1. Scheme, site plan, layouts and elevations including infrastructure modifications;
2. Basic plant services;
3. Budget costs;
4. Tentative planning assessment;
5. Preliminary project programme.

These items should be formulated against optional approaches, each option being tested against one another (and rated accordingly) on the basis of:

1. Capital expenditure, cash flow and operating cost analyses;
2. Impacts on existing operations (productivity, quality, personnel, etc.);
3. Project-completion times (including the options for phased completion);
4. Comparison of operational, spatial, servicing simplicity, internal environmental performance (daylighting, thermal transmittance, acoustic break-in/out, etc.), parameters between options.

The adoption of the best option should be based on all these parameters.

3.6.3 Other considerations

Many extraneous and site-specific considerations may have to be taken into account. Certainly, the construction and layout of existing facilities will play a major role in deciding the basic choice of location and configuration of extensions.

Particular attention should be paid to existing site arrangements, bay widths, material handling, foundation design and construction methods. For instance, it may prove impractical to extend the bays of a traditional steel-framed lightweight structure if the impact on road rerouting, statutory services extensions, substation requirements or other existing facilities seriously affect the overall cost or programme time.

Equally, the most logical (and least externally disruptive) extension method may conflict with desired material handling or work flow requirements. Generally, economic bay widths should be adopted (typically *c.* 15 m), if possible. Roof design should be adapted to accommodate roof-supported plant and services while minimizing steel tonnage. The integration of daylighting, service routes, cranage, etc. should all be early design issues, solved during the evolution of the basic structural design.

Attempting to modify structure or services to accommodate structural idiosyncrasies later is always problematic. Protection and isolation of existing facilities from the disruption of construction should be resolved early in the design. The reconciliation of building and production activities is never easy, but early planning for construction traffic, personnel, site screening, security, site access and site communications can minimize these adverse effects.

Where existing buildings are of an age which would indicate that their design and construction were performed in accordance with statutory requirements,

planning, building control, standards or codes of practice subsequently superseded, care must be taken to ensure that extensions to such facilities are designed and constructed in accordance with *current* requirements.

3.6.4 Re-use of materials

The re-use of materials, components and installations is seen as an environmentally benign and potentially cost-effective means of construction, but the process of ensuring their fitness for purpose, or altering them to achieve current standards, may negate many of the benefits. Examples of issues that must be considered are:

1. Physical damage and deterioration
2. Proscribed materials
3. Thermal performance
4. Reaction to fire
5. Compatibility with other materials and components
6. Demonstrating fitness for purpose/compliance with current standards
7. Durability/life expectancy
8. Insurer's requirements

3.7 Fire protection, detection and suppression

3.7.1 Fire Regulation

Statutory control over fire safety matters is shared between the Building Control body (who carry out a generic risk assessment through the Building Regulations) and the Fire Authority, who control fire risks and fire safety management through the Fire Precautions Act, 1971, and the Fire Precautions (Workplace) Regulations, 1997. Under the latter, the operator or manager of the building is required to carry out and record the results of a fire risk assessment of the premises and processes for which they are responsible.

The primary objective of these controls is the preservation of life. A building may achieve this by means which do little to protect the building itself and its contents. Early consultation with the insurers will ensure their requirements are met, and any benefits of additional fire precautions are fully recognized by statutory bodies.

3.7.2 Passive and active measures

In general, the fire resistance of a building will be related to its use, height of the top storey and the fire compartment size. In some circumstances, the installation of sprinkler protection or further sub-division of the building into smaller compartments can reduce the fire resistance period.

In all but the very smallest of premises, an automatic fire detection and alarm system will be necessary, which can be used to compensate for 'inner room' situations and may allow some flexibility in means of escape travel distances.

Establishing the appropriate levels of passive and active measures can be very complex. It is likely to be unwise (and incompatible with statutory and insurance needs) to rely entirely on either one. The correct balance will be appropriate to the hazards involved without impacting excessively on the processes carried out or the building management.

More detailed guidance on these issues can be found in Chapter 8.

3.8 Cost comparisons and contract procedure

Building costs per square metre for the construction of new buildings can readily be obtained from reference books such as *Spon's Architects' and Builders' Price Book* and *Laxton's Building Price Book*. Both are updated and issued on an annual basis, with the costs quoted based on the previous year's statistics.

The costs given are for a range of prices for average building work obtained from past records, and can vary by as much as 50% between minimum and maximum costs. They serve therefore as an initial rough guide to the probable cost of a new building. *Spon's* also gives details of fitting-out prices within similar ranges, but these are generally limited to office fit-outs. The introduction to the sections dealing with prices per square metre in both books should be carefully studied before applying the figures to new structures or costing alterations/extensions to existing buildings on a pro rata basis.

As stated elsewhere in this chapter, it is of vital importance to assess the cost effectiveness of any proposed design (whether it be for a new building and/or alterations/extensions to an existing one) at an early stage. This can best be accomplished by seeking professional advice at the earliest opportunity. Such advice is normally provided by a quantity surveyor, who can work alongside the building owner and his engineers in assessing the cost of alternative designs/use of various materials/construction methods/construction times, etc. and evaluate the various proposals as the design develops. This will ensure that the most cost-effective solution is arrived at in the minimum time.

The correct selection of the form of contract to be used when inviting tenders is of paramount importance, as it constitutes the signed agreement between the employer and the contractor and forms part of the conditions of contract. The JCT (Joint Contract Tribunal) issue several different forms of building contracts while the Joint IMechE/IEE Committee on Model Forms of General Conditions of Contract (Institution of Mechanical Engineers/Institution of Electrical Engineers) have recently issued Model Form MF/1, replacing both the original Model Forms A and B3. Broadly speaking, the JCT forms are for General Building Works (from large contracts to minor contract) while Form MF/1 should only be used for works which are substantially of a mechanical or electrical nature.

3.9 Structural and services supports

When considering the introduction of supplementary structure for *any* purpose there are a number of general items of design data which must be examined and formulated:

1. *Support function:* What are the functional usage loads likely to be applied (Figure 3.10)?
2. *Existing conditions:* What are the existing spatial, civil, structural and access conditions within the facility? Typically, the following data should either be accessed from existing records and design requirements defined by the support function assessment or acquired by new site survey/investigations:
   (a) Ground conditions (soil-bearing capacity, water table, etc.) for ground-based support systems;
   (b) Existing construction elements; state of repair, materials, composition, bearing capacity, etc., allowable attachment methods, existing loading conditions;
   (c) Current access and people/materials flow in the area. Assessment of disruption, modifications to existing operations required both *during* installation process and *after* completion of installation.
3. *Alternative optional approaches:* Based on the constraints of space, cost, time, disruption, etc., what are the viable options? The following questions are pertinent when considering installation options:
   (a) Effects on facility downtime;
   (b) Use of proprietary, modularized systems;
   (c) Phased installation capabilities;
   (d) Cost comparisons;
   (e) Capabilities for later expansion;
   (f) Consolidation of support functions (e.g. multiple service gang hangers, access/personnel safety features (Figure 3.12)).
4. Where possible the 'best option' solution should provide the optimum mix of:
   (a) Cost effectiveness;
   (b) Personnel safety;
   (c) Minimum impact (downtime, disruption, structural alterations, ease of installation, etc.);
   (d) Expansion capability;
   (e) Multiple use;
   (f) Fitness for purpose;
   (g) Off-the-shelf materials, devices, etc.

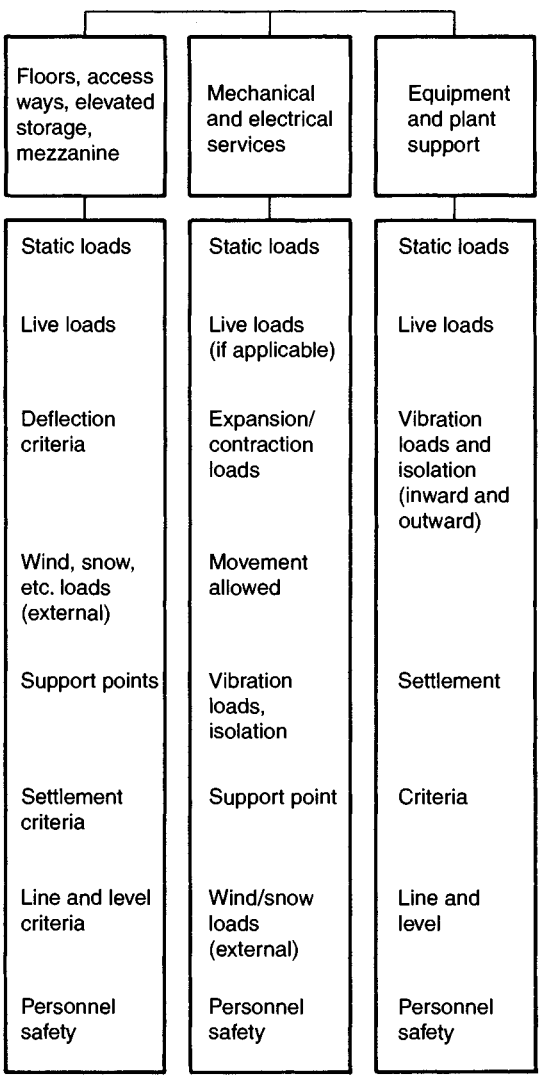


Figure 3.10

While the statements made above are necessarily general, it is essential that the conceptual approach delineated be adhered to. The necessity for compiling adequate design data for the new installation, followed by examination of existing conditions against the design requirements, is paramount.

In many instances, adequate existing civil/structural or services installation information may not be available. Guessing the likely bearing capacity of floor slabs, foundations, structural steel or sub-slab ground, etc. can prove disastrous. Equally, assuming likely operational conditions for new installations can lead to embarrassing (and quite possibly dangerous) underperformance. The cheapest or quickest installation is not always the best or most cost effective when effects on current operations or potential future expansion plans are examined.

Care must also be taken where large live loadings are concerned such as gantry cranes, hoists, materials handling, etc. to ensure that structural and safety implications are properly addressed during both design and construction stages.

Where multiple service support systems are concerned, apart from operational movement, sufficient separation must also be provided to preclude electrical interference, water damage, inadequate clearance for insulation, cladding, cable de-rating (due to inadequate ventilation), mechanical damage during maintenance, etc. (Figures 3.12 and 3.13). It is essential that competent professional engineering personnel with applicable design experience be utilized for design of the installations.

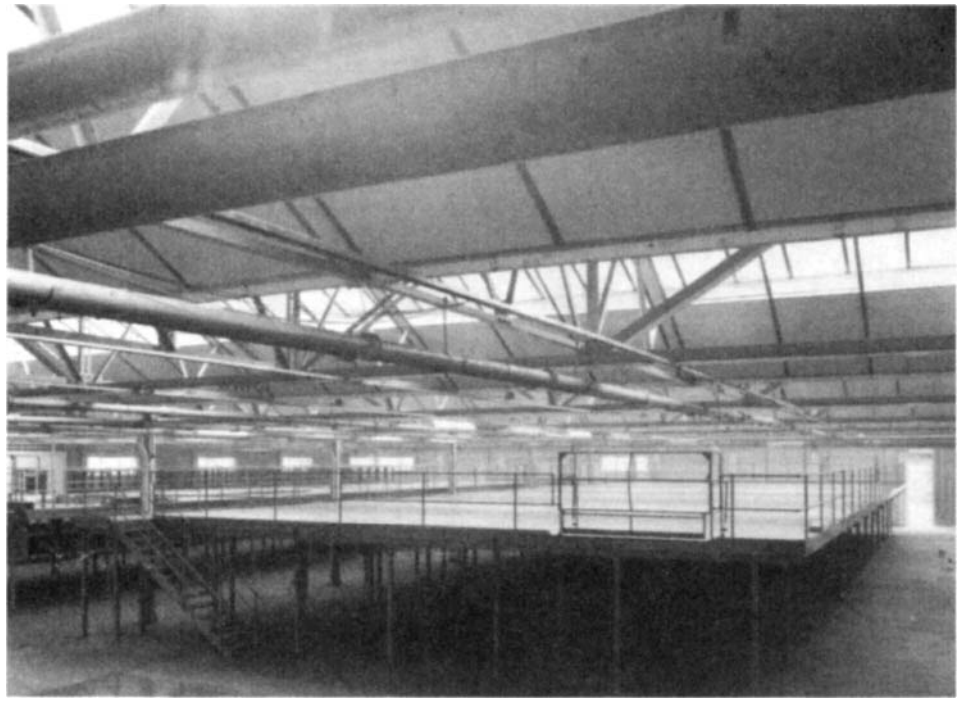


Figure 3.11 A typical modular mezzanine floor (courtesy of The Welconstruct Co. Ltd)



Figure 3.12 Multiple piping system anchor of guide installation (courtesy of Industrial Hangers Ltd)

3.10 Natural ventilation

3.10.1 Usage

Natural ventilation can be described as a process for providing fresh air movement within an enclosure by virtue of air pressure differentials caused primarily by the effects of wind and temperature variations in and around the enclosure. The primary usages of natural ventilation are to provide:

1. Fresh air introduction for odour and carbon dioxide dissipation;
2. Fire control/smoke clearance;
3. Heat dissipation/cooling;
4. Provision of air for fuel-burning devices;
5. Control of internal humidity (primarily condensation reduction/exclusion).

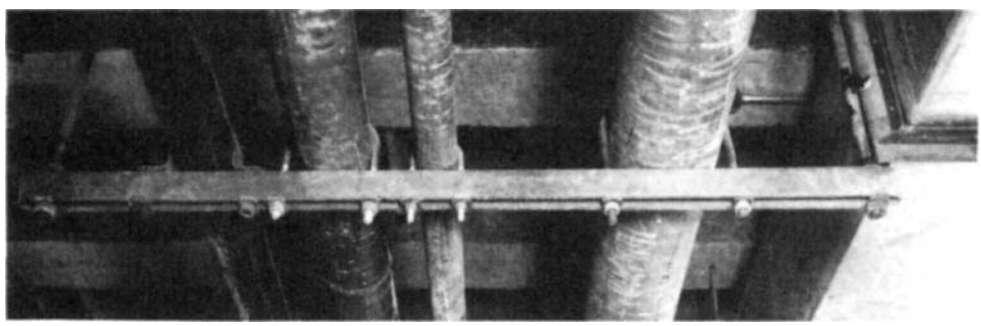


Figure 3.13 A typical multi-service gang hanger (courtesy of Industrial Hangers Ltd)

3.10.2 Requirements

For engineering purposes the composition of fresh air is generally taken at the following 'standard' conditions:

20.94%	Oxygen (O_2)
0.03%	Carbon dioxide (CO_2)
79.03%	Nitrogen and inert gases (N_2 + xenon, zeon and others)

These fractions are, of course, somewhat variable, dependent on geographic location (i.e. urban versus rural).

Generally, average humidity for Britain is as follows:

75–95%	sat Winter
55–75%	sat Summer

General guides to fresh air requirements for odour control and general ventilation are given in Table 3.1 and Figure 3.14. Note that requirements for removal of lavatory odour or for other highly concentrated areas are dealt with elsewhere. Figure 3.14 pertains to generally ventilated spaces only.

3.10.3 Occupational exposure limits

With regard to limiting the concentration of particular contaminants, these are generally referred to in terms of 'occupational exposure limits', expressed either in terms of a time-weighted average (TWA) which represents the average concentration for a normal working day over a 40-hour week to which nearly all workers may be exposed on a repeated basis or as a short-term exposure limit (STEL),

Table 3.1 Recommended outdoor air supply rates for air-conditioned spaces (extracted from BS 5925: 1991)

Type of space	*Smoking*	*Outdoor air supply (l/s)*		
		Recommended	*Minimum (the greater of the two should be taken)*	
		Per person	*Per person*	*Per square metre floor area*
Factories[a,b]	None	8	5	0.8
Open-plan offices	Some	8	5	1.3
Private offices	Heavy	12	8	1.3
Boardroom, executive offices and conference room	Very Heavy	25	18	6
Toilets[c]	–	–	–	10
Corridors[c]	–	–	–	1.3
Cafeterias[a,d]	Some	12	8	–
Kitchens[a,c]	–	–	–	20

[a]Rate of extraction may be overriding factor.
[b]See statutory requirements and local byelaws.
[c]A per capita basis is not appropriate in these cases.
[d]Where queuing occurs in the space, the seating capacity may not be the appropriate total occupancy.

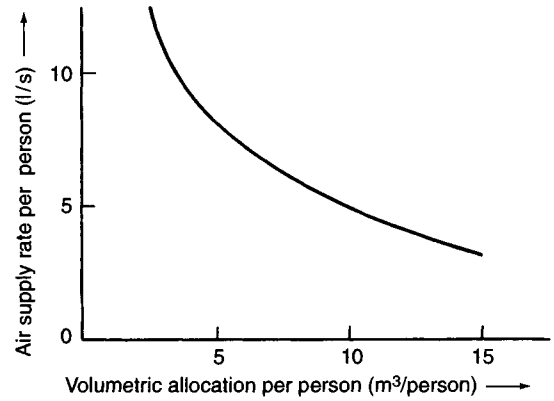


Figure 3.14 Approximate air supply rate for (human) odour removal (extracted from BS 5925: 1980)

which represents the maximum concentration to which workers can be exposed for up to 15 minutes. Clearly, these value vary, depending on the particular contaminant.

Reference should be made to *Occupational Exposure Limits, Guidance Note EH40/99*, issued by the Health and Safety Executive (HSE), or *Industrial Ventilation* (American Conference of Governmental Industrial Hygienists). In all cases, proposals should be reviewed by and submitted to the relevant local authority agencies.

Space does not permit a detailed investigation of all the requirements concerning ventilation for the remaining usages listed. However, a brief description of the rationale for provision is given below, and further details can be obtained from the references listed at the end of this chapter.

3.10.4 Fire control/smoke clearance

Depending on the requirements of local legislation, statutory regulations and insurance bodies (or any other documents or bodies having jurisdiction), there may well be a need to address the clearance of smoke from escape routes, the control of smoke spread generally and the removal of smoke during and after firefighting activities.

3.10.5 Heat dissipation/cooling

Human occupants, electrical/electronic equipment and process plant all emit varying quantities of sensible and latent heat. Equally, these various elements require (or can tolerate) differing environmental conditions. Depending on these operational constraints, the need may well exist to provide natural (or powered) ventilation to maintain environmental conditions (temperature and/or humidity) consistent with the occupational/process requirements.

3.10.6 Provision of air for fuel-burning devices

All combustion equipment (oil, gas, solid fuel) requires primary air to support combustion and secondary air to permit adequate velocities in flue ways, etc. These requirements are governed by the minimum air/fuel ratio and operating flue-way parameters. There are also published

recommended minimum requirements (British Standards, British Gas, etc.) which are generally in excess of these.

3.10.7 Control of internal humidity

Where human occupancy or 'wet' process plant is present, the emission of water vapour will occur. Depending on external conditions and building fabric construction, the attendant potential for excessive ambient humidity or surface condensation may exist.

Consequently the introduction of external air ventilation may be required in order to reduce ambient moisture contents. However, this will need to be balanced against energy costs and the use of other design solutions such as building fabric moistureproof membranes, local air exhausts, etc.

3.10.8 General design considerations

The use of openings within the building fabric to provide natural ventilation is predicated on various primary factors:

1. Location and orientation of building;
2. Building height and configuration;
3. Shape, size and location of openings;
4. Wind and temperature effects.

Identifying specific quantified building ventilation rates can be difficult due to the number of non-linear parallel paths that may have to be simultaneously considered.

However, simple-case type solutions (which are often good enough to establish whether mechanical ventilation is required or excessive air infiltration problems may exist) can be identified. These simple solutions are based on a knowledge of:

1. Wind direction and velocity;
2. Building opening locations and size;
3. Temperature differentials (internal and external).

These solutions are discussed in more detail in many publications, including Building Research Establishment (BRE) *Digest No. 399*, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) *Fundamentals Handbook* and Chartered Institute of Building Services *Engineers Guide* (Books A and B).

3.11 Building durability

The durability of a building (i.e. its life expectancy and its resistance to deterioration) is determined by deliberate design decisions relating to structure and choice of materials as much as to the natural or precipitate process of ageing. Within certain limits, the design of an industrial building can and should take into account the predicted use or lifespan of the process or method of operation which it is to accommodate. To aim at durability beyond that has ascertainable cost implications. These may be acceptable if the building is to serve future known or even unpredictable purposes.

3.11.1 Durability and plan form

If the plan of the building (and the same applies to its cross-sectional features) is precisely and inflexibly related to the initial plant layout and the production processes known at design stage, non-adaptability to later desirable changes in use is clearly a durability factor.

3.11.2 Structure and durability

The structural design of an industrial building will, first, reflect the requirements of plant layout and manufacturing procedures. Apart from holding up the building envelope, structural members will be designed and placed to support particular static and dynamic loads. As with the plan form, the shape and disposition of the structural features may either curtail or allow extension of the life of the building. Load-bearing perimeter walls exemplify the former and maximum freedom from internal columns the latter. The cost implications of reducing structural constraints and thereby increasing durability need to be considered.

3.11.3 Cost of construction materials

There is a clear correlation between quality or cost of materials and the durability/life expectancy of buildings. Greater resistance of better materials to wear and tear can be assumed, with obvious implications on future maintenance. Striking the best balance in each case between initial capital outlay and maintenance cost calls for complex calculations which take into account such intangibles as future interest rates and taxation of building operations.

Performance and costs in use of buildings: a new approach (BRE Report 277) is one such example.

3.11.4 Durability of materials

Apart from selecting better, more durable and expensive (rather than cheaper) materials, their life can be prolonged by appropriate treatment, coating or other protection, e.g.:

Mild steel: Galvanizing/plastic coating
Extruded aluminium: Anodizing/polyester powder coating
Concrete: Integral or applied hardeners
Brickwork: Joint formation/masonry paint
Cement screeds: Mineral or metallic aggregate hardeners
Timber: Impregnation/staining.

Obviously, durability is greatly enhanced by specifying stainless rather than mild steel, engineering rather than common bricks, etc. Comparative life expectancies of materials are tabulated in reference books such as that published by NBA Construction Consultants Limited in 1985.

3.11.5 Damage and protection

Industrial buildings, more than most, are prone to damage. Causes range from mechanical impact to chemical attack resulting from the production process – quite apart

from heavy wear in normal use. Examples of causes and available protective measures are as follows.

3.11.5.1 Mechanical impact

Vehicles (external): Buffer rails, ramps
Transporters (internal): Bollards, route demarcation, column base plinths, guide rails, flexible/automatic doors
Production processes: Wall/floor shields pipe cages, resilient rails
Craneage: Electromechanical limiters
People: Wall rails, door kick plates, footmats (shopfloor offices)

3.11.5.2 Chemical/atmospheric attack

Plant/process emissions: Anti-corrosion coatings heat shields, extractors
Humidity (condensation): Dehumidifiers, insulation, ventilation, warmed surfaces
Atmosphere (external): Corrosion-resistant coatings, fungicidal treatment, overcladding
Fire: Smoke detectors, intumescent coatings/seals

3.11.6 Details and specification of construction

Design for durability, as defined above, will be negated if it does not take into account the essential need for ease of maintenance or ignores sound specification of workmanship and constructional details. Deterioration factors notorious for shortening the life of a building include the ingress of moisture and structural or thermal movement. Necessary safeguards against these and others are covered by Building Regulations and Codes of Practice, all fully referred to in the National Building Specification.

3.12 Building maintenance

Maintenance is estimated to represent more than one third of all building expenditure, which underlines its significance in the economic lifecycle of any building, the vital importance of designing for it and skilfully managing its execution. There is a wealth of published literature on every aspect of maintenance, and more recent studies are listed at the end of the chapter.

3.12.1 Building records

The prerequisite for proper planning and performance of building maintenance is the comprehensive set of drawings, specifications and servicing manuals compiled by architects, engineers, contractors and suppliers, respectively. Those responsible for maintenance must ensure that all records are kept up to date; computers are increasingly used for this purpose.

3.12.2 Maintenance work

Depending on the scope and complexity of maintenance as well as economic considerations, inspections and performance will be (both or either) the responsibility of in-house permanently employed staff or outside specialists or contractors. In the latter case particular expertise is required, and this should be reflected in the selection/tendering procedure.

3.12.3 Maintenance planning

Whoever carries out the work, basic strategy, programming and procedures will be established by the plant engineer and his maintenance manager. Inspection checklists and record sheets (of which those designed by the Department of the Environment/Property Services Agency are very good examples) are necessary for systematic location of critical elements/potential defects and setting out frequencies of inspection. Computers and work processors are an obvious aid to effective maintenance management. Inspection-based preventive methods are demonstrably cost effective.

3.12.4 Monitoring equipment

Most, if not all, of the equipment listed below is required, even where outside specialists are generally retained to carry out maintenance (for either access or measurement), including:

1. Tubular towers, ladders, long-arms, cleaning cradles;
2. Levels, tapes, thermometers, hydrometers, light meters, smoke detectors, audio-sensors.

Features such as cradle rails, safety eyes and climbing irons should be incorporated into the design of the building.

3.13 Building repairs

The need for building repair arises from the inevitable process of ageing, and such deterioration is brought to light by systematic maintenance. There is also repair work necessitated by damage from observable causes such as physical impact (discussed elsewhere in this chapter).

3.13.1 Repair work

Depending on its complexity and urgency, repair work may best be carried out by in-house staff employed and trained for this purpose (but not necessarily to the exclusion of other work) or by directly employed labour skilled in particular trades or by specialist contractors. In many cases immediate (but adequate) steps can be taken by permanent staff, sufficient to deal with an acute problem while deferring more comprehensive or permanent repairs to be carried out by outside specialists (possibly as part of a regular maintenance programme with resultant economies). Useful reference books include *Building Failures: a guide to diagnosis, remedy and prevention* 2nd ed. Butterworth Architecture 1989 and Technology of building defects – E & FN Spon 1996.

3.13.2 Repair: works specification

Leaving aside stop-gap emergency repairs, the work should be done to a standard set by the original material

and workmanship specification (which must be referred to by whoever carries out the work), unless this has been found to be inadequate. Any deviation from original materials or methods must be assessed by qualified professionals with regard to compatibility, cost and compliance with building regulations. The specification must also take into account limitations of the structure as originally designed.

If faulty specification or unsuitable materials are found to be the cause of defects requiring repairs, replacement work should be considered in anticipation of problems arising on a wider scale. A less disruptive repair programme may thereby be adopted compatible with routine maintenance operations.

3.13.3 Advisory bodies

The assessment of underlying causes of defects and/or the optimum methods of rectifying them are sometimes not within the competence of the original designers of the building or specialist contractors. In such cases reference is best made to organizations which have detailed or broader expertise, such as the Building Research Establishment at Garston.

Examples are given below of two kinds of body which can be approached for independent advice. More can be found in reference books published by the RIBA and other professional institutions.

3.13.3.1 Testing laboratories

These should preferably be drawn from the list approved through the UKAS Accreditation Scheme for Testing Laboratories (UKAS Feltham, Middlesex Tel (0208) 917 8400)

3.13.3.2 Advisory associations

Aluminium Federation, Birmingham Tel (0121) 456 1103
Asbestos Removal Contractors Association, Chelmsford Tel (01245) 259744
Association of Consulting Engineers, London Tel (0207) 222 6557
British Flat Roofing Council, Nottingham Tel (0115) 956 6666
Brick Development Association, Windsor (01344) 885651
British Cement Association, Crowthorne Tel (01344) 762676
Concrete Society, Crowthorne Tel (01344) 466007
External Wall Insulation Association, Haslemere Tel (01428) 654011
Fire Protection Association, London Tel (0207) 902 5300
Galvanizers Association, Birmingham Tel (0121) 355 8838
Glass and Glazing Federation, London Tel (0207) 403 7177
Lift and Escalator Industry Association, London Tel (0207) 935 3013
Metal Cladding and Roofing Manufacturers' Association, Merseyside Tel (0151) 652 3846
National GRP Construction Federation, London Tel (0207) 580 5588
Single Ply Roofing Association, Nottingham Tel (0115) 956 5002
Steel Construction Institute, Ascot Tel (01344) 623345
Steel Window Association, London Tel (0207) 637 3572

3.13.4 Flat roof defects

Unlike other defective building elements, roofs generally require prompt repairs. Latent defects in roofs can go undetected with correspondingly more serious consequences when they do manifest themselves. Regular inspection of roofs is therefore doubly necessary, as well as a recognition of potential causes of damage, e.g.:

1. Inadequate falls and unimpeded water discharge;
2. Ultraviolet ray attack of unprotected roofing;
3. Cracking caused by alternating expansion and shrinkage;
4. Distortion of roofing due to heat rejection (insulation);
5. Traffic and impact damage of unprotected roofing;
6. Perimeter constraint/upstand and flashing details.

3.13.5 Roof repairs

Diagnosis of defects by inspection of visible causes or more sophisticated means (tracer-dye inundation to find sources and routes of leaks, infrared photography, etc.) is a prerequisite for correct repair specification. Greater skill in detailing and specifying suitable materials and methods are required in the design of flat roofs and the same applies to repairs. Here, too, durability and effectiveness are, to some extent, cost related.

Specialists should be employed to carry out roof repair work who are able and willing to guarantee its quality and life.

The British Flat Roofing Council Technical Information Sheets 1 to 13 provide useful reference material.

3.14 Domestic facilities

3.14.1 Sanitary accommodation

Sanitary accommodation encompasses the provision of water closets, urinals, wash basins and/or washing troughs and, depending on a particular trade or occupation, the provision of baths and/or showers. Provision of toilet accommodation is specified under Acts of Parliament, British Standards, regulations and HM Inspector of Factories.

The provisions given in the various standards are essentially minimum requirements only, and when assessing quantities and type, the following should be considered:

1. Number of personnel and male/female ratio;
2. Is a shift system operating within the building?
3. Type of process in operation – dirty or clean, wet or dry;
4. Specialized usage – sterile conditions, radioactive contamination;
5. Provision for remote-actuated appliances (i.e. foot operated, photoelectric cell, etc.);

6. Ethnic considerations relating to siting of toilet accommodation;
7. Provision for disabled personnel;
8. Provision of facilities for female hygiene;
9. Changing-room facilities for male/female personnel.

3.14.2 Canteens

Canteen facilities for staff personnel can generally be divided into two categories:

1. Provision of cold meals (sandwiches, cold buffets, etc.);
2. Provision of both hot and cold meals prepared by resident staff or delivered under contract by outside caterers.

Many industrial buildings offer canteen facilities free of charge or at subsidized rates. However, before embarking on the provision of canteen facilities the following points should be considered:

1. Proximity of building relative to adjacent village, town facilities;
2. Hot and/or cold food and selective menu;
3. Number of meals to be catered for and operating hours;
4. Ethnic requirements (i.e. vegetarian, etc.);
5. Secondary catering facilities for senior staff and/or visitors;
6. Provision of separate hot, cold and drinking-water services for canteen facilities.

3.14.3 Rest rooms

Statutory requirements dictate that a space be set aside within an industrial building for use as a rest room. The usage and facilities available are often extremely varied, and can be sub-divided as follows:

1. Use of room for morning/afternoon breaks;
2. Consumption of food at lunch time in the absence of canteen facilities;
3. Combined usage as a recreation room.

In providing rest room facilities the following points should be considered:

1. Prime use of room as defined above;
2. Number of persons to be accommodated;
3. Provision of drinking and snack facilities (i.e. tea-preparation sink, vending machine, automated snack bar, etc.);
4. Self-service or resident catering staff;
5. Male/female segregation;
6. Provision of recreation activities (i.e. darts, table tennis, television, etc.);
7. Provision of room furniture.
8. Smoking/non-smoking areas.

3.14.4 First-aid facilities

It is a statutory requirement that first-aid facilities be available at all times for staff personnel. This facility is very diverse and can extend from a first-aid cabinet to the provision of a first-aid room and attendant semi-resident nurse/doctor. The extent of first-aid facilities are dependent on the following:

1. Type of building and nature of business (i.e. dirty production line, computer components);
2. Number of staff personnel to be serviced and male/female ratio;
3. Proximity of building to easily accessible external medical facilities;
4. Provision of first-aid trained staff from within the building personnel;
5. Provision of emergency equipment for specialized building activities (i.e. chemical, radio-active contamination);
6. Provision of bed furniture, stretchers, respirators, etc.;
7. Provision of separate toilet facilities for resident nurse/doctor;
8. Ethnic considerations.

3.14.5 Detail design

Having established the design parameters for the domestic facilities as outlined above, the following references should be used in the development of detail design:

1. Factories Act of 1961 and revised 1971;
2. Sanitary Accommodation Regulations SR and O 1938, No. 611;
3. Sanitary Accommodation (Amendment) Regulations 1974, No. 426;
4. HM Inspector of Factories recommendations;
5. BS 6465: Part 1: 1994: Sanitary installation.

Quantity of sanitary fittings shall be based on total numbers of personnel per shift and not total number of employees per day.

Where dirty or wet processing occurs continuously within a building, consideration may be given to the provision of baths and showers for use by personnel at the end of the day or shift. Discussion with the operator and HM Inspector of Factories would be an advantage in assessing quantities required.

Working areas within certain industrial buildings may have restricted access (i.e. sterile laboratories, radio-active areas). Separate toilet accommodation may be required in these areas, an assessment of which may be obtained from the operator and reference to such publications as Atomic Energy Code of Practice, Laboratory Practice. It may also be necessary to operate such appliances remotely by photo-electric cell, sonic control or foot control.

Where building employees are from mainly ethnic communities consideration should be given to the positioning of toilet facilities so that religious beliefs are not compromised.

In addition to the general employees of a building, the following specialized personnel should also be considered:

1. Disabled
2. Elderly
3. Administration

4. Catering
5. Visitors.

It is a requirement of the Building Regulations 2000 to provide access and facilities for disabled people in new buildings and in any extensions which have a ground floor – refer to Approved Document M (DETR). Any existing means of access to, or facilities within, a building, should not be removed or otherwise adversely affected. The Building Act and Regulations are not retrospective in operation. However, the Disability Discrimination Act phases in requirements to review and, if necessary, make reasonable adaptations to existing buildings to accommodate disabled people.

Where provision within industrial buildings for elderly persons are required, reference should be made to the DSS. Consideration should also be given to providing water at lower temperatures to appliances exclusively for used by elderly and/or disabled persons.

Sanitary-towel disposal must be provided in each female toilet. The type of disposal can be by macerator, incinerator, bag or chemical.

Separate changing-room facilities for male and female personnel would include the following:

1. Personal locker with lock for change of clothes at the end of a shift or day;
2. Bench/chair for seating.

The location of an industrial building relative to adjacent shops, village and town may well influence the provision of canteen facilities as well as the type of service to be provided.

Where full canteen facilities are provided an accurate assessment of the hours of operation must be obtained so that plant and services are correctly sized. The operating hours will also greatly influence the need to provide separate plant from the main building, especially if meals are to be provided at the end of each shift.

3.15 Lifts

3.15.1 Introduction

The planning of lift systems should be one of the first to be considered, usually alongside the initial building structure, bearing in mind the long lead in times and structural requirements. It is important that the correct configuration is established early, as changes at a later date can be difficult to incorporate.

The first essential step in the system design is goods and pedestrian planning, i.e.

1. How many people require transportation?
2. What will be the peak demand and how and when will it occur?
3. How many floors will the lift system serve?
4. What are the loads/sizes of goods/equipment requiring transportation?

The responses to these questions can be used to determine the number of lifts required, the size of the care, the door arrangement and the speed of car travel. Other major considerations should be the location of lifts within the building and accessibility for disabled users.

3.15.2 Lift system design – drive systems

There are various types of drive systems employed throughout the lift industry, and the following are the most commonly used:

1. Electric a.c. motor with gearbox;
2. Gearless electric d.c. motor;
3. Hydraulic

3.15.2.1 Electric a.c. motor with gearbox

Lifts of this type are normally rope driven and are the most common drive used in lift installations. The gearbox is fitted with a grooved traction sheave on which a series of steel ropes are wound. The ropes are attached to the top of the lift car, wrapped around the traction sheave (and occasionally secondary sheaves) and attached to a counterweight of equal mass to the car and a percentage of its rated load (normally 40%).

This drive can be used for a wide range of car sizes but has a limit to the speed of travel of approximately 2.5 m/s. The lift machine room is usually located above the lift shaft. However bottom-of-shaft machine rooms are not unknown, although they tend to be more costly.

3.15.2.2 Gearless electric d.c. motor

Lifts of this type are of a configuration similar to the geared drive systems mentioned above. The difference lies in the increase in the physical size of the drive as the required operating torque of a gearless d.c. motor is produced at a fraction of the rpm of a geared a.c. motor.

The cost of these drives is significantly greater than that of a comparable geared drive, but the quality of ride and maximum speed of car travel are much improved. Gearless drives usually have applications in prestige offices and hotels where the lift travel is in excess of 35 m.

3.15.2.3 Hydraulic lifts

Lifts of this type are generally used for low-rise applications and also if good levelling accuracy at each landing is required. Hydraulic lifts are either the direct-acting type, where a hydraulic ram acts on the underside of the lift car, or the suspended type, where the ram acts on the top of the car via a series of ropes or chains and pulleys. Hydraulic lifts can be used for very large goods lifts when two or more hydraulic rams are used, but are limited to a slow car speed, which improves to a maximum of 1.5 m/s for small lift applications. Hydraulic lifts have an advantage over rope-traction lifts in that the lift machine room can be situated remotely from the lift shaft with a connection to the lift ram via flexible hydraulic pipework. Hydraulic lifts have a limited maximum travel which is approximately 12 m for (up to) 1000 kg car size and 8 m for car sizes over 1500 kg.

3.15.3 Lift machine rooms

Each lift or group of lifts requires a lift machine room which should be designed complete with:

1. Drive system machinery, pulley mechanisms and control panels;
2. Lifting beams tested for safe working loading;
3. Adequate emergency lighting, small power and 110 V sockets;
4. Adequate ventilation/cooling/heating/frost protection as required by BS 5655;
5. Fire detection and alarms;
6. An electrical switchgear panel which provides an electrical supply to each lift machine.

The lift motor room should be identified with safety signs as required in BS 5655 and should be secured to allow access by authorized persons only.

3.15.4 Lift control in the event of fire

In the event of fire within a building the controller for each lift should isolate all manually operated inputs and return automatically to the evacuation level, usually the ground floor. An output from the building fire alarm panel is 'hard wired' to the lift controller, giving the signal for a fire condition. The lift remains disabled at the evacuation level and the car doors open. If control of a lift is required by a fire officer a key switch or break-glass unit should be used to re-activate the lift.

3.16 Site health and safety

3.16.1 The Construction (Design and Management) Regulations, 1994

Apart from the obvious benefits deriving from a well-organized and safely run site, it is in the interests of both employer and employee to work towards a safe working environment. In addition, there are statutory obligations. Predominant among these are the Construction (Design and Management) Regulations, 1994 (CDM).

These Regulations are designed to ensure that health and safety are integral to the procurement strategy, design process and construction operations. The approach is to improve co-operation and the sharing of information between all parties involved and to take a 'risk assessment' approach to each element of the design and the construction methodology, resulting in minimized hazards and associated risks.

Duties and responsibilities are attached to the roles of client, planning supervisor, designer and principal contractor. If the client does not have the resources, skills or experience in-house to deal with these matters, then a client agent (who must demonstrate to the client's satisfaction that s/he does) may be appointed.

At the project inception stage, consideration should be given to the appointment of the Planning Supervisor, who co-ordinates health and safety activities throughout the project.

3.16.2 Assessing competence and resources

The ability of each party to fulfill their health and safety obligations should be subject to formal assessment. Evidence of similar projects successfully completed or references from recent employers can be used as initial evidence of competence and the ability to deploy suitable resources.

Some highly specialized or high-risk projects may necessitate outline method statements being provided at the tender stage by potential contractors.

It is consistent with the requirements of CDM for a client with appropriate health and safety skills to take on the duties of designer, planning supervisor and main contractor. However, it is essential that those given the tasks are assessed objectively and given authority commensurate with their responsibilities.

For further guidance, refer to Health and Safety Commission document 'Managing Construction for Health and Safety' which is the Approved Code of Practice, and relevant CIRIA publications.

3.16.3 The Factories Act 1961

The Factories Act also contains pertinent requirements for construction activities. These primarily relate to:

1. Environmental conditions (lighting, etc.);
2. Machinery safety (where applicable);
3. Fumes;
4. Welfare facilities;
5. Accident notification.

However, due to the age of the Act, in many instances particular sections have been overtaken by more recent specific legislation. Reference should be made to the listings given below.

3.16.4 Other sources of information

Useful information can be obtained from various codes of practice, some of which are listed at the end of the chapter. The Construction Health and Safety Manual published by Construction Industry Publications (CIP) provides considerable guidance to construction industry employers regarding the formulation and implementation of safety policy.

From a practical viewpoint it is essential to ensure that all contractors working on a site are well organized and have a clearly stated safety policy. Where the employer has existing corporate safety guidelines these should be made part of all construction contracts and compliance monitored.

In addition, each contractor has to submit 'Method Statements' for the work they are to perform. These should include definitive statements regarding safety policy and implementation on the site, including named personnel, individual responsibilities, organizational arrangements, safety measures to be adopted and training to be performed. A safety officer should be identified.

3.17 Sub-ground pits and basements

Sub-ground pits may be required for access, service distribution or process requirements. Depending on pit dimensions and water table levels, problems that may have to be considered at the design stage include 'heave' due to relief of overburden, buoyancy from water pressure and waterproofing.

3.17.1 Waterproofing

There are three standard solutions to waterproofing pits and basements:

1. Watertight concrete construction;
2. Drained cavity construction;
3. External continuous impervious membrane (tanking).

3.17.1.1 Watertight concrete construction

This relies on the integrity of the concrete construction itself with reference to design (crack control, joint spacing and detailing, concrete mix) and skilled workmanship and supervision.

3.17.1.2 Drained cavity construction

This is also based on watertight concrete construction but accepts that some seepage may occur through the external concrete wall. The water is kept away from a separate inner-skin wall by an intervening drained cavity. An internal vapour barrier may be applied to the inner-skin wall to limit humidity, but the cavity may then require ventilation to prevent condensation.

3.17.1.3 External waterproof membrane

Two possible forms of membrane are hot applied mastic asphalt or bitumen/butyl rubber sheeting with welded or glued joints. The membrane under the floor slabs has to be lapped with that around the walls. It is essential that the membrane is protected during construction, and a typical arrangement is as shown in Figure 3.15.

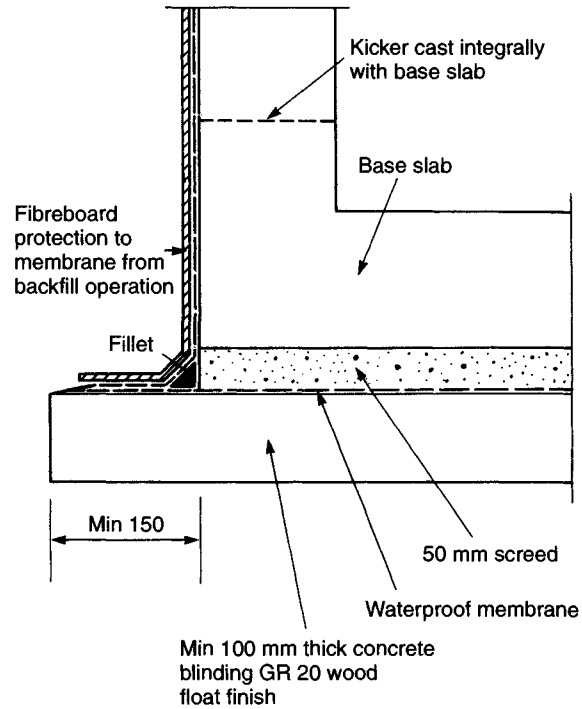


Figure 3.15 A typical external waterproof membrane detail

3.18 Internal and external decoration

3.18.1 Internal

Ceiling, wall and floor finishes can be separated into 'wet' and 'dry' finishes. Below is a listing of the common types of wet and dry finishes currently in use.

3.18.1.1 Wet finishes

1. Plasterwork
2. Screeds
3. Tiling
4. Paint finishes
5. Wet structural fire-protection systems

3.18.1.2 Dry finishes

1. Dry lining (plasterboard)
2. False (suspended) ceilings
3. Wall claddings
4. Dry floor finishes (thermoplastic sheeting, carpeting, raised deck flooring, etc.)
5. Dry structural fire-protection systems

The selection of finishes is generally made against the following parameters or constraints:

1. Acoustic performance
2. Environmental conditions
3. Life expectancy/maintenance requirements
4. Safety requirements (both installation and use)
5. Fire rating/flame spread
6. Aesthetic considerations
7. Flexibility of use
8. Load-bearing requirements
9. Costs
10. Installation time/disruption.

3.18.1.3 Environmental conditions

All finishes should be selected to be resilient to expected average and worst-case environmental exposure such as high/low humidity or temperature, airborne contaminants, vibration, possible aggressive liquid spillages, cleanliness/hygiene requirements, etc.

3.18.1.4 Life expectancy/maintenance requirements

Many finishes exhibit low maintenance requirements (e.g. plasticized metallic sheetings, epoxy coatings, continuous tiling systems, etc.). Others may be more maintenance intensive and may provide lower durability. However,

selection must also consider the other operating parameters such as acoustic performance (which may mandate heavier mass or more porous-surfaced materials) or load-bearing capabilities, etc.

3.18.1.5 Safety requirements

Materials containing toxic or irritant materials should be avoided. Flooring finishes should exhibit non-slip properties but be cleanable and not provide excessive crenellations, etc., for contaminants. Some materials (such as PVC) emit toxic fumes when burning. Structural integrity must also be assessed where secondary cladding or suspended finishes are being utilized, particularly where load-bearing abilities are required (such as suspended ceilings or wall claddings).

3.18.1.6 Aesthetic considerations

While this may appear to be self-explanatory, the need to change colour schemes or textures over the lifetime of the installation will need to be reviewed. Self-coloured materials do not typically take secondary coatings such as paint or stain.

3.18.1.7 Flexibility of use

Consideration should be given to likely layout or usage changes. Generally, wet materials will provide least flexibility in terms of subsequent removal and reinstallation. However, they may be more conducive to changes in usage of the space.

3.18.1.8 Costs and installation time

It is generally accepted that the use of dry materials results in shorter and less disruptive installations, particularly if modular systems are used. However, these materials may well not offer the least expensive solution.

3.18.2 External

In many ways, the same criteria apply to the selection of external finish materials as to internal finishes, and can be identified as 'wet' or 'dry' types. However, increasingly, dry cladding (roof and wall) and bonded roof membrane systems are being used in preference to more traditional rendering and liquid applied roofing membranes.

If extensions are being made to existing facilities or buildings adjacent to 'traditional' structures then this may require the use of brickwork cladding or block and render in order to satisfactorily 'marry' with the existing structures. Care must be taken to ensure such extensions/additions meet current building regulations, bye-laws, standards and codes of practice.

Of major importance when selecting suitable exterior finish materials are their weather resistance and 'weathering' characteristics (with particular reference to ultraviolet resistance and moisture staining), including resistance to biological/vegetable growth. Cladding systems, particularly, should be examined against their wind and moisture penetration resistance. External building elements, either individually or when viewed as a collective system, must comply with the thermal transmittance requirements of the building regulations.

Corrosion resistance should also be considered with particular reference to the ambient environment. Painting schemes, coating materials and other protective skins (along with the substrate bonding method) should all be reviewed against the prevailing conditions.

3.19 Industrial ground floors

The ground floor of an industrial building is arguably the most important structural element. Failure of a floor slab or even a topping can lead to enormous expense and disruption due to repair or replacement. Considerations in the design of a ground slab may include:

1. Loading (uniformly distributed loads and point loads)
2. Abrasion/impact resistance
3. Chemical resistance
4. Flatness
5. Ease of cleaning.

It is important that these are accurately assessed since underspecification may lead to severe maintenance problems while overspecification may result in substantial cost increases.

3.19.1 Structural form

Dependent on ground conditions, loading requirements and settlement limits, industrial ground floors may be ground bearing, raft construction or piled. The piled option should, if possible, be avoided, as the cost is comparatively very high.

3.19.1.1 Rafts

Rafts fall into a category between fully stiff (behaving as a rigid body) and fully flexible. The raft may also support the superstructure. A soil/structure interaction study must be carried out to estimate the degree to which loads are distributed by the raft. Hence the resulting slab forces and required reinforcement are calculated.

3.19.1.2 Ground-bearing slabs

Ground-bearing slabs are typically the cheapest and most common form of industrial ground floor, and rely on the tensile capacity of concrete. Any reinforcement provided is to reduce the potential for cracking from shrinkage and thermal effects. The degree of reinforcement is therefore primarily dependent on slab thickness and joint spacing (Figure 3.16).

The detailing arrangement of joints is of prime importance in the slab performance. The purpose of these joints is to concentrate cracks at specific locations, isolate the slab from other structural elements and sometimes to allow for expansion or articulation.

The main elements of a ground-bearing slab are:

1. *Sub-grade:* the material at formation level after excavating or infilling;

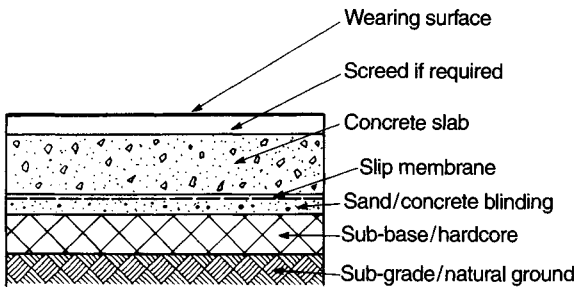


Figure 3.16 A typical section through a bearing slab

2. *Sub-base:* selected imported granular material to form a stable level surface on which to construct the slab. Where lean-mix concrete is not used the surface is normally blinded with sharp sand;
3. *Slip membrane:* serves to reduce friction between the slab and sub-base to minimize subsequent slab cracking. This is normally a polyethylene sheet. It may also serve as a dampproof membrane;
4. *Structural slab:* usually with single layer of reinforcement in the top;
5. *Wearing surface:* may be the finished slab surface or the surface of an applied topping.

3.19.2 Abrasion resistance

Abrasion resistance can be influenced by:

1. Concrete mix
2. Method of finishing the concrete
3. Method of curing
4. The addition of surface hardeners or sprinkle finishes (metallic or non-metallic)
5. The addition of toppings.

3.19.3 Chemical resistance

Chemical resistance is normally achieved by synthetic resin toppings, polymer or resin-modified cementitious toppings or modular (tiled or paviour) toppings.

3.19.4 Flatness

Flatness is of critical importance to some sections of industrial operations such as VNA (very narrow aisle) high rack warehouses or automatic guided vehicles. The degree of flatness achieved is dependent on construction techniques, workmanship and supervision.

Traditionally, global tolerances have been specified for any point on the floor relative to datum and local tolerances specified relative to a 3 m straight edge. For VNA type requirements tolerances distinguish between areas of defined movement (i.e. predetermined vehicle routes) and areas of free movement (the rest of the slab).

3.19.5 Dusting

High-quality concrete slabs that have been well finished should not give rise to dusting. Complete avoidance of dust, however, will only be achieved by the addition of a resin or chemical sealer. Chemical sealers (such as silicofluorides and silicates) give little increased abrasion resistance, and can themselves be prone to dusting on overapplication.

3.20 Ground considerations

3.20.1 Existing site conditions

The existing site conditions which can influence the design, construction and performance of industrial buildings and their operations include:

1. Topography – surface topology, watercourses, surrounding property, vegetation, access;
2. Geology;
3. Groundwater conditions;
4. Site history – industrial contamination, mining, domestic refuse, old foundations, cellars, tunnels;
5. Existing buried or overhead services;
6. Liability to flooding, wind or sea erosion, subsidence, slope instability;
7. Liability to vibration from earthquakes, railway tunnels.

3.20.2 Contaminated sites

Extensive available level sites have sometimes previously accommodated gas works, chemical works, munitions factories, or industrial or domestic refuse tips. These sites require special consideration as regards protection of the structure to be built, the construction workforce and the building occupants.

Refuse tips invariably result in the production of methane from the decay of organic matter. Measures are necessary to avoid trapping the methane in or beneath the building. This can be achieved by a system of methane vent pipes in the fill together with an impermeable membrane at sub-ground-floor level. Alternatively, a vented cavity can be constructed sub-ground floor.

3.20.3 Foundations

The foundation system will be based on such information as can be determined together with physical and chemical testing carried out on samples procured from a site investigation. In regions of very poor ground conditions there is sometimes an option of utilizing a ground-improvement technique such as dynamic consolidation.

3.20.4 Existing services

Existing services are important in two respects:

1. They may have to be rerouted or the structural scheme amended to avoid clashes;
2. The services required for the new industrial operation must usually tie into the existing infrastructure.

3.20.5 Car parking

Car parking area per car (space + road), is approximately 25 m^2. Standard car parking dimensions are 4.8 m × 2.3 m

(3.3 m for disabled persons) with access roads 6 m wide. Petrol interceptors for surface water from car parking areas are required where 50 spaces or more are provided.

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4 Industrial flooring

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4.1 Introduction

There are a considerable number of special proprietary floor treatments available for the architect and engineer to consider and much of the brief technical literature describing them suggests that many products would appear to offer the same improved service at vastly differing costs. It is, therefore, not surprising that many specifiers are totally confused and tend to stick to the products they know rather than consider some of the innovative products based on new technology which often offer distinct improvements over the materials traditionally used as flooring materials.

(1). Before attempting to classify the various types of special floorings available it is important to consider the concrete substrate itself. By proper use of good mix design and use of admixtures and with careful control of the water/cement ratio and attention to laying, finishing and curing techniques, concrete itself can serve as a highly durable flooring material under many industrial service conditions without the need for special separately applied finishes.

(2). Properly laid concrete provides an abrasion resistant floor surface which has good resistance to attack by alkalis and reasonable resistance to attack by mineral and vegetable oils, although oils do cause some staining and impair appearance. However, irrespective of how well it has been laid, concrete has poor resistance to acids and many other chemicals far too numerous to mention here. Where spillage of such materials is envisaged, the concrete must be protected by the application of a special floor topping or coating.

4.2 Selection of appropriate flooring material

Before selecting a flooring material it is imperative to consider carefully the precise service conditions to which the floor will be subjected.

Conditions that must be considered include:-

(i) Nature and concentrations of any materials likely to come into contact with the floor. *(The concentration is particularly important since more concentrated acids and alkalis can be very aggressive to some industrial floor finishes)*
(ii) Accuracy of the falls in the concrete sub-floor to allow spillages to run away reliably to drains.
(iii) Nature of traffic (maximum loads and types of wheels using floor) and traffic concentration.
(iv) Degree/ease of cleaning required.
(v) Anti-slip characteristics required.
(vi) Service temperature(s).
(vii) Rate of change of temperature, as rapid temperature changes can cause some heavy duty finishes to crack and debond due to the high stresses developed by thermal shock.
(viii) Grade of concrete laid for the subfloor.

Without such precise information and, on occasions, even with it, inappropriate floorings are all too often used, resulting in rapid breakdown of the floor in service. In some instances, some of the performance requirements are contradictory (especially (iv) and (v) above) and where this happens a compromise may have to be accepted.

4.3 Requirements of concrete substrate

If, at the specification stage, it is decided that the service conditions for the concrete floor do require special floorings to be applied subsequently, it is imperative that the contractor laying the concrete is fully aware of this factor and does not use a conventional spray-applied resin solution curing membrane as this could seriously affect the adhesion if any special flooring is to be subsequently applied, this is difficult to remove uniformly and reliably. In these circumstances and also for industrial buildings where the eventual use of the floor is not known but may require a special finish, overlapping polyethylene sheets or similar curing methods which do not affect the adhesion of any subsequently applied finishes should be used.

It is important to examine carefully the surface of the concrete substrate prior to applying the special flooring. Although the concrete laid by the contractor may indeed have cube strengths well in excess of that specified, it is still possible for the concrete slab to have a very weak surface due to over trowelling, for example. It is the top few microns of the concrete, which is critical to the success of the special flooring, will be applied and it is essential that any weakness in the surface be removed by a technique, which is appropriate to the type of flooring to be applied.

Most specialist flooring contractors have sufficient experience to assess the quality of concrete surface without site testing; however, if there is any doubt, the surface strength of the concrete should be tested using a simple "pull-off" test rig or other appropriate means. In general, a concrete substrate should have a tensile strength (by "pull off") of at least 0.8 N/mm^2 by BS EN 1542 Pull-off Test method.

As a general rule, any concrete base, which will be subsequently treated with special flooring, must not be subject to rising damp and thus any ground-supported slabs must incorporate an effective damp-proof membrane.

If there is any doubt, the concrete should be tested using a direct reading concrete moisture meter (maximum 6 per cent moisture) or an accurately calibrated hygrometer (not exceeding 75 per cent relative humidity after 24 hours). It should be stressed that these figures are based on the practical experience of a number of specialist flooring contractors and serve only as a guide. Other factors such as the depth of the slab, time elapsed since placing and degree of weather protection, all have an influence on the moisture content within the concrete substrate. A simple method of checking the moisture content of the substrate is to place a rubber mat on the concrete overnight. If there is no wetness when the mat is removed and the area under the mat does not appear darker – then moisture is unlikely to be a problem.

(Moisture levels acceptable for plastic sheet flooring and methods of test in BS8203; 1996 Code of Practice for Sheet Flooring also gives a good guide).

In some rare cases moisture movement due to osmotic pressure can be a problem in the long term – this is covered by FERFA Resin Flooring Industry Handbook 2000.

Another aspect, which is often overlooked, is the temperature of the concrete substrate in an unheated area. It is generally easy to raise the air temperature immediately above the concrete surface rapidly but to warm up the concrete, particularly a thick cold ground floor slab, is a slow process. In some cases the concrete surface may become wet whilst being warmed up due to dew point condensation with warmer air above the cold slab. Applying certain finishes to a cold concrete substrate can extend curing times before the floor can be put into service.

Finally, before considering flooring materials, mention should be made of the design and construction of joints and the selection of the appropriate joint filler. Joints are a major source of problems in industrial floors. Far too often, with a carefully laid concrete flooring insufficient attention is given to joint design and joint sealing.

This results in wrongly designed joints rapidly breaking up at the edges under heavy loads especially by rigid or semi-rigid wheeled traffic which can lead to expensive repairs.

Detailed information on joint design is given in the Second Edition of Concrete Society Technical Report No.34 Concrete Ground Floors – A guide to their Design and Construction 1994.

Apart from helping prevent breaking up at the floor edges, the right joint filler will help provide a easier to clean surface, ensure smooth running of forklift trucks and contribute to safety. However the selection of the right joint filler is a difficult problem. It is true to say that there is no one single ideal material for floor joints since it is impossible to combine all the performance characteristics ideally required in one product.

Over the past few years British Standards have prepared several Codes of practice for in-situ floorings under BS 8204. Parts 1 and 2, revised in 1999, cover concrete substrates for floor finishes and concrete wearing surfaces. Part 3 1993 covers polymer modified cementitious wearing surfaces. Part 4 1993 Terrazzo wearing surfaces and Part 5 1994 Mastic asphalt flooring.

Recently CEN TC 303 has been formed to draft European Standards for Floor Finishes for concrete.

There is an active Trade Federation, FERFA to which many of the specialist formulators and industrial flooring contractors belong. If specifiers/users carefully list all the service conditions which the flooring must meet, FERFA members should be able to recommend the most cost effective flooring materials to give good service under the conditions indicated.

FERFA have produced a guide to the specification and Application of Synthetic Resin Flooring which is updated in their Handbook 2000.

4.4 Special finishes

In this paper various types of finishes available for concrete floors are classified in order of increased cost.

4.4.1 Surface hardeners/sealers

4.4.1.1 Sodium silicate and silico fluoride solutions as concrete surface hardeners

Both sodium silicate and silico fluoride solutions are applied to clean, dry, sound concrete floors as dilute aqueous solutions (10 to 15 per cent solids) in 2 to 3 applications, taking care to ensure that the solution penetrates and is absorbed into the concrete surface. The silicate or silico fluoride reacts with the small amount of free lime in the cement to form glassy inert materials in the surface and the successful application of both materials depends upon filling the micropores in the surface of good quality concrete, leaving its surface appearance and non-skid characteristics virtually unchanged. The main difference between the two types are that the reaction products of the silico fluoride types are less soluble in water and are also harder, which may give better in-service performance, but at a slightly higher material cost. However, with recent developments in floor laying techniques, the concrete substrates for industrial floors are laid with much more dense low porosity surfaces so that neither silicate nor silico fluoride treatments are as effective as they used to be – say twenty years ago – when the concrete used had slightly more open finish and hence was more receptive to these treatments.

With modern concrete floors it is imperative to wash off any silicate/silicofluoride material not absorbed into the surface within a short period after application. Otherwise unpleasant white alkaline deposits, which are difficult to remove, may occur.

It is important to stress that neither sodium silicate or silico fluoride will improve the performance of poor, low strength, dusty concrete floors. If the surface is too porous, there is no way that all the material applied can react with the relatively small quantity of free lime in the concrete surface. All that will happen is that the pores will be filled with unreacted powder, producing a most unpleasant alkaline dust, which can be very irritating to the skin and eyes, when the floor is put into service.

Finally, it is important to note that sodium silicate or silico fluoride treatments, properly applied to clean and sound concrete floors may improve their performance, especially resistance to mild aqueous chemicals and oils, at a relatively low cost. However, they are not the answer to all industrial concrete floor problems, which many specifiers still appear to believe. (17).

4.4.1.2 Low viscosity resin based penetrating in-surface sealers

Liquid resin based systems which, like chemical surface hardeners penetrate into the surface of a concrete topping or directly finished slab and protect the acid susceptible cement matrix from attack, are now being increasingly used. At the same time, they strengthen the surface of the concrete and improve abrasion resistance. These in-surface sealers leave the slip resistance of the concrete floor virtually unchanged but treated floors are easier to clean and are more durable. In comparison with concrete

surface hardeners some resin solution penetrating sealers can achieve at least a five fold increase in performance.

Non-reactive and semi-reactive resin solutions Resin based penetrating sealers are now available which, for very large warehouse floors, are comparable in applied costs with the concrete surface hardeners and are now being increasingly specified. Experience indicates that certain acrylic resin solutions are proving more durable and offer better protection to chemical and oil spillages than concrete surface hardeners. Acrylic resin based sealers can markedly improve the abrasion resistance of concrete floors and have "rescued" a number of poor quality floors.

Other resin solutions, in white spirit or stronger solvent blends, used as penetrating floor sealers include:-

Air drying alkyds (similar to the resins in conventional gloss paints).
Styrene butadiene resins.
Urethane oils.
Styrene acrylates.

All such resin solutions are based on flammable solvents and are becomingly increasingly less acceptable on health and safety grounds and therefore there is increased interest in water-based polymer dispersion floor sealers, but to date none offer the same improvement to flooring performance that some of the resin solutions can provide.

Reactive resin solutions Solutions of reactive resins in volatile solvents have proved very effective for improving the wear and chemical resistance of both good and poor quality concrete floors. The epoxy resin solutions (approximately 20 per cent solids) are high strength systems, very similar to those used in heavy chemically resistant trowelled epoxy floors and, depending on the concrete, can penetrate to a significant depth into the surface of the concrete.

Here the solvent evaporates and the resin cures to form a tough, chemically resistant polymer, with a compressive strength of up to 70 N/mm^2, thus reinforcing the concrete surface. One pack low viscosity resin solutions based on moisture curing polyurethane systems are available which perform in a similar manner to epoxy resin solutions. Some of these polyurethane resin solutions demonstrate a greater ability to penetrate and bind the surface of concrete floors measurably better than other sealers.

Polymer dispersions Polyvinyl acetate (PVAc), acrylic and other polymer dispersions have been widely used as anti-dust treatments for concrete floors for many years. In general, the polymer dispersions used have been similar to those used in the manufacture of emulsion paints which tend to produce an "on-surface" seal and do not penetrate far into the surface. The chemical and water resistance of the various polymer dispersions, which are used, varies considerably from the PVAc types, which are rapidly softened and eventually washed out by water, to acrylic and SBR types which exhibit excellent resistance to a wide range of chemicals. Water based sealers are also gaining wider acceptance because of the stricter safety regulations on the handling of materials based on hydrocarbon solvents. Some of the newer materials also provide better penetration into the surface of the concrete.

4.4.2 Floor paints

Floor paints in a wide range of colours and based on a number of different binder systems are used extensively for concrete floors in light industrial applications.

4.4.2.1 Chlorinated rubber paints

Chlorinated rubber paints used to be the most common of the lower cost floor paints on the market. However, the manufacture and formulation of chlorinated rubber involves processes which are "environmentally unfriendly" and they are not now so widely used. The reason for the extensive use of chlorinate rubber floor paints is that they are tough and chemically resistant coatings but their adhesion to concrete is not always good. They tend to wear off in patches and cannot be considered as a durable floor treatment, except under light traffic conditions. However, re-coating is a simple job and floors can easily be re-painted over weekend shutdowns, for example. Similar solvent containing floor paints based on other resins such as acrylic, vinyl and styrene butadiene which give a similar level of performance are also used but there are now strong environmental pressures against the use of solvent based coatings where solvent free or water based coatings are available which give equivalent performance.

4.4.2.2 Epoxy resin floor paints

Two component Epoxy resin systems are used as "solvent containing","solvent free" and water dispersible high performance floor paints. "Solvent containing" coatings are similar in performance to penetrating sealers except that they give a thin slightly glossy chemical and abrasion resistant coloured floor finish. Depending upon the porosity of the concrete substrate, 2–3 coats are generally required.

"Solvent free" high-build floor paints are also available which can readily be applied by brush, roller or spray to a prepared concrete substrate at a thickness of 0.10 to 0.20 mm per coat. Normally, two coats are applied and the first coat is often lightly dressed with fine sand or carborundum dust to give a non-slip, chemically- resistant and durable coloured floor suitable for light industrial traffic conditions, for example, traffic shod with rubber wheels. Solvent free epoxy coatings tend to be more expensive than the "solvent containing" types but are often preferred because they do not give off unpleasant solvent vapours during application and give much better resistance to chemical spillage.

Two component water dispersible epoxy resin coating are also being used increasingly. With special epoxy resins and hardeners specifically developed for the formulation of water dispersible systems their performance in terms of both chemical resistance and abrasion resistance is much better than the two pack water dispersible epoxy coatings which have been available in the past.

4.4.2.3 Polyurethane floor paints and multi-coat treatments

Solvent containing moisture cured or two-pack polyurethane resin paints are also extensively used. They combine excellent abrasion resistance with good chemical resistance and are normally applied in two coats to give a coating thickness of 0.10 to 0.15 mm. In addition, moisture cured polyurethane resin solutions are used for quite thick durable decorative floorings. Several coats of resin are applied to the prepared substrate at approx. 4 to 6 hour intervals, with one or more coats being dressed with coloured paint flakes which are sealed in by the next coat and then lightly sanded. This type of flooring was widely marketed in the UK about ten years ago but, in the main, was considered unsatisfactory due to rapid discolouration of the floor because of the lack of ultra-violet stability of the urethane resins, which rapidly turned yellow-brown and looked dirty. However, ultraviolet stable urethane resins which do not suffer this discolouration are now available and this type of durable decorative flooring is gaining in acceptance, for example, in kitchens, toilets and reception areas.

At present with the environmental pressures towards not using solvent based coatings for any application where there are "greener" solvent free or water dispersible systems which will give equivalent performance are now available. Over the next few years high performance water dispersible two component polyurethane systems will be used increasingly to replace the solvent based floor coatings which have been widely used over the past two decades.

4.4.3 Self levelling epoxy, polyester or reactive acrylic resin systems

Like the high-build epoxy paints, epoxy self levelling finishes are solvent free low viscosity systems which can readily be applied onto a prepared level substrate to provide a jointless thin (approximately 1.5 mm) chemically resistant floor finish in a single application. The term "self levelling" by which they are commonly described is somewhat of a misnomer as they require spreading out to a near level finish with a squeegee or the edge of a steel trowel in order to flow out and give a smooth finish. A better description is "self smoothing". Before the system is cured, the surface is normally lightly dressed with fine abrasion resistant grit; without a non-slip dressing, there is a tendency to produce a slippery, very glossy surface which shows every scratch mark. This can be overcome to some extent by careful formulation and also by the application of a slip inhibiting industrial floor polish on a regular basis when the floor is in service.

This type of flooring is widely used in laboratories, pharmaceutical factories and food processing areas where easily cleaned, chemically resistant durable floors are required.

Self levelling finishes based on polyester resins more recently acrylic resins, have also been used. Polyester resin based systems have a tendency to shrink and application is very critical. Acrylic resin systems developed in Germany are similar to polyester resins, but, by careful formulation, the problems due to shrinkage have been largely overcome. The acrylic resin based systems are currently based on highly flammable materials (flash point 10°C) which can present hazards during laying. However, there are systems available which can take foot traffic within two hours of application even when applied at very low temperatures.

4.4.4 Heavy duty flooring

A considerable range of different toppings are available for heavy duty applications. The correct selection of the most appropriate topping on a cost/performance basis can only be made, if service conditions are very clearly defined. In general, heavy duty toppings require a sound (preferably 35 N/mm^2 strength) concrete substrate.

4.4.4.1 Concrete floor finishes with high abrasion resistance (Often called granolithic toppings)

In effect, granolithic toppings are just a method of producing a high cement content concrete wearing surface on a concrete substrate. The application of separately laid granolithic toppings is always fraught with the danger of debonding and curling and, therefore, generally monolithic grano-toppings only are considered. However, for many industrial floors, where good resistance to abrasion under heavy traffic is specified, a suitable floor could be achieved more economically by direct finishing of a high cement content, high strength (40–60 N/mm^2) concrete. This has been confirmed in research work which demonstrated that abrasion resistance, measured by a number of different methods, can be directly related to the compressive strength of the concrete. This work also showed that the abrasion resistance and compressive strength could be correlated to the Schmidt hammer test results, which is of considerable interest for the future non-destructive site testing of concrete floors.

"Dry shake" finishes Another method of producing concrete floors with high abrasion resistance is to trowel a blend of abrasion resistant fine aggregate and cement (approx 1/1 by weight) into the surface of the concrete immediately after laying. This technique is often called "dry shake" A pigment can be included in the blend so that a coloured finish can be achieved. The concept of this method is exactly the same as the laying of a monolithic grano-topping and is favoured by many specialists when laying large concrete floors where high abrasion resistance is required.

Where it is considered essential to apply a granolithic topping separately onto an existing concrete substrate, the danger of debonding can be significantly reduced by the use of a polymer based bonding aid. Two type of bonding aid commonly used are:-

1. Epoxy resin specially formulated for bonding freshly mixed cementitious materials to well prepared and cured concrete substrates. The strength of the bond achieved can be greater than the shear strength of both the topping and the concrete substrate.

2. A polymer latex (also known as a polymer emulsion or dispersion) such as styrene butadiene (SBR), polyvinyl acetate (PVA) acrylic or modified acrylic. These are applied to the prepared concrete as neat coats of emulsion or, more commonly, as slurries with cement.

Polymer latex bonding aids are cheaper and simple to use than epoxy resins and give a good tough bond which is 'less structural' than that achieved by the right epoxy bonding aid. The so called "universal" PVA bonding aids are not recommended for external or wet service conditions as there is a danger of the polymer breaking down.

4.4.4.2 Bitumen emulsion modified cementitious floors

The use of specially formulated bitumen emulsions as the gauging liquid for graded aggregate/sand/cement screeds can produce a dustless, self healing, jointless surface for industrial areas subject to heavy wheeled traffic under normally dry conditions. This type of topping is normally laid approximately 12 mm thick and has been used very successfully for more than thirty years, particularly in warehouses and exhibition halls such as the Birmingham Exhibition Centre. The bitumen modified cementitious floor topping is less hard underfoot than concrete and has proved popular with warehousemen. However many warehouses now have high rise racking, heavier forklift trucks and narrow aisles between racking. Under these conditions the topping tends to "indent" or "creep" and as a consequence the truck forks can become misaligned with the pallets stacked on the higher shelves of the racks thus preventing access to the goods stored on the higher levels. Point loads of above about 8 N/mm^2 for short term and 4 N/mm^2 for an indefinite period are, therefore, not recommended for bitumen emulsion modified cementitious floors.

4.4.4.3 Mastic asphalt floors

Hot applied mastic asphalt floors have been used for many years in industrial environments, where a good degree of chemical resistance under normally wet conditions is required. Properly laid mastic floors are totally impervious to a wide range of chemicals but not solvents. In terms of mechanical performance, mastic asphalt floors are similar to the bitumen modified cementitious floors but they are generally laid at a minimum of 25 mm thickness and tend to deform and corrugate in service under heavy loads. Mastic asphalt floors are not very commonly used now, except where the floor is essentially tanked, such as car park decks over shopping precincts.

4.4.4.4 Pumped floor toppings

In recent years there has been considerable interest in heavy duty toppings for the renovation of existing warehouse floors and similar applications which can be applied as flowing compositions which can be laid very rapidly by pumping using specially developed application equipment. Both rapid setting cementitious compositions and systems based on Anhydrite are used for pumped floor toppings. Those based on Anhydrite are recommended for dry service conditions only but systems based on specially formulated shrinkage compensated hydraulic cement blends are now widely used – generally with an epoxy resin finish coat.

4.4.4.5 Polymer modified cementitious floor toppings

Polymer modified cementitious floor toppings (PCCs) are now widely used instead of separately laid granolithic toppings. The polymers used are normally supplied as milky white dispersions in water and are used to gauge a carefully selected and/aggregate/cement mix as a whole or partial replacement of the gauging water. They must always be mixed in a forced action mixer.

The polymer latex acts in several ways:-

1. It functions as a water-reducing plasticiser producing a flooring composition with good workability at low water/cement ratios.
2. It ensures a good bond between the topping and the prepared concrete.
3. It produces a topping with good tensile strength and toughness.
4. It produces (based on the correct choice of polymer latex) a topping with good water and chemical resistance.
5. It acts to a significant degree as an integral curing aid much reducing the need for additional curing. (Curing, for at least the first 24 hours, is essential for large areas of PCC floor toppings).

Polymer modified cementitious floor toppings are normally laid 6–12 mm thick. Two polymer latex types are most commonly used – styrene butadiene and acrylics – which have been specifically developed for incorporation in cementitious compositions. The principal difference between the two types is that acrylic latices give higher early strengths than can be achieved with the SBR latices currently available. Toppings based on acrylic latices are used in food processing industries, particularly meat processing. Toppings can be laid in a Friday–Monday shutdown period and are reported to be capable of withstanding full service conditions 48 hours after laying, However, longer curing periods are desirable.

When adequately cured, polymer modified cementitious toppings based on acrylic/SBR latices can be cleaned by steam cleaning techniques without problems of thermal shock breakdown, which has been observed with other heavy duty polymer toppings. They are resistant to many chemicals encountered in the food and printing industries but, being based on an acid sensitive cement matrices, their resistance to organic or mineral acids is limited. There are now becoming available special polymer powders derived from these latices which can be preblended with sand, aggregate, cement and additives (requiring only mixing with water on site) resulting in factory produced, quality controlled, flooring compositions of at least similar performance to the site mixed mortars which require the addition of liquid latex.

In recent years BSI have published BS 8204 Parts 1–3 Codes of Practice for the correct laying of in-situ floor finishes. Parts 1 & 2 cover both the substrates to receive in-situ floorings and concrete wearing surfaces. Part 3 which was published in 1993 covers polymer modified cementitious wearing surfaces. The fact that industry needed such a code of practice indicating how widely polymer modified cementitious surfaces are now used as industrial floor finishes.

4.4.4.6 Epoxy resin mortar floors

Trowelled epoxy resin flooring approximately 6 mm thick is used extensively where a combination of excellent chemical resistance and good mechanical properties are required; in particular, abrasion and impact resistance and resistance to very heavy rolling loads. Epoxy toppings are available with compressive strengths up to 100 N/mm^2 and tensile strengths up to 30 N/mm^2. These are achieved by careful formulation of the binder and the incorporation of high strength fillers. When formulating a system for optimum abrasion resistance, both the epoxy resin hardener binder system and the filler blends used appear to have an influence. The simulation of abrasive service loads on industrial floor toppings in a laboratory is not simple and numerous wear test machines have been devised. Correlation between different wear test machines is not always good although most laboratory tests on abrasion resistance give an indication of the floor's likely performance in service in a qualitative rather than quantitative manner.

In formulating resins for heavy duty floors, it would appear that the adhesive properties of the resin binder used to bond the aggregate particles firmly together is a critical factor when selecting a resin system. In the selection of systems for highly abrasive service conditions, costs must also be considered and, on this basis, bauxite, calcined under defined temperature conditions, has often been used as the abrasion resistant aggregate.

Another aspect of epoxy resin mortars, or indeed other high strength resin mortar toppings is that their coefficients of thermal expansion are approximately three times that of concrete. This, coupled with the relative low thermal conductivity of epoxy mortar, can cause stresses to be induced at the resin mortar/concrete interface under conditions of thermal shock (e.g. steam cleaning), resulting in break up of the flooring due to initial failure in the concrete.

4.4.4.7 Polyurethane mortar floors

Polyurethane mortar flooring systems based on three component systems–specially formulated polyol blends, low viscosity isocyanate prepolymers and specially graded aggregate blends, incorporating cement or lime are being used increasingly in food processing areas and in chemical plants and giving excellent service. In general polyurethane polymers are more elastomeric than epoxy resins and can be formulated to have good temperature performance at over 100°C. This combination of toughness combined with good performance at elevated temperatures gives excellent resistance to thermal shock. Over the past ten years this type of flooring has been widely used in food processing areas where steam cleaning lances are often used. The adhesion of the urethane systems to damp concrete is to some extent suspect but there are now available bonding primers with excellent adhesion to damp substrates.

4.4.4.8 Polyester resin mortars

Polyester resin floor toppings, similar in performance to the epoxy mortar toppings, have been used. However, as indicated earlier, polyester systems tend to shrink and, without careful formulation and laying, shrinkage stresses can develop at the interface between the topping and the concrete substrate. Coupled with the additional stresses due to the differences in their coefficient of thermal expansion, this can cause failure at the surface of the concrete substrate. With the improvement of polyurethane screeds, polyester resin mortars are rarely used for large scale industrial floors. However, because polyester resin mortars can cure within two hours of placing to give greater strength than concrete they are are widely used for the rapid repair of small areas of damaged concrete floors. With the use of "igloos" to isolate an area of floor they can be used for rapid repairs in cold stores at normal operating temperatures. The cured product gives a tough floor topping which, over the past twenty years, has been widely used in many industrial applications.

4.4.4.9 Reactive acrylic resins

Reactive acrylic resins similar to polyester resins are also being used increasingly in heavy duty floors. Acrylic resins primarily based on methyl methacrylate monomer are low in viscosity and wet out fillers very effectively enabling the production of heavily filled flooring compositions which are easily laid. The high filler loadings and the use of a lower modulus acrylic resin binder much reduce the danger of problems due to shrinkage. Most acrylic resin systems in the uncured state are highly flammable (flash point below 10°C) and special precautions need to be taken.

4.4.4.10 Industrial tile floorings

There are industrial flooring situations where the service requirement or the time allowed for laying do not permit the use of jointless floor toppings. For such applications, a wide range of industrial tiles are available which will meet most requirements, in terms of either mechanical properties or chemical resistance. When tiles are used in very aggressive chemical environments, the potential problem area is the grout between the tiles having adequate chemical resistance. Grout systems based on specially formulated furane resins (which in particular resist very strong acids) and epoxy resins are available for this purpose, tiles laid in very fast setting mortar beds and properly grouted can often be installed and returned to service in under 48 hours. A typical application for tiles is in dairies, many of which operate every day. By using a fast setting fondu based mortar bed bonded to the underlying substrate with an epoxy adhesive one day

and then laying quarry tiles bonded and grouted with an epoxy resin system the following day, it is possible to repair a completely broken down and impossible to clean floor to a good standard with no interruptions to production.

4.5 Comparative applied costs

It is difficult to give precise costs of floor treatments because the total area, areas to be coated at one time, degree of surface preparation required and other factors all influence costs. The following is a rough guide to comparative costs of floor finishes in the UK:-

Floor treatment/flooring	Comparative cost index
Concrete Surface Hardeners, 2 to 3 coats	1 to 1.8
In-surface seals:	
Resin Solution Non Reactive, 2 coats	1.2 to 3
Reactive Resin Solutions, 2 coats	2 to 3.5
Paints: Alkyds, 2 coats	2 to 3
Polyurethane, 2 coats	3 to 5
High Build Epoxy, 1 to 2 coats	3.5 to 7
Multicoat Polyurethane Flake, 4+ coats	5 to 12
Epoxy Self Levelling, 1 to 2 mm	10 to 16
Polyester, 2 to 3 mm	9 to 12
Bitumen Modified Cementitious, 12 to 16 mm	7 to 10
Mastic Asphalt, 25 mm	9 to 13
Polymer Modified Cementitious, 12 mm	8 to 15
Epoxy Trowelled, 6 mm	18 to 24
Polyurethane Screeds	16 to 24
Polyester, 6 to 9 mm	15 to 20
Industrial Tiles, various	15 to 30

4.6 Conclusion

The range of special flooring materials available is very wide and to many extremely confusing. Specifiers, however, will find out that, if they carefully list all the service requirements for the floor, specialist manufacturers should be able advise on a suitable specification and to recommend specialist flooring contractors to lay their materials to satisfy their requirements.

5 Planning and plant layout

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5.1 Introduction

Plant layout can affect the total operation of a company, including the production processes, equipment, storage, dispatch and administration. It has a direct effect upon production efficiency and economics of the operation, the morale of employees and can affect the physical health of operatives.

A production facility will be considered as a facility for processing pharmaceuticals or food products or manufacturing engineering products or consumer goods. The facility must utilize real estate, equipment, materials and labour to generate profit for investors and, philosophically, to enrich the life of all associated with it.

Layout planning involves knowledge of a wide range of technologies that will extend beyond those of individual planners and the full range of expertise may not exist in a production facility. Consultants can provide the expertise but guidance can be found in the published works listed in the References

The design methods presented here allow a layout plan to be quickly formulated. The methods rely upon a thorough understanding of factory operations gained from experience and a good understanding of the relationship between people and equipment. When such an understanding is not present a more rigorous approach is recommended. Muther[1] published a formalized procedure in 1973 and Tompkins and White[2] a more academic method in 1984, both valuable contributions to problems of layout planning.

The first step in any design is to identify the real need, and this is often the most difficult task. Without it, designs can be produced which do not satisfy the requirements and the end result is often unsatisfactory. It is essential to clearly define the objectives of the task and to re-confirm the objectives as time progresses. A useful aid is a value analysis at the end of the concept design stage. This assesses the design for value for money while meeting the defined project objectives. A good source document is *A Study of Value Management and Quantity Surveying Practice*, published by The Royal Institute of Chartered Surveyors.

A criterion of effective plant operation used to be efficient utilization of capital equipment. The main requirement is now recognized as short door-to-door times, not short floor-to-floor times. The prime need is therefore to achieve a plant layout which facilitates reception of raw materials and dispatch of finished goods in the shortest possible time with minimum capital tied up in work in progress (WIP). This involves access to the site, reception of goods vehicles, raw material goods storage and issue to production, procurement of component parts and sub-assemblies from sub-contractors, process technology and process routes, integrating the sub-contractors' supplies, finished goods storage and dispatch to the customer.

5.2 Technological development and its effect upon plant layout

There have been important world developments in the philosophy of factory operation and they affect plant layouts. These developments, employed by companies now called World Class Manufacturers (WCM),[3] must be examined by the company management who are contemplating establishing a new factory or expanding or reorganizing an existing plant.

Much of the new thinking on strategy has centred on Advanced Technology and the exploitation of the computer, but the following recommendations, requiring minimum investment in new plant, should be considered first:

1. Establish the operational priorities:
   (a) Production to be sales driven;
   (b) Make only what can be immediately sold;
   (c) Make every part right first time.
2. Reorganize production equipment:
   (a) Consider process orientation but employ product-oriented flow when possible;
   (b) Organize products into groups that require the same manufacturing equipment;
   (c) Arrange equipment into product cells.
3. Re-form the structure of production teams:
   (a) Form accountability teams for each product;
   (b) Bring staff functions onto the shopfloor and into the teams, form quality circles and establish total quality control (TQC).

These ideas, interestingly described by Goldratt and Cox,[4] provide flexible production and cater for customer requirements. They have become known as Just In Time (JIT) manufacture, but are often overlooked by many who think that investment in computer-controlled equipment is the only way to go. The concept, simplify before you automate, can provide significant improvements in production and can point the way to later Advanced Manufacturing where:

1. Equipment cells can be replaced by computer-coordinated machines – direct numerical control (DNC), flexible manufacturing systems (FMS), flexible manufacturing cells (FMC);
2. Warehousing automated to include computer-controlled storing and retrieval (AS/AR) and movement by automatic guided vehicles (AGV);
3. Whole manufacturing processes computer linked (CAM);
4. Computer-aided design (CAD);
5. Sales and management computerized, leading to computer-integrated manufacture (CIM).

The development of these technologies can be followed in the proceedings of the professional institutions and the many magazines, some available free.

You should define the state of technological awareness in the company and consider how this affects the plant layout.

5.3 Layout planning concepts

Designs are often executed by a process of analysis. The methods vary from the traditional and well tried to experimental techniques. These include:

1. A conventional plan drawing;
2. Cardboard cut-outs depicting blocks of buildings pinned to an outline drawing of the site;
3. Three-dimensional scale models;
4. Software calculation and simulation packages.

Proprietary systems are available[10,11] employing Lego type blocks which can be constructed and placed on a base board to represent a three-dimensional visualization of the layout. Another system employs aluminum castings of the actual items of equipment and operatives. Cardboard cut-outs have been the most commonly used method, particularly with those who rarely plan layouts.

The above methods allow proposed layouts to be visualized, analysed and altered. These methods are often a try-it-and-see process, and the associated analysis is rarely structured. The old saying that 'If it looks right, it is right' is often used to justify results, but it may be more true to say that if it looks right it is conventional, and the analysis method will rarely produce something original. This applies, of course, to any design activity, whether it is a plant layout, a piece of machinery or a consumer product.

Computer-aided methods are increasingly being used to assist design and a process of synthesis, described later, employs techniques to produce a design that will satisfy predetermined criteria. This produces a layout that can be subjected to critical review, and suggested changes to the layout can be examined for violation of the criteria.

The introduction of computers to many companies allows proprietary software to be used for layout design.[5] Spreadsheet, mathematical modelling and computer-aided design (CAD) techniques are available and greatly assist the design process, and have added to the resources available to planners. However, the traditional scale models described above will still be useful to present the final result to management and shopfloor personnel.

5.4 Plant data

5.4.1 Collection

The objective of the production process is to produce the right goods of the right quality and at the right price in order to generate a financial profit from the capital investment, but the plant layout fundamentally affects this objective.

The essential requirement for any design exercise is a thorough understanding of the working medium. For layouts this means collecting sufficient data to describe those characteristics of the company which affect the layout. Data collection is time consuming and difficult, and it requires the contribution of factory personnel from many departments.

The data required includes:

1. *The company organization structure*
   All departments, including maintenance
   This should be readily available from the personnel department but may need to be updated.
2. *Number of employees in each department and shift*
   Administration staff
   Technical staff
   Factory workers direct
   Factory workers indirect
   This and the next item will be obtained from the personnel department, but the actual working situation will probably need to be confirmed with the individual managers of the various process departments.
3. *Hours and the arrangements for shift working*
   Administration and technical staff on day shift
   Difficulty is often experienced when workers are shared between departments. Some information will not be documented but since employees are generally paid for attendance hours these are meticulously recorded.
   Factory workers on each of the worked shifts
   Consider the arrangements for holidays
   Quantify work contracted to outside organizations
   Work contracted out is usually difficult to quantify. The accounts department will probably have records of the cost of such work and this can be employed to provide an indication of the significance of the work in relation to the operations within the company.
4. *Process flow diagram*
   Description of the products
   Description of the processes
   Flow diagram showing process material flow, scrap and recycled material. Brief descriptions of the products are usually sufficient for the early stages of analysis of the company operation. The information will be amplified during the subsequent stages of the study.
5. *Layout plans for all areas of the site*
   Calculate the covered areas for all process areas. Calculate the areas taken up by services such as the boiler house, fuel-storage farm, etc. Layout plans are often available but the areas devoted to the various activities in the plant will need to be discussed with the individual area managers. The actual area in square meters will need to be estimated by scaling from the drawings and measurement on site. List the items of equipment on the site. Identify the location of the items on the layout plan. This information may exist. It will be needed for designing the layouts of the internals of the factory buildings and it is useful to initiate the quest for the information during the early stages of the project.
6. *Vehicle movements*
   The *types and numbers of vehicles* moving around the site and vehicles arriving from outside the plant. Identify interdepartmental vehicle movements. It is useful to start with the records from the gatehouse, which will indicate the number of vehicles arriving at the plant each day. This will need to be confirmed with the plant manager who will know if abnormal conditions existed during the time for which the records are valid. Aim to establish average and maximum numbers.
7. *Consumables*
   The *quantities* of main consumables used. Electricity, water and gas will be included in this item but of more importance to the plant layout are those items which

occupy site space. Fuel oil is such an item, and it is important to establish whether the existing facilities, e.g. a fuel-storage farm, are sufficient for the planned operations in the factory.

8. *Effluent*
   It should be established whether the area allocated to effluent treatment is sufficient, whether the technology is up to date and determine what influence the findings will have upon the effluent treatment area and the whole plant layout.
9. *Site features*
   Site features can be obtained by observation and ordnance maps may be available from the drawing office. The features that need to be recorded are listed in Section 5.7.2.
10. *Future plans*
    It might be assumed that if an examination of the plant layout is being carried out, the future plans, as they affect the site layout, will be known. This is not always the case, therefore management should be questioned at the beginning of the project. Particular attention should be paid to hazardous substances which may be used on the site, and the health and safety document[6] should be consulted.

Pareto, the Italian economist, observed that 85% of wealth is owned by 15% of the population, and it is sometimes stated that 15% of a company's products generate 85% of the turnover. Some workers have interpreted this to mean that 15% of the data will suffice, but Tompkins and White[2] demonstrated that this is not always true, so data collectors should use their judgement regarding what is sufficient.

The data needed to plan the site layout are shown in the form of a questionnaire in Figure 5.1.

After the site layout has been determined the layout of equipment inside the buildings will need to be considered. Details of the individual items of equipment will be needed, and Figure 5.2 lists the required information in the form of a questionnaire.

The areas for administration and amenities will need to be identified and in some countries space will be required for accommodation and a mosque.

5.4.2 Analysis

The collection and tabulation of data will provide an opportunity to become familiar with the company and will generate a good understanding of the operation of the plant. Much of the data will be needed to establish the models needed to size the various areas of the plant. For instance, hours worked should be analysed to identify shift work, direct and indirect effort, and the normal and overtime activity. Outside contractors may be employed, and this contribution will need to be determined, sometimes by visiting the contractor's facilities. When expansions are being planned it may be necessary to discuss the contributions which outside contractors make to the factory and assess the increase which they can accommodate.

Description: Manufacturer:

Sketches or Manufacturing literature attached Y/N: .....
Dimensions: Equipment Size (m)
Working envelope (m) ... L x W x H Equipment weight (Kg) .....

LOCATION: Building No: Zone:

ELECTRICITY:
Single phase, isolated ..... Flameproof (Zone 1) .....
Three phase, isolated ..... Flameproof (Zone 2) .....
Three phase & neutral, isolated ..... Emergency supply .....
Direct current ..... Controls required .....
Waterproof ..... Emergency stop .....
Clean supply ..... Voltage ....
Special earthing ..... Power requirement (kW) ....
Uninterruptible supply ..... Other voltage .....
Other frequency .....

WATER: FLOW: lit/sec PRESSURE: bar CONNECTION: Details
Cold/hot .....
Soft .....
Demineralised .(Silica free Y/N ...) .....
Distilled .....
Drinking .....
Circulating Cooling ..... (Softened Y/N .....)
Flow temp (°C) .. Return temp (°C) .....

DRAINAGE:
Gravity ..... Discharge flow rate (litres/min) ....
Pumped ..... Discharge temperature (°C) ....
Solids/Sediments ..... Outlet connection size (mm) .....
Oil/Grease/Wax ..... Number of outlet connections .....
Collection Tank .....
Hazardous (eg. radioactive/solvent/biological/chemical) give details .....
.....
.....

STEAM:
CONDENSATE RECOVERY: Y/N Kg/hour psi
COMPRESSED AIR: litres/sec bar
NATURAL GAS: litres/sec bar

Model No. ..... Equipment Identification No .....

SPECIAL GASES: ..... Y/N If YES complete separate SPECIAL GASES DATA SHEET

FUME EXTRACTION:
Located in fume cupboard .....Y/N If YES complete FUME CUPBOARD DATA SHEET
Fume hood .....Y/N If YES complete FUME/DUST HOOD DATA SHEET

Local extract ductwork required ..... Scrubbing required .....
Discharge to central system ..... Filtration required.....
Discharge through wall (inbuilt fan) . ... Extraction rate (m^3/s) ... .
Connection of ductwork to equipt .. ....
Connection size and type ... . Type of fumes .....

MOUNTING:
Free standing ..... Wall mounting .....
Static/Mobile ..... Antivirbation mounts (type) .....
Floor fixing ..... Concrete plinth (m) .....L x W x H...
Bench mounting ..... Depth of embedment of bolts .....
Specify specific spacing or .....
access requirements

SAFETY AND OPERATIONAL CONSIDERATIONS:
Heat (kW) .... Radiation .....
pn Noise (decibels) .... Dust/Fumes/Vapours .....
Chemical ..... Fire/Explosion .....
Moving parts ..... Biological .....
Vibration (frequency) ..... Others (specify) .....
(emplitude) ..... (acceleration) .....

ADDITIONAL INFORMATION/COMMENTS:
Frequency of use of equipment ....
Duration of usage ....
Please list other users of this equipment .....
.....
Will this equipment require: Specialist disconnection? .....
Specialist reconnection? .....
Specialist commissioning? .....
Specialist transport? ..

Figure 5.1 Equipment data sheet

The organisation is segregated into divisions, departments, sections, rooms etc. A separate Basic User Requirement (BUR) form should be filled in for each section so that those with special needs can be identified by the planner.

DEPARTMENT/SECTION - NAME: .....

STAFF LEVELS: Indicate split function/responsibilities of staff.

Grade	Number
.....	.....
.....	.....

FLOOR AREA: (square metres) excluding corridors and common areas etc.

	Current/Projected		Current/Projected
Office	.....	Workshop	.....
Machine Room	.....	Lab Wash-Up	.....
Clean Room	.....	Computer Room	.....
Tank Farm	.....	Storage - General	.....
- Lockers	.....	- Disks	.....
- Fuel	.....	- Acid	.....
- Solvent	.....	- Paint	.....
- Temp Controlled	.....		
- Process areas - List	.....	.....	
Car park	.....	.....	
Other	.....	.....	

FLOOR TYPE: No Special Requirement .....
Vehicular traffic (detail heavy, long, awkward loads) .....
Fork Lift ..... Drain .....
Acid Resistant ..... Solvent resistant .....
Static Conductive ..... Other .....

REQUIRED LOCATION:
Ground Floor ..... First Floor .....
Basement..... Not Critical .....
Proximity to other facilities .....
Other eg. proximity to other facilities .....

CEILING: No special requirement .....
Special requirement - act as plenum .....
Lighting - No special requirement .....
Integral..... tear drop .....
Yellow ..... flameproof .....
Non-Fluorescent ..... other .....
Lighting levels see Room Environment

INTERNAL WALLS AND WINDOWS:
Internal Walls - Standard partition walls unless otherwise stated.
Acoustic ..... Soundproof .....
Stainless Steel .....Electro Static Discharge.....
Other - Non Reflective? .....

EXTERNAL WINDOWS: No Special Requirement .....
Special Requirements .....
Fixed .....Opening .....
Sealed .....Grilles .....
Blinds .....Curtains .....

INTERNAL DOORS: No Special Requirements .....
Special Requirements .....

ROOM ENVIRONMENT: - Not critical .....
Noise Level 40dBA ... 45dBA ... 50dBA ... 55dBA ... 60dBA ... Other ...
Temperature - Non critical .....
Special requirement ..... Temp °C ..... tolerances .....
Relative Humidity
Not Critical ..... Special Requirement .....%
Lighting Levels (LUX) .....
Cleanliness Based on British Standard 5295 measured at working level:
Class 1 ..... 2 ..... 3 ..... 4 ..... 5 .....
Air Lock .....Air shower .....
Storage - Lockers ..... Overalls ..... Other .....
Security - Secure Area .....Contraband .....
No Smoking .....Controlled .....
Recorded Access ..... Locks ..... Grilles .....
Secure Communications System ..... Other .....

GASES:
Oxygen ..... Carbon Dioxide .....
Nitrogen - Ordinary ..... High purity .....Ultra pure .....
Hydrogen ..... Helium .....
Argon ..... Air: ..... Press ..... (Bars).....
Other .....

Figure 5.2 Basic user requirements schedule

5.5 Process/site layout modelling

Site and factory layout designs are needed when new installations are being planned or changes to existing facilities are investigated. New layouts are examined when increased efficiency is being sought and when plant managers are planning expansions to the existing installations. There is also a need for plant managers to anticipate the changing requirements of both site and plant over future years.

When a new installation is being planned the site requirements will be predetermined, but when future expansions are being investigated a model for sizing is invaluable.

5.5.1 Computer modelling

The use of computer models to assist in plant layout decisions can often be helpful, but a clear understanding of what they can and cannot do is needed. Used blindly, they can lead to solutions which are, in some sense, optimal but which have little practical merit.

In discussing the benefits and limitations of modelling we distinguish between three types:

1. Optimizing calculations for plant layout;
2. Flowsheet models for sizing the individual items of equipment;
3. Simulation models for understanding the interaction between different manufacturing units.

5.5.1.1 Optimizing plant layouts

Historically, modelling techniques have had little impact on the problem of designing plant layouts. This has been for two reasons. First, the calculations are difficult, and second, practical constraints and considerations essential to the decision are often ignored.

To understand the mathematics, consider a large empty space into which a number of production units are to be placed, and assume that the major variable to be optimized is the cost of transporting materials between them. If the manufacturing process is essentially a flow-line operation, then the order in which units should be placed is clear (from the point of view of transport costs), and the problem is simply to fit them into the space available. In a job-shop, where materials are flowing between many or all the production units, the decision is more difficult. All the potential combinations of units and locations could be

SERVICES SUPPORT:
Vacuum pressure .....
Water - Town mains ..... Specific pressure .....
- Softened ..... De-mineralised .....
- Chilled (open circuit) . Distilled .....
- Heating .....
- Process cooling water (closed circuit) .....
Other .....
Fume Cupboards Ordinary ..... Ordinary.....
Acid ..... Solvent .....
Water Drench ..... Radioactive .....
Other .....

EXTRACTS:
to atmosphere ..... scrubbed.....
filtered ..... dedicated .....

CRANES: (Tonnes)
Overhead ..... Gantry .....
Manual ..... Electric .....

ELECTRICS:
Total power KW .....
Process/machine load KW ..... No of machines .....
Other load KW .....
Bus bar system/Trunking system.....
3 Phase ..... 3 phs + Neutral .....
Clean Supply ..... Uninterruptable .....
Stand-by Generator ..... Emergency Lighting .....
13A Sockets (do not specify number) ..... with RCCB .....
Earthing requirements .....
Faraday Cage .....
Special Lightening requirements.....Other .....

CONTAMINATION: Do you need to be separate from:
Noise ..... Vibration .....
Electrical Interference ..... Fumes .....
Gases ..... Others .....
Vibration Requirements .....
Equipment Specific ..... Room in total .....
Detune Structure .....
Electro Magnetic Interference Counter-Measures .....
Electro Magnetic Interference from Satellites aircraft etc. .....
Screened enclosures ..... GHz .....

WASTE AND EFFLUENT: (Large quantities - please specify)
Paper ..... Cardboard .....
Glass ..... Metal .....
Solvents ..... Acids .....
Cutting Fluids ..... Other .....
Powders ..... Radioactive material .....
Special wastes .....
Do you generate contamination? Please specify levels where known:
Noise ..... Vibration .....
Electrical Interference..... Fumes .....
Gases ..... Others.....

FIRE:
Local Fire regulations will apply throughout but special
requirements which need to be drawn to the Fire Adviser's attention
should be stated below:
No Special Requirement .....
Special Requirement .....

SAFETY HAZARDS - not brought out in answers above: .....
.....
FLEXIBILITY: How often do you anticipate changing your layout ... yrs

Figure 5.2 *(continued)*

enumerated on a computer and the resultant cost of each option obtained. The number of combinations quickly becomes large, however, and more sophisticated methods, such as branch-and-bound techniques, are required for complex problems. Alternatively, the location of subsets of plant, within which the layout is assumed to be fixed, could be optimized.

Solutions of this nature ignore practical considerations of noise, hazardous areas, etc. unless these are specifically entered as constraints. Furthermore, if the site is geometrically complex, then additional detail will need to be included in the problem formulation.

5.5.1.2 Flowsheet models for plant sizing

The consistent sizing (i.e. balancing the capacities) of the equipment which is to make up a plant is obviously of importance in the overall design. Models used for this type of decision are usually an extension of the manual calculations that a designer would normally make.

They are based on a network of activities (or machines) with flows of materials between them. Relationships between the activities are expressed in terms of yields or unit consumptions and, for a given output of finished products, the required output from each of the other activities can be calculated.

The complexity of the plant and the type and number of sensitivity tests to be carried out will determine whether a formal model or a simple calculation is needed.

Flowsheet models assume that activities operate at a constant rate. This is an important limitation, and may be an oversimplification. To overcome this, simulation techniques can be employed.

These models, however, can be useful if estimates are to be made of operating costs. By assigning fixed and variable costs to each activity, average and marginal unit costs at each stage of the process can be easily calculated, which will assist in decisions regarding pricing policies or whether to buy in components and materials or make them on site. ATPLAN[12] is an example of a network-based model of this type.

5.5.1.3 Simulation models

Simulation models aim to replicate the workings and logic of a real system by using statistical descriptions of the activities involved. For example, a line may run at an average rate of 1000 units per hour. If we assume that this is always the case, we lose the understanding of what happens when, say, there is a breakdown or a halt for routine maintenance. The effect of such a delay may be amplified (or absorbed) when we consider the effect on downstream units.

A simulation model has 'entities' (e.g. machines, materials, people, etc.) and 'activities' (e.g. processing, transporting, etc.). It also has a description of the logic governing each activity. For example, a processing activity can only start when a certain quantity of working material is available, a person to run the machine and an empty conveyor to take away the product. Once an activity has started, a time to completion is calculated, often using a sample from a statistical distribution.

The model is started and continues to run over time, obeying the logical rules that have been set up. Results are then extracted concerning throughputs, delays, etc.

It is clear that simulation models can replicate a complex production system. They can be used to indicate the level of shared resources needed by the operation (e.g. forklift trucks or operators), the speed of lines, sizes of vessels or storage tanks, etc.

A number of packages are available for quickly building simulation models. HOCUS[13] and SEEWHY[14] are two major UK systems. They allow graphical displays to be used to show, for example, the movement of men and materials between machines. This can be useful for understanding the way in which the operation is reacting to particular adverse circumstances and can assist in designing methods of avoiding them (for example, by building in redundancy).

Simulation models can be expensive to build and the results obtained need to be analysed with care because they are statistical in nature. For example, two runs of the model may give different results – just as the performance on two real days in a factory can vary. Sufficiently large samples need to be taken therefore for a proper understanding of the performance of the plant.

5.5.2 Model construction

A simple model can be produced using the areas required for the various site activities for different scenarios. These might include redistribution of a company's manufacturing facilities, changes in the market demand, or simply increased factory output.

Constructing the model is an area where innovative effort is needed to maximize the validity of the model. The model will vary from industry to industry, but a simple one can start with a relationship between the number of employee hours and the output produced in each discrete activity area on the site, e.g.

Activity area	*Output*	*Manning hours*
Raw material store	Tonnage/volume handled	No. and shift no.
Process areas	Output tonnage or volume	No. and shift no.
Finished goods store	Tonnage/volume handled	No. and shift no.
Maintenance	Specific area output	No. and shift no.

Service facilities, electrical sub-station, water treatment, fuel storage, etc. will depend upon process parameters, mainly tonnage or volume handled, and may need to be assessed from the summation of the individual activity areas, but it will be affected by technology when improved techniques are being introduced.

Office accommodation will depend upon the factory manning and the car parking facilities upon the total manning during the day shift.

5.5.3 Model for change

The recent introduction of inexpensive desk-top computers has allowed their extensive use throughout many companies. The standard spreadsheet packages which accompany these machines enables the above data to be laid out in an interactive way, so that 'what if' situations can be explored at the planning stage and the implications of, for example, market trends in the food industry, to be examined over the long term for its effect on the plant layout. The model may include a factor to take into account improvements in technology and working practices in both the office and factory.

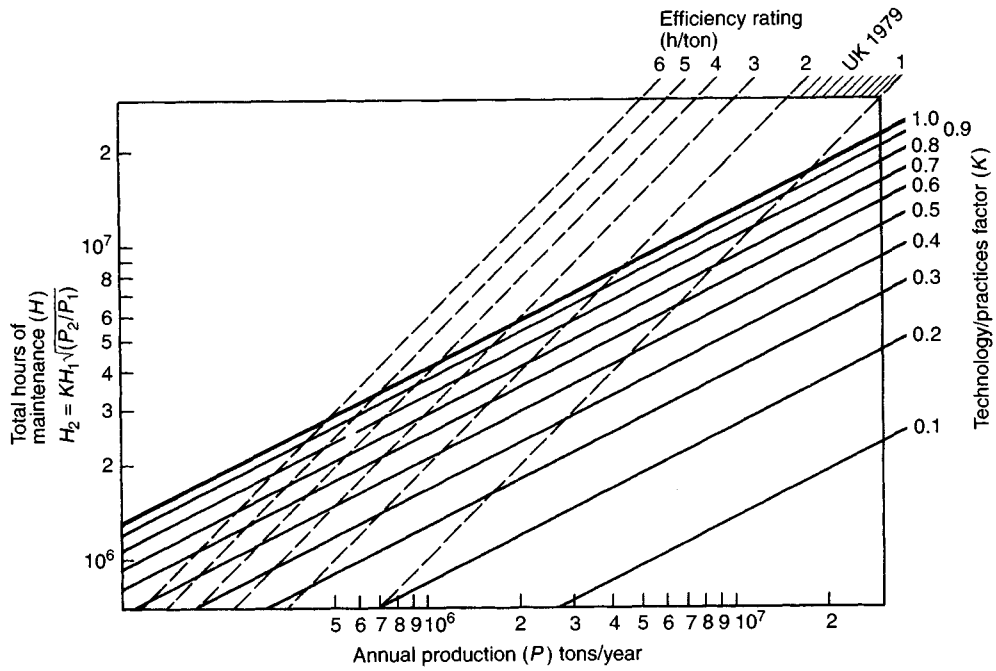
In determining the area required for increased production the relationship between the output and the area may not be linear, and needs to be examined in some detail. When the output required exceeds the maximum output of a process line then increased shift working may be considered. Alternatively, a second process line may be needed.

The model for the maintenance requirements of a large metallurgical plant was recently constructed by relating the man hours to the production output, but the relationship was not linear, and a more sophisticated model was needed to examine the site requirements for different output tonnages.

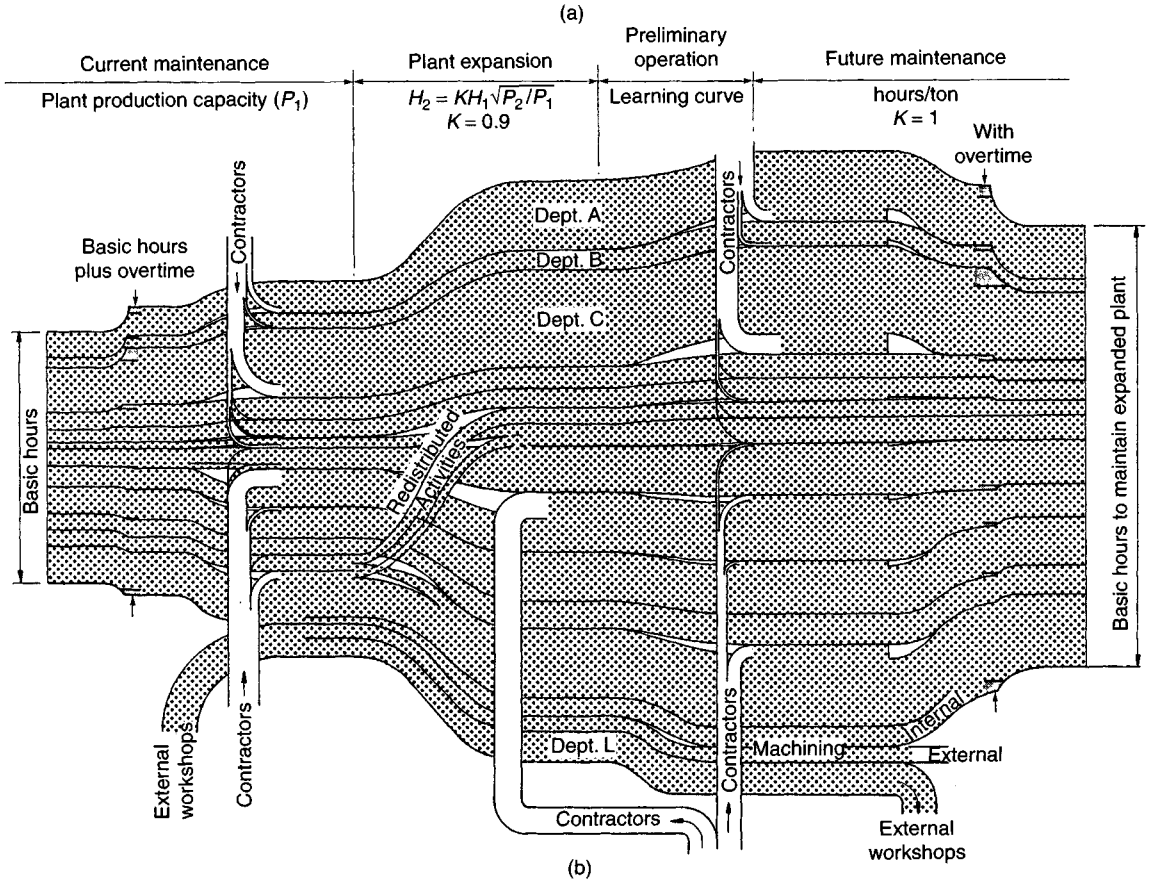
Mechanical wear is a feature which is significant among the causes of machinery failure and the James Clayton Lecture delivered to the Institution of Mechanical Engineers in 1981 discussed friction and wear and identified tribological losses as 45–50% of all maintenance costs in metallurgical plants. This suggested that mechanical transmission of energy could be investigated to obtain the relationship between production output and the maintenance requirements.

The model equation produced was:

$$H_2 = H_1 \times K \times \sqrt{P_2/P_1}$$



(a)



(b)

Figure 5.3 (a) Model of manning requirements related to plant output; (b) Sankey diagram of the changing manning requirement in an expanding plant

where

H_2 = Future man hours,
H_1 = Current man hours,
K = Technology or practices factor,
P_2 = Future production output,
P_1 = Current production output.

This produces a global requirement chart and a chart showing the discrete, departmental requirements in Figure 5.3.

New plants and expanding plants rarely produce maximum output on start-up. In large capital plants it may need many months for staff training and equipment commissioning before output is sufficient to need maximum manning. The technology factor K in the above equation can be used to reflect this. In Figure 5.3(a) a technology factor of 0.9 has been used.

It is important to test models, and in the above case, figures were obtained for other plants and the validity of the model confirmed.

5.5.4 Determination of factory areas

When existing factories are being examined the floor areas occupied by the various items of equipment can be measured on site during the data-collection period. It is important to consider and include the equipment outline (maximum travels), space for maintenance activity, operator movement and the handling of material and workpieces. In many cases the space needed for handling exceeds that required accommodate the operative part of the equipment. Aisle space is also needed for through-shop movement.

When planning new installations, manufacturers' catalogues may be the only information source of equipment data, but they rarely indicate the space needed outside the equipment outline. This requires careful consideration from an experienced facility planner to establish realistic space requirements.

In the absence of reliable information and during the preliminary planning stage (feasibility studies, etc.) the following occupancy values can be employed:

Activity	*Occupancy (m^2/person)*
Service industries	15–30
Manufacturing	20–35
Machine tool shop	20
Electrical/plastics	25
Mechanical fitting	27
Pottery/glass	35
Transport	30–65
Cars/mobiles	33
Locos	37
Wagon shop	55
Lorries	65
Distributive trades (average)	–80

These values will change with the future move towards unmanned factories.

Dividing the areas established in Section 5.5.3 by these occupancy values will give building areas. Bay widths can be established for each type of building and dividing the areas by this width will establish a building length which can be arranged into a convenient building block shape.

5.6 Design synthesis

5.6.1 Plant activities and intercommunications

In 1973 Richard Muther[1] published a method of analysing the interrelationships of activities within industrial plants, and the method allows a high degree of detail to be examined. The method proposed here is similar in that a relationship grid is constructed, but this technique employs the power of the modern desk-top computer to rapidly examine alternative layouts to obtain best solutions.

The design synthesis starts by listing the activities or areas in the plant and indicating the access which each activity needs to the other activities. The access may be required for internal process, traffic, people movement or plant services. Rather than go into the detail of examining all interrelationships for all of the above requirements, the experienced layout planner can decide which requirement predominates and employ it to produce quick results. The method allows inexperienced planners to iteratively examine the implications of changing requirements as the project proceeds and plant knowledge increases.

Table 5.1 shows the construction of a typical activity chart using one of many computer spreadsheet packages. The cross (+) identifies an activity in the plant and stars (*) in the vertical lines denote where access to other activities is needed or an interrelationship exists. A wide scattering of the stars away from the diagonal line of crosses indicates large distances between the activities and thus large communicating distances.

A feature of PC spreadsheets is that the position of rows or columns can be changed at the touch of a key, so the sequence of the rows of activities can be rapidly altered, and the position of the columns varied to preserve the diagonal pattern of crosses. This exercise can be executed a number of times to reduce the scatter of the stars away from the diagonal line and reduce the communicating distances between the activities. This has been carried out, and the result is shown in Table 5.2, where it can be seen that the stars are clustered more closely around the diagonal line. The list now shows the activities arranged in a preferred order of sequence.

5.6.2 Location criteria and boundary groups

There may be reasons why individual activities cannot be located near to those which are adjacent in the determined sequential list, so design criteria are needed to determine which activities are compatible and can be near, and which are incompatible and cannot.

Particular plants will have characteristics which will determine the importance of particular criteria, but typical

Table 5.1 Plant activity intercommunications: first design criteria

Activity	*Access to each other*																													
Heavy plant repairs	+	*	*		*		*				*	*		*		*								*	*				
Vehicle hot washing	*	+		*		*			*							*									*				
Vehicle cold washing	*		+	*		*			*																*				
Public health repairs		*	*	+	*							*	*	*		*									*	*			
Store for large tyres	*			*	+						*											*			*	*			
Service station		*	*			+										*									*	*			
Electrical repairs	*						+			*						*									*	*			
Bus washer								+								*													*
Vehicle test area		*	*						+																*	*			
Mechanical repairs							*			+		*		*		*									*	*			
Tyre shop	*				*						+					*						*			*	*			
Welding shop	*			*						*		+	*		*	*									*	*			
Panel beater				*								*	+		*	*									*	*			
Radiator shop	*			*						*				+		*									*	*			
Paint area												*	*		+	*								*	*	*			
Compressor house	*	*		*		*	*	*		*	*	*	*	*	*	+														
Tailor																	+							*	*	*			
Carpenter																		+	*						*	*			
Store – carpenter																		*	+						*	*			
Store – tyres					*						*										+				*	*			
Store – tailor																	*					+			*	*			
Store – paint															*								+	*	*	*			
Store – general	*			*	*	*	*		*	*	*	*	*	*	*		*	*	*	*	*	*	*	+	*					
Administration block	*	*	*	*	*	*	*		*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	+					
Filling station																										+	*			
Vehicle park								*																		*	+			

Table 5.2 Rearranged activities to improve plant operation

Activity	*Access to each other*																													
Filling station	+	*																												
Vehicle park	*	+	*																											
Bus washer		*	+						*																					
Vehicle hot washing				+		*			*	*	*		*	*																
Vehicle cold washing					+	*				*	*		*	*																
Service station				*	*	+			*		*	*																		
Tyre shop							+	*	*		*	*	*																	
Store – tyres							*	+			*	*			*															
Vehicle test area				*	*				+	*	*	*																		
Compressor house			*	*		*	*		*	+			*	*		*	*	*	*	*	*									
Administration block				*	*	*	*	*		*	+	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Store – general						*	*	*		*	*	+	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Heavy plant repairs				*	*		*		*		*	*	+		*	*		*	*											
Public health repairs				*	*				*		*	*		+	*			*	*	*										
Store for large tyres								*			*	*	*	*	+															
Electrical repairs									*		*	*	*			+	*													
Mechanical repairs									*		*	*				*	+	*	*											
Welding shop									*		*	*	*	*			*	+		*	*									
Radiator shop									*		*	*	*	*			*		+											
Panel beater									*		*	*		*				*		+	*									
Paint area									*		*	*						*		*	+	*								
Store – paint											*	*									*	+								
Carpenter											*	*											+	*						
Store – carpenter											*	*											*	+						
Tailor											*	*													+	*				
Store – tailor											*	*													*	+				

criteria will include the following:

1. The hazardous nature of the activity;
2. The ease of access to the entry gate which the activity needs;
3. The amount of dirt and potential contamination that the activity would generate;
4. The amount of noise and potential disturbance which the activity will normally generate.

Each of the listed plant activities can be assessed for each of the chosen criteria and a star rating determined for each assessment. An experienced engineer will find that a qualitative assessment is sufficient, but quantitative measurements can be used if necessary. The results of this exercise are shown in Figure 5.4.

For each of the criteria a two-star rating difference between an activity and an adjacent activity is taken to indicate incompatibility. Activities that are hazardous, dirty, noisy or needing good access to the entry/exit gate are consequently rated with many stars. In the site layout they should not be located near other activities with fewer stars because they could adversely affect that activity. However, an activity that is not critical and has a low star rating may be located next to an activity with many stars.

Boundary maps can be drawn around groups of stars which are compatible and horizontal lines drawn through the incompatibility points to show groups of compatible activities on the right-hand side of the chart Figure 5.4.

Groups of compatible activities together with their major characteristic can be listed, e.g. for a transportation maintenance facility, as follows:

Boundary group	*Characteristic*
Filling station	Hazardous
Vehicle park	High traffic density
Servicing facilities	Dirty
Administration and stores	Quiet and clean
Repair facilities	Medium traffic, dirt and noise
Body shop	Noisy
Accommodation	Quiet

The synthesized layout can be described in terms of the characteristics of the various zones within a hypothetical site boundary as shown in Figures 5.5 and 5.6.

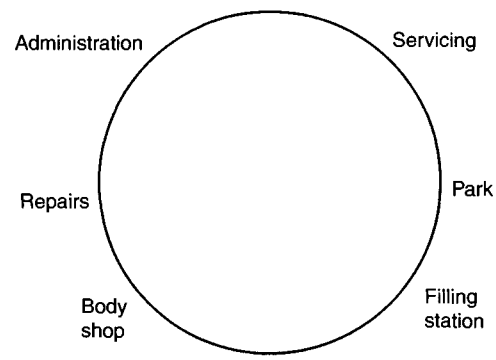


Figure 5.5 Synthesized location of plant activities

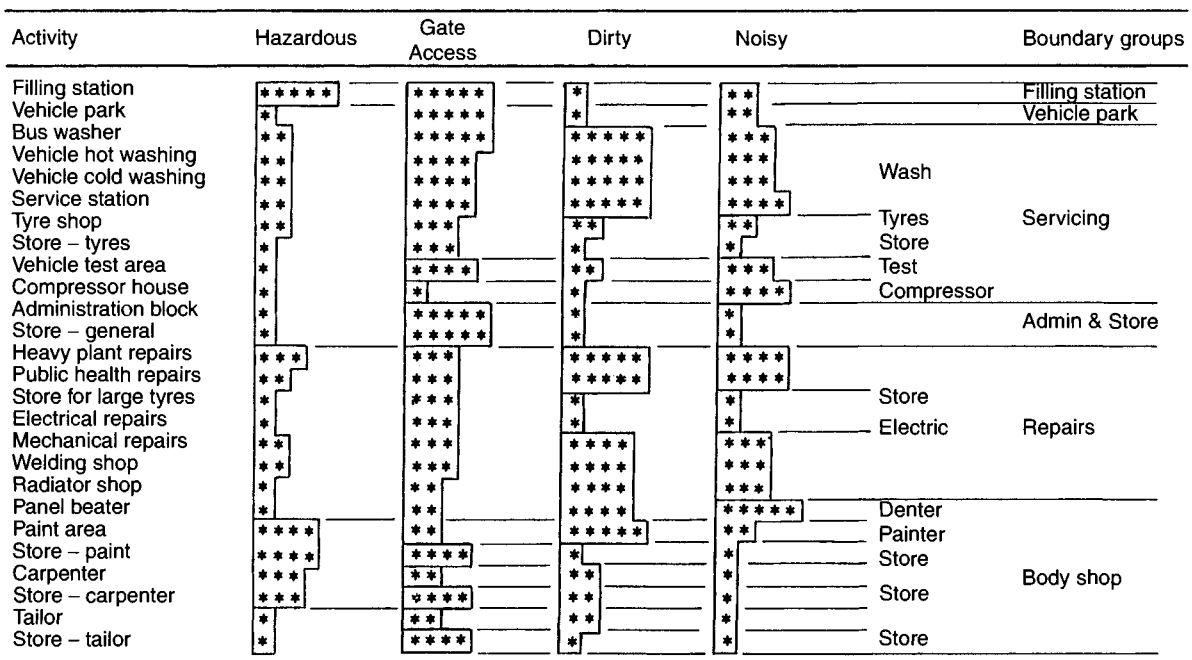


Figure 5.4 Compatible activities and boundary groups: secondary design criteria

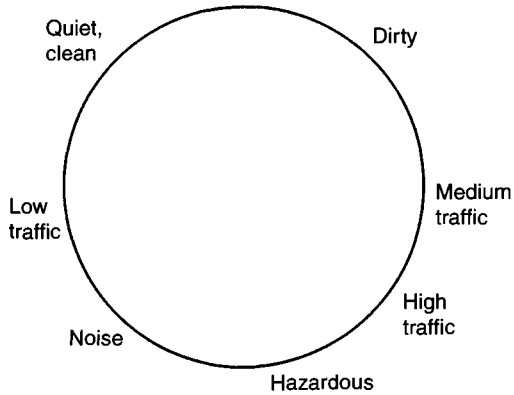


Figure 5.6 Characteristics of the synthesized layout

5.7 Site layout realization

5.7.1 Process and traffic flows

Traffic and material movement is a major consideration, and should be arranged so that cross flows are minimized and the potential for congestion and accidents reduced. Much useful information on both the analysis and practice of movements is contained in the References.

Using the example of a transportation maintenance facility, Figure 5.7 shows that a counter-clockwise rotation of the traffic flow could achieve minimum crossing and give a graduation of decreasing traffic density in the counter-clockwise direction as vehicles are diverted off the main stream (Figure 5.8).

The circulation diagram indicates that, in a left-hand drive environment, activities with a high traffic density

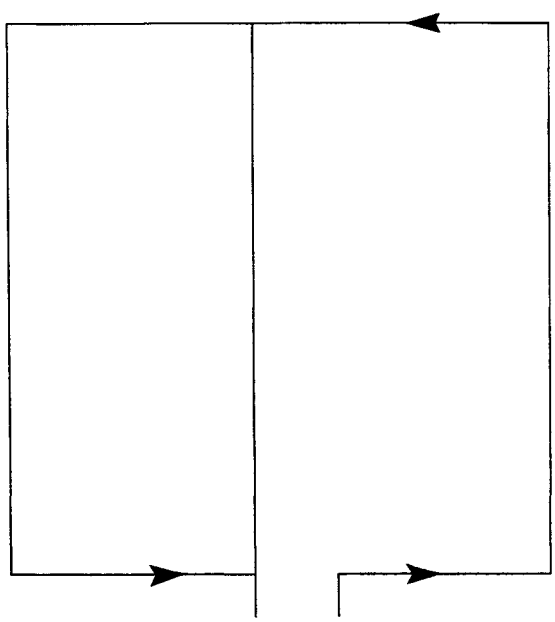


Figure 5.7 Ideal traffic or material flow

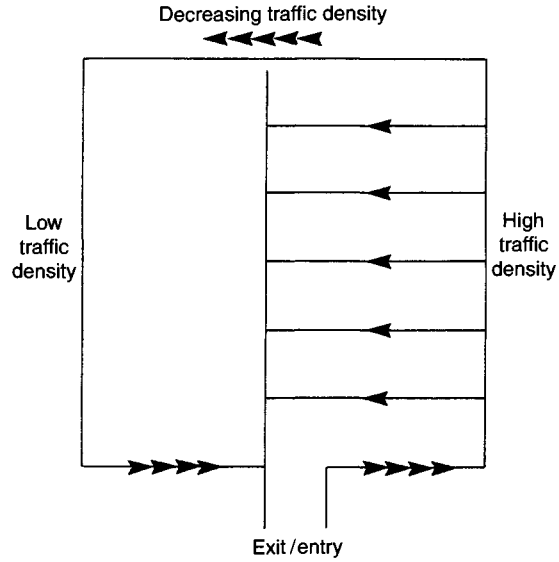


Figure 5.8 Traffic density zones

should be located on the right-hand side of the traffic circulation diagram and the activities with low traffic on the left-hand side.

With this arrangement, the vehicle needing no servicing or maintenance could be parked on the right-hand side of the site in a park designated Overnight Park, and the filling station which handles all the vehicles could be located towards the centre of the site in the flow line of the vehicles leaving the area.

The servicing area could be located on the right-hand side of the site but remote from the gate, and part of the park near to the servicing area could be allocated to vehicles which arrive for their scheduled routine service.

The left-hand side of the site has a reducing traffic density and could thus accommodate the vehicle repair shops. The body shop is a repair function, and thus would be located on the left-hand side but remote from the existing administration office.

The technical administration office needs to be quiet and clean and central to the facilities which it administers. Hence it should be located in the central area between the service and repair shops. This is remote from the dirty, washing facility and the noisy body shop while providing good access to the gate.

The remaining corner on the left-hand side of the site can be arranged to be sufficient distance from the body shop so that it can be quiet and thus suitable for staff accommodation and the plant administration office. Thus the synthesized layout becomes as shown in Figure 5.9.

5.7.2 Site constraints

The real design must consider design criteria derived from the physical constraints of the chosen site and the current operating procedures. In this exercise the site must be examined to list the features of the site which will affect

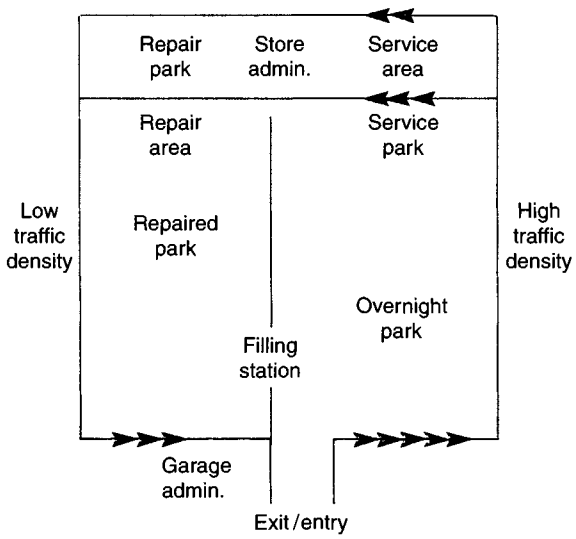


Figure 5.9 Combination of synthesized layout and ideal flows – garage layout

the plant layout. These will include the contour of the site and the location of the following:

1. Main highways and access to the site area
2. The main and other gates to the plant
3. Factories near the boundary of the plant
4. Domestic dwellings near the boundary
5. Natural features such as streams
6. Effluent routes
7. Prevailing wind directions.

These can be drawn onto a plan of the site area, which does not show the existing or any proposed arrangement of the plant layout (Figure 5.10).

The site constraints must be considered for their effect upon the design and the practicality of implementing the design. When the plans are for an existing plant, the implementation must consider the minimum disturbance to the everyday functioning of the existing plant. These limitations can be listed as follows:

1. The location of the gate;
2. The existing buildings which have been found, during the structural survey, to be structurally sound and will be retained;
3. The logistics of erecting new buildings and rearranging the plant with minimum disturbance to the plant functions;
4. The requirement to allow for future expansion of the production and subsequent activities in the plant.

As an example, the synthesized design takes all these limitations into account in the following ways:

1. The gate is taken as a starting point for realization of the layout and high traffic densities are placed near to it;
2. The structural survey dictates which of the existing buildings will be replaced;
3. The final report will need to include a detailed description of the implementation procedure to demonstrate that the synthesized layout is feasible.

The final layout characteristics are shown in Figure 5.11.

5.7.3 Ease of expansion

Layout planners normally have to consider that activities within the site may change in the future. The changes may be the result of increased product demand or the introduction of new product lines. They may be predicted from the model designed in Section 5.5.2 or allowance for unpredictable changes may be needed.

The dilemma facing the planner is between designing the layout with minimum distance between buildings and allocating free space between buildings to accommodate future process units. Often the problem becomes one of providing a single building for economy or multiple separate buildings for ease of expansion.

The solution may be a policy decision, but this decision will be assisted by the results of the internal layout configurations, which may indicate how simply or otherwise expansion can be accommodated.

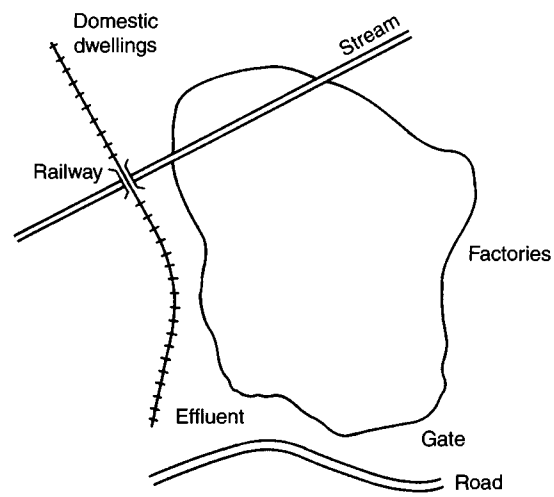


Figure 5.10 Site constraints

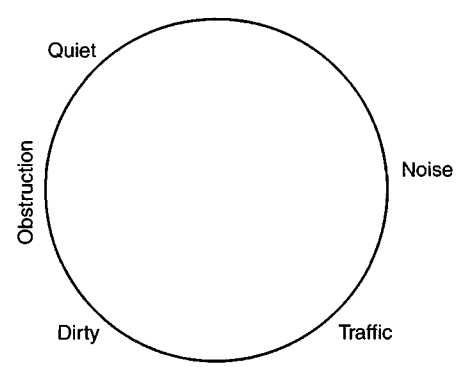


Figure 5.11 Conceptual layout design on the real site

5.7.4 Options

Management usually wish to see alternatives to a particular design in order to say that the alternatives have been considered. Unique design solutions are rare, consequently the layout planner will normally be able to interpret the results of the finding of the study to show alternative possibilities. Each alternative option should be accompanied by a critique listing the advantages and disadvantages.

5.8 Internal layouts of buildings

Material, traffic and people are involved, and the constraints on internal layouts will be different to those for site layouts but will not affect the design process. The constraints will include organization of the factory work tasks, which may involve trade practices and the type of organization adopted for the control of the process equipment. This is discussed in Section 5.2.

5.8.1 Process flows and performance indicators

The same method as described above can be employed to plan the layout of factory building interiors. Establishing the interior activities and characteristics of the activities must, however, derive from a thorough understanding of the products and processes.

The management of production is well described by Hill,[7] but the prime consideration is product flow, and all features of the layout must assist flow. There are some indicators which can be used to measure the quality of the production facilities, and these can be employed to demonstrate the viability of the proposed new layout.

5.8.1.1 Performance indicators

The relative importance of each indicator will vary according to the type, quantity, end quality, variety and value of the product and the capital cost, flexibility and required utilization level of the plant. There are three variables which will serve most industrial processes:

1. *The stock value*. The value of the stores stock represents a significant investment for many manufacturers and financing the work in progress can also represent a significant cost. It is a useful indicator of the financial health of a company and is a prime target for cuts in the drive for increased economic efficiency. Section 5.2 highlighted this.
2. *The cycle time*. This represents the maximum time interval between the start of a single operation on a product on a particular flow line and the start of the same operation on the next product on the same flow line. The cycle time is calculated by dividing the target production volume (annual or monthly) by the working time (hours, minutes or seconds) and then adjusting for the reject rate and the percentage of lost time (downtime). If every operation is conducted within the cycle time then the steady-state functioning of the flow line will produce the required production rate. The number of sequential process operations multiplied by the cycle time is the actual process time.
3. *The door-to-door time*. This represents the total elapsed time from the delivery of the raw materials or component parts to the despatch of the finished product. This figure can be adjusted to control the value of the stock of materials, parts, work-in-progress (WIP) and finished goods in the process. The gross excess stock carried can be found by dividing the door-to-door time by the actual process time and multiplying the result by the stock value. The difference between the gross and the net excess stock values will depend on individual circumstances. Reducing these figures to a minimum requires strategies for purchasing, stock-level monitoring and process control.

5.8.2 Process equipment

When the idealized flow routing has been determined, the equipment must be located and the practicalities of the interrelationships between, and integration of, equipment, services and people must be considered.

Equipment information would have been collected during the data-gathering exercise described in Section 5.4, but a thorough understanding of the process is vital during this phase of the work.

Adequate space for the equipment must include:

1. The machine itself with the maximum movement of all machine elements;
2. Space for maintenance activities, withdrawing shafts, etc.;
3. Process material movement;
4. Operator mobility.

5.8.3 Material handling

Knowledge of material-handling techniques is vital to the layout planner, and detailed consideration will need to be given to the various techniques and equipment, which are available. References 2, 8 and 9 contain valuable information and trade journals report the current state of the market.

In the absence of reliable information and during the preliminary planning stage (feasibility studies, etc.) the following space requirements for aisles can be employed:

Traffic type	*Aisle width (m)*
Tow tractor	3.7
3-ton forklift truck	3.4
2-ton forklift truck	3.0
1-ton forklift truck	2.75
Narrow-aisle truck	1.85
Manual truck	1.6
Personnel	1.0
Access to equipment	0.85
Allow extra for door openings	

5.8.4 Storage

Storage in plants range from simple facilities to fully automated flow through warehouses. Simple facilities are installed to contain the day-to-day requirements of, for instance, maintenance workers, and the just-in-time supply of components on the production floor. Fully automated flow-through warehouses are employed in the food industry where the shelf life of many products is short and a high throughput is involved. Much has been written about storage and References 8 and 9 are excellent.

5.8.5 Electrical distribution

The plant layout design and whether the processes involve dry, wet or contaminated environments with possibly elevated temperatures will affect the principles adopted for the support and containment of electric cables and bus bars. Cables from the incoming supply sub-station to load centres would normally be run in the ground, either directly buried with suitable route marking and protection, or in ducts or concrete trenches. Depending on the number of cables, the latter may incorporate support trays or cleats fixed to the trench walls.

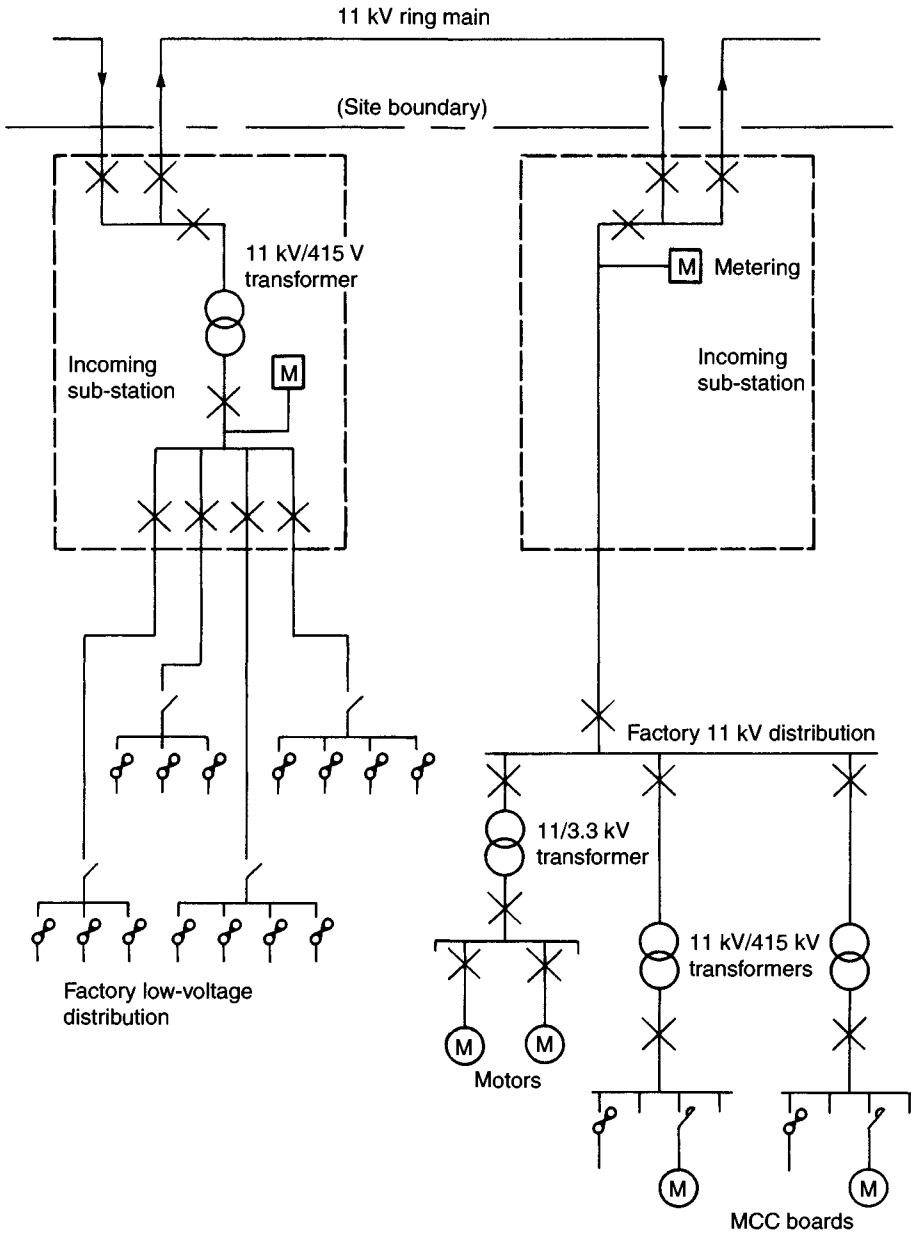


Figure 5.12 Typical power distribution system

Inside the factory buildings, below-floor trenches are frequently the preferred method for main routes, but where there is danger of flooding, due to storms or process fluids, above-ground routing must be considered. Single or few cable runs could be clipped to walls and building structures but multiple cable runs need traywork, involving space equivalent to major pipes and air ducting, and routing must be coordinated with other services.

Busbar trunking systems are frequently employed in machine shops to facilitate relocation of the equipment. The busbars are located overhead, suspended from the roof structure, and arranged, in conjunction with the lighting system, in a suitable grid pattern. Fused plugs and sockets provide outlets to individual items of equipment.

In some installations (e.g. clean rooms), the electrical distribution system can be located in the sealed ceilings, allowing maintenance access without affecting the clean facilities (Figure 5.12).

5.8.6 Building utilities

These include the canteen, toilets, workers' rest rooms, access routes and the car parks. Hygiene, traffic density, traffic flow and sizing need to be addressed and have been discussed in the section on the sizing model.

5.9 Selling the concept

The site layout needs to be presented to management, union, staff and possibly others to obtain approval, and the design procedure described here, together with a visualization, will assist the presentation.

Photographs of the proposed site are useful and a site layout drawing is needed, but a perspective artistic impression showing buildings with architectural facades, vehicles and other site activities improves the presentation. Employing three-dimensional models[10,11] discussed in Section 5.3 helps communication and allows layout options to be easily demonstrated and discussed.

5.10 Implementation

One of the principal tasks facing the manager responsible for implementing a new plant layout is the planning and scheduling of the many activities involved in the project. Modern computerized systems have evolved into easy-to-use tools that avoid the need for a detailed technical knowledge of planning techniques.

Project plans for the installation and commissioning of new plant should be prepared in order to:

1. Provide a readily understood and concise description of the scope of work for all involved in the project in order to facilitate easy communication between all parties;
2. Provide an informative management tool for the monitoring and control of progress, including the effect of changing circumstances that so often occur in the form of extended delivery timescales, revised requirements and new external constraints on the project completion date.

The project plan should be started as soon as possible so that all aspects of the early layout planning can be incorporated into the plan.

Most detailed programmes for plant-related projects are prepared using simple Critical Path Analysis (CPA) techniques. CPA is a well-known and familiar technique to most engineers and is incorporated into most modern PC-based planning and scheduling systems. Such a system typically has the following features that a plant project manager will find useful:

1. Easy screen-based data entry of related task details;
2. Ability to allocate material and labour resources to each activity to allow a picture to be built of the total resource requirements over time;
3. Simple production of barcharts or Gantt charts detailing the task timescales;
4. The ability to schedule the tasks logically within the constraints of available resources.

The definition of what constitutes a resource from a scheduling point of view may vary, but would normally include materials, labour, special tools, temporary services and also access to space on the plant floor if the layout is particularly tight. This last item is of great importance, as it is easy to forget that a given amount of space will limit the number of people working in it, and the scheduling system can take it into account when re-scheduling start dates.

For the more sophisticated requirements of complex one-off projects, techniques such as PERT, resource, levelling and precedence diagrams should be investigated.[15]

The most important aspect of planning the work is that the plan should be constantly monitored for progress and the individuals responsible for particular areas of work should be kept well informed regarding delays or advances in the programme.

Frequent updates and reports will ensure that surprises are kept to a minimum and allow smooth progress of the project towards completion.

Should problems occur in the project at any time, the modern planning systems allow rapid changes to the logic or task details and the consequent update to the project programme.

5.11 Consultants

5.11.1 The case for

Planning the layout of a manufacturing facility should be an infrequent activity for an operational manufacturing company. The staff of such a company will normally be fully committed to the day-to-day activity of assisting factory output, and they will rarely have the time to consider the design problems associated with plant layout. They do have intimate knowledge of the products and processes but not the practice and techniques of the design of plant layout. In these circumstances, it is normal to engage the services of a firm of consultants.

The consultants will need to conduct in-depth discussions with company personnel to acquire the data described above, but will bring to the task the skills of years of practice, often employing modern computing techniques, knowledge of industrial trends and undivided attention to the task.

The best way to select a consultant is to seek recommendations from other companies who are known to have carried out a similar exercise. Failing this, a useful guide is the Association of Consulting Engineers yearbook, which lists the consultants classified according to the type of engineering work they engage in and their specialist discipline. An alternative approach is to contact associations set up to serve particular industries (e.g. the Production Engineering Research Association (PERA) in Melton Mowbray for engineering production and the Rubber and Plastics Research Association (RAPRA)).

The consultant will discuss and determine the objectives of the activity, but it is useful if a specification is prepared in advance of the consultant being engaged.

5.11.2 Specification

After a short introduction to the company and its products the specification should describe in some detail the reasons why a new layout is needed. This will vary from the introduction of, or change to, new products, the establishment of a new factory or the need to explore the changing future demands on an existing site as a result of changing technology or market forces and opportunities. (Contracts are described in detail in Chapter 5.)

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Software programs

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13 HOCUS; PE Consultants, Egham, Surrey.
14 SEE-WHY; ISTEL, Redditch, Warwickshire.
15 PERTMASTER; Pertmaster International Ltd, Bradford.

6 Contract management

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6.1 Contracts

In the course of his career the plant engineer will be a party to a contract. His employment is a contract between himself and his employer unless he is self-employed. What is a contract? A contract is an agreement between at least two parties to a matter. The important aspect is that the agreement is to the same thing. This is known as *consensus ad idem*, and follows an offer which is accepted. An invitation to tender is not an offer, the offer being made by the tenderer in submitting his tender. English law says that certain essential elements need to be met before a contract can be enforceable, and these are:

1. *Agreement* – as mentioned above;
2. *Intention* – The parties must intend to create legal relations;
3. *Consideration* – This is essential in simple contracts, which most are. An example is that *A* makes a contract to purchase a car from *B* at a cost of £10000. In paying the £10000 *A* is fulfilling the essentials of consideration. A contract would not exist if *B* gave his car to *A* because there would be no consideration.

The law of contract is exceedingly complicated, and the pitfalls experienced by engineers keep a substantial number of solicitors, barristers and judges in the style to which they have become accustomed over the past few hundred years or so.

Contract law is a combination of common law and statute law. Common law is judges' law, which is continually being revised as important cases come up in the High Court and above. The earliest recorded common law case is *Luddesden v Elham* (1201). Statute law is made by Parliament and Acts of Parliament which are current Acts going back to the thirteenth century. European law now takes precedence and Parliament must make statutes either by Acts or Regulations to change the law to accord with European Directions.

This chapter is concerned with contracts, specifications and management of engineering works and the way in which they should be approached by the plant engineer. Health and Safety is an important feature of all contracts whether for the supply and installation of machinery or connected with works of engineering construction and maintenance. These matters are dealt with in Chapter 39 under Health and Safety.

6.2 Approaching the contract

A contract is made when the essential elements have been fulfilled and the offer and acceptance communicated, and, apart from contracts involving land, can be verbal (or oral). A common misconception is that a party signs a contract. In reality, a party signs a document which contains the terms of the contract being entered into. Almost all contract documents omit many matters which are important, and the reason for this is that the law says that certain matters are implied to be contained within a contract. An example is that if *x* buys an item of plant from *y* it is implied that *x* will receive it within a reasonable time, and that it will be satisfactory when he receives it.

Whilst express terms in a contract are advisable, some are of no value at all, and in fact can work against the author. An example is an unfair contact term which may be included, but if it is not sufficiently brought to the attention of the other party before the contract is made, it is not enforceable.

The object of contractual documents in the supply and installation of plant is to have a clear and unambiguous agreement to supply and install the plant in accordance with the specification and drawings, and installed within the time agreed, or within a reasonable period if none is stated.

What documents will be drawn together to form a contract? These will include:

1. Drawings of the installation sufficient for the tenderer to be able to provide a tender;
2. A detailed technical specification of the works, which will contain other matters such as defining the parties, standards of work, programme and basic contractual positions, and duties for safety particularly with respect to the CDM Regulations;
3. Tender forms, which will include provision for the tenderers to submit a lump sum tender, or a rate for labour and materials, or both;
4. Letter of invitation to tender.

6.3 Types and forms of contract

In English law there are two main kinds of contract – Simple and under seal. Simple contracts require consideration, whereas contracts under seal do not.

There are many standard forms of contract which are used in the engineering industry, most of which are published by professional bodies or groups of professional bodies. It is usual for large companies and government organisations to produce their own, to suit their needs and protect their interests. In the case of air conditioning, because the works are likely to be carried out alongside other building works, it is likely that either the JCT Domestic Sub-Contract, MF/1 or Model Form A will be used.

A contract document cannot go against a common law rule or Act of Parliament, by the introduction of an express term.

The Unfair Contract Terms Act will ensure that any onerous term must be sufficiently brought to the attention of the other party, otherwise it will have no effect.

There are several ways to employ the contractor, and some of these are outlined below:

1. Lump sum fixed price. This is the most commonly used method, and ensures that the client will know exactly how much he will be paying;
2. Lump sum fixed price with a schedule of rates to cater for variations to the works;
3. Measured Bill. A bill of quantities based on a measurement of the amount of work, with remeasuring at the end of the job;

4. Daywork (or Quantum Meruit) based on the agreed cost of labour per hour and on cost of plant and materials. This is sometimes the only fair way where the amount of work is uncertain, or cannot be sufficiently estimated by the tenderer.

6.4 The specification and drawings

The smooth running of the contract and the satisfactory operation of the system will depend to a large extent on the way the plant engineer designs the plant, and expresses it in his specification and drawings. There is a tendency for designers to adopt standard specification formats, and whilst this is to be applauded, a 50-page specification for a small job can mean that only a small percentage is applicable to that particular project. It should be remembered that the foreman on the job will have the task of interpreting what the designer had in mind.

The General Specification must coincide with the drawings to be credible. It is all very well inserting a clause to the effect that 'The Engineer shall determine the interpretation of any clause' which implies that he has the power of an arbitrator, but in reality, if he has negligently specified anything by being ambiguous, then his client or the contractor may have a claim against him if either of them suffers loss as a result.

The General Specification itself can be divided into the following headings:

Conditions of Contract
Technical Clauses
Specification of the Works

The following is a checklist and brief description of the various clauses:

6.4.1 Conditions of contract

1. *General* – This is a description of the type of contract and the relationship with other parties. For example, whether the contract is to be nominated, main or domestic, fixed price or fluctuating.
2. *Interpretation of Terms* – Name of all known parties and their positions. Some terms may be outlined, i.e. 'month' means calendar month and 'shall' means action by the contractor.
3. *Form of Tender* – A more detailed description is given regarding the form of tender and of prime cost and provisional sums, handling and profit on cost.
4. *Bills of Quantities* – The client can require a successful tenderer to supply a priced-up bill of all items tendered for within a certain time after being requested to do so. This is useful in a lump sum contract where variations to the contract occur. The bill in this case is provided by the tenderer.
5. *Tender make-up* – Invitation to the tenderers to clarify points prior to tender. Alternative makes of equipment may be offered instead of the ones specified, but the tenderer must tender for what was specified, and include the alternatives as a separate list.
6. *Attendance* – In the case of a sub-contract it should be made clear to the tenderer any attendance which will be provided to him by the main contractor, and any conditions attached.
7. *Programme* – The programme of works should be outlined, and any special provisions, such as working in phases to suit either the client or the main contractor.
8. *Health and Safety* – Reference will be made to the duties of the tenderers which will in any event be governed by legislation such as the CDM Regulations. Fines of £20 000 have recently been ordered against firms not complying with these Regulations.
9. *Site Meetings* – The frequency of site meetings should be outlined and a commitment to attend any *ad hoc* meetings which may be called by the client or main contractor.
10. *Related Documents* – A list of all the documents which make up the contract. Interpretation of terms.
11. *Payments* – Details of when valuations and payments are to be made.
12. *Variations* – The procedure for variations will be outlined and may in any event form part of a standard form of contract.
13. *Insurance* – It is essential that adequate and appropriate insurance is maintained by the tenderer if he obtains the contract.
14. *Completion* – Practical completion and defects liability period details.
15. *Arbitration/Mediation Clause* – This is likely to be mentioned in most standard forms of contract, and if repeated here, should be verbatim.

6.4.2 Technical clauses

1. *Scope* – general description of the works.
2. *Regulations* – a general list of regulations which apply to the particular type of works (e.g. Health and Safety at Work Act 1974), etc.
3. *British Standards and Codes of Practice* – A general note that the installation shall comply with all relevant British Standards and Codes of Practice.
4. *Drawings* – Details of drawings and manuals which the contractor shall supply to other parties (e.g. building work, drawings and working drawings, and a description of details to be supplied).
5. *Site visit* – Invitation to tenderer to visit site to see for himself any possible site problems. A disclaimer against extras in the event that the tenderer does not appreciate obvious site problems.
6. *Tests/commissioning* – Details of any specific tests required, and commissioning format, and who is to witness and reports to be submitted.

6.5 Estimates and bills of quantities and estimates

In some contracts, mainly connected with general building projects, rather than specifically plant and machinery, a quantity surveyor is appointed to draw up a schedule of

items which require pricing, and which the total is the tender figure.

A qualified quantity surveyor has a first-class knowledge of building construction, and is an expert in drawing up a bill of quantities, and very often has a good knowledge of contract law, which makes him invaluable where there are complicated issues. While the plant engineer may not often be presented with bills of quantities, it may be useful to have a grasp of the general approach. There are three stages to a bill: taking off, abstracting and billing. Taking off is a detailed measurement of drawings or on site of the subject matter. This is carried out in conjunction with a manual used by all quantity surveyors called the *Standard Method of Measurement*. The items contained are complete in that they include for all labour and materials. The abstract is a sheet where all similar items are grouped together, and the bill is where the items are listed for the tenderer to add his prices. The tenderer is also given the opportunity in the bill to add his profit and on-cost for other contractors under his control.

Another method widely adopted by smaller firms is to measure all materials and plant to be supplied and then add labour costs, separately. Overheads for the tenderer, transport etc. are then added, and then appropriate profit. This method does not give a ready method of pricing variations.

6.6 Specific sums stated in tender documents

In most engineering contracts for works to be carried out on site, there are unknown costs at the time of tender and costs which are known, where the work is to be carried out by others, but to be under the control of the successful tenderer. These sums are shown below:

6.6.1 Prime cost (PC) sum

This is a sum which has been determined prior to tenders being obtained for the main works, and which can be expressed accurately as a sum to be included in the tender build-up. The tenderer has the opportunity to add a sum within his tender for profit or on-cost in administering the works.

An example would be where the consultant had already invited competitive quotations for supplying air-handling units so that he could design a particular make into the system and ensure that his client received the best value for money. The tenderer would include in his tender, either separately shown or in the body of his figures, a sum to cover profit and on-cost in handling the equipment. The contractor appointed would be responsible for organising delivery and would give a warranty on the equipment, in accordance with the contract. This aspect is amplified in Section 6.18.

6.6.2 Provisional sum

This is a specific sum included in the tender documents to indicate to the tenderer that it is contemplated that the particular work referred to will be carried out, but that, at present, no firm plans have been made as to cost, and usually the work has not been detailed either. The contractor is not entitled to profit or on-cost, unless the works go ahead. An example of this would be a general intention by the client to provide special ventilation to a laboratory, which is part of a larger scheme, but that no firm plans as to the full requirements have been drawn up at the time of inviting tenders.

Let us assume that £5000 has been included as a provisional sum. At a later date a scheme is produced and priced up by the successful tenderer, and his price is £4875, including profit and on-cost. At the end of the contract, when the final account is submitted, the contractor will show that of the £5000 provisional sum, £4875 has been spent, and the client will be £125 better off than expected.

6.6.3 Contingency sum

In most contracts of supply and install, a sum of money is included in the tender figure for which there is no allocated use. This is known as a contingency sum. The amount of the sum varies according to the size of the contract and the degree of complexity of the works to be carried out. For example, the installation of a piece of plant which will be delivered to site fully tested and ready to run on its own, once services are installed to it, will not need a high sum. On the other hand, a system which is a one-off, designed and built specially for the occasion on site, depending on items such as distribution ductwork or pipework or unknown structural and services matters will need a substantial sum of contingencies. There is no hard and fast rule, but the sums range from 4% to 10% of the contract sum. Generally, where there are known problems which cannot be accurately assessed (such as diverting an underground water main) a provisional sum should be put in rather than a contingency sum.

The danger is that often many issues are left to the contingency sum, which means that it is spent before other as yet unknown matters come to light. It is better to report a higher tender figure which has the possibility of being reduced at the end of the job, rather than a lower one which is almost certain to increase.

6.7 Tender documents

These are documents to be completed by the tenderer after he has studied the specification and drawings, where appropriate, and which contain the special commitment of him with respect to the particular job. His chances of being successful will depend largely on how he fills in the forms contained in the documents. Very special care should be taken in preparing these documents, and equally important is analysing them after tender, as will be discussed in Section 6.12.

Standard forms of tender such as the JCT 1980 contain information and questions which are carefully put together and understandable in the industry. Contents of tender documents should include:

1. Clear indication of what the document is (i.e. 'Form of Tender');

2. Who the employer (client) is with full address. He will be party to the contract;
3. What the tender is for, briefly but specifically, and reference to the documents which will form part of any contract;
4. Date and time by when tenders are to be received;
5. Where the tenders are to be sent and the manner in which they are to be submitted (for example, in a plain or specially marked envelope);
6. A note that the employer does not bind himself to accepting the lowest or any tender, and that the tenderer will not receive any remuneration or expenses for providing a tender.

The tenderer should be invited to submit the following:

7. His full name and trading address;
8. His lump sum tender for the works, where appropriate;
9. His rate for labour, materials and on-cost, separately or as a composite rate in the case of a bill of quantities;
10. A statement of how long he needs to do the work following receipt of an order or the contract being signed;
11. Date and signature, with position of signatory (see Figure 6.1).

6.8 Direct and bulk purchasing contracts

To bypass the contractor or installer by purchasing plant directly from the manufacturer usually has an advantage of a saving in cost. The drawback is that the contractor does not have control of delivery or of quality, and this can lead to disputes or a defence against a claim for faulty workmanship or materials. Any saving can quickly become meaningless if the works are delayed, and a loss and expense claim is submitted. In a competitive situation a tenderer will keep his 'mark-up' to the absolute minimum, and a saving by approaching the manufacturer direct will be small. It is always possible to obtain a price with a manufacturer following competitive quotations, and then include a PC sum in the tender documents. This gives the tenderer the opportunity to add a modest mark-up, and also place him in a position where he is responsible for ordering, obtaining delivery and then paying for the equipment, in addition to installing it. There is still a responsibility on the client or his agent for nominating the equipment.

Bulk purchase of equipment is carried out in order to bring the price down per item. Having established that a large number are required, a client can then negotiate or invite competitive tenders to supply the number involved over a certain period. Care needs to be taken that the number agreed are actually required within the period, otherwise the supplier can sue for damages if he is frustrated from supplying the number agreed.

Some local authorities group together to make contracts to purchase substantial amounts within a set period thus making very large savings.

6.9 Programme of works

Prior to inviting tenders, the client should decide when he wishes the work to be carried out. Factors affecting his decision will be availability of funds either from loans or grants, or in the case of local authorities or central government departments it may be that a capital or revenue allocation needs to be spent within a particular financial year. Other factors will be other trades such as a building to house the plant, whose timing is obviously important. Replacement of existing plant will need to be co-ordinated to mitigate down time, and replacement of heating systems will need to be carried out during the summer months.

The Engineer, or when an architect is involved, will draw up a general programme incorporating design time as well as installation, and this will be submitted to the plant engineer for his views before design commences. Having agreed the programme, the tenderers will be informed in the tender documents how it is intended that the works will proceed. However, where a main contractor is involved it is vital that he be given the opportunity to submit his own programme of works, incorporating all the various trades, keeping within the programme completion date as laid down in the tender documents.

Difficulties arise when delays in obtaining tender approval occur, because time moves very quickly, and the work may not actually commence on the date stated in the tender documents. This causes problems when the contractors have carefully arranged their own work schedules. It is better not to be too optimistic regarding start and completion dates, unless various stages to a contract document being signed are clear.

6.10 Selection of tenderers

There are four ways in which a tender list can be drawn up for a particular project:

a) Advertise in the local press or trade journals for firms to apply and then draw up a short list.
b) Seek out firms of good reputation.
c) Draw up a list from firms who have shown an interest in working for you in the past.
d) Use firms who are known to the client and who have given good service in the past.

Vetting prospective tenderers has become a science, and for those who work in local government the rules are laid down by statute in the Local Government Act 1988. The procedure in inviting tenders under (a) would be to invite firms on an annual, biannual or job-by-job basis to apply for a questionnaire in order to consider whether they should be placed on the list of tenderers. Any questionnaire sent out by or on behalf of a local authority must not contain questions of a commercial nature. For example, the question 'Are you a Member of the Heating and Ventilating Contractors' Association?' would be wrong in law. However, the question 'Are you registered with the National Inspection Council for Electrical Installation Contractors?' is permissible because it is connected with

TENDER FORM

(1) Job title: .....

(2) Name and address of employer: .....

.....

(3) Location of project: .....

(4) Tender for: .....

(5) (a) This is a fixed/fluctuating price tender (delete as appropriate)

(b) Schedules of rates are/are not attached (delete as appropriate)

(c) Labour and material rates and on-costs are shown in a separate document attached

(6) I/we agree to keep this tender open for acceptance within ..... weeks of the date of this tender.

(7) I/we agree to commence the works within ..... weeks of receiving an official order, and to complete the works within ..... weeks of commencement.

(8) I/we intend to employ the following subcontractors to carry out part of the works, if this tender is accepted:

Name Address Description of works

(9) I/we agree to carry out the works referred to in the drawings and specification attached to the invitation letter dated ..... for the sum of £..... Amount in words ..... excluding VAT and which sum includes the following:

Contingency sum £..... Provisional sum £..... Prime cost sum £.....

(10) Name of tenderer .....

Address .....

Signed by ..... position ..... date .....

(11) Tender to be returned to ..... in the endorsed envelope provided, not later than 12 noon, on the ..... day of .....

(12) The employer does not bind himself to accepting the lowest or any tender, and the tenderer will not receive any remuneration or expenses for providing a tender.

Figure 6.1 Typical tender document for a principal contractor

quality of work. However, it could reasonably be argued that membership of the HVCA or the ACE is a demonstration of competence and acceptability by a senior body.

All other clients are able to ask their own questions. A consulting engineer who did not properly assess a firm prior to recommending that they be placed on the tender list would be liable in negligence to his clients for not discharging his duties with diligence. Questions which the plant engineer should ask when compiling a questionnaire are:-

1. Address from which firm would carry out contracts.
2. How long in business.
3. Number of office and site personnel and their trades.
4. Expertise professed by the firm and size of projects which they can undertake.
5. Sample of six jobs recently undertaken.
6. Names of three referees who can be approached.
7. Any pending litigation or recent court judgment against the firm.
8. Name and address of bankers.

Having received completed questionnaires a shortlist can now be drawn up. After discarding the non-starters, the hopefuls should be vetted.

Remember that firms will put their best face forward. Where possible, it is advisable to visit at least two jobs recently carried out, and to contact at least two referees.

A banker's reference can be misleading, although perfectly accurate. Since *Hedley Byrne & Heller* (1966) banks will usually give references 'Without Responsibility'.

A banker's reference will say that the firm is in a trading position, and sometimes that the firm is in a position to carry out the sizes of contact envisaged, but it will mention nothing about the reputation of the firm, its quality of work or administrative ability. A bank will not deal directly with a client, but only through his bank.

A different questionnaire needs to be sent to the referees, remembering to enclose a stamped addressed envelope. The referee is doing an unpaid favour in completing the questionnaire, and for his sake it should enable him to return it without having to write a thesis with an attached letter. A box to be ticked for most questions will suffice, with a space at the end for general comments. Questions which should be asked of the referee are:

9. How long have you known the firm?
10. What size of contracts have they carried out for you in the past 3 to 5 years?
11. How do you rate their workmanship, administrative ability to keep to programme, after-sales service?
12. Would you use them again?
13. General comments.

Having passed the test so far, the way is now open to visit the premises occupied by the firm and meet the management of the company. Once a firm is accepted for the list it should be placed in the size of contract category and within the range of its financial capabilities.

6.11 Inviting tenders

Most large organizations, particularly in central and local government, have set procedures in the form of standing orders, and this area is usually of most interest to internal and external auditors. The object of inviting competitive tenders is to obtain the lowest price for the job, based on a fair method which enables every tenderer to tender for the same thing.

A design and build tender can cause problems in that different design engineers have their own views on approaching a design. To help overcome this, the client or his agent should issue a design brief which limits the design parameters. For example, in a scheme to relight a warehouse, the brief could say that the lighting levels should be in accordance with the *CIBSE Guide* or could quote actual lighting levels to be achieved.

When drawing up the tender list for a particular contract from those already vetted successfully, note should be made of the points referred to below before deciding to place a firm on the list:

1. Financial capability;
2. Location with respect to project;
3. Workforce and administrative strength to carry out the project.
4. Check that the firm has carried out similar projects of that type in the past;
5. It should be ensured that a firm is not offered too many contracts at once. An overstretched firm can cause severe problems of performance.

Prior to inviting tenders each firm should be contacted, preferably in writing, to seek their agreement to tender. Information to be given to them will include:

1. Approximate value of works;
2. Type of contract;
3. When tenders will be sent out and closing date;
4. Programme of works, start and finish dates.

Having agreed to tender, if a firm does not submit a tender without good reason, consideration should be given to removing it from the tender list for a short period, because when a firm does not tender, it reduces the competitive element, possibly increasing the cost of the job. It also denies another firm the opportunity of tendering.

The number of tenderers invited to tender should be determined by the size of the works. Good contractors should be encouraged to tender and not be disillusioned by too many tenderers. For most contracts, a tender list of six firms should be sufficient to keep the tendering competitive and allow for the odd firm which does not return its tender.

On important contracts it may be advisable to invite tenderers to pick up the tender documents, or they could be delivered to them. Documents do go astray in the postal system. Fax and e-mail are not appropriate when it comes to legal documents of this type.

Tenders should be returned in endorsed envelopes so that it can be seen that a tender for a named project is enclosed, but should not disclose whose tender it is. In large organisations it is normal for tenders to be returned by a certain date and time, to a certain place, which is usually either a legal or an administrative department. Tenders should be opened by someone other than the person involved, after details of tenders have been noted. Tenderers cannot expect to be paid for the time or other costs in ordinary circumstances for preparing their tenders, as in *William Lacey v Davis* (1957), therefore it is even more important that everything is done fairly and correctly.

6.12 Analysing tenders

When the plant engineer receives all tenders returned, he will need to analyse them to ensure that they have been properly completed, and that each tenderer has understood what is being tendered for. A predesigned analysis sheet can be helpful and a typical sheet is shown in Table 6.1. All tenderers are shown on one sheet with their prices compared together. The first task is to check

Table 6.1 Analysis of tenders for replacing a drying machine

	Tenderers			
Item Detail	*1*	*2*	*3*	*4*
1 Strip out	2000	1600	1900	2200
2 Steelwork	1500	2500	1300	1700
3 Rein.conc.	2000	950	2100	1900
4 Machine	99 000	98 000	97 000	101 000
5 Elect.	3000	2900	2950	3100
6 Piping	2500	2300	2600	2700
7 Ductwork	2700	4700	5200	5100
8 Insulation	2000	1950	1900	2000
9 Painting	1000	970	1100	1050
10 Test/commission	1000	990	995	1100
11 Contingency	5000	5000	5000	5000
12 Provisional	500	500	500	500
13 Prime cost	1000	1000	1000	1000
Total tender	£123 200	£123 360	£123 545	£128 350

the arithmetic, which seems to cause problems even in these days of computers. Where the arithmetic is incorrect it should be brought to the attention of the firm quickly to enable it to either withdraw or stand by the figure. If the correct addition would have meant lower costs, the firm should be given the opportunity of revising the tender, but only after consultation with the legal or administrative department. Action taken now without consultation can be hard to explain later.

The addition may be correct, but a tenderer may have underestimated a particular item. With an itemized tender it is possible to spot an error of this kind. For example, referring to Table 6.1 and looking at item 3, tenderer 2 has less than half in his tender for item 3 than any other tenderer. On the other hand, item 2 appears to have made up for it. Where an apparent mistake has occurred, the firm concerned should be contacted, and should be asked to look closely at a certain item which appears low. For example, tenderer 1 has a much lower amount for item 7 than any other, and if he had tendered similarly to the other tenderers for that item, he would not be the lowest tenderer. It is better to lose a low price than have the firm lose money on a job which can cause difficulties with performance.

Where the scheme was designed before being sent to tender, the tenders should be grouped fairly closely together, because design decisions have already been made. Design-and-build tenders will need much more attention to find out which is the best value for money. For example, in lighting the warehouse mentioned earlier tenderers may have been advised of the lighting level, but if they have not been told of the type and manufacture of fittings, there can be a substantial difference in cost.

Tenders received can vary by up to 100% over a range of firms. The higher tenders may be from firms who do not want the job but wish to keep contact with the client. Where there is a difference of more than 10% between the lowest and second-lowest tenders, this can cause problems. For example, the Electrical Contractors Association offer a guarantee of completing through their members, at no extra, cost, in the event that a member is unable to do so, but only if after through investigation there are no overriding problems. In some circumstances this could be enough to seriously consider not accepting the lowest tender. Therefore tenders should be carefully analysed.

6.13 Selection of the contractor

Having established that the lowest tenderer is in fact the lowest, after taking all matters into consideration there are other aspects to consider before agreeing to a contract.

A qualified tender can make the offer void, and most organizations would disqualify a tender which was qualified. An example of a qualified tender would be where the specification says that electrical attendance is part of the contract, whereas the tenderer says in his tender documents or in an accompanying letter that he has not included for electrical work, and is not prepared to carry it out. A common qualification is where a contractor puts forward a manufacturer of plant different to that specified. The plant may be just as good, but the tender is nonetheless qualified, and would give an unfair advantage to the offeror.

A *bona fide* qualification is where the specification is unclear.

An area of increasing importance financially is the programme. Large sums are being claimed by contractors with respect to delays, and it is important to take note before the contractor is appointed of any qualifications he may make to the tender. For example, if a tenderer says in his tender that he can carry out the works in 40 weeks and it is known that the period envisaged is 52 weeks to coincide with other trades, then if he is frustrated from doing the work he can sue for loss and/or expense for the 12 weeks when he will have, in theory, to lay off men. The solution is to challenge the period inserted, and if the tenderer will not amend his period, then do not appoint him.

Tenders are normally kept open for a specific period of time, which is usually 4 weeks. Tenderers who agree to their offer being kept open for a specific period of time may find that they have committed themselves to an implied contract, therefore, cannot withdraw their tender so long as it is accepted within the stated time as in City Polytechnic of Hong Kong v Blue Cross (Asia-Pacific) Insurance HCA (1993). In any case, without a specific period being mentioned, in law, a tender must be accepted within a reasonable period, otherwise it will lapse. In the event that a decision cannot be reached, or an appointment made for some time, the tenderers should be approached in order to ensure that their tenders are kept open. The problem for the contractors is that wages and salaries increase regularly, as do materials and other on-costs.

In contract law the acceptance of an offer must be unequivocal. Where a tender is accepted subject to an amendment on, say, programme, the client is making a counter-offer, and acceptance is then made by the tenderer.

The successful tenderer should be informed as soon as possible that his tender is to be accepted, to give

him the opportunity to plan his operation. Equally, the unsuccessful tenderers should be sent a letter expressing appreciation of the time they have spent in preparing their tenders, but informing them that they have been unsuccessful.

6.14 Making a contract

A simple contract for any value need not be in writing, but can be verbal and is known as a parole contract. Many contracts are made which are verbal. When a person goes into a supermarket, takes an item off the shelves, carries it to the checkout and makes an offer to purchase it at the price shown, this constitutes an offer in contract law. The checkout cashier takes the money and is, at the same time, accepting the offer. Verbal contracts are fraught with problems and should be avoided where possible. For example, to prove that a verbal contract has been entered into without the work having been carried out will need parole evidence in court. Where arbitration is entered into later, a verbal contract does not come under the Arbitration Act 1996.

Letters of intent can be the cause of problems, and there are varying views as to their validity. These are sent in advance of contractual documents, being signed because either the documents are not fully prepared or a decision has not yet been confirmed. For example, in local government a tender may have been accepted by a committee but needs ratification by the full council, which can be up to six weeks later. It is rare for a council to overturn a decision made by a committee, but it does happen. In an attempt to expedite matters it is common policy to send out letters of intent directly following the committee. These will be marked either 'Subject to Contract' or 'Subject to Council Approval', and in these cases they are useless as a contract if the client does not go ahead. Where the contractor has reasonably relied upon the letter and the client has encouraged him to purchase the equipment, then a court may order that he be paid for the work done under *quantum meruit*. A letter of intent without a qualification will infer a contract and will commit the client to the whole works.

6.15 Relationships between contractor and other parties

Where only one contractor is involved, then his relationship with the client is direct and contractual. Most contracts have more than one contractor, and the client must decide how he intends this to be arranged. A few of the possible compilations are:

1. *Direct contract* (sometimes known as a principal contract), where only one contractor is involved;
2. *Main and nominated sub-contract*. This is where one contractor is appointed and known as the main contractor and the client nominates or instructs this contractor to appoint a named firm to carry out part of the works. Sometimes tenders will have been sought separately prior to the involvement of the main contractor;
3. *Main and nominated supplier*. The client may wish a certain firm to supply materials for the contract which may be for installation by the main or a sub-contractor.
4. *Principal contractor with domestic sub-contractor and supplier*. The expression 'domestic' does not necessarily infer housing, although housing contracts can be carried out in this manner. A domestic sub-contractor is a contractor who is appointed by the principal contractor. The client has no relationship with a domestic sub-contractor, unless he interferes with his selection such that the appointment becomes nominated. This type of appointment has become very common.

The contractors have no contractual relationships with any independent consulting engineers who are appointed by the client. Where the client decides to appoint a firm to 'design-and-build' there is a different duty on the designer. When a consulting engineer is appointed he must exercise reasonable skill and care in carrying out his duties, as an average firm of this type would do. However, where the client entrusts his design and installation to a contractor, the contractor owes a strict duty to his client to ensure that the installation works, and that it is fit for its purpose, as in *Independent Broadcasting Authority v EMI* (1981).

A nominated sub-contractor has no contractual relationship with the client, but the case of *Junior Books v Veitchi* (1982) placed an 'almost' contractual duty upon the nominated sub-contractor. Where a separate agreement has been signed between the client and nominated sub-contractor then a direct contractual relationship applies.

Problems can arise where a main contractor says that he is being delayed by his nominated sub-contractor or supplier. Because the client has instructed him to use a firm which was not of his choice, the main contractor could claim damages in the form of loss and/or expenses from his client. Where the principal contractor has brought in his own domestic sub-contractor, then he is responsible for his actions. That is the main reason domestic sub-contracts have become popular. The client must decide upon which trade will become the main contractor. In building matters it is usual for the main contractor to be a firm who can carry out the most substantial works, and this will be a general building firm. Some general building firms carry their own mechanical and electrical departments, which reduces the need for sub-contractors.

There are occasions when it is more appropriate to appoint a mechanical or electrical firm to be the main contractor. An example would be the laying of a district heating mains, where the largest value and complexity is in mechanical engineering. However, experience shows that not all specialists are geared to this role, and this can cause problems, especially from a main contractor who is more familiar with the role of sub-contractor. On the whole, it is recommended that the main contractor be a building or civil engineering firm, unless those works are very small.

When the essence of a contract is the supply and installation of a large machine, it is likely that the manufacturer will have their own specialist to carry out attendance works.

6.16 Site meetings

Meetings are a necessity on a project of any size to keep a contract moving. The first meeting is normally at the offices of either the client or consulting engineers, and is a pre-contract meeting. A pre-contract meeting is a gathering of all interested parties to discuss the format of the contract and is a chance for views to be expressed, prior to the actual formation of a contract, which very often takes place after the meeting.

Matters which are likely to be on the agenda of a pre-contract meeting are:

1. Names and addresses of all parties and introductions;
2. Names of specific persons from each firm who will be handling matters, such as site engineers and clerks of works;
3. Format of site meetings to be agreed (who will take minutes and who will chair meetings);
4. General lines of communication agreed;
5. How often site meetings will occur;
6. Accommodation for sub-contractors, site engineer, clerks of works and meetings;
7. General programme discussed. At this stage the main contractor may not have drawn up a bar chart or critical path programme;
8. Procedures for variations and interim valuations may need to be cleared up, depending upon the form of contract adopted;
9. Where nominated suppliers or sub-contractors are involved, the main contractor has the opportunity to voice his opinion of those selected by the client.

There are generally three kinds of site meetings. One is where all parties are present, another is where the professional team meets with the main contractor and the third is where the main contractor organizes his own meetings with his sub-contractors. The job itself will determine the kind of site meeting to be held. *Ad hoc* meetings are held throughout the job, and these meetings should always be with the knowledge of the main contractor, if not chaired by him.

Full site meetings may be held monthly or weekly, depending on the size and pace of the job. A typical site meeting will be chaired by the main contractor or the project leader, who could be the architect or engineer, and matters for the agenda will include:

1. Apologies for absence;
2. Previous minutes read;
3. Matters arising from previous meeting;
4. Main contractor's report;
5. Sub-contractor's reports;
6. Progress (various clerks of works' reports);
7. Consulting engineers' reports;
8. Any other business;
9. Date and time of next meeting.

Minutes are then published through the chairman and circulated to all parties, even to those not present at that meeting. When receiving the minutes it is worth studying them to ensure that they are accurate and to note any action needed. It is usual to have a column drawn on the right-hand side of the minutes for the names of the parties who need to take action. The smooth running of the project can depend on all parties complying with action noted in the minutes. Inaccurate minutes should be challenged at the next meeting. Site meetings and publication of minutes are vital to a large or complicated project to avoid misunderstandings, which can cost money.

There will be *ad hoc* meetings, particularly inspections by visiting or permanent clerks of works. Points worth noting at these inspections are:

1. The site is under the control of the main contractor, and he must be informed of all visitors, who are advised to comply with requests (e.g. wearing hard hats).
2. An apparently simple visit can result in disputes later. Therefore, it is wise to meticulously record all salient points of discussion. The time and date of arrival and time of leaving may seem pedantic, but can avoid difficulties later. Clerks of works' diaries are often admitted as contemporaneous evidence in litigation and arbitration. This is discussed further in Section 6.17.

Site Safety inspections are ongoing by the safety officer to ensure that safe practice are being adopted.

6.17 Progress and control

The client will have decided at the very beginning when he wants the job to be finished on site. Circumstances such as approvals, preparation of contract documents or availability of labour and materials will determine when the works start.

At the beginning of the contract, before work starts on site, the main contractor will produce a Health and Safety plan in accordance with the CDM Regulations and a programme of how he intends to carry out the works. In some tenders the contractor is invited to state what his programme will be if he is successful. This method has merit where the programme is very tight. The most common type of programme is a bar chart, and will show at what periods the various sub-contractors will be on site. A typical bar chart is shown in Figure 6.2.

The value of having one contractor to control the progress of the work can be seen where there are several contractors on a site at different periods. Progress can suddenly come to a halt if a key contractor does not comply with an agreement. For example, if the electrical sub-contractor does not provide a temporary electrical supply, there may be no light and power, causing other contractors to be delayed.

In the matter of progress, the Principal contractor is in charge of the works and he is also responsible for co-ordinating the activities of all contractors and sub-contractors and to ensure that they comply with relevant Health and Safety legislation and with the developed health and safety plan. Principal contractors also have a duty in relation relation to the provision of information, training and consultation with employees including the self-employed. However, the client or his consulting engineer will need to monitor the works to satisfy themselves that programmes are being adhered to. There is a

Name of project: Replacing drying machine

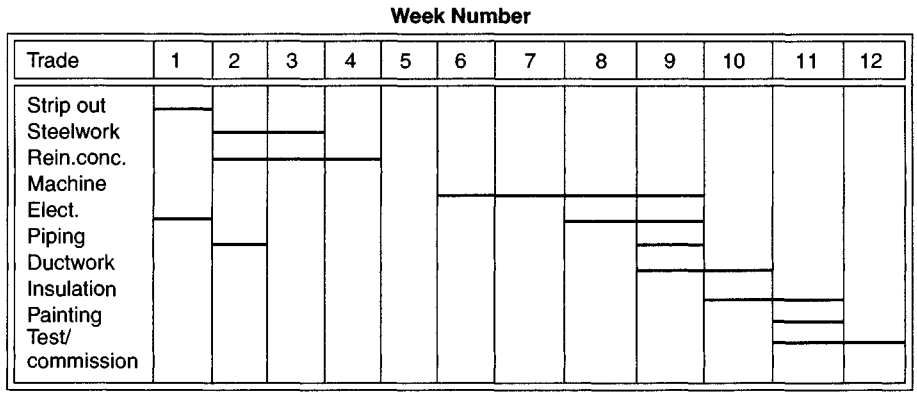


Figure 6.2 Typical bar chart programme

temptation for a client or his consulting engineer to assist the contractor by instructing him how to carry out the work. This can amount to interference, and if the contractor suffers loss as a result he can sue for damages, as in *Oldschool v Gleeson* (1976).

There are varying degrees of monitoring which a consulting engineer can recommend to his client:

1. Occasional inspection visits by the design engineer, as necessary, on a small job;
2. Regular clerk of works visits;
3. On-site engineer or clerk or works.

It is the duty of the consulting engineer to make a recommendation to the client as to the type of supervision required, and the client must not refuse a reasonable request by him for on-site supervision. Where a client refuses a reasonable request for on-site supervision, the consulting engineer should warn him of the possible consequences, otherwise he may face a claim for negligence later.

On most contracts, there are requests by the contractor for clarification of the specification or for instructions with regards to variations. These requests need to be answered promptly to avoid a claim for damages by the contractor which may result from delay of the works caused by him waiting for information.

All progress should be carefully noted in the diary of the supervisor or clerk of works. Points worth noting are:

1. Number of men on site;
2. Weather (where appropriate);
3. Name and title of any person spoken to. Note that instructions should generally be given through the main contractor's site agent;
4. Progress of job and quality of workmanship;
5. Any items discussed.

6.18 Quality control

The contractor is under a duty in contract to provide and install plant which is satisfactory and fit for its purpose. There is no duty on the client to ensure how the contractor carries out those duties, except where safety is an issue, although the consulting engineer can be sued in negligence by his client, if he is not diligent in detecting faulty workmanship, such that he suffers loss as a result.

Where an industrial firm employs a contractor he will have a chief engineer who will organize the monitoring of the quality of workmanship and materials. Where a consulting engineer is involved, he will recommend to his client the degree of supervision required, as mentioned in Section 6.17. The person appointed will need to consider the following and be satisfied that the works being installed meet the requirements which should be laid down in the specification and drawings:

1. Materials and plant which are specified are new and unused;
2. That workmanship is up to the standard expected in this type of contract. The Codes of Practice, IEE regulations and other bodies related to standards should be used as a measure of standard. It was ruled in the case of *Cotton v Wallis* (1955) that a lower standard of work can be accepted in a known cheap job, as long as the work is not 'rank bad'.

A problem which seems to occur frequently is that contractors do not give sufficient thought to allowance for maintenance in the future. To install plant without means of maintaining it is bad practice and should be avoided. The plant engineer should make sure that the design allows for adequate maintenance. It is not sufficient for the specification to say that allowance must be made for maintenance if the design can not accommodate it.

6.19 Interim payments

In a lump sum contract the contractor does not have a common law right to interim payments. Most larger contracts have an express term within them giving the right to interim payments, or payments on account, notwithstanding that they have not fulfilled their contractual duties in completing the works. The matter of interim payments

and their frequency should be resolved before the contract is signed, and not left until a dispute arises.

Interim payments on the contract follow a valuation of the work done. Valuations are normally carried out by the plant engineer, the quantity surveyor, the architect or the consulting engineer and, in the light of recent case law, should be assessed very carefully.

Until 1974 an architect was considered in law to be a quasi-arbitrator, and his valuation was final. However, the case of *Sutcliffe v Thackrah* (1974) saw an end to this role. In that case the architect overvalued the work which had been carried out, and because the client ordered the contractor off the job he suffered loss, as a result of which he successfully sued the architects for damages. Architects and engineers suddenly had a greater interest in professional indemnity insurance.

An obvious solution would be to undervalue the work done, in order to avoid a claim from the client. The case of *Lubenham Fidelities and Investment Co. v South Pembrokeshire District Council* (1986) took care of any tendency to undervalue. In that case the Court of Appeal ruled that the contractor may sue the architect in tort for any damages suffered by him as a result of the negligent valuation.

There are occasions when a contractor will apply for an interim payment based on plant obtained by him for the contract and stored by him on his premises. This is a difficult situation, and should be approached with care. Two problems can arise:

1. Should the contractor end up in dispute with the client before the plant is installed, he may refuse to release it, despite having been paid for it.
2. The contractor could go into liquidation before the plant is installed.

A way around these problems is to have the plant isolated from other equipment and clearly marked 'This is the property of (name of Clients)' and while it may not be a complete guarantee of success, it is at least better than not marking it.

6.20 Budget control and variations

At the beginning of the contract it will be known to the client and his consulting engineer how much money is budgeted for the project. The contractor will be aware of the contract value, of course, and he will also know of any contingency sums which have not yet been allocated.

Contingency sums are included in a contract in case there are any additional works which need to be carried out and have not been covered in the contract. This may be because the client wishes to have more items of plant than he originally envisaged, or there may be unknown features, or it could be for items which have been forgotten in the original design. (See Section 6.6 for a description of contingency sums.) Where a consulting engineer forgets to include an item which is necessary for the proper completion of the works he can be sued for negligence by his client, or advised to pay for this work himself. Where a contractor forgets an item which is necessary and reasonably implied as being part of the works which he should have included, he will have to provide and install it himself at no extra cost.

There is a temptation for the contractor to see contingencies as extra work, or there is always a danger that it will be spent by the end of the contract because the client will see it as available monies.

Provisional sums are already allocated when the contract is made, and while the true value is not known at tender, the estimate should be reasonable. Where a schedule of rates or a bill of quantities is available, there is no problem in arriving at the figure after the contract has been let. However, where the contract is simply lump sum, there is no basis to determine any variation, and this will sometimes mean a difficult negotiation. When a variation to the contract becomes apparent it should always be agreed in writing, preferably with a firm agreement on price or at least an agreed rate. A major part of a dispute when the final account is being agreed variations. Where the variation is too difficult to assess accurately, such as an underground gas or water main being found which was not known previously, the contractor will have to be instructed to carry it out on day work (*quantum meruit*) In the tender there will be a rate for labour and an on-cost figure for labour, materials, plant and other expenses, and the purpose of this is for items of daywork which may occur. Certain standard forms of contract such as the JCT form contain specific documentation when dealing with variations.

6.21 The Construction (Design and Management) Regulations 1974

These regulations first came into force on the 31st March 1995, their purpose being to place duties upon clients, clients' agents (where appointed), designers and contractors with respect to safety in the construction industry. This includes the carrying out of any building, civil engineering or engineering construction work and encompasses all but the very smallest of projects.

An in depth study is not given in this chapter which deals with contractual matters. The regulations are only actionable by the HSE as criminal prosecutions with severe penalties on those found guilty. In the case against a Planning Supervisor involved in a site in Cornwall in 2000, the firm was fined £15 000 and ordered to pay costs of £5000. Readers are invited to obtain a copy of the HSE Approved Code of Practice L54. It will be seen that clients take on a responsibility to ensure that they appoint competent agents, designers, planning supervisors and principal contractors.

6.22 Safety on site and Legal Action

Unfortunately, deaths occur every year in industry due to accidents in construction, engineering and maintenance work which occur in spite of the CDM Regulations. Accidents are more likely to occur where firms are under pressure to meet targets, and safety measures have been ignored. The author has investigated over 1500 incidents

and very few are true accidents, almost all having been caused by negligence and breach of statutory duty by both employers and employees.

The Health and Safety Executive (HSE) was set up to administer the Health and Safety at Work etc. Act 1974 and incorporates the Factories Inspectorate. General duties of employers described in Section 2 of the Act are that 'It shall be the duty of every employer to ensure so far as is reasonably practicable the health, safety and welfare at work of all his employees'. The emphasis is on the expression 'reasonably practicable', and courts interpret the meaning of it, under the particular circumstances. The Health and Safety at Work etc. Act 1974 is an enabling act. The HSE can use it to bring in other legislation such as the Provision and Use of Work Equipment Regulations 1998 or the Construction (Health, Safety and Welfare) Regulations 1996. Helpful guidance can be found in the HSE publication 'Health and Safety for Small Construction Sites HS(G) 130.

The HSE prosecutes firms or their employees in the Magistrates or Crown Courts when safety measures are not taken by them and the courts impose substantial fines with 2 years' imprisonment for convicted offenders. Where gross negligence occurs such that someone is killed, then the Department of Public Prosecutions can bring a charge of manslaughter against a person, or more recently against a corporate body. The maximum penalty for manslaughter is life imprisonment. Prosecutions of this type are also being pursued.

While Codes of Practice and the IEE regulations are not statutory, in a situation where injury was caused through neglect of them the HSE can prosecute under Section 16 of the Act.

A plant engineer may become involved with a visit from the HSE inspector when he/she arrives on site to carry out an inspection of the works or to generally inspect the factory under powers given to the Executive by Section 20 of the Act. The HSE will visit at any reasonable time, or at any time where the situation may be dangerous in the inspector's opinion. He/she may take with him/her a police officer if he/she has reasonable cause to apprehend any serious obstruction in the execution of his/her duty.

Having carried out an inspection of the works, the inspector has powers under Section 21 to serve an improvement notice if, in his/her opinion, a person is contravening one or more of the relevant statutory provisions, or has contravened one or more of those provisions in circumstances that make it likely that the contravention will continue or be repeated. The person concerned then has a duty to remedy the contravention or as the case may be, the matters occasioning it within such a period as may be specified in the notice.

An inspector can order under Section 22 that activities be prohibited which have not yet commenced, and may be about to be carried on or are already being carried on, by serving a prohibition notice.

To ignore either of the notices above is a criminal offence, and a prosecution is likely to follow such contravention. There is an appeal to an industrial tribunal against an order.

An HSE inspector has the power under section 25 to enter any premises where he/she has reasonable cause to believe that, in the circumstances, any article or substance is a cause of imminent danger of serious personal injury. He/she may then seize the article or substance and cause it to be rendered harmless, whether by destruction or otherwise.

6.23 Delays and determination

Contractors are all too frequently delayed in their completion for a variety of reasons, some of which are:

1. Client adds extra work or changes his mind;
2. Client or consulting engineer takes his time in giving instructions or clarifying the specification;
3. The contractor starts on site later than agreed;
4. Sub-contractors do not coordinate properly;
5. Site conditions are not as expected;
6. Materials are not delivered as promised;
7. Exceptionally bad weather;
8. Slow progress generally by the contractor.

Delays to contracts can be costly to both client and contractor, and, in some cases, suppliers. There has been a tendency in the past few years for an injured party to sue for damages under the contract, and where there is no contract, in tort. Since the case of *Marden v Esso Petroleum* (1978) it is possible to sue both in contract and tort at the same time.

The various forms of contract make a provision for registering a delay or possible delay, and this aspect of a contract should be taken very seriously, because it can be the greatest source of financial claim, particularly by the contractor. Some contracting firms examine contracts very carefully to see if a claim of delays can be made, and this starts on the day that the contract has been signed.

Close control of the contract should be kept at all times. This is where formal site meetings, with reports of progress, can be most useful and can help to steer a late contract back on the right course. When a contract begins to fall behind the agreed programme it is important to find out why and to rectify the problem. It is in everyone's interest to see the plant commissioned on the agreed date, and a casual attitude by the project leader should never be taken. He should be strict with anyone who causes a contract to slip behind schedule.

There are legitimate reasons why a contract can fall behind, and some of these are referred to in 1 to 8 above. However, item 8 must not be tolerated, and the contractor should be taken to task early in the contract when this occurs. Close monitoring will show how the contractor is progressing, and where the contractor has fallen down so badly that there seems to be no end to the contract, then the client should seriously consider determining the contract, especially, if money is being lost.

Most standard forms of contract contain specific procedures for determination, and these should be rigidly adhered to. For example, the contract document may lay down that the contractor be given 14 days' notice in writing to rectify his progress before determination is carried

out. Any letters should be sent by recorded delivery or served by hand. While liquidated or unliquidated damages can be claimed with respect to late or incomplete work, expense claims usually follow the events shown below, which are also mentioned in Section 6.24:

1. Client adds extra work or changes his mind. It may seem reasonable that where the client authorizes extra work and pays for that extra work, he should not then be required to pay, because the contractor needs to stay on site longer. This is, however, the case, and the claim because of the delay very often exceeds the actual extra costs of the works. Where a client simply changes his mind and cancels some of the work, then the contractor can insist on his profit, and overhead costs for the time he will be without work as a result.
2. Delay in instructions being issued to the contractor can be a loss to the contractor if he is waiting for the instructions, and he can sue for damages for his loss.

6.24 Liquidated damages and loss and/or expense

This is an aspect of a contract which should not be contemplated by either party at the outset of a contract. However, it is common for the client to set a figure for liquidated damages which he considers that he will genuinely lose if the contract is not completed on time, and should not be confused with a penalty clause, which is for punitive damages.

The expression 'unliquidated damages' means actual losses which are incurred by a client, and could be claimed in the absence of an agreement to a specific amount in the contract. Loss and/or expense can be suffered by a contractor due to other parties who caused him to be delayed. These sums per week are invariably far in excess of any liquidated damages amount set in the contract.

In practice, what happens is that where a contract is falling behind programme the contractor will apply to the client for an extension to his period for completing the works. Should the contractor not make an application then he will be in breach of his contract to complete the works by the date agreed, and the client can claim liquidated or unliquidated damages as a result. Where no specific date for completion has been set, in a dispute situation, the court will set a date which, under the circumstances, was or ought to have been in the contemplation of the parties at the outset of the contract. For example, a firm agrees to supply and install a machine, and while no particular date is set for installation, the firms knows that production would be affected badly if it was not installed within three months. Without extenuating circumstances prevailing, the firm could be in breach of its contract if, say, the machine was not installed within three months.

The contract could include a penalty clause for non-completion by the contractor, and paid by him. A bonus clause could also be included and paid by the client to the contractor in the event that he completes his contract on or before the agreed completion date. This bonus clause can be on a reducing scale (say, from 75% of the time onwards).

Liquidation of the contractor's company or firm has nothing to do with liquidated or unliquidated damages, although these can still be claimed to a company in liquidation. Some forms of contract, such as the JCT form, make provision for automatic determination in the event of a firm going into liquidation but that the contractor may be reinstated under certain circumstances.

6.25 Practical and final certificates

The essence of a plant engineering contract will be that the plant actually performs to the criteria laid down in the design, and this must be established before a Practical Completion Certificate is even considered. Tests will need to be made to the plant, and then it will be commissioned by the contractor and left in a condition whereby it can be operated as specified. When the works within the contract are completed, a certificate acknowledging that fact should be issued by the client (or employer) to the contractor. This duty is normally performed by the architect or consulting engineer, acting as agent. Standard forms of contract have particular formats, but the points which should be noted are:

1. Names and addresses of parties
2. Name and reference of job
3. Date
4. Brief outline of contract and note that the works are now practically complete
5. Period of guarantee from contractual documents
6. Signature.

The works should be fully complete when the Practical Completion Certificate is issued, without any defect or omission at that point. This is clear from the High Court decision in *H. W. Nevill (Sunblest) Ltd. v William Press & Son Ltd.* (1981). Other cases which went to the House of Lords substantiate this, as in *Jarvis & Sons v Westminster Corporation* (1970) and *P. M. Kaye Ltd. v Hosier & Dickinson Ltd.* (1972).

There is a tendency in the building industry, for expediency, to issue a Practical Completion Certificate subject to a list of defects. Very often this is done in order to see the end of the main works.

From the date of the Practical Completion Certificate the contractor is no longer liable for liquidated damages, and the defects liability begins to run. Latent defects which appear for the next six or twelve months, depending upon the agreed period, have to be made good by the contractor, free of charge to the client.

The final certificate is issued when the end of the defects period has been reached, and when all defects which have appeared within that period have been attended to.

The client is not prevented from making a claim for latent defects after the twelve-month period ends, but may be prevented from making such claims by the Limitation Act 1980 and the Latent Damages Act 1986, after a period of six years for a simple contract and twelve years for a contract made under seal.

6.26 Disputes and arbitration

It is unfortunate when a dispute arises between any of the parties. The two most common areas are a claim by the client that the materials are unsatisfactory and the work has been done badly, or taken too long. The contractor may say that his contract has been interfered with by the client or the nominated sub-contractors. Materials and services must be of satisfactory quality as laid down in the Sale and Supply of Goods Act 1994.

Most disputes take the form of strongly worded letters between the parties, with eventual threats of litigation or arbitration, very often in an attempt to cause a party to capitulate. Where there is a genuine attempt to settle a dispute the letters between the parties can be marked 'Without Prejudice' and letters so worded cannot be used in evidence without the consent of both parties. If a binding contract has been effected as a result of 'without prejudice' interviews or letters, this may be proved by means of the 'without prejudice' statement, as in *Tomlin v STC Ltd.* (1969). The standard forms of contract invariably contain agreements to arbitrate in the event of a dispute and some even name the arbitrator, or a professional body who will appoint an arbitrator, upon the application of one of the parties. Where no agreement to arbitrate exists, the injured party may sue in either a County Court or High Court, depending upon the value of the claim, and he must then prove his case before a judge.

A more speedy method, although not necessarily less expensive, can be for the parties to make an agreement to arbitrate, and to appoint their own arbitrator, who should not have been previously connected in any way with any of them. Where a written arbitration agreement is made, the arbitration will be conducted under the Arbitration Act 1996 and, unless otherwise agreed, before a single arbitrator, whose powers are almost those of a High Court judge.

Alternative Dispute Resolution (ADR) is an option which should always be considered before either litigation or arbitration and is discussed in 6.28 below.

6.27 Hearings

An arbitration hearing can be held anywhere convenient to the parties, and at times agreed. The arbitrator will not meet any one party separately or take instructions from him. However, he will take instructions jointly from all of the parties. For example, if the parties wish the hearing to be held in a certain place, as long as the facilities are adequate for the hearing for the parties to meet their legal advisers, the arbitrator is likely to agree. On matters of the conduct of the hearing, the arbitrator is in complete control, subject to a limited appeal by the parties to the High Court, who can, on matters of law and conduct, direct the arbitrator to take certain action. The Arbitrator may seek the views of the parties jointly as to the proceedings. For example, whether the hearing is to be adversarial or inquisitorial.

The hearing itself will be conducted in a less formal manner than a court trial. The room is usually set out like a conference room, with a seat at the head for the arbitrator and places called 'the box' at the opposite end for the witnesses. To the left of the arbitrator is usually the claimant and his advisors and to the right the respondent and his advisors. It is normal for all present to stand when the arbitrator enters or leaves the room and address him as 'Sir/Madam', referring to him/her during the hearing as the 'Learned Arbitrator'. A judge needs to be treated with more respect and a procedure of bowing upon entering and leaving is traditional. A County Court judge is referred to as 'Your Honour' or 'Sir/Madam' for a district judge and a High Court judge as 'My Lord/Lady'.

The plant engineer may be asked to give expert evidence, which means giving his opinion to the court or tribunal on the subject matter.

6.28 Mediation

Mediation is a form of alternative dispute resolution (ADR) and means that unlike a hearing in court or before an arbitrator, it is the parties who make their own judgement or settlement, by agreement, with a person acting as an advisor. The parties could agree at the outset to appoint a mediator to assist them to come to a decision which will settle their dispute. In the event that agreement is not eventually reached, the parties may then resort to either arbitration or litigation.

In the event that litigation is chosen by one party, assuming that an arbitration clause does not exist, then the Civil Procedure Rules 1998 will apply, giving wide powers to the court. Rule 1–4 (2) (e) and (f) says that active case management (by the judge) includes *"encouraging the parties to use an alternative dispute resolution procedure if the court considers that appropriate and facilitating the use of such procedure. (f) helping the parties to settle the whole or part of the case".*

6.29 Common problems and solutions

There is no sure way of avoiding claims with respect to contracts, but the following summary may be of assistance to the plant engineer:

1. Vet prospective tenderers carefully prior to invitations to tender to ensure as much as possible that they are capable of carrying out the work.
2. Ensure that the provisions of the Construction (Design and Management) Regulations (CDM) are fully adhered to.
3. Select the type of contract most appropriate for the work.
4. Where possible, avoid nominating a sub-contractor or supplier.
5. Make sure that the drawings, specifications and tender documents are clear and unambiguous. Do not rely on exclusion clauses in the specification or tender document to make up for negligent documentation. Have designs checked and use methods and equipment which comply with British Standards and Codes of Practice.
6. Unless there is a clear programme of works which has been mentioned in the tender documents, before accepting tenders make sure that the contractor or

supplier has specifically stated his commencement and completion dates. In the event that the completion date is too early or too late, resolve the matter before entering into the contract.

7. Ensure that site meetings are as short as possible and organized to assist the project, and that they serve the purpose for which they were intended (i.e. review progress, sort out problems and ensure satisfactory reports).
8. When a contractor indicates that he is or may be delayed, take him seriously and solve the problem without delay. Do not interfere with the way in which the contractor carries out his work, unless he is patently incompetent, or safety is in doubt.
9. Make sure that all site supervisors, clerks of works and site engineers keep good records, and that they are kept contemporaneously, so that, if necessary, they will be admissible in evidence in the unfortunate event that a dispute arises.
10. Be careful on the matter of interim valuations for payments to contractors. To undervalue can be as serious as overvaluing.
11. Keep up to date with variations to the contract. Do not wait until the end of the contract before extras are added up.
12. Safety should be primarily in the hands of the contractor controlling the site in accordance with CDM. Keep a high profile in dealings on safety matters, and ensure that staff and any other parties are conscious of the need for safety.
13. The plant engineer should be careful of giving casual advice to parties with whom he has no contract. Under the *Hedley Byrne & Heller* rule the plant engineer could be sued for a negligent mis-statement if his advice was wrong, and the receiver of the advice could reasonably rely upon it, and he suffered loss as a result. A heading of 'without responsibility' may avoid such a claim.
14. When attempting to settle a dispute the heading 'Without Prejudice' can be used in correspondence which, subject to the rules of privilege, cannot be used in court.
15. If a dispute arises, do not expect it to sort itself out. Meet with the parties and review the situation. It is always less expensive to settle matters early on rather than involve lawyers, mediators or arbitrators. The successful party does not usually recover all his costs.

7 Finance for the plant engineer

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This page has been reformatted by Knovel to provide easier navigation.

7.1 Accounting

Ultimately, all activities of an organization will be expressed in money, the common denominator within the accounts of the proprietor, be it a company, a partnership or a statutory organization. The accounting for these activities will be under the control of the finance department, which, in turn, will be controlled, through the financial director, by the board of directors.

A typical accounting organization is shown in Figure 7.1. These divisions, depending on the size of the organization, may be broken down further to provide accounting services at each plant or operating facility. There will normally be an accountant at each plant, or, in the case of very large organizations, at each major profit or cost centre at plant level. By this means, close liaison can be maintained with and management services information provided for the locally based operating management, in addition to providing the flow of information and appropriate documentation to enable the organization to prepare timely and informative accounts.

Many of the financial functions will tend to be centralized in order to enjoy economies of scale available through the use of specially qualified staff and of computers, but the modern trend is for all information to be made available at all levels within an organization thanks to the power and versatility of modern computer systems.

Prompt and accurate accounting is vital for the well-being of the organization and for the early detection of problem areas needing corrective treatment by management. The achievement of this promptitude and accuracy depends to a very large extent on the cooperation and attention to detail by staff in non-accounting departments responsible for the recording of information (e.g. fuel and water consumptions, meter readings, the taking of stocks, etc.). Such staff may not recognize their involvement in these areas as one of their prime concerns. Each of these departmental chains will normally be staffed and headed by appropriately qualified people.

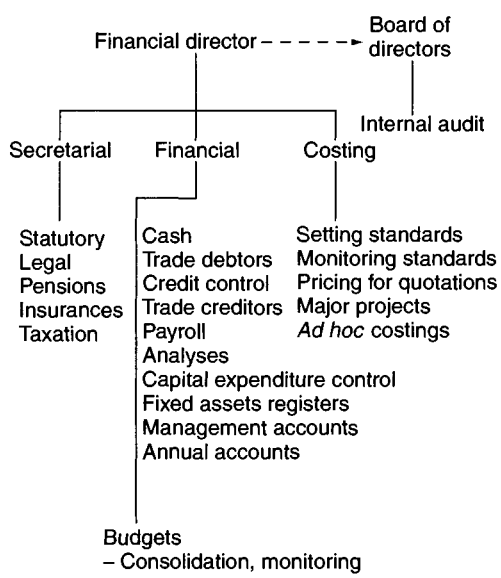


Figure 7.1 A typical accounting organization chart for a large company but the trend is towards a more flexible organizational structure that best suits the needs of the business

7.2 Types of organization

The most common of the organizations operating in today's industrial scene is the joint stock company with limited liability. In different countries there exist variants of this format, but there is a wide spread of organizations based upon broadly similar principles.

The partnership and sole proprietor types of organization are suitable for businesses while they remain small and can be managed and financed by the owners, but as expansion takes place and the business demands more capital, then the ability of relatively small numbers of proprietors to provide additional capital from their own resources becomes increasingly difficult. In the search for additional funds recourse may be had to a variety of institutions such as banks and the specialist venture capital companies which have been set up, often by the banks themselves in conjunction with insurance companies and merchant banks, to cater for this need.

These specialist lenders will often wish to take a share in the capital or 'equity' of the business as part of the arrangement by which they will advance capital. In order to achieve this the business will normally be required to incorporate.

In the UK the share capital of a company is expressed as a sum of money, the 'Authorized Share Capital', made up of a stated number of shares, each of which has a 'face' or nominal value.

On incorporation, a small, family-owned firm may start with an initial capital of, say, £10 000 divided into 10 000 shares of £1 each. A large public limited company, on the other hand, may have a share capital of many millions of pounds, sub-divided into many more millions of shares or stock units, of perhaps as little as 25p.

Not all the shares in a company may, or need to be, issued. By the issue of more shares, at an appropriate stage in the company's growth, capital may be raised from the institutions mentioned above or, through a flotation on the Stock Exchange, from the investing public at large. When this happens the price paid per share by the purchasers may be many times greater than the nominal value.

Example

Company A has an authorized and issued share capital of 300 000 ordinary shares of £1 each held by five shareholders. After many years of successful trading it is decided to seek a listing on the London Stock Exchange. The capital is increased to £3 million and is then divided into 12 million shares of 25p. Of these, 8 million are offered for sale to the public at £1 each. Subject to the costs of the issue, this will raise £8 million of fresh capital, some of which will be used in the business and some will go to the original owners of the business.

Before the issue:

	Shares of £1	
	No.	*Value*
Original shareholders	300 000	£300 000

After the issue:

	Shares of 25p	
	No.	*Value*
Original shareholders	4 million	£1 million
Outside shareholders	8 million	£2 million

The original shareholders' ownership of the business has declined from 100% to 33.3%, and it may be necessary for the owners to accept the appointment of further directors from outside the business, possibly in a non-executive capacity.

A price for the shares will be set by the market, based upon its assessment of the prospective performance of the company and the perceived quality of its management, and trading in the shares will begin. This price does not affect the money value received by the company for the sale of the shares at flotation.

7.3 Definitions

7.3.1 Capital

Capital is variously described, but is generally taken to be the amount of finance provided by the proprietors or outside lenders to enable the business to operate and earn a profit, from which the lenders will expect to receive an income. Share capital is that part which is regarded as fixed in the sense that it changes infrequently, and is increased only when the business requires additional permanent finance. In a limited company the amount of accumulated profits left in the business by the proprietors (i.e. not drawn in dividends) is grouped with the share capital and termed 'Shareholders' Funds'. Under present-day legislation it is also possible for a company to reduce its share capital by buying back its own shares or, by applying to the court, to have its capital reduced to enable a reorganization of the company's structure to take place. In this context, proprietors may be shareholders, stockholders, partners or sole traders. Capital is often termed the 'equity'.

7.3.2 Capital and revenue expenditure

The difference between capital and revenue expenditure can be compared broadly with that between expenditure on fixed and current assets. Capital expenditure is incurred in the acquisition of fixed assets and positioning the organization in order to start or continue its operations. Revenue expenditure relates to the purchase of goods and materials for manufacture or resale and in bringing those goods or materials to a condition suitable for sale, providing the facilities to bring about the sales and in the general administration and running of the business.

7.3.3 Cash flow

This is the amount of cash passing through the hands of an organization in an accounting period. The cash flow statement analyses the sources and the disposition of cash during a given period. It is akin to the Sources and Application of Funds Statement found in the published accounts of companies.

In addition to their historical use, Cash Flow Statements are prepared as part of the budgeting process in order to identify the effects upon the cash facilities of the proposed activities for the period under review. A typical, simplified, statement would give the following information.

Cash flow statement

Operating profit	×
Depreciation	×
Cash flow from operations	×
Fixed assets bought	(×)
Fixed assets sold	×
Loans received	×
Loans repaid	(×)
Corporate taxes paid	(×)
Interest paid	(×)
Interest received	×
Increases in working capital*	(×)
Decreases in working capital*	×
Dividends paid	(×)
Net cash inflow (outflow)	×
Opening cash balances	×
Closing cash balances	×

*Working capital normally includes Stocks, Trade Debtors, Prepayments, Trade Creditors, Accruals, Current taxation, etc.

7.3.4 Liquidity

This is usually defined as the ratio that liquid assets (debtors + cash) bear to current liabilities. The ratio is a measure of the relation of short-term obligations to the funds likely to be available to meet them.

Example

Liquid assets	£300 000	
Current liabilities	250 000	Ratio 1.2:1

Ratios well below 1 may indicate financial problems ahead while those substantially greater than 1 may point to poor credit control or under-utilization of cash. This ratio is sometimes known as the 'Acid Test'. The principal profitability ratio in use is the net profit before interest and tax (NPBIT) to net assets or return on capital employed.

7.3.5 Financial and operating ratios

Ratios are widely used to compare the performance of a business with predetermined objectives set by the business itself, with standards used by banks and other lenders, with other businesses in the same segment of industry (Inter-firm Comparison) and by the Stock Exchange and

its attendant analysts. The principal criteria are profitability, return on capital, liquidity and growth. To undertake growth by acquisition a high standing in the market is required. This is often a reflection of the performance against these criteria.

The ratios which follow are illustrated by reference to the following balance sheet and profit and loss account.

Balance sheet		£000
Current assets		
Cash		1175
Stocks		4700
Debtors and prepayments		4935
		10810
Current liabilities		
Creditors		3634
Short-term loans		600
Current taxation		373
Dividends		573
		5180
Net current assets		5630
Fixed assets		5750
		11380
Financed by:		
Share capital – Preference	825	
Ordinary	3050*	3875
Reserves		4700
Shareholders' funds (Net worth)		8575
Long-term loans		2500
Deferred taxation		305
		11380

*12 200 000 shares of 25p each.

Profit and Loss Account		£000
Sales		22000
Cost of sales (72%)		15800
Net profit before interest and taxation (NPBIT)		2555
Loan interest		200
Taxation		700
Net profit after taxation (NPAT)		1655
Dividends – Preference	47	
– Ordinary	549	596
Retained profits		1059

1. Gearing – the ratio of fixed rate capital and borrowings to other capital, that is:

$$\frac{\text{Preference capital + long-term loans}}{\text{Ordinary capital + reserves}}$$

$825 + 2500 : 3050 + 4700 = 43\%$

If the gearing is high the capacity to borrow may be affected, since the risk to creditors is high and the company may already be burdened with heavy interest charges.

2. Outside liabilities to shareholders' funds

	£000
Long-term loans	2500
Taxation – deferred	305
Current liabilities	5180
	7985
Shareholders' funds	8575
Ratio	0.93:1

The total of capital and reserves is the amount by which the assets can fall below the balance sheet value without depleting the amount available for creditors. A high ratio will reduce borrowing capacity.

3. Current assets to current liabilities

$10810 : 5180 = 2.1 : 1$

Shows the margin of safety available to short-term creditors. Significantly higher ratios than 2:1 may indicate excess stocks, poor credit control or inadequate control of cash resources.

4. Stocks, debtors, creditors to sales

The ratio of the minimum net assets required to support the sales volume of the business. From these ratios can be calculated the additional working capital needed if sales are to be increased:

$4700 + 4935 - 3634 = 0.273 : 1$

or

Stocks plus debtors minus creditors = 27.3% of sales

The average for manufacturing industries is usually around 25% of sales.

Changes in sales levels will give rise to movements in the working capital required to support them. The amounts can be calculated:

Increase in sales 15% of 22 000 = 3300

Increase in working capital

15% of $(4700 + 4935 - 3634) = 901$

or 27.3% of 3300 $= 901$

5. Profitability

The most widely used gauge of profitability is the ratio of profit to net assets (or return on capital employed):

$$\frac{\text{NPBIT} \times 100}{\text{Shareholders' funds + Long-term loans + Deferred taxation}}$$

$2555 \times 100/11\,380 = 22.5\%$

Two ratios amalgamate to provide the profitability ratio.

	£000
Sales	22 000
Net assets	11 380
NPBIT	2555
Return on capital	255 500 : 11 380 = 22.5%
Profit/Sales	255 500 : 22 000 = 11.6%
Sales/Net assets	22 000 : 11 380 = 1.93
	1.93 × 11.6% = 22.4%

These two ratios indicate funds usage efficiency and provide a basis for deciding the order in which improvements can be made.

6. Stock ratios
Expressed as a 'Stock turn', representing how many times stocks are turned round in a given period and/or as the number of days' stock of finished goods available to meet sales demand.

	£000
Stocks – Raw materials	1530
– Work in progress	1300
– Finished goods	1740
– Other	130
	4700

$$\text{Stock turn} = \frac{\text{Cost of sales}}{\text{Finished goods}}$$
$$= 15\,800/1740 = 9.1 \text{ times}$$
$$\text{Days' stock} = 1740 \times 365/15\,800 = 40 \text{ days}$$

7. Debtors' ratio
Expressed as days of sales outstanding or 'Debtors' Days'. Used in conjunction with prior figures for measurement of credit control efficiency and trends:

	£000
Debtors	4935
Sales	22 000
Ratio	$\frac{4935 \times 365}{22\,000} = 82$ days

Sometimes refined by deducting the sales for the current period as being not yet payable, and therefore leaving figure to represent *overdue* debt only. The ratio is also known as 'Collection Period'.

8. Liquidity
Liquidity can be expressed as the ratio of liquid assets (cash plus debtors) to current liabilities. Such assets are also known as 'Quick Assets', i.e. capable of swift realization.

$$\frac{(1175 + 4935)}{5180} = 1.2 : 1$$

The ratio shows the ability to settle short-term liabilities and should not normally be lower than 1:1, though it very often is! The lower the ratio, the greater indication of possible financial strain. A high ratio could mean poor credit control or under-utilized cash.

9. Earnings per Share

$$\frac{\text{NPAT} - \text{Preference dividend}}{\text{Number of issued shares}}$$
$$\frac{1655 - 47}{12\,200} = £0.132$$

Growth in earnings per share is used widely by analysts as a measure of a company's success. Adjustments must be made where issues of shares have taken place to satisfy acquisition purchase considerations.

10. Dividend Cover

$$\frac{\text{Earnings per share}}{\text{Dividends per share}} = \frac{0.132}{0.045} = 2.93 \text{ times}$$

The ratio indicates by how much earnings can fall before the dividend must be reduced and also shows the company policy towards the payment of dividends and profit retention.

11. Price/Earnings Ratio (P/E Ratios)

$$\frac{\text{Market Price}}{\text{Earnings per share}} = \frac{1.4}{0.132} = 10.6$$

This shows the number of years' earnings represented by the current market price. It evidences the Stock Market's assessment of the company's ability to maintain or increase earnings. A low P/E Ratio will normally indicate a high-risk business, a high ratio a company with potential for growth.

12. Dividend yield
Yields on shares are normally quoted on a gross basis so that they are comparable with the returns on gilts and other interest bearing securities. In this example the tax credit is deemed to be 10%.

$$\frac{\text{Dividend per share} \times 100/90 \times 100}{\text{Market price}}$$
$$= \frac{0.045 \times 100/90 \times 100}{1.4} = 3.57\%$$

The ratio gives the return which the grossed up dividend provides on the market price.

7.4 Budgetary control

7.4.1 Preparation

Financial data on their own provide only an historical record of the transactions of a business. The accounts of a company published annually are mainly of historical value but must, by law, include comparisons with the figures for a prior corresponding period.

Until information can be compared with similarly classified data its use must be limited. In order to plan ahead, a business will prepare a strategy or budget for the next trading year and probably several years thereafter, with that for the next year broken down into the business's scheme of accounting periods.

The final form of the budget will include profit and loss account, balance sheet and cash flow statement for the planning periods together with such supporting statements as are deemed necessary (for example, proposed capital expenditure). These will provide management with advance warning of points of stress upon resources, and enable steps to be taken to ease their effects or to avoid

them altogether. The financial controller or chief accountant will have the responsibility for bringing together the relevant information in the final budgets to be presented to senior management.

Budgeting practices vary from one business to another. Imposed budgets will be drawn up by senior management and, as the name implies, be imposed on those lower down the hierarchy. Participation budgets require the input of data and information at the formulatory stages by the people who will be responsible for bringing about the achievement of the results envisaged in the budgets.

The process of compiling the budgets will start with the preparation of estimates of the physical requirements of the plan, be they manpower, materials, tonnes of fuel, cubic metres, kWh of gas or electricity, cubic metres or litres of water. These estimates will be prepared in relation to the estimates of output by manufacturing or process departments which, in turn, will have been based on the quantities or other measures forecast in the sales budgets.

It is therefore vital that detailed and accurate records are kept by the operating and engineering departments of the usage and consumption of fuel, water and other services in order that performance against budget can be properly measured and so that data are available for use in compiling future estimates.

The budgets will also require estimates of expenditure upon equipment of a capital nature in the plan periods. This expenditure will normally fall into the following categories:

1. Replacement of existing machinery and equipment at the end of its useful life. (Straight replacement is rarely possible, since improvements in technology will usually have taken place.)
2. Items requiring replacement because of changes in the law. (for example, those relating to fire prevention, safety measures for the protection of employees and public).
3. Items which will improve profitability by saving costs or by carrying out processes faster or by using less manpower (see Section 7.5).
4. Expenditure in connection with new projects or necessary to provide increased throughput.

Motor vehicles can also fall within the above categories but businesses will usually have specific policies for their replacement.

As said elsewhere, the importance of realistic estimates of costs cannot be over-stressed, if, in turn, realistic comparisons can be made as the budget periods progress.

The compilation of figures for the budget should almost always be done from 'the bottom up', that is, by calculating the costs for the individual accounting periods by taking estimated quantities and prices for each period and summing for the whole of the budget. Thus, for example, holiday periods and known peaks and troughs can be recognized and catered for within the figures. Estimates made in the first instance on an annual basis can rarely be analysed satisfactorily to individual periods except where the costs themselves are expressed in annual terms (e.g. rents and rates).

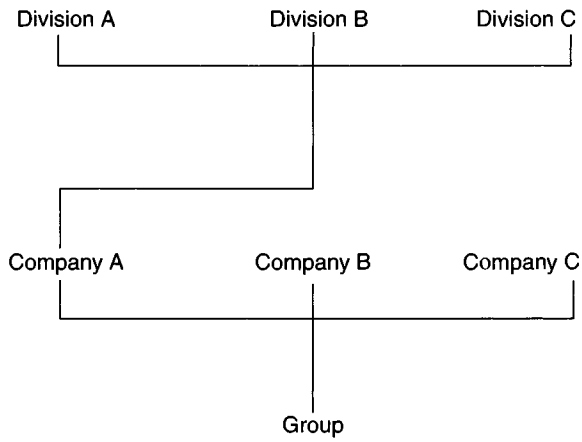


Figure 7.2 A typical group's profit centres

The sources of information from which the data are obtained are infinitely variable, but will include manufacturers' and suppliers' price lists, direct contact with suppliers and long-term contracts with sources of fuel and power.

At all times the interrelationship between budgets must be maintained – sales with finished products – products with consumption of materials – consumption of materials with labour using them, machine time and power. Machine time will influence maintenance, which will have its own content of labour, materials and work by outside specialist contractors.

When all the budgets have been prepared they will be consolidated by the finance department for submission to the approving authority. In large businesses there will be several levels at which authorization will be made before the final total plan for the business and its component divisions is agreed.

In group organizations, company budgets will themselves be consolidated into group form for final approval by the group board. A typical budget programme might be based on profit centres taking the form shown in Figure 7.2. (In multinational organizations this consolidation will continue worldwide.)

7.4.2 Control

During the progress of the financial year budgets will be compared at intervals with the actual performance to enable adjustments to be made to ensure that the planned outcome is achieved as nearly as possible. Because of changing circumstances after the start of the budget year, the budgets may be revised, possibly at three-monthly intervals. In practice, particularly in large and complex organizations, this is rarely practicable, given limitations of staff and time. An alternative is to require that a forecast of the immediately following period(s) is included with each report to identify areas diverging from planned

performance and to alert management to the need for correction.

7.5 Capital expenditure – appraisal methods

There are a number of accepted methods available for the comparison and appraisal of the virtues of proposed capital expenditure projects. Those considered here are as follows:

1. *Pay-back period.* This consists of calculating how long it will take for the profits generated by the capital outlay to equal the outlay itself, such profits usually being calculated after taking into account tax and any grants receivable. The defects of this method are that it takes no account of the profitability of the schemes after the break-even point is reached and the same value is placed upon each pound of profit, whether it is earned in year 1 or year 10. This latter shortcoming is avoided by the use of Discounted Cash Flow assessment.
2. *Rate of return.* A rate of return is calculated on the profits remaining after the initial outlay has been written off. This method suffers from the same defect mentioned in (1) above and also from the use of arbitrary periods for the writing down of the initial expenditure and of arbitrary rates of interest for the calculation of the rate of return.
3. *Discounted cash flow (DCF).* This method recognizes that £1000 income in five years' time is worth less than £1000 receivable this year. The use of DCF in appraising two or more competing projects offers two methods of assessment: the Net Present Value (NPV) or DCF Rate of Return.

The principle of NPV is best understood by applying an agreed discounting rate, that is, the best investment rate obtainable by the company, to the sum to be invested. A discounting rate of 10% assumes that £100 invested now will be worth £110 in a year's time. Conversely, it is assumed that £110 in a year's time is, at 10%, worth £100 today. From these assumptions it is possible to construct DCF tables for varying numbers of years and discounting rates (see Table 7.1).

To use Table 7.2, which is based on the formula $1/(1 + i)^n$, where i is the rate of interest and n is the number of years, the relevant factor is found for the rate and number of years and multiplied by the amount for which the NPV is required. Thus to find the NPV for £1500 receivable in 5 years at 10% from the table is found the factor of 0.621 and this, multiplied by £1500, gives an NPV of £931.5. Most spreadsheets used on personal computers include a formula for calculating NPV, so avoiding the need to construct tables.

The use of NPV (or DCF) leaves unresolved an important problem, that of determining the rate of interest or return to be used. Different rates of return could alter the ranking of the projects by changing the point at which the returns shown by the projects are in balance. If the company's own rate of return on capital is higher than that revealed by the NPV calculation then the apparently more viable scheme may not prove to be the more acceptable.

An alternative is therefore to use another method, using the same principles, by calculating a DCF rate of return. This has the advantage of not involving any assumptions as to interest rates, but calculates the effective rate of return on each project. The DCF rate of return is defined as the rate which reduces the NPV to zero. This method is more difficult to calculate in that it necessitates taking several trial values until two are found giving values on either side of zero. A weighted average can then be applied to 'fine tune' the result.

Where there are constraints upon the provision of funds then the DCF rate of return method will be the more appropriate. Where the organization has ready access to finance then the NPV method, using the known long-term borrowing rate, should be used.

Table 7.1 Application of NPV. To illustrate the uses of the two DCF methods the following example assumes the following data relating to two competing projects

Year	*Net cash flows*	
	Project A £	*Project B* £
0	−100 000	−200 000
1	−15 000	−50 000
2	20 000	5000
3	25 000	10 000
4	35 000	25 000
5	40 000	40 000
6	50 000	75 000
7	−5000	75 000
8	65 000	90 000
9	85 000	110 000
10	100 000	130 000
Totals	300 000	310 000
Year	*Net present values at 10%*	
	Project A £	*Project B* £
0	−100 000	−200 000
1	−13 367	−45 455
2	16 528	4132
3	18 783	7513
4	23 905	17 075
5	24 836	24 836
6	28 225	42 338
7	−2566	38 490
8	30 323	41 985
9	36 049	46 651
10	38 550	50 115
Totals	101 266	27 680

Although Project B shows a greater total of net cash inflows over the whole period, at net present values Project A indicates a more satisfactory return, all other factors being ignored.

Table 7.2

n	*5%*	*10%*	*15%*	*20%*	*25%*	*30%*
1	0.9524	0.9091	0.8696	0.8333	0.8000	0.7692
2	0.9070	0.8264	0.7561	0.6944	0.6400	0.5917
3	0.8638	0.7513	0.6575	0.5787	0.5120	0.4552
4	0.8227	0.6830	0.5718	0.4823	0.4096	0.3501
5	0.7835	0.6209	0.4972	0.4019	0.3277	0.2693
6	0.7462	0.5645	0.4323	0.3349	0.2621	0.2072
7	0.7107	0.5132	0.3759	0.2791	0.2097	0.1594
8	0.6768	0.4665	0.3269	0.2326	0.1678	0.1226
09	0.6446	0.4241	0.2843	0.1938	0.1342	0.0943
10	0.6139	0.3855	0.2472	0.1615	0.1074	0.0725
11	0.5847	0.3505	0.2149	0.1346	0.0859	0.0558
12	0.5568	0.3186	0.1869	0.1122	0.0687	0.0429
13	0.5303	0.2897	0.1625	0.0935	0.0550	0.0330
14	0.5051	0.2633	0.1413	0.0779	0.0440	0.0253
15	0.4810	0.2394	0.1229	0.0649	0.0352	0.0195
16	0.4581	0.2176	0.1069	0.0541	0.0281	0.0150
17	0.4363	0.1978	0.0929	0.0451	0.0225	0.0116
18	0.4155	0.1799	0.0808	0.0376	0.0180	0.0089
19	0.3957	0.1635	0.0703	0.0313	0.0144	0.0068
20	0.3769	0.1486	0.0611	0.0261	0.0115	0.0053
21	0.3589	0.1351	0.0531	0.0217	0.0092	0.0040

The cash flow expected for each period is discounted by the factor for the rate of interest chosen and the number of periods in which the cash flows will occur. The number of periods is calculated from the commencement of the capital expenditure. The factors are arrived at from the formula $1/(1+i)^n$, where i is the rate of interest expressed as a decimal and n is the number of periods. In reality, the factors assume that the cash flow passes on the last day of each period but can be adopted where the flow is roughly even throughout the period.

7.6 Control of capital expenditure

Significant capital expenditure usually represents a substantial commitment of the resources of a business, both financially and in terms of man-hours. It is therefore incumbent upon management to ensure that proposals for such outlays receive proper and full consideration of all the relevant implications before implementation. Once policies as to levels of authorization and commitment are laid down, there should follow the formal appraisal of the financial effects of the proposal. These can be formulated only after detailed discussion with the appropriate departments as to all the physical, technical and environmental factors involved in making the final decision. There will also be brought into consideration, where pertinent, the marketing and sales effects.

Most organizations will have sets of forms for use in the authorization and control of capital expenditure and these will vary in design and content. A basic guide for such documents would include the following:

1. *Capital variation proposal* (Figure 7.3, on page 7/10). This should embrace the following:
   (a) Description;
   (b) Amount for which authority is requested;
   (c) Reasons for application (e.g. to increase production, to maintain production, to reduce costs, for the introduction of a new product, etc.);
   (d) Expenditure or losses not included in the proposal, such as staff amenities, transport requirements, self-competition, etc.;
   (e) Summary of the cost;
   (f) Disposal or modification of existing assets;
   (g) Details and timing of the outlays;
   (h) Extra working capital demands which will arise from the implementation of the project;
   (i) Index of the documents supporting the application.
2. *DCF calculations* (Figure 7.4). These will normally be in the form of working sheets and/or graphs, the latter being used for interpolation where the calculations are too numerous or too detailed for tabulation. Calculations will normally be carried out using computers but where this is not possible, DCF tables should be utilized.
3. *Calculation document* (Figure 7.5). This document provides a means of calculating the DCF rate of return or a net present value where these are required, usually where profitability of the project is of major concern.
4. *DCF rate of return graph* (Figure 7.6). This may not be necessary in all cases but would be used for the interpolation of rates of return where a precise answer is not obtained from the detailed DCF workings described above.
5. *Payback graph* (Figure 7.7). This provides a view of the profile of the cash flows emanating from the project and forms a useful adjunct to the DCF information.
6. *Summary of cash flows* (Figure 7.8). This document is an essential part of every capital expenditure project evaluation. The forecast thus provided will be needed in the preparation of the overall cash budget.

7.6.1 Current and post-event monitoring

Large and complex projects will be monitored as the expenditure proceeds while smaller outlays will be looked at after completion. The purpose of such monitoring is to provide a comparison of actual expenditure with that estimated when the project was sanctioned. This will normally be carried out by the accounting or internal audit departments. However, for a sensible comparison to be achieved it is essential that the planned expenditure demonstrated in the project be classified in the same way that the actual expenditure will be analysed. While somewhat obvious, this is an area where very great difficulty is often met in practice, especially where large projects are involved.

Considerable thought should be given to this aspect at the planning stage, with consultation taking place between the engineering and accounting functions. Apart from its obvious use to prevent serious over-runs of expenditure, 'post-event monitoring' provides useful lessons for the future preparation of capital projects.

7.7 Standards and standard costing

Standard costing is usually thought of in connection with manufacturing production but can be used with advantage in the measurement of the efficiency of supporting plant

Description	Amount	£
	New	
	Other	
	Total	
	Budgeted	

Reason
New product
Cost reduction
Legal requirement

RELATED EXPENDITURE not included here
Staff amenities
Transport and distribution costs

SUMMARY OF EXPENDITURE	£	ASSETS TO BE DISPOSED OF	Value £
Buildings			
Other			
Sub-total			
Working capital			
Grand total			

Prepared by | Recommended by

Approved by Board | Date

Details of expenditure for approval

	£	Comments	Timing

Details of additional working capital required

	£	Comments	Timing
Stocks increase			
Debtors increase			
Minus creditors increase			
Total			

Figure 7.3 A capital variation proposal

Cash outflow

Year	Cash	0% Factor	0%	5% Factor	5% NPV	10% Factor	10% NPV	15% Factor	15% NPV	20% Factor	20% NPV	Factor	NPV
0		1.0		1.0		1.0		1.0		1.0		1.0	
1		0.952		0.909		0.870		0.833					
2		0.907		0.826		0.756		0.694					
Total £		£		£		£		£				£	

Cash inflow

1		0.952		0.909		0.870		0.833					
2		0.907		0.826		0.756		0.694					
3		0.986		0.751		0.658		0.579					
4		0.823		0.683		0.572		0.482					
5		0.784		0.621		0.497		0.402					
6		0.746		0.564		0.432		0.335					
7		0.711		0.513		0.376		0.279					
8		0.677		0.467		0.327		0.233					
9		0.645		0.424		0.284		0.194					
10		0.614		0.386		0.247		0.162					
Total £		£		£		£		£				£	

Figure 7.4 DCF calculations

Project _____

Year ending _____	1	2	3	4	5	6	7	8	9	10
Revenue from project										
Other income arising										
Total income										
COSTS										
Operating profit (loss)										
Capital allowances										
Taxable profits										

	1	2	3	4	5	6	7	8	9	10	11
Tax											

Figure 7.5 Profit calculation

and equipment. Most readers of this book will already be familiar with the measurement of efficiencies against, for example, manufacturers' standards for a specific item of equipment. The standards related to such plant will themselves play a part in setting the production standards mentioned above.

It is not proposed here to provide instruction in the techniques of standard costing but merely to illustrate the uses to which certain of the methods can be put. This can best be shown by the use of a worked example.

The following is the statement for a service department supplying a factory which uses both fuel and materials.

	Budget	*Standard*	*Actual*
Output units	32 000	33 600	29 400
Operating days	20	21	21
Cost per unit	83.5p	83.5p	90.0p
Fuel – Consumption	200	210	213
– Unit price	£50	£50	£49
– Cost	£10 000	£10 500	£10 437
Materials – Consumption	800	840	700
– Unit price	£2	£2	£2.10
– Cost	£1600	£1680	£1470
Labour – Hours	80	84	105
– Hourly rate	£5	£5	£7
– Cost	£400	£420	£735

Repairs			
– Rate per output unit	10p	10p	11p
– Cost	£3200	£3360	£3234
Variable overheads			
– Rate per output unit	20p	20p	22p
– Cost	£6400	£6720	£6468
Fixed overheads			
– Rate per output unit	16p	16p	14p
– Cost	£5120	£4704*	£4116
Total cost	£26 720	£27 384	£26 460

*Actual output × standard cost.

Variances from standards are then calculated as follows:

			£	
Fuel				
Usage variance	SP (SQ – AQ)	= 50 (210 – 213)	= 150A	
Price variance	AQ (SP – AP)	= 213 (50 – 49)	= 213F	63F
Materials				
Usage variance	SP (SQ – AQ)	= 2 (840 – 700)	= 280F	
Price variance	AQ (SP – AP)	= 700(2.00 – 2.10)	= 70A	210F
Labour				
Rate variance	AH (SR – AR)	= 105 (5 – 7)	= 210A	
Efficiency	SR (SH – AH)	= 5 (84 – 105)	= 105A	315A
Repairs				
Volume variance	SC (SV – AV)	= 0.10 (33 600 – 29 400)	= 420F	
Price variance	AV (SC – AC)	= 29 400 (0.10 – 0.11)	= 294A	126F
Variable overheads				
Volume variance	SC (SV – AV)	= 0.20 (33 600 – 29 400)	= 840F	
Price variance	AV (SC – AC)	= 29 400 (0.20 – 0.22)	= 588A	252F
Fixed overheads				
Expenditure variance	AFO – BFO	= 4116 – 5120	= 1004F	
Volume efficiency	SC (AQ – SQ)	= 0.16 (32 000 – 33 600)	= 256A	
Yield	SC (SY – AY)	= 0.16 (32 000 – 29 400)	= 416A	
Capacity	SC (RBQ – SQ)	= 0.16 (33 600 – 33 600)	= NIL	
Calendar variance	SC (RBQ – BQ)	= 0.16 (33 600 – 32 000)	= 256F	588F
				924F

SC	= Standard cost	BQ	= Budgeted quantity
SQ	= Standard quantity	AQ	= Actual quantity
SP	= Standard unit price	AP	= Actual unit price
AH	= Actual hours		
SH	= Standard hours	AH	= Actual hours
SV	= Standard volume	AV	= Actual volume
AFO	= Actual fixed overheads	BFO	= Budgeted fixed overheads
SR	= Standard rate per hour	AR	= Actual rate per hour
SY	= Standard yield	AY	= Actual yield
BQ	= Budgeted quantity	RBQ	= Revised budgeted quantity
A	= Adverse	F	= Favourable

Fixed overheads require some amplification. Budgeted output for the year is 400 000 units, budgeted fixed overheads for the year are £40 000. There are 50 working

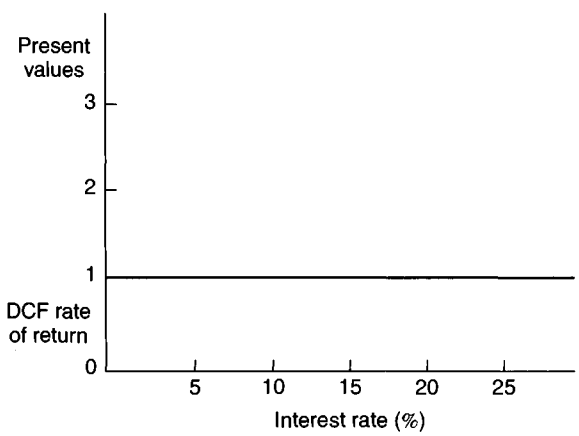


Figure 7.6 Interpolation of DCF rate of return

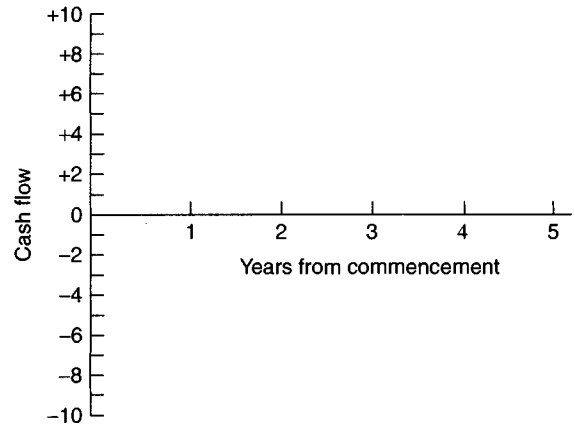


Figure 7.7 Cumulative cash flow

weeks in the year with 4 weeks in the period being reviewed, with one extra day being worked. The actual fixed overheads for the period amounted to £4116.

Actual output for the period	29 400 units
Budgeted output for the period	32 000 units
Standard output for the period	33 600 units

(Budgeted output is 1600 (400 000/250) units per day, so 21 days' standard output is 33 600 units.)

It is necessary to present this information in an understandable way, and this may take the following form:

		£
Budgeted cost of output		26 720
Output variances		
Volume	2171F	
Unit cost	1911A	260F
Actual cost of output		26 460
Less: Standard cost of output		
Fuel	10 500	
Materials	1680	
Labour	420	
Repairs	3360	
Variable overheads	6720	
Fixed overheads	4704	27 384
Favourable variance		924

Analysis of variances:			
Fuel	– Usage	150A	
	– Price	213F	63F
Materials	– Usage	280F	
	– Price	70A	210F
Labour	– Rate	210A	
	– Efficiency	105A	315A
Repairs	– Expenditure		126F
Variable overhead			252F
Fixed overhead			
– Expenditure		1004F	
– Volume efficiency		256A	

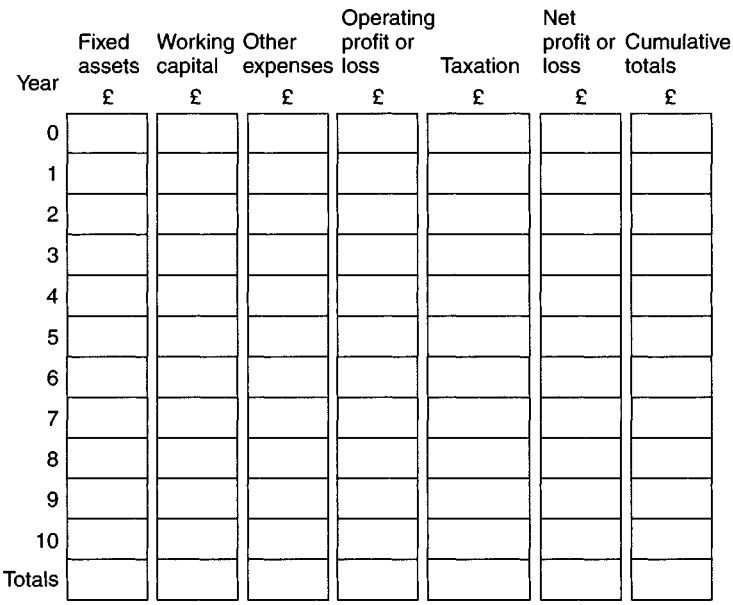


Figure 7.8 Summary of cash flows

– Yield	416A	
– Calendar	256F	588F
		924F

Comments

Fuel suffered from excessive usage, which was partly offset by a lower unit price.
Materials showed lower usage but a higher than expected price was paid.
Labour both cost more per hour and was utilized longer.
Repairs and variable overheads both benefited from lower than expected expenditure.
Fixed overheads were less than forecast but this saving was partially offset by lower volume and yields. The extra day's working increased the net advantage gained from these factors.

7.8 Capital

Businesses require funds for day-to-day operations ('working capital') and for expansion by acquisition and for the provision of plant and machinery, buildings, etc. Most working capital needs are normally (and should be) met from the company's own cash generated from its own operations. Indeed, the need to meet this criterion serves as a discipline upon the company's standard of cash management in relation to credit control, payment of suppliers, etc.

Short-term needs will be met mainly from the company's own cash flow and from overdraft facilities provided by the company's bankers. Medium-term facilities can be provided by entering into arrangements for the hire purchase or leasing of specific items of equipment. The facilities available are many and varied. Long-term resources will normally be met by the raising of further capital by way of Stock Exchange placings or flotation or by the securing of loans through debentures secured upon the assets of the company, bearing fixed rates of interest and redeemable at a date in the future.

7.8.1 Short term

The main sources include:

1. *Overdrafts.* Usually the least expensive; interest is charged on the daily balance usually at a premium (often substantial) over the bank's base lending rate.
2. *Factoring.* Usually applied to sales invoices (effectively, the debtors). Specialist finance houses provide a service whereby the company is paid promptly a percentage of its sales value for a period and the finance house then collects the full amount from the debtor. In some cases the finance house will undertake the invoicing of the customers direct, providing a complete sales ledger service. Confidentiality as to the arrangement is lost in this case. There are many schemes with considerable variations available.
3. *Acceptance credits.* Provided mainly for exports by the major banks and specialist accepting houses.

7.8.2 Medium term

This may be provided by:

1. *Hire-purchase.* Normally for periods of up to three or five years. The ownership of the goods remains with the finance company until the instalment payments are complete and a final option to buy is exercised. Payments remain fixed throughout the term of the

agreement with a predetermined unchanging rate of interest included.
2. *Leasing*. The asset is leased for a term of years at a fixed rental. The term can then be extended for secondary or tertiary periods at nominal rentals. Recently-introduced accounting standards in the UK require that assets acquired under contracts of this sort must appear in the balance sheet at cost and be depreciated even though not legally owned by the company.
3. *Lease purchase*. There are on offer many variants of the two previously illustrated sources, giving choices of both methods in combination with each other. The underlying principles are the same.
4. *Contract hire*. Although not strictly a source of outside finance, this is a method of avoiding capital outlay, especially favoured for vehicles. Again, there are many varying systems to be found.
5. *Sale and lease-back*. Once considered only for land and buildings, schemes are now available for other assets, notably sizeable fleets of vehicles.

7.8.3 Long term

The principal sources include:

1. *Flotation on stock markets*. This involves transferring in whole or in part the ultimate ownership of the business to persons outside the company and, dependent upon the proportion sold, may leave the business vulnerable to takeover by competitors or unwelcome bidders.
2. *Share placings*. Shares are issued for a consideration to known and specific parties at an agreed price, usually through the medium of a large financial institution. This reduces the element of vulnerability to takeover bids but does not eliminate the possibility, should any of the 'placees' be prepared to sell their holdings at a future date.
3. *Issue of debentures*. These will normally carry a fixed rate of interest and have a predetermined date of redemption, possibly at a premium. The holders of debentures will usually require security perhaps by means of a fixed charge over specific assets (or all the assets), and will have a right of prior payment in the event of a liquidation. Debenture holders can also sometimes exercise their rights on the occurrence of certain events. Widespread security given to one class of lender can militate against the provision of short-term finance from other lenders who require collateral.
4. *Loans from specialist companies*. There is a number of companies and institutions who specialize in providing long-term finance to industry. The forms of loans offered vary from one deal to another and, in some cases, will be accompanied by a request for some degree of participation in the equity of the borrower.

7.9 Value added tax

The calculation of VAT is straightforward when the rate at present in force is applied to a value to which it is to be added. The formula is:

Value + (Value × Rate/100)

Where the amount of Value Added Tax included in a value is required the calculation is as follows:

Value × Rate/(100 + Rate)

Where the amount exclusive of Value Added Tax included in a value is required the calculation is:

Value/[(100 + Rate)/100]

7.10 Break-even charts

It is often useful to prepare break-even charts in order to illustrate and give a clear picture of the position of a business. They can be adapted to help in showing the viability and profiles of individual projects.

The two most common designs of break-even charts are shown in Figures 7.9 and 7.10. In both cases the y (vertical) axis is used for sales (output) and costs while the x (horizontal) axis is used for volumes, capacity or time.

Illustration

Output (000s)	10	20	30	40	50	60
Fixed costs	5000	5000	5000	5000	5000	5000
Variable @ 30p	3000	6000	9000	12 000	15 000	18 000
Sales @ 50p	5000	10 000	15 000	20 000	25 000	30 000

The angle of incidence, if wide, will indicate a high rate of profitability. If this is coupled with a high margin of safety an extremely advantageous investment is demonstrated.

The position of the break-even point serves as an indicator. If it is well to the right of the chart then the margin of safety will be poor. Conversely, a position to the right of the chart will hold out opportunities for expansion.

The guidance obtainable from break-even charts is limited and should be used only with other criteria in formulating decisions. The effects of policy decisions may alter the data used and vitiate or amend the results disclosed.

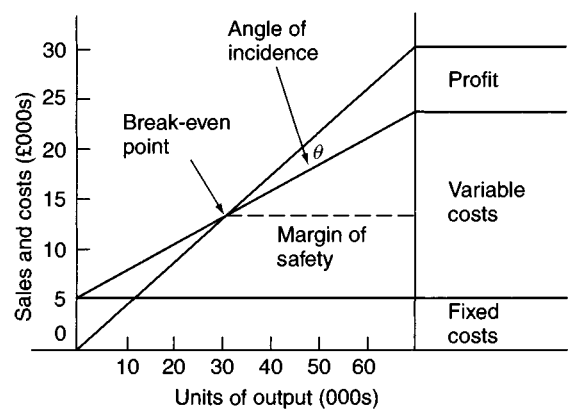


Figure 7.9 Break-even chart (1)

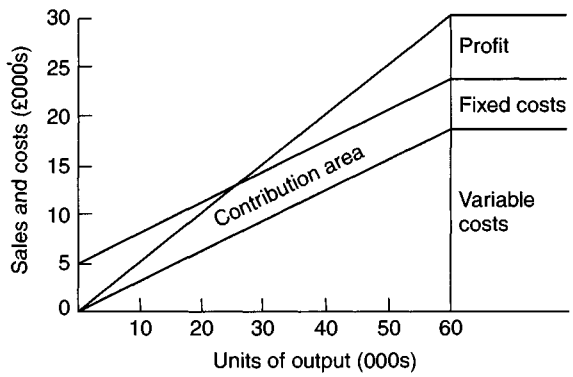


Figure 7.10 Break-even chart (2)

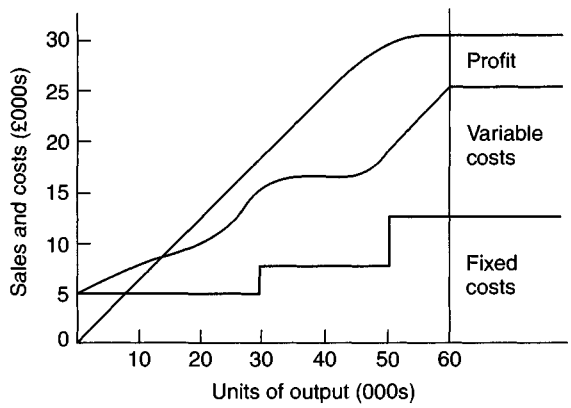


Figure 7.11 Break-even chart (3)

In Figure 7.10 fixed costs are shown above the variable costs and the non-recovery of the fixed costs below the break-even point is more clearly demonstrated. The 'contribution' to fixed costs is of significance in the consideration of marginal costing.

In practice, costs do not increase smoothly or remain absolutely constant. Fixed costs frequently move in a series of steps and variable costs also change unevenly. There may be several break-even points at different levels of sales and outputs (Figure 7.11).

7.11 Supply of steam, power, water, etc. to other departments

The plant engineer is frequently called upon to assist and advise on the bases for charging to other departments within the plant or to outside purchasers where there is a central generation plant for a variety of users, as may occur in an industrial estate or where the plant providing the service has a surplus. The elements to be considered and brought together in formulating a basis for charge can be summarized as follows, always bearing in mind individual needs and circumstances:

1. *Expenses associated with the capital cost of equipment.* Depreciation will be provided over the useful life of the equipment, varying according to the engineer's estimate. Present-day custom is to write assets down on a straight-line basis, but there are several accepted ways of providing the necessary depletion of the asset value. For tax purposes, a reducing-value method is employed in the UK.
2. *Costs relating to the space occupied by the equipment.* These will usually include rent and rates or similar taxes, together with the upkeep of the buildings housing the machinery. Where the buildings are owned by the operator a notional rent should be included to reflect the full cost of occupancy. Such costs will normally need to be allocated to the department by reference to the area occupied, but may require more complex calculations where the buildings on a site differ in age, or in standards of construction or maintenance.
3. *Costs of gas, electricity, etc.* These are usually readily ascertainable from the suppliers' accounts, but for charging purposes great reliance will be placed on results from regular meter readings. The importance of an efficient routine for reading meters has been stressed elsewhere. It will be essential for accurate and fair apportionment between users for there to have been a recognition of the need for and acceptance of the cost of metering equipment for all user departments, down to individual machines if necessary. Where the main source of energy is gas then it will be usual to have a stand-by oil-fired system, especially where the gas supply is interruptible. The tanks for this reserve will form part of the capital equipment and the oil itself will need to be included when considering the capital employed. Where electricity is produced on site as a by-product in periods of low demand for steam, more cheaply than that obtained from the utility company, adjustments to the charges on a seasonal basis will be required.
4. *Water.* Costs are available from the supplier's invoices but where the operator has reservoirs and/or licences for extraction from canals or rivers the annual fees and penalties which are sometimes leviable should not be forgotten. Projections of future demands will need to be carefully considered where this type of arrangement is made, since such contracts are often available only on long-term bases. Water-treatment plant will produce its own range of costs across the whole field of depreciation, materials, electricity, labour, etc. and these will need to be apportioned to the steam cost departments before final allocation to the user departments.
5. *Labour costs.* In arriving at the total labour costs there must be included social security costs, pension costs and any provisions for holiday pay. It may be desirable, where users take steam overnight, to apportion costs in such a way as to reflect the higher cost of labour employed on night work.
6. *Maintenance expenses.* The nature of these is generally self-evident, but long-term maintenance contracts, insurance inspection fees and any subsequent requirements arising therefrom should not be overlooked. Inspections are commonly undertaken at weekends, at premium labour rates.

7. *Recovery of appropriate proportion of overheads.* The overhead charge to the supplying department will usually be provided by central finance in accordance with the company's policy for allocation of overheads.
8. *Recovery of proportion of exceptional financing and interest charges.* This will normally depend upon the policy of individual companies and will probably have been included, if at all, in the general overheads referred to in (7). It should not be left out of consideration where provision has been made for a particular user's requirements involving, say, special extension or modification of existing plant.

7.11.1 Computation of charges to users

Assumptions

For a site operating four gas-fired boilers each of 10 000 kg/h output, operating at 70% efficiency for 60 hours per week, employing three people directly in the department, annual costs may be summarized as follows:

Annual cost of producing steam	£
Depreciation of boilers and equipment	100 000
Gas	850 000
Electricity (for steam production)	30 000
Water and water treatment	12 500
Labour for steam production	36 000
Repairs, maintenance and insurance	35 000
Stand-by oil	1500
Proportion of site overhead	25 000
Proportion of finance overhead	6000
	1096 000

These costs would then be allocated to the user departments in proportion to actual use, using metered records and adjusted for the incidence of peak-time usage, overnight working, weekends or early starts.

Given that metering equipment is in place, the allocation of the steam production costs to individual users is straightforward and needs no amplification here. If the allocation has to be made employing estimates of usage, perhaps by using the ratings of individual pieces of equipment, then everything will turn upon the general and continuing acceptance of those estimates by all the users concerned. Should these conditions not be met or maintained then the life of the plant engineer will be an uneasy one!

7.12 Charges for effluent and environmental services

These services are now very often a significant part of the costs of a factory and are worth a note here. Projecting accurate costs can be difficult, since water authorities commonly render accounts quarterly with charges fluctuating from month to month in relation to both volumes and chemical content ('toxicity') of the effluent, all of which can be highly variable. Monthly liaison with the authority's representative and inspection of sampling reports will often enable more accurate information to be available, both for the assessment of costs where charges are to be made to individual departments and for the accruing of costs by the management accountant.

8 Fire safety

Eur Ing Dennis A Show CEng, MIMechE, HonFSOE, HonFIPlantE, HonFIIPE

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8.1 Introduction

Among some of the other major decisions that the plant designers have to consider is 'Fire Safety'.

Under this category come a number of very important headings:

The requirements and compliance with local Authority Requirements (such as Building Regulations and Planning Permissions etc).
Fire Risk Assessment.
Means of Escape in Case of Fire
Fire Prevention.
Moral obligation to personnel, whether they be employees or external visitors, and in particular Disabled people.
Fire Fighting Equipment
The dangers associated with the activities of the plant.
The storage of waste, chemicals and materials associated with the plant operation.
Control of methods used if waste is disposed of using incineration or other similar systems.

Apart from the Statutory requirements, one of the most important decisions must be considered and in this category come the responsibilities associated with fire prevention and means of escape in case of fire. To improve escape route flow.

8.2 Means of escape in case of fire

Dealing first with means of escape, there are a number of ways that this aspect can be approached, but initially full appreciation of the processes or occupational requirements is essential.

It is with this knowledge that one should be able to foresee where and how plant layout and workflow can be contributors in determining the direction of escape routes and possible obstructions. Then having first seen the problems changes can be incorporated in order to be able to improve an escape route flow. These changes could be by modifying the plant layout, or changing the building design or incorporating suitable alternative means. Under all these situations one must be guided by the appropriate rules and codes of practice stipulated, but initially personal appreciation of the situation should be the natural first approach and those that are obvious situations will, in all probability, follow a close association to those stipulated under the codes of practice.

8.3 The legal requirement

Specific regulations governing fire precaution legislation. In the UK these include the Fire Regulations and the Fire Precautions Act 1971 F (in Northern Ireland the Fire Services (Northern Ireland) Order 1984 (as amended) and more generally under the Health & Safety at Work etc Act 1974 together with regulations made under that Act.

The Fire Regulations and the Fire Precautions Act 1971 and the Northern Ireland equivalents are the responsibility of the Home Departments, and are enforced by the Fire Authorities.

However, with Crown Occupied and Crown Owned premises, enforcement is carried out by the Fire Service Inspectorates of the Home Departments (In Northern Ireland) by the Department of Economic Development).

Fire Precaution legislation deals with general fire precautions, which include:

Detection and fire warnings,
Means of Escape
Means for Fire Fighting.
The training of personnel in fire safety.

The fire regulations also include a requirement to undertake an assessment of fire risks. This covers the risk of fire occurring and any risks, that may be present, to people and property in the event of a fire occurring.

The Health & Safety at Work Act 1974 together with all the other Regulations made under them together with the references to the various 'Codes of Practice' for the various industries, and are designed to cover fire precautions associated with various processes, and are intended, to prevent the outbreak of a fire, or at least minimise the consequences should a fire occur.

Matters that fall under the scope of the Acts include such things as storage of flammable materials, control of flammable vapours, standards of good housekeeping, and the safe systems of working, the control of the sources of ignition and the provision of appropriate training of personnel involved in the industry concerned.

These precautions are enforced by inspectors from the Health and Safety Executive.

8.4 To summarise

What do the Fire Regulations and the Health & Safety at Work Acts really boil down to direct your operations?

- Carry out a risk assessment of your plant – you must consider all of your employees and everybody else who could be affected by a fire within your establishment, and you must also make sufficient provision for any disabled people taking into account all their possible special needs who may be employed or may be visiting your plant or premises.
- You must identify significant findings of the risk assessment and the details of anyone who might be especially at risk in case of fire (these must be recorded if there are five or more people involved).
- You must provide and maintain such fire precautions as are necessary to safeguard those who use your workplace.
- You must also provide information, instruction and training to your employees about your fire precautions within your establishment.

Your risk assessment will help you to decide the extent and the type of precautions you should take depending on processes involved.

There are a number of legal duties that you are required to address:

- Where it is necessary for you to safeguard the safety of your employees, you must nominate people to undertake any special roles which are required under your

emergency plan (you as the plant engineer can nominate yourself if necessary or, should you be otherwise involved, can nominate a person or duty holder, who should be present, at all times, with a suitable alternative in case of absence.

- You should consult your employees or their elected representative, or Trade Union representative, about the nomination of people to carry out particular roles in connection with fire safety and about any proposals which may be under consideration for the improvement of the fire precautions.
- You must inform other employers who may have plants within the same premises, in the case of multi-occupancy, of any significant risks you found which may affect the safety of their employees and co-operate with them about the measures proposed to reduce or control those risks.
- On the other hand, if you are not a direct employer, but you have control or authority over the premises, you still have a duty to make certain that all those involved within the premises, are acquainted with the Fire Regulations and that they are complied with.
- You must establish a suitable means of contacting the emergency services and you must ensure that they can be summoned easily.
- The law also requires your employees to co-operate with you to ensure the workplace is safe from fire and its effects, and not to do anything which will place themselves or other people at risk.

In many places within the UK you may need to apply for a FIRE CERTIFICATE before you can operate your plant. It is your responsibility to make suitable enquiries from the Local Authorities, the local Health & Safety Executive office, to see whether you come under this directive.

However, it is advisable, in any case, for all plant planners and developers to seek formal advice from the local Fire Authority for fire precaution advice before attempting to plan an establishment. Compliance with their requirements, known in advance, can in the long run, be an economical solution to problems which might otherwise come to light at a later date, when alterations may become an expensive necessity. Time for compliance can, in some cases, if delays can result, be even more expensive.

Fire Precautions & Means of Escape built into the plant, in the first place, enable the engineer to be able to concentrate on the project without having to bother at a later date, especially if building works are necessary, or if major, a change in plant location may avoid unnecessary or extensive precautions having to be incorporated later as a retrofit.

8.5 Risk assessment

8.5.1 What is a risk assessment?

It is a structured look at your process and plant workplace and other associated activities which could at any time give rise to fire or to harm people. It will enable you to assess whether you have taken into consideration and made sufficient provision to avoid problems and to decide whether addition consideration is necessary to enable you to have 'peace of mind' and to comply with the appropriate regulations.

You have to decide what is a HAZARD and what is a RISK.

A hazard can be defined as something, which, has the potential to cause harm, whereas a risk is the magnitude of chance, whether high or low of that harm occurring at some time. Whether or not previous approval has been sought and approved, you still have to go through the routine to carry out a risk assessment. If, however, the previous approval covered all the matters required by the Fire Regulations, and conditions have remained unchanged (that is the number of people employed, the work processes have not changed etc.), then your risk assessment may well show that few, if any, additional precautions are needed.

Your risk assessment may highlight additional matters which need attention if the previous approval was given according to an out of date standard of fire precautions or the approval was under legislation which does not cover all the requirements of the Fire Regulations. If there is any doubt then you should consult the local Fire Authority.

8.5.2 Doing the risk assessment

You will assess the chances of a fire occurring and the dangers that a fire will have on the people working and others using the area concerned.

Your risk assessment can be part of an overall assessment of the general Health & Safety assessment or can be carried out as a completely separate operation. As with all evaluations of whatever nature it is usual to make a professional approach by making a methodical plan so that the whole procedure is carried out to a correctly predetermined plan of action.

However, a risk assessment is not a theoretical exercise but can be prepared as a paper exercise initially based upon the knowledge you, your employees and others have of your work and processes. Once done the paper exercise a practical examination, visit, or inspection should be made to confirm, amend and add to your original thoughts.

The Home Office have issued a publication called 'Fire Safety–An Employer's Guide' which contains advice on your requirements and assessment procedures. Their flowchart for risk assessment (Figure 8.1) is reproduced as a guide to the exercise.

8.5.3 The five steps to the risk assessment

1. Identify the Fire risks
2. Decide who may be at risk in case of fire and will include workers, visitors and when escaping from the workplace and locate their various areas of work.
3. Evaluate the risk arising from the hazard and decide whether your existing fire precautions are adequate or whether more should be done to eradicate the hazard or to control the risk, by improving the fire precautions,

4. You should then record your findings and details of the action you should take as a result. Notify your employees of your findings.
5. You must then keep your assessment continually under review and adjust as and when found necessary.

There will be few people who know as much about your own particular business and processes, as you and your workforce know. Therefore you are the best people to undertake the assessment and to enable you to have the best advice of those process conditions from your staff. Talk to them, ask for their advice and what is more pay attention to their suggestions as they are possibly the people closest to the hazard.

You should be able to put the hazards into categories of those which are identified as expected to cause a danger whilst there are others in a lower category with a lower risk and unlikely to be of major concern although still classified, albeit at a lower level.

On completion of the assessment, if the premises are of the shared type, then discussion must take place with other occupiers so that they are fully aware of the hazards and the level of risk.

8.5.4 After the event

Having completed the risk assessment you should now be in a position to make decisions regarding your fire precautions and the modifications that you have found necessary to bring protection up to standard. But there are other areas that have to be taken into consideration. First if there is any chance that your premises are covered by some form of certification, licensing or other form of regulation you need to check that what you have discovered and propose to amend will in no way conflict with those methods that are already approved and certified.

You must carry out this investigation before making any changes so that there is no conflict of interest.

THE FLOWCHART.

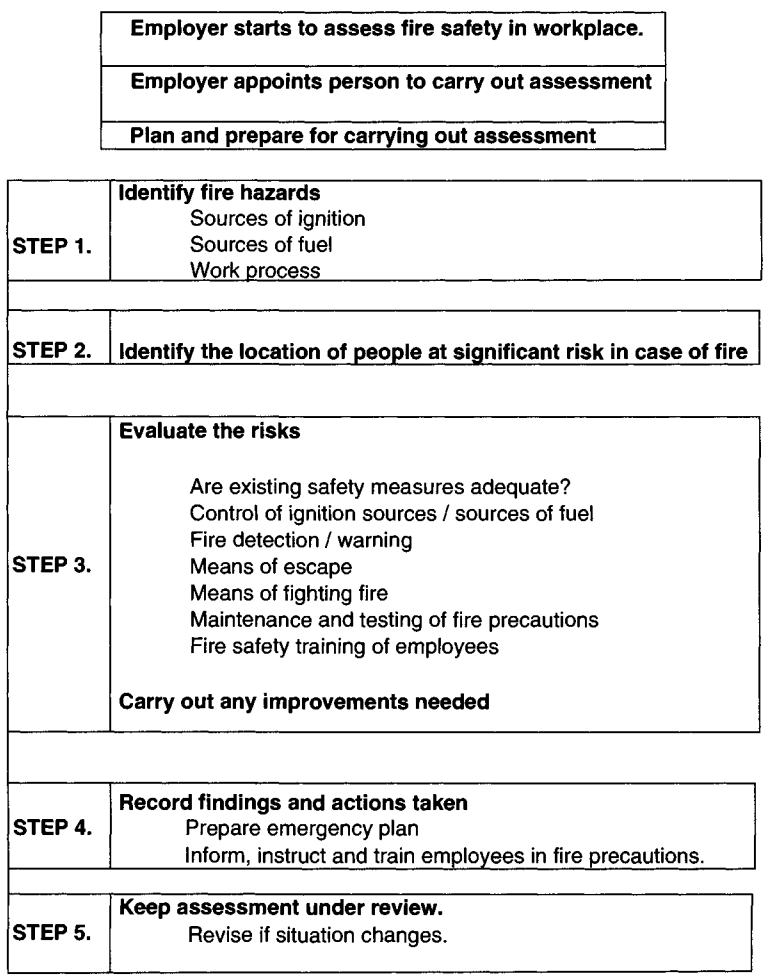


Figure 8.1 Flowchart of an action plan for a risk assessment

In any case you should now be talking to your local Fire Authority and they should advise you on your proposals. They should also advise you of other legislative approvals that may be necessary. Likewise if building alterations are being considered then the appropriate authority should also be brought into the discussions.

Having now looked at the practical approach where else does one have to go to comply with requirements?

One avenue, which tends to be forgotten under these circumstances, is your insurance company. In all probability you will be covered for alterations to your operating procedures and fire precautions, but it is always wise to report your proposed modifications to them before carrying them out, as there may be some clause within the small print which can cause problems at a later date, should a claim be envisaged. Your broker will probably advise on these matters.

8.6 How does a fire start?

In order for a fire to commence it is essential that certain ingredients are present, namely:

A Source of ignition
A Fuel
Oxygen

Without any one of these then it is not possible for combustion to commence, although spontaneous combustion could be classed as a source of ignition in a few rare cases.

8.6.1 What are the sources of ignition?

Hot surfaces
Static electricity
Electrical equipment
Naked flames
Smoking materials etc.
Spontaneous combustion (sometimes found in textile processing plants, dye houses or laundries).
Arson.

8.6.2 Where does the fuel come from?

These can be Liquid fuels
Gaseous fuels
Solid fuels.
Gaseous fuels are obvious but solid fuels can be any materials that will combust.

8.6.3 Where does the oxygen come from?

Oxygen is always present in the air so can be available in abundance anywhere air is present.
Additional sources can come from oxidizing substances.

Having started, a fire can spread very quickly by travelling from one source of fuel to another. As the fire travels so does the heat increase and in due course further fuels or materials can be self ignited, still providing that there is oxygen present.

8.6.4 Where do the sources of ignition come from?

Smoking materials, cigarettes, matches.
Naked flames.
Electrical, gas or oil fired heaters, both fixed or portable.
Hot processes such as welding, grinding, soldering, flame cutting.
Cooking, domestic and industrial.
Engines, exhausts, boilers, hot pipes, steam pipes.
Machinery, portable and static.

Faulty and misused electrical equipment.
Some new high temperature lamps – halogens.
Hot surfaces.
Blocked ducts producing overheating of motors etc.
Overloaded machinery.
Incorrectly installed electrical wiring.
Misused time switches.

Office equipment left running under certain circumstances.
Friction heat from poorly maintained bearings.
Ventilation systems not regularly maintained.
Static electricity.
Metal impact operations.
Deliberately fired, arson.

There are sometimes tell-tale signs of near combustion – scorch marks on materials like furniture, office equipment, cigarette burns on wooden surfaces, damaged or discoloured electrical plugs, splash splatter on socket outlets. These signs should never be ignored as they give an indication that a fire could have started given the right circumstances.

8.6.5 What about the fuels and their sources?

Wood
Flammable chemicals
Paper and cardboard,
Packaging materials
Flammable chemicals, of which: liquid based products such as paints, varnishes, thinners, some paint removers, adhesives etc.
Flammable solvents: petrol, paraffin, methylated spirits, white spirit etc.
Plastics, rubbers, some foams, polyurethane, polystyrene, and in particular some foams that have been used within the furniture upholstery business and now banned.
Flammable gases such as Liquefied petroleum gas (LPG), acetylene.
Packaging materials
Dust, paper, waste materials, sawdust, wooden shavings, textile materials, all wooden objects.
The construction materials of the building if not suitably protected or selected.
Building linings, hardboards, some ceiling materials, some block-boards, polystyrene ceiling tiles.

The misuse of any of these materials is risking eventual problems and the occupier should seek advice on their use

before installation or storage, so that the risk of fire can be considerably reduced.

8.6.6 We have the fuels, the ignition, where does the oxygen come from?

The main supply of oxygen comes from the air, usually in abundance.

If you are dealing with an inside area in a building then the ventilation system is probably providing sufficient quantities, although open doors, windows, other openings etc. provide the remainder.

If extract ventilation is only in use this can assist in bringing in air but could reduce the quantity somewhat if there are restrictions on inlet areas. It can also assist in drawing the fire in a particular direction along the air flow passage.

Some chemicals, which may oxidise, can provide a fire with additional oxygen and so assist with the burning operation. These materials should have suitable identification on the labels of the container or tin. You should seek advice on the correct method and conditions of storage.

Oxygen can also be supplied direct into a fire by hoses attached to oxygen cylinders associated with gas welding sets, or even piped systems depending upon the size of the welding operations being carried out.

Health care rooms may also have an oxygen supply installed, this is, of course, more than obvious in the hospital situation.

8.7 What should happen if a fire starts? who can be harmed?

The greatest danger in a plant is the speed at which a fire can spread and the amount of heat and smoke generated becomes the main hazard. A plant should have the proper means of fire detection that a fire has started and that adequate warning is given to all personnel within the building, and having given them the warning that they can escape safely. Having assessed the warning system you should concentrate attention to the fire itself.

What are the chances of a fire starting and what can you do to reduce the risk of it actually happening or can you reduce the possible source of ignition or reduce the possible fuel for a fire. Look at the fire precautions you propose and decide whether they are sufficient for the risks you have identified and are you satisfied that escape systems are adequate.

Are the escape systems in order and are the means to deal with a small fire in position, to enable personnel to deal with such a fire safely (always providing that this is safe to attempt without risk).

8.8 How does a fire spread?

As a fire develops it is essential to appreciate what happens in a fire and what sort of patterns it normally follows.

In the open a bonfire gives you warning to stand back as it gets hotter because the radiant heat forces you away gradually as it gets bigger and the fire grows. If the wind blows the smoke towards you it is easy for you to move away to the windward side so as to avoid being choked by the smoke. It is usually quite easy to move away to safety usually without very much difficulty.

Fires within an enclosed space such as a building behave very differently to those in the open air. The smoke rises and gets trapped by the ceiling or roof and then spreads over an area and gradually gets deeper and will also escape through holes in the ceiling, walls and doors and eventually into other parts of the plant.

The heat also gets trapped in the building and gets even hotter, and as the temperature goes up it helps the smoke to rise as well.

There is also the added danger that the smoke will contain toxic gases and therefore people are at greater risk from a fire, which is enclosed within a building. Hence the reason for good means of escape, good fire detection and a good evacuation procedure. The warning system must be capable of being put into operation to enable the Means of Escape routes to be used before the fire takes a real hold. As a rough guide the target should be to make certain that a fire will be detected and warning given within 2 minutes of it starting in order to enable adequate evacuation. However, where highly flammable materials are concerned detection should be made, and warnings given, within seconds rather than minutes in view of the impending dangers.

Where are there areas needing particular attention?

- Isolated and unoccupied areas where there could be a delay in detecting a fire.
- Areas where a warning system may go unnoticed
- Areas where people may be unable to react quickly.

8.9 Reducing sources of ignition

Removing unnecessary sources of heat from the workplace or replacing them by safer alternatives, ensuring that sources of heat-producing equipment is used in accordance with the manufacturer's instructions and maintained to their standard requirements.

Selecting and installing equipment which has been designed to minimise the risk of fire or explosion.

Replacing naked flames and radiant heaters with fixed convector heaters or fixed central heating systems.

Ensuring that all electrical fuses and circuit breakers etc. are of the correct rating and suitable for the purpose for which they are being used.

Ensuring that sources of heat do not arise from faulty or overloaded electrical or mechanical equipment such as overheating bearings.

Keeping ducts and flues clean.

You should operate a 'permit to work' system for maintenance workers and contractors who carry out 'hot work' involving processes such as welding or flame cutting.

Operating a safe smoking policy in designated smoking areas and prohibiting smoking elsewhere.

Enforcing the prohibition of matches and lighter and other sources of ignition in high fire-risk areas.

Ensuring that all equipment that could provide a source of ignition, even when not in use, is left in a safe condition.

Making sure that any smouldering material, including smoking materials, is properly extinguished before leaving the workplace.

Taking precautions to avoid the risk of arson.

8.10 Minimizing the potential fuel for a fire

There are various ways that can reduce the risks caused by materials and substances, which burn. These include:

Removing flammable materials and substances or reducing them to the minimum required for the operation of the business.
Replacing materials and substances with less flammable alternatives.
Ensuring flammable materials, liquids, and vapours and gases are handled, transported, stored and used properly.
Ensuring adequate separation distances between flammable materials.
Storing highly flammable substances in fire-resisting stores and, where necessary, keeping a minimum quantity in fire-resisting cabinets in the workplace.
Removing, covering or treating large areas of flammable wall and ceiling linings to reduce the rate of flame spread across the surface.
Replacing or repairing furniture with damaged upholstery where the foam filling is exposed.
Ensuring that flammable waste materials and rubbish are not allowed to build up and are carefully stored until properly disposed of.
Taking action to avoid storage being vulnerable to arson or vandalism.
Ensuring good housekeeping.
Improving the fire-resistance of the construction of the workplace.

8.11 Reducing sources of oxygen

The oxygen supply to a potential fire risk can be reduced by:

Closing all doors, windows and other openings, not required for ventilation especially during non-working hours.
Shutting down ventilation plant when not required.
By not storing oxidizing materials near or with any heat source or flammable materials.
Controlling the use or storage of oxygen cylinders, ensuring that they do not leak, are not used for non-official purposes and that they are located in adequately ventilated spaces.

8.12 Provide detection and warning system

Consult approved fire alarm suppliers for proposals and suggested systems.

The degree of detection and warning will depend on the type of building, as a single storey open plan building is an easier project than a multi-storey building having a considerable number of workers employed within.

Suitable detection systems may also be incorporated with automatic fire fighting systems especially in areas of high flammability.

The minimum warning system is likely to be a manually operated 'push-button' system, but this will only be adequate depending upon the prevailing conditions within the area concerned.

Domestically, over recent years, there has been a tendency to try and educate individual home dwellers to have simple fire alarm systems fitted, even primitive battery operated systems, but still people have been reluctant for this to happen, and where it has, keeping the maintenance of these has been neglected, where only the changing of a simple battery has been all that is necessary. Even this simple system has been neglected and lives have been lost.

Commercially or industrially, it is essential, that any system must be easily maintained, fully operational at all times and foolproof, as vast losses of business or even lives can result in a failure. The system must be regularly maintained on a planned system and tested at regular intervals combined with a personnel evacuation exercise, with records being kept of all occurrences. Routine checking to allow the working personnel, within the plant, to become familiar with the routines and evacuation routes and assembly points.

8.13 Means of escape in case of fire

When a fire has been detected and the appropriate warning signal given it is essential that all personnel within the area and in adjacent areas should be able to evacuate the workplace without being under any risk or danger.

Where a fire occurs within a building most 'loss of life' is usually brought about by the inhalation of smoke. Likewise where smoke is concerned people are usually unwilling to travel through even two or three metres of smoke in order to make their escape.

It is therefore important, to make sure that, in the event of a fire in one part of a building, people in another part of the building, can use an escape route to get out safely without being exposed to smoke or gases from the fire area.

It is therefore important, when making an assessment of the 'Means of Escape' you should look to see that they can escape from their working area safely without the chance of being cut off and exposed to any risk.

In small, single storey buildings, where routes of escape may be short, an escape may probably be executed within a few seconds rather than minutes. It is therefore always possible that the normally fitted doorways may be quite adequate to act as the 'means of escape'. However, in larger and more complicated buildings, where travel distances may be greater and where it is always possible that the normal route may be blocked by the fire or smoke, that it will probably be necessary for alternative routes always to be provided.

In most cases where the 'Means of Escape' has recently been approved under the building regulations, a fire certificate or licence, the existing arrangements will probably suffice. If your risk assessment suggests that changes may be necessary your proposals should be checked out with the appropriate authority before putting into being.

8.14 Escape checklist

- How long will it take for everybody to escape from the workroom following warning that a fire has been detected?
- Is it a reasonable length of time or is it too long?
- Are there sufficient exits and are they in the correct locations?
- Are the type and size of the exits of the right size to be able to cope with the escape of the numbers involved?
- In the event of a fire will all the exits be available, and will there always be at least one available?
- Are all the routes easily identified, free from any obstructions, illuminated adequately?
- Has your staff been suitably trained in the escape procedures and the using of the Means of Escape?
- Have you provided written instructions for your workforce in the use of the means of escape?
- Has your 'Means of Escape' procedures been included in your emergency plans?
- Do you always inform contractors working on the site of your systems?

8.15 Fire fighting

We have so far considered the risks and the 'Means of Escape' but what happens when a fire occurs – who puts it out and with what?

You should provide sufficient fire fighting equipment spread throughout the plant and in the right places to allow employees easy access to them to tackle a fire in its early stages, should it be within their scope and without danger to themselves,

The equipment that you provide must be suitable to the risks involved and the staff will need to be trained in the use of whatever is installed.

If the premises are small then a number of portable extinguishers suitably placed may be all that is necessary.

In larger and more complicated premises with specific processes may require a more elaborate set of equipment commensurate with the risks involved. But whatever equipment is installed it is still necessary for the operation procedures to be taught to those who are likely to be involved in attempting to extinguish a fire. It may be necessary for specific equipment to be used for specific risks, and identification of the correct equipment for the particular type of fire is essential, as incorrect equipment used on a fire may add to the problem and increase the risk.

8.15.1 Checklist for fire fighting equipment

- Are your extinguishers suitable for the purpose and of sufficient capacity?
- Are there sufficient extinguishers sited throughout the plant?
- Are the types of extinguishers located close to the fire hazards and can users gain easy access to them without exposing themselves to risk?
- Are the locations of the extinguishers easily visible or have notices to be provided indicating where they are?
- Have the people likely to use the equipment been instructed and trained on the equipment being provided.
- Has the fire-fighting equipment been included within the emergency plan?

8.16 Maintenance and testing of fire-fighting equipment and systems

It is essential that all fire-fighting equipment is subjected to routine maintenance and testing. This can be carried out by a nominated person within your organization or can be sub-contracted to some form of external agent or supplier.

This routine maintenance should cover:

All fixtures and fittings such as fire doors (especially those self-closing on fire alarm), staircases, corridors, fire detection and alarm equipment, fire-fighting notices and emergency lighting.

It is essential that regular checks, periodic servicing and maintenance whatever the size of the establishment. Any defects should be rectified as soon as possible and the rectification recorded appropriately.

All fire-fighting equipment, installed alarm and signal systems, emergency lighting etc. should be included.

An up to date record must be established so as to demonstrate that all the equipment has been maintained, actions have been taken where necessary, and that the company has demonstrated compliance with any statutory requirements that may be relevant.

8.16.1 Checklist

- Do you regularly check fire doors and escape routes and associated lighting and signs?
- Do you regularly check all your fire-fighting equipment?
- Do you regularly check your fire detection and alarm equipment?
- Do you regularly check any other equipment provided to help means of escape arrangements in the building?
- Are there instructions for relevant employees about testing of equipment?
- Are those who test and maintain the equipment properly trained to do so?

8.17 Fire training and operating procedures

In the event of a fire starting it is important that your employees know what to do. You therefore have to have an emergency plan in place and your employees must have been trained adequately in them. The procedures must also be regularly reviewed and tested and brought up to date as required.

MAINTENANCE OF FIRE PRECAUTIONS

Equipment	Period	Action
Fire detection and fire warning systems including self-contained smoke alarms and manually operated devices	Weekly	Check all systems for state of repair and operation. Repair or replace defective units Test operation of systems self-contained alarms and manually operated devices.
	Annually	Full check of systems by competent service engineer. Clean self-contained smoke alarms and change batteries.
Emergency lighting equipment including self-contained units and torches.	Weekly	Operate torches and replace batteries as required Repair or replace defective unit.
	Monthly	Check all systems, units and torches for state of repair and apparent working order.
	Annually	Full check and test of systems and units by competent service engineer replace batteries in torches.
Fire fighting equipment including hose reels.	Weekly	Check all extinguishers including hose reels for correct installation and correct working order
	Annually	Full check and test by competent service engineer.

The above actions can be carried out by the user.
Manufacturers may recommend alternative or additional actions. Further, more detailed information can be found in the relevant British Standards, or other recommended publications.

Figure 8.2 Maintenance of fire procedures – schedule

In small premises these may be fairly simple but in the more extensive buildings or plants they may be far more extensive. In all cases the emergency plan will need to take into account all the people that are likely to be on the premises at any time, the problems occur in the case of shops where the staff may be few but the customers may be a far larger number.

If you have a fire certificate you will probably have certain requirements imposed on you, by the certifying body detailing your training and your procedures. You are therefore bound to comply with these directions.

18.17.1 Training checklist

- Do you have an emergency plan?
- Does the emergency plan take into consideration all reasonable foreseeable circumstances?
- Are your employees fully familiar with the plan, trained in its use and involved in testing it?
- Is the emergency plan available to all who may need to be aware of it?
- Are the procedures to be followed clearly indicated throughout the workplace?

- Have you considered all the people who are likely to be involved within the workplace as well as others who may have a share of the building?

8.18 Making provision for disabled people

You should make provision for disabled persons and those that require special needs who may be present at any time on the premises not forgetting the possibility of visitors. Disability does not only mean lack of mobility but covers those suffering with loss of hearing, sight or some other ailment.

Further information covering the arrangements for the disabled can be obtained, developed by consultation with disabled people, or by consulting British Standard 5588 (Part 8 gives further guidance and provides further information).

In the UK the current legislation does not directly call for specific requirements regarding means of escape. However, the 'Disability Discrimination Act 1995' requires employers to make 'reasonable adjustments' to their premises to ensure that no employee is at a disadvantage. This includes ensuring that disabled people can leave the premises safely in the event of fire occurring.

This means that as an employer you are obligated to take the appropriate steps to follow this directive. So you must take into consideration their requirements during the planning of your plant and when putting together your escape and emergency plans and evacuation procedures.

You should at the same time consider those of a less able bodied nature who may at sometime or other have access to your premises.

8.19 Management considerations

Fire precautions can be improved by good household management.

- Ensuring good housekeeping
- Ensuring escape routes are kept free and clear at all times.
- Ensuring that suitable security measures are taken to reduce the chance of vandalism or arson.
- Ensuring that all your fire systems at checked at regular periods.

8.20 Housekeeping

- Keep all passageways clear and more especially the 'Means of Escape' routes.
- Do not store anything in a passageway even if it only a temporary measure.
- Make certain that materials or any trucks, however small, are not allowed to be parked in or obstructing passageways.
- Make certain that flammable materials are not stored in cupboard or small rooms, but make certain they are confined to the special facilities that you have provided.
- Do not allow waste materials, cleaning materials, rubbish, boxes, or other items that could provide fuel for a fire. Provide suitable containers for such items and make certain that they are used.
- Educate the personnel in keeping and maintaining clear all escape routes.

8.21 Security

Vandalism and Arson should come under the heading covered by security and include them as part of your 'Risk Assessment' especially as it is an area that can be adequately catered for.

You may consider that you can trust your staff implicitly, but can you trust intruders?

Install a security system that will prevent unauthorized persons gaining access to the plant to possibly cause acts of vandalism or arson.

Make certain that outside the buildings are kept clear of waste or flammable materials that may encourage vandalism or arson, which could put your workforce at risk of fire.

The majority of deliberately started fires occur in areas with known history of vandalism and fire setting. Typically local youths light fires outside factories as acts of vandalism, using flammable materials found adjacent. If the plant takes care of avoiding these materials being available then the main part of the risk is removed and the vandalism avoided. It is therefore advisable to make certain that there are suitable enclosed containers, tanks or bins provided to house these surplus materials to remove the possibilities of encouraging these wrong-doings.

You may also wish to take advantage of talking to the local police or fire authority or consulting the Arson Prevention Bureau who will advise on what measures you should take for various types of building.

Arson attacks or acts of vandalism can sometimes be traced to disgruntled employees who may bear a grudge against the firm possibly following some form of management decision which may have gone against them or following dismissal or reprimand.

Suspicion may be raised if a company finds a number of insignificant fires occurring which may be an advance warning of something more extensive to come.

Depending on the size of the establishment or the nature of the manufacturing or process being carried on within the company, will dictate how important a part the security system, if employed, will have to be.

Do you rely on a security-manned gate or automated access possibly monitored from an office, using a variety of communication systems such as Closed Circuit Security Cameras, automated gates etc. The importance will determine the level chosen.

Out of hours security will also have to be considered. There are a number of systems available, from a full on-site guard to routine regular site visits from a guard firm, or camera-controlled patrol (off-site monitored by a security firm). Dummy cameras suitably positioned. The local police will probably assist in helping you make your decision as they are more likely to have knowledge of the locality and the crime levels.

8.22 Fire safety checks

Most safety checks which you will carry out for the premises will also help in their protection whilst the plant is not occupied.

- Make certain that all windows are closed.
- That all electrical equipment that is not being used is isolated or turned off.
- Smoking materials are correctly extinguished and not left smouldering.
- All naked flames are extinguished or at least left in a safe condition.
- All flammable rubbish and waste is removed to a safe place and kept in suitably designed container.
- That all highly flammable materials are safely stored.
- The workplace is secured against unauthorised entry.

8.23 Plant emergency plan

You must plan the actions that the employees and others in the workplace have to take in the event of a fire. If more than five people are employed then you must have a written 'Emergency Plan'. The Emergency Plan must be kept in the workplace, be available for all the workforce and the employee's representatives (where appointed) and form the basis of the training and instruction you provide. Any written plan should be available for inspection by the fire authority.

8.23.1 What is the purpose of your Emergency Plan?

- To ensure that the people in your workplace know what to do in case there is a fire.

FIRE RISK ASSESSMENT RECORDS.

To assist you in carrying out your Risk Assessment a suggested form for your deliberations is suggested:

Significant hazard	People / Groups who are at risk from the hazard	Existing controls and risks which are not adequately controlled	What further action is needed – By when ? – By whom ?

Figure 8.3 Simple Risk Assessment Record Form

The date of the training or drill	
Duration of training	
Fire drill evacuation times	
Name of person giving instruction	
Names of people receiving instruction	
The nature of the instruction or drill	
Any observations / remedial action	

Figure 8.4 Simple training record

- To ensure that the workplace can be safely and quickly evacuated.

When you compile your emergency plan you should be taking your Risk Assessment results into consideration as one will depend very much on the other.

In most cases it should be fairly easy to prepare a workable emergency plan, especially in a small plant, where it may be just a simple instruction notice outlining some very straightforward instructions on a notice called a FIRE ACTION NOTICE and suitably positioned.

Larger premises may need a little more complex plan, and may require more detailed information.

If you share the building with other organizations then the plan will have to be made in consultation will all the others involved as the plan must cater for all occupiers. Usually it will be more convenient to have a co-ordinator to ensure there is full co-operation between all concerned.

8.23.2 The emergency plan should cover

- The action employees should take if they discover a fire.
- How warning is given if there is a fire.
- How the evacuation should take place
- Where the workforce should assemble after leaving the workplace, and the method for checking to see that everybody has left the building.
- Identification of the escape routes and how people can gain access to them and escape to places of safety.
- The fire fighting equipment provided.
- The duties and identity of the employees who have specific responsibilities in the event of fire.
- Arrangement for the safe evacuation of people who are identified as being especially at risk, such as contractors, those with disabilities, members of the public and visitors.
- Where appropriate, any machines, processes or power supplies, which need to be stopped or isolated in the event of a fire.
- Special arrangements, if necessary, for high fire-risk areas of the workplace,
- How the fire fighting forces and any other emergency services will be called and who will be responsible for doing this.
- Procedures for liasing with the fire fighting service on arrival and notifying them of any special risks, e.g. the location of highly flammable materials.
- What training employees need and the arrangements for ensuring that this training is given.

It may be helpful or even necessary, in some cases, to provide a simple drawing focusing attention on the various areas requiring special attention and the escape routes.

In detail the drawing should show:

- Layout of the plant and escape routes.
- Doorways, walls, partitions, corridors, stairways etc. (Fire resisting structures and self-closing doors provided to protect the means of escape routes).
- Means for fighting a fire (details of numbers, type and location of the fire-fighting equipment).
- The location of any manually operated fire alarm call points and control equipment for fire alarm.
- The location of any emergency lighting equipment and any exit route signs.
- The location of any automatic fire-fighting system and sprinkler control valves.
- The location of the main electrical supply switch, the main water shut-off valve, and where appropriate, the main gas or oil shut-off valves.

8.24 Training the employees

The following is a suggested series of points that should form the basis of a training programme for the personnel:

- The action to be taken when discovering a fire.
- How to raise the alarm and what to do next.
- The actions to be taken on hearing the alarm.
- The actions for alerting members of the public or visitors, including where appropriate, directing them to the exits.
- The arrangement for calling the fire brigade.
- The evacuation procedures for everyone in the workplace to reach an assembly point at a safe place.
- The location and, when appropriate, the use of the fire fighting equipment.
- The location of the escape routes especially those not in regular use.
- How to open all the escape doors, including the use of any emergency fastenings.
- The importance of keeping the fire doors closed to prevent the spread of fire, heat and smoke.
- Where appropriate, how to stop machines and processes and isolate power supplies in the event of fire.
- The reason for not using lifts (except those specifically installed or adapted or installed for the evacuation of disabled people.
- The importance of general fire safety and good housekeeping.

8.24.1 Possible additional training

Having given training on the general points of safety it is also essential that specific training should cover areas where higher risks are involved.

- Standards and work practices for safe operation of plant and equipment and safe handling of flammable materials (especially flammable liquids).
- Housekeeping in process areas.
- Reporting of faults and incidents, including leaks and spills of flammable liquids.
- Emergency procedures for plant or processes in the event of fire, spills or leaks.
- Relevant legal requirements depending on the materials or processes in use.

(Further information can be obtained on training in the Approved Code of Practice to the Management of Health and Safety At Work Regulations, 1992).

8.25 Maintenance of plant and equipment

- Poorly maintained plant and equipment can lead to hazardous situations occurring and could possibly lead to a situation where it could contribute to a fire being started.
- Blocking of ducts or passages for ventilation air and overloaded filtration equipment in ventilation systems or situated within operating plant, are situations which can lead to overheating and hence could contribute towards a fire outbreak.
- Overheated bearings, incorrectly adjusted belts or poor adjustments can all be contributors towards a fire starting.
- The malfunctioning of electrical equipment, which could be caused by incorrect fuses or other incorrectly adjusted safety devices or overloading and hence overheating etc.
- The use of flammable materials being used on or adjacent to hot or overheated surfaces.
- Uncorrected leaking valves, flanges or pipework, which allow flammable materials, liquids or gases to discharge, can all lead to potentially dangerous situations.
- Lack of correct earthing devices or the discharge of static electricity are all possible ignition points for starting a fire.
- Apart from the obvious possible causes of a fire starting, a plant should always have some form of Planned Maintenance system in place, and what is even more important is that the system takes everything into consideration and that the system is correctly operated and fully supervized.

A system must be effective and any problems rectified, recorded and used for the benefit of updating the system and feeding back detected shortcomings.

8.26 Storage and use of flammable materials

Plants in which large quantities of flammable materials are either displayed, used or stored will usually present a greater hazard than those where the amounts are kept small.

- Quantities of flammable materials should be reduced to the smallest amount necessary for carrying out the process or for running the business and should be kept away from the escape routes.
- Flammable materials should be replaced by less flammable materials, where possible.
- Excess flammable materials should be taken outside and stored in an appropriately designed storage place, receptacle, or building. Alternatively in a suitable space separated from the workplace by an appropriate fireproof construction.
- You should make certain that all personnel who have access to or who work with hazardous materials are adequately trained in the handling and use of such materials as well as the dangers and actions required in the case of an emergency.
- Stores of a combustible nature should not be kept in the same area as flammable materials.
- One area of possible exposure can come from storing small quantities of cleaning materials used within an office block, or for use with office equipment such as some solvents supplied with or for printing equipment (photocopiers, computer printers, keyboards etc).

Flammable liquids can present a significant risk of fire. Vapours associated with flammable liquids are usually heavier than air and can travel long distances, so are much more likely to find a source of ignition.

Liquid leaks and evolution of vapours can be caused by faulty storage (both bulk and containers) plant and process design, installation, maintenance and use.

There is always a possibility that ignition can occur until such time that the vapours are sufficiently dissipated by air and no longer will support combustion.

Each flammable material has its own problems and recommended methods of storage and use. It is up to the user or proposed user, designer or whoever may be involved with the eventual use, to seek information from the suppliers, or from the codes of practice associated with those materials and most importantly with the fire authority concerned.

If you are storing or using flammable liquids on your premises it is important that the local fire brigade are fully acquainted with your plant and where and what you are using, so that they can be fully aware of the problems should a fire occur.

You can also gain information on the storage of flammable liquids through the Health and Safety Executive guidance documents.

Care should also be taken where a number of flammable or explosive materials and liquids are in use and you should be aware that sometimes mixtures can produce very potent or unstable gasses, which may have disastrous effects on personnel.

You should also be aware that accidents do occur and the obvious mixing may not necessarily happen, there may be other mixtures that can take place.

8.27 Storage of flammable liquids

- The quantity of flammable liquids in workrooms should be kept to an absolute minimum, possibly no more than half a day's or half a shift supply.
- Flammable liquids, including empty or part empty containers should be stored safely. Up to 50 litres of highly flammable liquids can be stored in the workroom if in closed containers, metal cabinets or that are designed to contain leaks within.
- Quantities greater than 50 litres should be stored in a properly designed store, either in the open air, or well ventilated, impervious ground, away from ignition sources, or in a suitably constructed storeroom.
- Where large quantities of a flammable liquid are used, they should be conveyed by means of a properly designed closed piped system. Where a connection, in

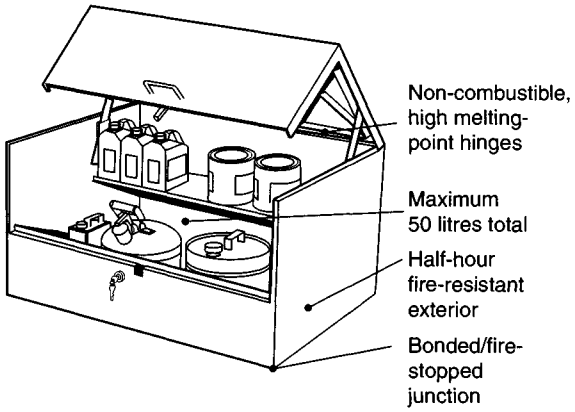


Figure 8.5 Storage container inside a building or workroom

such a system is frequently uncoupled and remade, a sealed end coupling device, should be fitted and used.

- Flammable liquids should not be dispensed within the store. Dispensing should take place in a well-ventilated space set aside for this purpose, with appropriate facilities to contain and clear up any spillage.
- Container lids should always be replaced after use, and a container should not be opened in such a way that it cannot be closed and be safely resealed.
- Flammable liquids should always be handled in well-ventilated spaces and where necessary a proper ventilation system should be employed to reduce the concentration of vapour in the air.
- Storage containers should be kept covered and proprietary safety containers, with self-closing lids, should be used for dispensing and applying small quantities of flammable liquids.

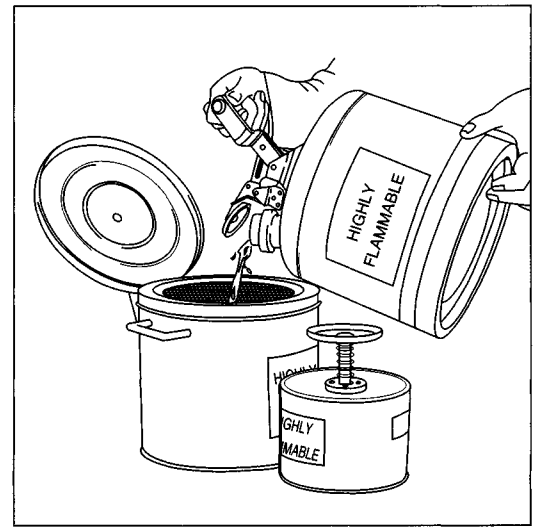


Figure 8.7 Example of special purpose containers for flammable liquids

- Rags or cloth that have been used to wipe up or apply flammable liquids should be disposed of in metal containers with well fitted lids and removed from the workplace at the end of each shift or at the end of the working day.
- There should be no potential ignition sources in areas where flammable liquids are used or stored as flammable concentrations of vapour may be present at any time.
- Any electrical equipment, including lights and fire alarm systems etc, used in this area, need to be suitable for use in flammable atmospheres.

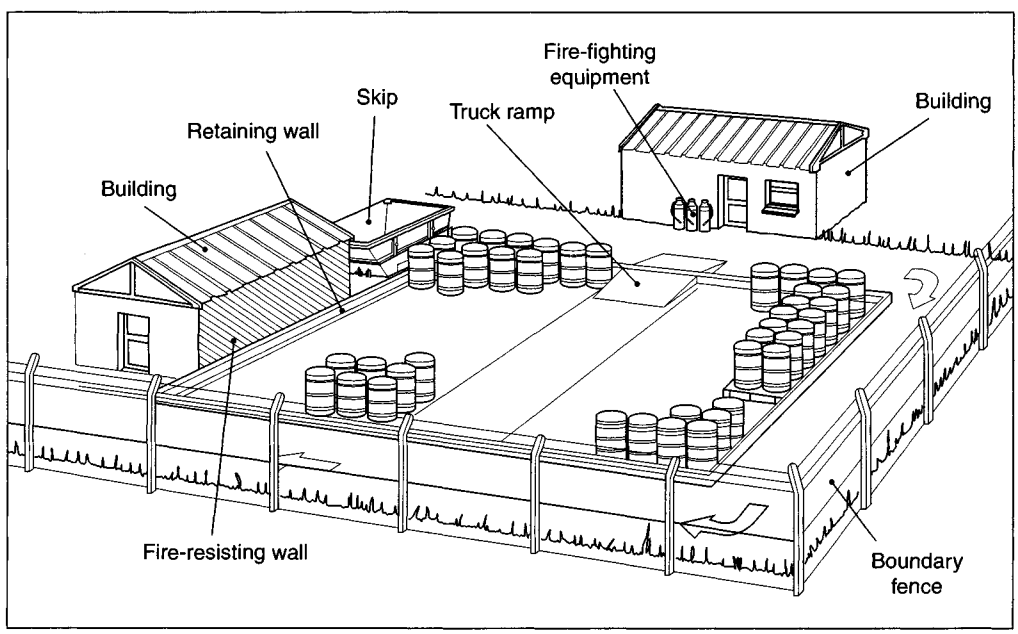


Figure 8.6 A well laid-out external storage area

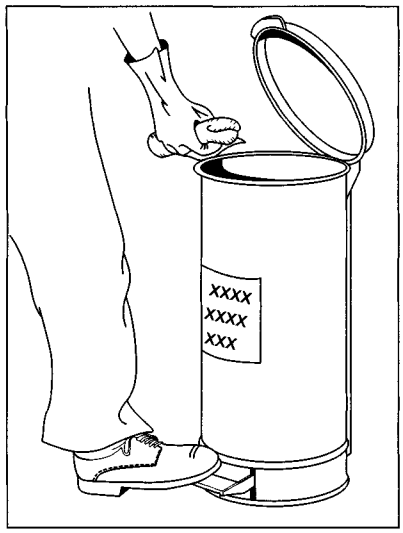


Figure 8.8 Example of metal container for cloths contaminated with flammable solvents

- It is extremely important that having taken all the various precautions to operate and control your flammable liquids that you continue to have control of the disposal of the residues and your impregnated cloths. This can be done by making use of one of the approved disposal contractors who can deal with this problem adequately.

8.28 Hot working activities in areas near flammable liquids

Working with equipment such as welding, flame cutting, use of blow torches or using grinding equipment can lead to providing the ignition necessary to start a fire and therefore special care must be employed in doing so.

Obviously it is an ideal situation for employing the system of: *'Permit to Work'* whether it is for your own personnel or for contractors brought onto your premises to carry out work on a contract basis.

A permit to work is appropriate in situations of high hazard/risk and, for example, where there is a need for the following:

- To ensure there is a formal check confirming that there is a safe system of work is to be followed.
- Co-ordinate with other people or services or activities.
- Provide time limits when it is safe to carry out work.
- The provision of specialized personal protective equipment such as breathing apparatus or special methods of communication.
- Isolation of some special services, such as electricity supplies etc.

When a 'Permit to Work' is issued it is imperative that the person issuing it explains what is involved and that is recorded and the person receiving it also signs it.

The appropriate protection required to go with a particular permit will depend entirely upon the work to be carried out and the location.

8.29 Electrical equipment

One of the main causes of fire can be put down to electrical equipment, or to be more precise, the failure of electrical equipment.

What are some of the problems?

Overheating of electrical cables and electrical equipment due to overloading.

- Damaged or inadequate electrical insulation on cables or wiring.
- Flammable materials being placed too close to electrical equipment which may give off heat when operating normally or become hot due to a fault.
- The use of inappropriate or unsafe electrical equipment in areas where flammable atmospheres might be present, such as flammable liquid stores.
- Arcing or sparking by electrical equipment.
- All electrical installations must comply with the regulations laid down according to the latest edition of the Electrical Regulations issued by the Institution of Electrical Engineers.
- There are also a number of British Standards governing the use and installation of electrical equipment which should be consulted and complied with as appropriate. British Standard 7671 also offers practical advice on systems operating at up to 1000 volts. (See reference section).
- Only suitably trained/qualified persons should be allowed to install, maintain or otherwise work on electrical systems or equipment.
- Further specific guidance on the use of electrical equipment and systems is given in the Health & Safety Executive's Memorandum of Guidance on the Electricity at Work Regulations, 1989 (See reference section).

8.30 Heating appliances

You should make certain that all individual heating appliances, particularly those, which are portable, are used safely, as some common causes of fires include:

- Failure to follow the manufacturer's instructions when using or changing gas cylinders associated with the use of Liquefied Petroleum Gas (LPG).
- Placing materials on the top of heating appliances.
- Locating portable heaters too close to flammable materials, or likewise placing the flammable materials too close to the heating device.
- Careless filling of heaters using flammable materials, such as paraffin or kerosene.
- Special care should be taken in the use of heating equipment during temporary situations such as: extra cold weather, failure of existing heating or at some other time when the use of portable heaters are required on an emergency basis when standing rules tend to get overlooked for whatever reason.

8.31 Smoking and the provision for smokers

- Experience has shown that it is probably better to provide smoking areas and adequate means for the disposal

of smoking materials than to have a situation where the personnel tend to smoke in unauthorised places where the possibility of risks of fire are considerably increased.
- Make certain that metal trays are provided in areas set aside for smoking and that the containers are emptied regularly especially at the end of a day or shift so that 'risks' are more controlled.

8.32 Building and maintenance work

Many serious fires tend to start during times that maintenance work is being carried out or whilst building works are in operation. This type of activity can increase the chance of fire occurring and therefore, during these activities, extra caution may be necessary and carefully controlled and monitored. Extra fire precautions may be necessary.

Depending upon the nature and the extent of the work being carried out it may be necessary to carry out a special 'Risk Assessment' for that one project, especially if the works could be extensive. So that all the hazards created by the work are identified and plans put into place to control the risks. Particular attention should be directed to:

- Accumulation of rubbish, flammable waste and building materials.
- The loss or obstruction of some of the exits due to the works being carried out, possibly only of a temporary nature.
- Fire doors being wedged open.
- Additional openings being created in fire-resisting partitions.
- The introduction of additional electrical equipment or other sources which could be sources of ignition.

To overcome these possible problems:

- Check the escape routes at the beginning of the working day. Make certain that these routes are and will be available all day whilst working is in progress.
- Make certain that all fire systems and safety equipment is always available.
- At the end of the day the site should again be checked to make certain that all risks have been removed.
- Check that all flammable adhesives and cleaning materials, have been securely dealt with following use and stored in the correct fashion etc.
- That rooms that have been used for flammable materials have been adequately ventilated etc. and free from gas and sources of ignition.
- That gas cylinders have been removed and stored correctly.
- That smoking is not allowed in the area where flammable materials and liquids are used.
- In areas where automatic fire alarm and detection systems are fitted these should be checked for correct operation and that they cannot be inadvertently set-off giving rise to a false alarm – a hazard which does go with building works.
- If an alarm system has been deactivated during the project work, it should be tested and made operational so that cover is maintained during non-working hours.
- Special care must be taken when restoring gas or electrical supplies so that no risks are taken and that any chance of a fire starting are avoided.

8.33 Fire detection and fire warning

It is difficult to differentiate between detection and fire warning, as the two are so closely linked or at least they should be, as the result would probably have the same end result.

All workplaces and domestic premises should have some means of automatic alarm system installed, capable of giving warning that a fire has started.

During normal working hours fires are usually detected by the workforce observing or smelling smoke or seeing a fire.

You should give consideration to the following:

- Fitting fire detection sensors.
- The term fire detection also covers smoke detection. Including air density as well as air temperature.
- Fitting an automatic sprinkler system (see chapter on sprinkler systems).
- Put into operation a regular test routine coupled with an evacuation operation and assembly point routine.
- Fit a manual fire alarm system so that personnel can alert the remainder of their colleagues that a fire has started and to start an evacuation operation.
- Consider coupling the alarm system to a device for calling the local fire brigade.
- In a building which is occupied by more than one employer any detection system must be linked to the adjacent premises so that the whole building will have the benefit of being notified that a fire has started, and will also be alerted to carry out a total evacuation.
- Adequate training of personnel on the procedures necessary following the sounding of an alarm system, including evacuation and assembly location.

8.34 Number and width of doorways

There should be enough exits, of adequate widths, from every room, storey or building. The adequacy of the escape routes and doors can be assessed on the basis that:

- A doorway of no less than 750 mm in width is suitable for up to 40 people per minute. (Where there is likely to be wheelchair access the width should be increased to 800 mm) As wheelchair access is now considered so important you should automatically go for the wider width initially with any new installation.
- A doorway of no less than 1 metre in width is suitable for up to 80 persons per minute. As a rule of thumb as the numbers increase so the width should go up by 75 mm per additional 15 people.
- When assessing door widths, it is advisable to always consider that widest door should not be considered available. This means that the remaining doorways

should be capable of providing a satisfactory means of escape for everyone present.

8.35 Corridors and passageways

Corridors and passageways should in general be at least 1 metre wide, although a wheelchair user will need 1.2 metres, so if starting from scratch then the wider width should be used.

Passage lengths should be tailored so that no passage is longer than, say, 30 metres, without the provision of automatic, close fitting, self-closing fire doors.

Lengths of corridors in factories and offices may be longer, say up to a maximum of 45 metres, although conditions in certain situations may vary these suggested widths and lengths.

8.36 Stairways

When designing the pitch and width of stairways they should be based against the number of people who are required to use them in an emergency situation.

As with the doorways one should assume, when deciding on widths, that the widest stairs are not available, so that the others are adequately sized and able to take everyone who is likely to be present.

Each stairway should be suitably protected by access through a protected lobby and preferably the whole stairway is protected by fire protection throughout the whole length, including self-closing fire doors and fire resistant materials throughout the full length.

Obviously these guidelines can vary based upon each individual situation and the premises and processes concerned, but in any case advice will be forthcoming from the local fire prevention officer whilst going through the design stages or whilst seeking advice when making provisional application for a means of escape in case of fire.

When making provision for external stairway fire escapes attention must be given to how close the stairway passes to window openings, which could provide a hazard if fire should break through those windows.

The base where the staircase alights onto a path or roadway, a suitable barrier should be provided so that the escaping personnel do not have the added hazard of being involved in a traffic accident or parked vehicles blocking their exit.

8.37 Items prohibited on an escape route

The following are suggested items that should not be allowed to become a potential hazard on an escape route:

- Portable heaters of any type.
- Heaters which have unprotected naked flames or radiant bars.
- Fixed heaters using a gas supply cylinder, where the cylinder is within the escape route.
- Oil fuelled heaters or boilers.
- Cooking appliances.
- Upholstered furniture.
- Coat racks.
- Temporary stored items including items in transit e.g. furniture, beds, laundry, waste bins etc.
- Lighting using naked flames.
- Gas boilers, pipes, meters or other fittings (except those permitted in the standards supporting the building regulations and installed in accordance with the 'Gas Safety Regulations'.
- Gaming or vending type machines.
- Electrical equipment (other than normal lighting, emergency escape lighting, fire alarm systems or equipment associated with a security system) e.g. photocopiers.

8.38 Fire fighting equipment

Portable fire fighting equipment in the form of fire extinguishers and small hoses allow suitably trained persons to tackle a fire at the very early stages, providing that they can do so without putting themselves in danger.

Every plant should be provided with adequate equipment.

When you are deciding on what to install it will depend on what materials are likely to be in the vicinity of the extinguishers and in what sort of quantities.

Fires are classified in accordance with British Standard EN 2 as follows:

CLASS A: Fires involving solid materials where combustion normally takes place with the formation of glowing embers.
CLASS B: Fires involving liquids or liquefiable solids.
CLASS C: Fires involving gases.
CLASS D: Fires involving metals.
CLASS F: Fires involving cooking oils or fats.

8.38.1 CLASS 'A' fires

These involve solid materials usually of organic matter such as wood, paper etc. They can be dealt with by using water, foam or multi-purpose powder extinguishers, with water and foam considered the most suitable. The risk assessment exercise will help indicate how many will be required.

8.38.2 CLASS 'B' fires

These involve liquids and liquefiable solids such as paints, oils, and fats. It would be appropriate to provide extinguishers of foam (including multi-purpose Aqueous Film Forming Foam (AFFF). Carbon dioxide, dry powder types. Carbon dioxide extinguishers are also suitable for a fire involving electrical equipment.

The fire extinguishers currently available for dealing with Class A & B fires should not be used on cooking oil or fat fires.

8.38.3 CLASS 'C' fires

Dry powder extinguishers may be used on Class C fires. You need to consider the circumstances for their use and combine this with action such as stopping the leak, to

remove the risk of a subsequent explosion from the build up of unburnt gas.

8.38.4 CLASS 'D' fires

None of the extinguishers referred to above will deal effectively with class D fires as these involve metals such as aluminium, manganese, sodium or potassium. Only specially trained personnel using special equipment should tackle such fires. If your assessment identifies the risk of a fire involving these metals, you should consult the local fire authority about the best way of dealing with them.

8.38.5 CLASS 'F' fires

Special extinguishers are available for use on fires involving cooking fats and oils (for example, chip pans and deep fryers), but these should only be used by specially trained people. (This is not an established class within the current British Standard but may be added as a new fire classification when the relevant standard is reviewed and revised. This class is specifically identified for ease of separation or specific identification).

8.39 Types of portable fire extinguishers

The contents of a portable fire extinguisher are usually expelled by using an internal pressure, which is either pressure permanently enclosed or by the use of a gas cartridge. There are basically five types of extinguisher based according to the extinguishing medium that they contain:

Water
Foam
Powder
Carbon dioxide
Vaporizing liquids, including halons.

Note: Halons will be banned from the end of 2003 for normal use, due to the fact that they have ozone-depleting potential.

It is somewhat difficult to make any direct recommendations for what fire fighting equipment to install for specific situations. There are a number of well known reputable manufacturers who have good technical advisory services, and the best course of action is to make contact with these companies to seek advice and to put forward a package quotation.

A proposed maintenance programme should accompany any extinguisher recommendation as the two are very much linked.

To avoid the monitoring of a maintenance programme in-house, it always seems appropriate that this sort of operation is better done on a contract basis, by a company who are fully conversant with fire fighting extinguisher maintenance.

Contracts of this nature will also give you the advantage of having available instant replacements or of recommendations that may occur due to changes in the location-based processes.

BRITISH Standard 5306 provides advice about the selection and allocation of portable fire extinguishers.

Fire Extinguishers should conform to a recognized standard such as **British Standard EN 3** for new ones and **BRITISH Standard 5423** for existing ones. For extra assurance look for British Standard Kitemark, The British Approvals for Fire Equipment (BAFE) or the Loss Prevention Council Certification Board (LPCB) mark.

8.39.1 Colour coding

Fire extinguishers may be colour coded to indicate their type. In the past extinguishers had their whole body colour coded to indicate their type, but since **January 1st 1997 British Standard EN 3.: Part 5**, brought about a change which requires that all new extinguisher bodies should be RED. A colour zone of up to 5% of the external area, positioned immediately above or within the section used to provide the operating instructions, may be used to indicate and identify the type of extinguisher. This colour coding should follow the ***British Standard No: 7863***, and the zone should be visible through an arc of 180 degrees when the extinguisher is correctly mounted.

Because of the lasting ability of fire extinguishers, which may be up to about 20 years there is always the possibility of having a mixture of types and colours displayed throughout the plant, although they should be kept apart, and in no way mixed, in the same location such as on the same floor. Hence it is important that suitable markings and instructions are always prominently displayed, adjacent to the equipment.

It is imperative that the older extinguishers ***'should not be repainted'*** to bring them into line with the latest coding, as certain technical changes were also incorporated with the colour changes, as they would then contravene ***British Standard EN 3.*** (Which brought in those technical changes).

It is advisable for extinguishers to be grouped together to form ***'a Fire Point'*** which should be clearly marked.

If for any reason the extinguishers are placed in positions hidden from direct view, the ***Health and Safety Regulations 1996 (Safety Signs & Signals)*** require that their regulations should be indicated by signs and where appropriate, directional arrows. Suitable signs are described in the Health & Safety Executive Guidance on the Regulations.

8.40 Installation, maintenance and testing of fire precautions and equipment

- Any control panels should show that all electrical fire detection and alarm systems are operating normally or ensuring that any faults indicated are recorded and dealt with.
- All emergency lighting systems that include signs are lit and any defects recorded and dealt with.
- That escape routes, including passageways, corridors, stairways and external routes are clear of obstruction, free of slipping or tripping hazards and available for use when the premises are occupied.

- That all fastenings on doors along escape the routes operate freely, so that they can be opened quickly in an emergency without delay.
- That all self closing doors and automatic door holders/releases work correctly and that each door closes correctly and completely, this should also include flexible edge seals so that a smoke-free trap can be established when the doors close.
- That all fire extinguishers are in position, and that they have not been discharged and at the correct pressure and that they have not suffered any obvious external damage.
- That any defects are reported in line with the company procedures and are repaired or replaced as soon as possible so that 100% availability is maintained.

8.41 Recommended further reading and reference on fire safety

Fire Safety-An Employer's Guide. ISBN 0 11 341229. Her Majesty's Stationery's Office

The Fire Protection Yearbook	FSB 8
Fire & Hazardous Substances	FSCD 2
Guide to Building Fire Protection	Vol. 3.
Vol. 4. Guide to Fire Safety Signs.	FSB 36.
Vol. 5. Fire Risk Management in the Workplace. A guide for employers 2nd. Edition.	FSB.22.
Vol. 6. Prevention and the control of Arson	FSB. 40.
Vol. 7. Fire Protection Equipment and Systems.	FSB.41.
Fire Safety Management.	LB.1.
Fire Risk Assessment: Log Book Record Sheets.	LB2.
Chubb's Fire Risk Assessment.	
A Guide to Fatal Fire Investigations	IFEFF1.
Safety at Scenes of Fire & Related Incidents	FSB.27.
Emergency Service.	
Disasters & Emergencies	Y171.
Risk Assessment for the Emergency Services.	IFERA.
Fire Fighting Manual of Trauma Care.	IFEMTC.
Essential Fire Safety:	
Fire Safety in Retail Premises	FSB.151.
Fire Safety in Offices	FSB. 201
Fire Safety in Village Halls & Community Halls	FSB.32.
Fire Safety in Hotels: requirements for Europe.	FSB.231.
Fire Safety Management in Hotels & Boarding Houses.	FSB.7.
Security:	
An Introduction to Physical Security Techniques.	FSB.331
Guidance on the Acceptance of Electronic Locks To Doors required for Means of Escape.	IFLOC
Transport:	
Airports & Aircraft Fire Protection, Firefighting and Rescue Techniques.	Y169.
Marine Fire Studies.	IFE.
Codes of Practice and Related Guidance:	
The LPC Design Guide for the Fire Protection of Buildings 2000 (A code of Practice for the Protection of Business)	DG2k.
Fire Prevention on Construction Sites 5th. Edition.	FSB9.
Joint Code of Practice: Electrical Process Heating Fire Safety in the Metal Finishing Industry.	CPMF1.
Code of Practice for: The Safe Use of Chromium Compounds in Electrolytic Plating Processes.	CPCCEP.
Code of Practice for Occupational Fire Brigades 2nd. Ed.	CPOFB2.
Code of Practice for the Protection of Unoccupied Buildings.	CPPUB.
The IFSA Code: (The Intumescent Fire Seals Association).	
Sealing Apertures & Service Penetrations to Maintain Fire Resistance.	IFSAC.
Code of Practice for Fire Safety in Houses in Multiple Occupation.	CHPMO
LPC Code of Practice for Fire Protection in the Food & Drink Industry.	CPFCF1.
Code of Practice for Fire Safety when Dealing with Waste Materials.	CPWM.
Code of Practice for Fire Safety in Warehouses & Storage Areas.	CPWARE
Guidelines for the Supply of Water to Automatic Sprinkler Systems.	GFSS.
LPC Rules for Automatic Sprinkler Installations (Building Services Journal).	
Building Materials & Operations:	
Storage, use and filling of Liquefied Petroleum Gas in Containers	RC6.
Hot Work (Includes sample hot work permit)	RC7
Buildings & Building Services:	
Emergency power, heating & lighting.	RC1.
Fire protection of atrium buildings	RC2.
Electronic Data Processing Equipment:	
Part 1: Fire Prevention.	RC3.

Part 2: Security protection.	RC3B.
Part 3: Protection of Data & Software.	RC3C.
Part 4: Small Office system Protection.	RC3D.
Part 6. Protection against electrical disturbances.	RC3F.
Equipment:	
Cooking Equipment (other than fish & chip frying ranges)	RC16B.
Electrical equipment in flammable & explosive gaseous atmospheres.	RC30.
Fish & Chip frying ranges.	RC16A
Forklift trucks.	RC11.
Installation & maintenance of grain dryers.	RC10.
Oil fired installations.	RC9.
Organic thermal fluid heating systems.	RC26.
Organic thermal fluid heating systems.	RC26.
Portable & transportable space heaters.	RC15.
Space heaters burning waste fuel.	RC4.
Space heating: hazard classification.	RC27.
Spark detection & suppression systems on pneumatic conveying systems.	RC28.
Spark erosion machining.	RC29.
OCCUPATIONAL/STORAGE HAZARDS:	
Fire safety in automotive refinishing and spraying processes.	RC31.
Fire protection of laboratories	RC5.
Prevention & control of dust explosions.	RC12.
Storage of aerosol products	RC19.
Fire safety in the storage and use of flammable liquids	
Part 1. General principles.	RC20A
Part 2. Storage of flammable liquids in drums, cans and other containers.	RC20B
Part 3. Storage of flammable liquids in external fixed tanks.	RC20C.
Weather Protection:	
Frost protection for new buildings.	WP1.
Assessment of roofs' resistance to wind damage.	WP3.
Protection of commercial buildings against water damage.	WP2.
FIRE ENGINEERING:	
Gaseous Fire Protection Systems.	LPR16.
Halon alternatives.	LPR6.
Fire spread in Multi-Storey Buildings with Glazed Curtain Wall Facades.	LPR1.
Report on the State of the Art of Compartment Fire Modelling.	LPR1.
PROPERTY RISKS:	
Cladding Systems for Building: Introductory Guide.	LPR2.
Property Subject to Structural Movement guidelines on the assessment of cracks.	LPR3.
Subsistence & Domestic Housing: Survey: analysis of results.	LPR4.
Geology & Building Subsidence.	LPR7.
Glossary of Wind Terms used in Construction.	LPR15.
Wind Damage to Buildings in the United Kingdom.	LPR8.
TECHNICAL BRIEFING NOTES:	
Violence at work	TBN1.
Crime & Household Property	TBN2.
Legionella and Firefighting Systems.	TBN14.

All these publications can be obtained from:

The Fire Protection Association. Bastille Court. 2 Paris Gardens. London. SE1 8ND. Tel: 020 7902 5300. Fax: 929 7902 5301

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9 Fire sprinkler systems

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9.1 Sprinkler systems

"What!? How much? I'm not spending that much money on a sprinkler system just because some Insurance company tells me to. Chances are it's only going to sit there and do nothing all its life anyway."

I wonder how many people have said that and, out of that number, I wonder how many people have lived to regret it. I'm sure the people who did live to regret it would say, in hindsight, "I wish I'd installed sprinklers when it was first suggested."

9.2 Why are sprinklers installed?

Let us consider for a moment what a sprinkler system is. By definition it is a device, developed for installation within buildings, or in and around equipment, to automatically detect a fire in its early stages. The system is only designed to control a fire until the fire brigade can respond, but extinguishment is normally achieved. The operation of the system also gives a local alarm. Sprinkler systems were originally developed for the protection of property or equipment, however, in recent years, they have been used for the purposes of life safety, being an aid to the means of escape of personnel.

A sprinkler system consists of a water supply with one or more sprinkler installations.

Each installation consists of a main set of control valves and a pipe array fitted with sprinkler heads. The sprinkler heads are fitted at specified locations just below the ceiling or roof level and, where necessary, below obstructions, in storage racks/shelves or in and around plant and equipment.

The sprinklers operate at a pre-determined, fixed temperature and discharge water over the affected part of the area below. The flow of water through one sprinkler head, and consequently the alarm control valve, initiates an hydraulically driven, mechanical alarm. The operating temperature of the sprinkler heads is determined by the ambient temperature conditions in which they are to be installed.

Contrary to uneducated belief, only sprinkler heads in the vicinity of the fire, i.e. those which become sufficiently heated, will operate and discharge water.

The statistics for sprinkler systems are awesome. Those we have in the U.K. on the effectiveness of sprinkler installations are very conservative, and it is their very effectiveness that makes it so. In the majority of cases, one sprinkler operating actually controls or extinguishes the fire, which means there is very little damage and very little disruption, so it never actually gets into an Insurance company claim. As the Insurance industry is the main source of data for UK statistics, there are many fires which are controlled or extinguished which are never recorded. It is in this context we must read the statistics.

Of all known fires in the UK, more than 60 per cent are controlled by only one or two sprinklers operating, and over 90 per cent are controlled by five or less. The chances of a sprinkler operating spuriously with the consequences of the unnecessary discharge of water are approximately 1 in 16 million. Ever since automatic sprinkler installations have been installed in the UK, there has never been a death in a sprinklered building (excluding those fire involving explosions), and this only increases to 50 throughout the whole world. On the basis that automatic sprinkler installations have been installed for over 120 years, this is quite an amazing success story. Even sprinkler heads, which have been removed from installations after 70 or 80 years service, operate when tested by the same method new ones are tested.

If we look at the statistics in Australia, where all fires must be reported by law, over the 100 years to 1986 there were 9022 fires in sprinklered buildings. Of these 9022 fires 99.5 per cent were controlled by the sprinkler installations and 64.55 per cent by one sprinkler head.

It can be seen from these statistics how effective automatic sprinkler installations really are.

It must be remembered that any sprinkler installation must be designed, installed and maintained to the correct standard in order to have full confidence that it will be effective. If this is the case, it will be on duty 24 hours a day, seven days a week, 365 days of the year. A sprinkler installation can potentially save properties, save businesses and save lives.

Because of their proven effectiveness over many years, their value is appreciated by the following organizations, all of which strongly recommend their installation for property protection and, in recent years, life safety purposes.

1. Insurance companies: to reduce the "risk" of "total" loss of property and/or stock in the event of a fire. (they give discounts on fire insurance premiums.)
2. Local fire safety officers: to make the fire brigade job safer by responding to smaller fires and maintaining the integrity of the building structure in fire conditions.
3. Architects: savings can be made on building materials (lower fire rating/spread/larger compartmentation) this is referred to as trade-offs.
4. Building control: this is linked to item 3 above by national/local building regulations. (Approved Document "B")
5. Some building owners: simply because they have previous experience of their worth and effectiveness.

There are, of course costs.

- ☐ Direct Installation costs – i.e. the Installer.
- ☐ Associated Building work – hole cutting, trenching, tank bases, etc.
- ☐ Electrical Installation work – e.g. pumps, signalling, wiring
- ☐ Water Company connections/Roadway re-instatement.
- ☐ Alarm Company costs for signalling and Central Station costs
- ☐ Provision of ordinary Fire Extinguishing Appliances to insurer's scale – i.e. Extinguishers
- ☐ Operational and Maintenance costs – Water rate, Fuel costs, Electricity, Alarm company charges, increase in Rateable Value of premises.

There are also considerable benefits.

- ☐ Protection 24 hours a day × 365 days a year, for the assets and earning power of the business.
- ☐ In some high-risk categories, acceptance by Insurers may be only on condition of the installation of sprinklers.
- ☐ Can provide a construction "trade-off", in respect of compartmentation etc.
- ☐ Provide substantial revenue spending economies, by reducing Insurance premium.
- ☐ Corporate taxation concessions – qualifies as "Plant & Machinery" against tax.
- ☐ In some areas, DTI grants may be available.

It would be quite wrong not to balance the case for sprinkler protection, without a small mention of system failures. From time to time there are failures and these are rigorously investigated. Usually it is the interface with the human race which causes the problem to occur. The main reasons for failure are as follows:

- ☐ System turned off in error.
- ☐ Inadequate water supply.
- ☐ Protection does not match the risk involved due to alteration since installation.
- ☐ Poor or inadequate maintenance.
- ☐ Changes in building layout – i.e. Protection not updated.
- ☐ Exposure risks from unsprinklered buildings.
- ☐ System frozen – heating failures.

Where a system fails to control a fire, this is immediately followed by an investigation, usually initiated by collaboration between Insurers, Loss Adjusters and the Fire Brigade. In most cases, the reason for failure is fairly obvious.

9.3 Insurance premium costs

There are two aspects to insurance premium costs when relating to sprinkler installations.

Installing automatic sprinkler systems can reduce insurance premiums. The higher the risk, the greater the chance of substantial reductions, thus the lower the fire risk, the less the reduction, if any.

There may also be a consideration given to the fact that there are larger numbers of pipes filled with water. This *may* increase the premium. Any discounts given will be a balance between the two.

Different insurance companies have different policies on discounting premiums and each case will have to be evaluated individually. Some insurance companies will not accept risks with a very high fire load without an automatic sprinkler system. If the insurance company is insisting on a sprinkler system, they should provide a detailed specification for it. In the event of their not doing so, it is essential to enlist the services of an independent competent fire protection consultant to provide such a specification. Any specification must be submitted to the insurance company (and any other authority having jurisdiction) for their approval.

9.4 Safety

Safety can be split into two spheres. Safety of personnel in a sprinklered building and the safety of the equipment installed against mechanical damage.

The pipework, and all other system components, should be installed in a position such as not to create a hazard to personnel. If there is a hazard created unavoidably, it must be highlighted and dealt with in accordance with health and safety requirements. If there is a sprinkler head at low level, for instance, where someone could injure himself or herself, a guard can be fitted to prevent sharp edges catching anyone.

If there is a risk of mechanical damage to the equipment then, again, this must be highlighted and dealt with according to health and safety requirements. If a valve is installed in an area where forklift trucks operate, a substantial barrier should be fitted to prevent impact. If any sprinkler head is installed in such a position, which will make it liable to mechanical damage, a guard must be fitted and all other measures must be taken to prevent it getting damaged. Should the deflector on a sprinkler head be damaged, it will affect the distribution of water and could also affect the efficiency and efficacy of the whole system.

9.5 Statutory requirements

There are no statutory requirements for either who should install an automatic sprinkler installation or how it is installed. Authorities having jurisdiction should be consulted, however, to ensure the correct type and hazard classification of sprinkler system is installed.

The Loss Prevention Certification Board operates the LPS1048 scheme in which those sprinkler installing contractors who offer themselves for assessment, undergo two surveillance visits per year to ensure the correct standards are being maintained in design and installation of sprinkler systems.

The names of these contractors can be found in the Loss Prevention Certification Board's List of Approved Fire and Security Products and Services. The Loss Prevention Certification Board are now part of the Building Research Establishment in Garston, Watford, Herts. WD2 7JR.

9.6 The risks

The installation of a sprinkler system does not reduce the risk. The only way of achieving that is by good housekeeping practices. These practices should also include the regular testing and maintenance of the sprinkler system itself.

There will, inevitably, be times when the sprinkler system needs to be isolated and this should be for the absolute minimum period possible. Whenever an installation is isolated, the insurance company must be informed and, for risks with a very high fire load, the fire brigade should also be made aware. Both organizations should also be informed when it is returned to service.

It is possible to avoid any downtime whatsoever by installing a full-bore by-pass with an isolating valve

around the control equipment. The isolating valve on the by-pass would normally be closed and opened only when the main installation valves are to be taken out of service for maintenance. Another stop valve will be necessary downstream of the alarm control valve. This type of arrangement would normally be used in installations designed for life safety purposes.

9.7 Types of installation

There are several types of sprinkler installation available. The most common is the WET system. This type of system is charged with water constantly, which means there is always going to be water available immediately a sprinkler operates. It is for this reason the **WET** type of installation is preferred by the insurance companies.

The next most common is the **ALTERNATE WET/DRY** installation. This type of installation is used when there is the likelihood of frost damage during the winter months. The installation pipework is normally charged with water but, when freezing conditions are liable to occur, it is drained down and replaced with compressed air. This will, of course, mean that, under the latter condition, water will not be available immediately a sprinkler operates, but it should only be a matter of seconds before it begins discharging. As this situation only applies for approximately four months every year, the insurance companies will normally make this type their second choice. If, however, an American insurance company or American standards are involved, this type of installation would not be permitted.

With constant draining down and filling with compressed air (which will not normally be dry, despite Technical Bulletin 21 of the Loss Prevention Council Rules for Automatic Sprinkler Installations incorporating BS5306:Part 2:1990, calling for it to be so) and subsequently drained of air and refilled with water, there is a case for the use of galvanized pipework and the installation of flushing valves, to reduce the problems which may be caused by internal corrosion of the pipework. The standards to which sprinkler installations are installed in the UK do not call for this extra work to be carried out (which will clearly have a cost implication) even when using clean potable water, but it could be considered good Fire Engineering practice! Most sprinkler installation contractors will install equipment to the standard unless requested to do otherwise.

The third most common installation type is the **DRY** installation. As the name implies, the pipework is constantly charged with compressed air and only fills with water when a sprinkler head operates. This will obviously mean the water will not discharge immediately on operation of a sprinkler head throughout the year which accounts for it being less preferable than the previous two types of installation. It is this type which is preferred when American standards are involved and the **WET** installation is impractical. Despite the delay in discharge of water

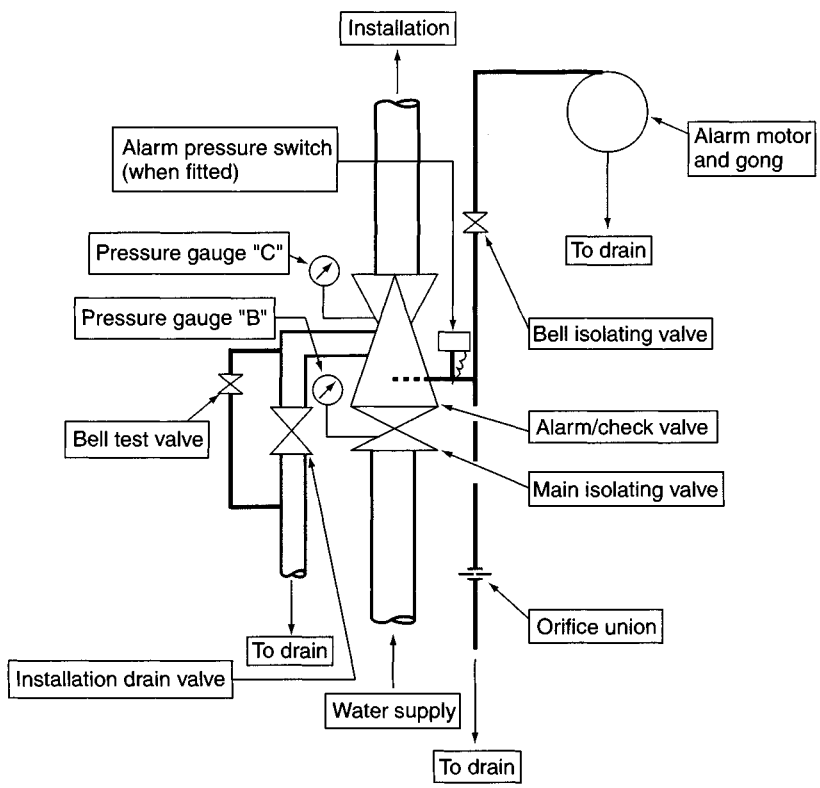


Figure 9.1 Schematic wet sprinkler installation control valves

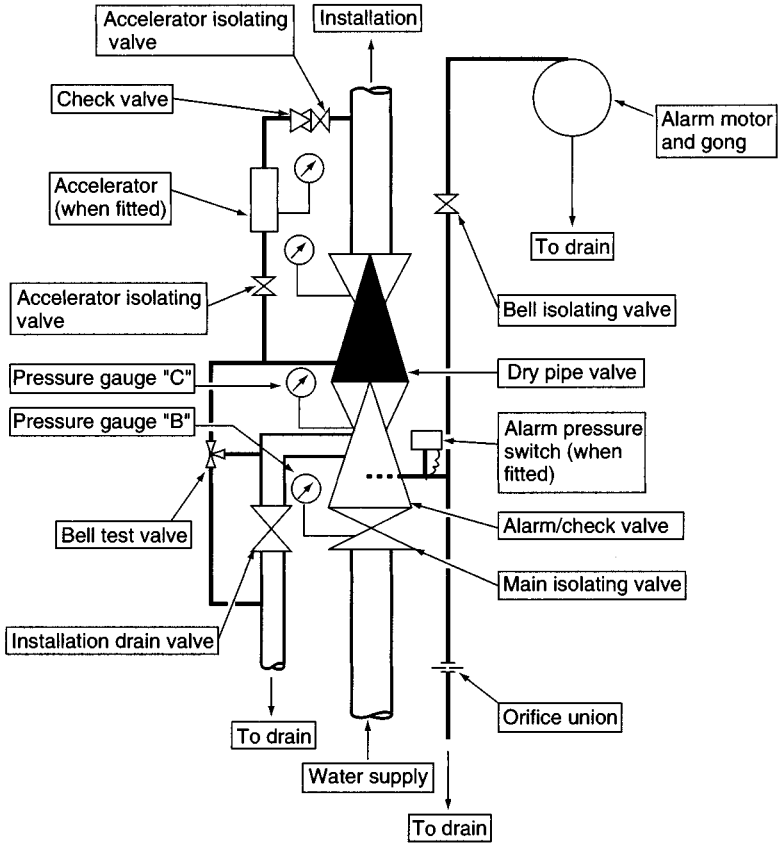


Figure 9.2 Schematic alternate wet/dry sprinkler installation control valves

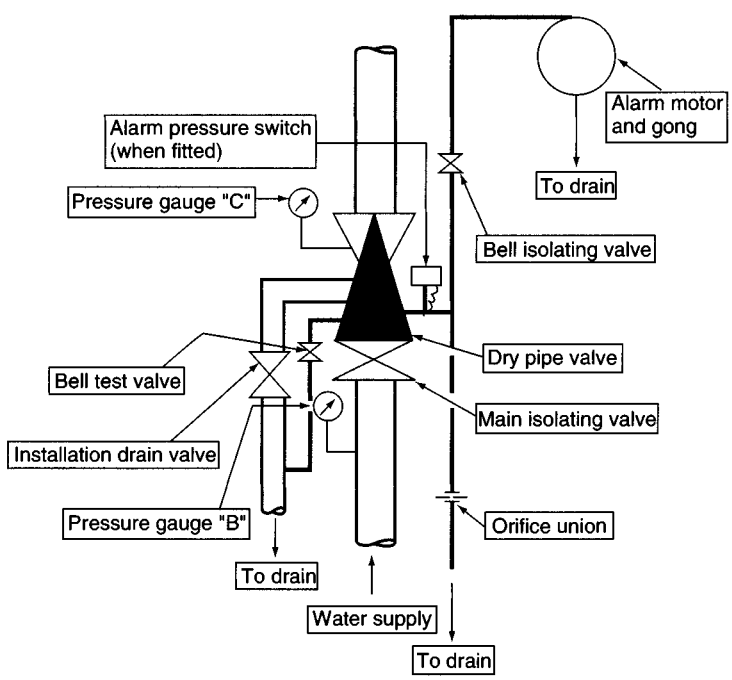


Figure 9.3 Schematic dry sprinkler installation control valves

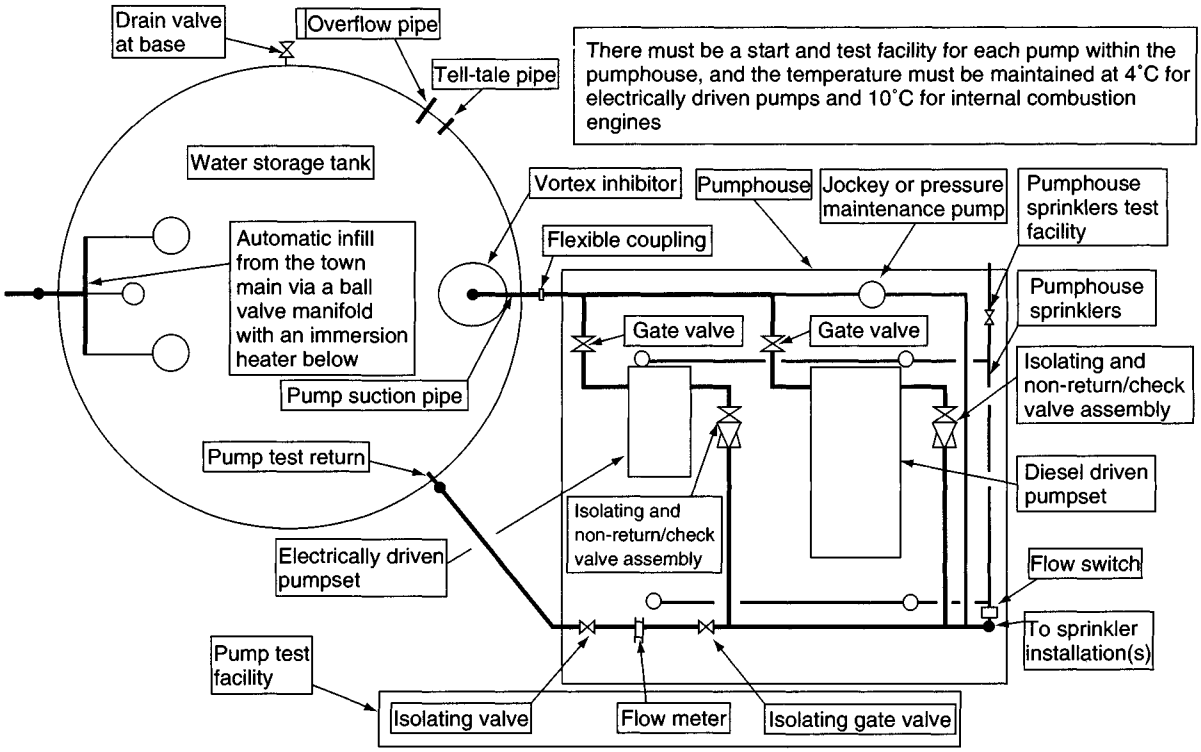


Figure 9.4 Typical schematic water supply pumps and water storage tank layout

(which would be minimized by the use of an accelerator or exhauster), there is a logic to this line of thought.

Once initial hydrostatic testing is complete, there is no need to fill the installation with water, except in fire conditions. This would serve to reduce corrosion during the life of the installation, and American standards require the installation of flushing valves, which will remove, as far as possible, the products of any corrosion that does take place when opened on a regular basis.

It is possible to have small areas, which may be subject to frost during the winter (external canopies for example), adequately protected whilst using a wet installation for the heated remainder of the premises. This is achieved by installing either a **TAIL END DRY** or **TAIL END ALTERNATE WET/DRY** installation. These are just small extensions to the main installation, which can allow a small area to be protected with pipework filled with compressed air.

There are some schools of thought that express concern over an installation being filled with compressed air. The worry is that the compressed air will fuel the fire with its oxygen content, and this will increase the size of the fire. This, of course, is quite true but the efficacy of the sprinkler installation will not normally be compromised by that fact. If, under exceptional circumstances, it is considered to be a real problem, the installation pipework can be filled with an inert gas such as Nitrogen.

There are several other types of sprinkler and water spray installations namely, pre-action, recycling, deluge, foam water, foam and ESFR. These are generally used in very specific circumstances and full details should be obtained from a competent and experienced fire engineer.

9.8 Specifying a sprinkler installation

In order for the layman to be able to assess tenders for the installation of sprinklers with any degree of confidence, it is essential that an independent body produce a full and comprehensive specification, acceptable to the insurer of the premises. Ideally this would be the insurance company themselves as any system or installation will need to be approved by them.

With a new building it may be that "trade offs" could be made on the back of a sprinkler system being installed. Thickness of concrete, size of structural steel, size of fire compartment, structure of the compartment envelope etc. can all be affected by the installation of sprinklers, so it is important to ensure an experienced and competent fire engineer is involved at an early stage.

Sprinklers are not the panacea for all fire protection ills. There are some circumstances where sprinklers may not, necessarily, be the most effective means of fire protection. A competent fire engineer would identify this and include an alternative, where necessary, in the specification package.

The standards in the UK are such that there could be several ways of achieving the one result. A competent and experienced fire engineer should be able to consider all the options and specify the one most appropriate for the circumstances being considered.

As the different methods are all part of the standard, any contractor may wish to offer one or more of these options on the basis that he considers it more cost effective. It is always best to ask for the main price to be fully in accordance with the specification, and any alternatives to be quoted as a separate price, to be added to, or subtracted from, the fully compliant price. The more comprehensive the original specification, the less the chance there is of any contractor wanting to alter it.

9.9 Making the decision

Once the specification has been compiled, and the insurance company's approval obtained if they did not compile it themselves, it should be just a question of simple price comparison. In the event of one or more contractor wishing to provide the system or installation using an alternative pipe material or water supply type, it would be necessary to consult the fire engineer who compiled the original specification for him to establish what implications (if any) these alternatives would have.

The decision to install a sprinkler system or installation carries with it some serious requirements and limitations on the owner/occupier of the building concerned.

A sprinkler system/installation is designed and installed according to current occupation. This means there is a limit upon what processes can be carried out on the premises, what materials can be stored and a maximum height of storage for that type of material. The means by which it is stored is also applicable (free standing, pallet racking etc). All these factors affect the Hazard Classification of the sprinkler installation so, by accepting a sprinkler installation, the owner/occupier accepts responsibility for ensuring the risk is kept within the parameters laid down by the installing contractor. If this does not happen, it could mean the difference between a fire being controlled with relatively little damage, and a total loss of the premises. It is not just a question of signing a cheque in payment but an on-going responsibility from the date of hand-over.

9.10 Materials

The materials used in a sprinkler installation will be dictated by the conditions under which it has to operate.

As, in the majority of cases, cold, potable water is the medium within a normal sprinkler installation, medium quality, mild steel tube to BS1387 is perfectly acceptable. If the conditions are more corrosive, consideration must be given to alternative materials. As pipework forms a large percentage of the materials used in a sprinkler installation, it is important to get it right. The pipe fittings will, obviously, need to be compatible with the pipework being used.

Unless it is a marine application, mild steel pipe, wrought steel fittings, brass sprinklers and cast iron control valves will normally be adequate.

If a corrosive atmosphere exists within the premises then the external surfaces of all the equipment will need to be protected. Any protective coating to sprinkler heads *must* be carried out by the manufacturer. The coatings available are chromium, cadmium, powder coating(colour), wax, petroleum jelly and even gold. These coatings are not only used as corrosion resistance but also for decorative effect.

9.11 Storage of materials

When considering materials in storage, it is necessary to take into account the materials stored, the way in which they are stored and the storage height. There must also be a minimum clearance between the storage and the sprinklers.

The insurance company will normally decide the category of materials in storage. An independent fire engineer can make an assessment, but the insurer must endorse any assessment.

Once the category of stored goods has been decided, the way they are stored and the height to which they are stored will decide the specification of the sprinkler installation. With a high piled storage risk, the greater the height of storage, the greater the quantity of water required from each sprinkler. When the decision has been made on the amount of water required from the sprinklers, the stored materials, along with the type (pallet racking, free standing etc.) and height of storage *must not be altered.*

For each category of stored goods and type of storage, there is a maximum storage height. Beyond this height, and if the type of storage permits, intermediate rack sprinklers would need to be installed, along with those at the roof. If there are more than 50 sprinklers within the racking, then there must be a separate valve set for those sprinklers.

Intermediate rack sprinklers are positioned in a predetermined manner, dependent of the category of goods stored. Where sprinklers within storage racking have their own control valves, and this will be in the majority of cases, then the roof and rack installations must be hydraulically balanced. As the design parameters for intermediate rack sprinklers are considerably different from those for roof sprinklers, the chance of having balanced flows and pressures at the valve sets is highly unlikely. When the pipe sizes have been adjusted as much as possible in an attempt to achieve balance, a calculation can be done to adjust the lower of the two flows to the higher of the two pressures. The most economical method, however, in terms of pump rating and water storage tank capacity, is to insert an orifice plate to achieve a pressure drop equal to the difference between the two pressures.

The calculations for a system of this nature are fairly complex and it is essential the installing contractor is competent to carry out such calculations.

9.12 Pumping systems and control

When pumps are installed they are probably the only source of water for the installations. It is imperative, therefore, to ensure the pressure and flow requirements are sufficient to support the installation with the highest demand on the system.

It is permissible to have one, two or three pumps forming the water supply and they must draw water from

a storage tank. Pumps boosting water direct from a town main are prohibited by the water authorities. The pumps can be electric motor or diesel engine driven. There will also be an automatic jockey, or pressure maintenance pump, which will be used to top up any small pressure drop and prevent the main fire pumps starting up (these require to be stopped manually).

The higher the hazard classification of the installation, the more reliable the water supply must be. Lower classifications are acceptable with only one pump but higher classifications require two or three. This is to provide a stand-by in the event of the primary pump failure. The primary pump is usually driven by electric motor and the stand-by by diesel engine. It is possible to have two electric motor driven pumps if the electricity supply to each motor is taken from two totally independent supplies. The cable from each supply must also take different routes to the control equipment.

When the pump pressure and flow characteristics have been established, the size of the water storage tank can be calculated. This is the product of the highest predictable flow (Q_{max}) and the time for which the water supply is required to keep the system going.

Each pump installed should have its own start and test facility in the pump house. The pumps are started by pressure switch on drop in pressure, and the jockey pump should cut in first to top up any small pressure drop. Once it has done that, it will cut out automatically. If a sprinkler has operated, the jockey pump should be so sized that it will not be able to provide too much water to prevent the primary fire pump from operating or delaying its operation unduly.

A direct-on-line starter normally controls the jockey pump but, due to the extremely high start-up current requirements of the primary pump electric motors, these are controlled by a stage start mechanism – normally Star-Delta. When considering the diesel pump it is a reasonable self-contained unit. The fuel tank and all the control equipment, with the exception of the starting pressure switch, form an integral part of the skid upon which the pump and driver are seated. The only electrical connection the diesel driven pump requires is that for the trickle charge battery charger.

There should be an alarm panel in the pump house with a repeater in the security lodge, if there is one. The repeater panel should be in a permanently manned area in the absence of a security lodge. Fire alarms can also be relayed directly to the fire brigade via a direct dialler or through a central alarm station.

All electrical connections for fire pumps must be taken from the incoming main prior to the building owner/occupier's contact breakers and fuse board. This will ensure a power supply to the fire pumps in the event of a power failure, during fire conditions, on the premises they are protecting.

9.13 Maintenance of a sprinkler system

Once a sprinkler system has been correctly designed and installed, it is essential it is properly serviced and maintained. Although the components of a sprinkler system are simple in operation, if they are neglected they may not operate in the event of fire.

The Loss Prevention Council Rules for Automatic Sprinkler Installations, incorporating BS5306:Part 2:1990, contain technical bulletin 6, which is dedicated to the care and maintenance of automatic sprinkler systems, and gives recommendations for procedures to be adopted, with recommended intervals between such procedures, to achieve an effective maintenance programme. Many insurance companies can provide their own recommendations, and sprinkler installing contractors will have standard procedures dependent upon the equipment installed. Individual manufacturers will recommend what spares and replacements will be necessary to be provided per annum but, with sprinkler heads, the number required to be provided is dictated by The Loss Prevention Council Rules for Automatic Sprinkler Installations incorporating BS5306:Part 2:1990. As sprinkler systems are designed to last for at least 50 years these will only be necessary either after a fire or when a sprinkler is damaged. There has never been a sprinkler head that has been taken out of an existing installation, irrespective of age, which has failed to operate within the acceptable parameters for that type of sprinkler. This statistic is conditional on a sprinkler head being removed in the same condition as it was originally installed.

Maintenance that is provided by an outside contractor is not all that is required. Any alarm given by the system must be tested weekly and pumps must be run weekly. It is an option to retain the services of a sprinkler system maintenance company, preferably the same one that originally installed the system but, unless they are just around the corner, this would be financially prohibitive. It is essential, however, to have an engineer trained in the procedures necessary for carrying out weekly tests, and it is the responsibility of the sprinkler installing contractor to carry out such training.

It is possible for organizations that have their own maintenance team to carry out the maintenance of valves, bells, pressure switches and gauges etc., but pumps normally require specialist attention. Whatever maintenance is undertaken "in-house", it is essential that accurate and comprehensive training be obtained. The installing contractor would not be responsible for training to that extent, and it would be advisable to seek the services of the equipment manufacturer for this depth of training.

Visual checking is a very important aspect of any sprinkler system. Even the layman can see if the fusible element of a sprinkler head is contaminated by paint, or a pressure gauge is not reading the pressure it has previously. When weekly alarm/pump tests are carried out is probably the best time to do visual checks. When there is more than one installation on a system, and each one is located in a different part of the premises, visual checks can be carried out when walking between locations. It should be remembered, however, that pumps, in particular diesel engine driven pumps, must not be left unattended when running. There are checks that can be done in and around the pump house during the pump run times (pump house temperature, running pressures, running current, engine coolant temperature etc.).

The water storage tank also requires checking. A visual check for leaks around joints of the tank panels and whether there is a discharge from the overflow pipes. Whether the contents gauge is reading correctly and the automatic ball valve is operating as it should. There are other checks but the tank manufacturer will itemize the maintenance requirements.

As well as the maintenance procedures to be adopted and intervals between such procedures, insurance companies will supply a weekly test card which must be completed. The format of this is normally a comprehensive list of tests to cover every single eventuality, whether or not that equipment is installed, so it is a question of completing only the parts relevant to the equipment installed in the premises concerned.

It is important to ensure test cards are completed each week. Hopefully, the results are going to be the same week in, week out, but it is when the results start changing, and the amount of the change increases, that there is an indication of something going wrong. Some information may seem unnecessary, such as the length of time taken for the alarm gong to sound after opening the test valve, but this information is important. With the instance of the alarm gong, it could indicate something simple like a blocked nozzle in the gong itself. Equally, it could indicate a sticking alarm control valve which, if left unattended, could have grave repercussions in the event of fire. The insurance company surveyor will want to look at this card during his visit, so it will need to be completed.

It is good practice to keep accurate records of maintenance on a sprinkler system. It is also good practice to record all occurrences relative to the sprinkler system. These could include false alarms, pipe leakage, sprinkler replacement, sprinkler or pipework mechanical damage etc. If a pattern starts to emerge, this information will help to diagnose any problem early and have it corrected. It should be remembered a sprinkler installation is going to have but one chance to prove itself. It is the responsibility of all concerned to ensure it is allowed the best possible chance!!

The sprinkler contractor should, at the completion of the work, produce operating and maintenance instructions for all the equipment installed, along with "As installed" drawings and hydraulic calculations. It is important to ensure these are kept in a safe place so any future alterations to the system can be carried out as easily and inexpensively as possible, without the need for surveys and hydraulic calculations on the existing installation(s).

Any operating and maintenance manual should state what equipment is installed and its normal mode of operation. All isolating valves should, where they could affect the operation of the system or its alarms, be secured in their normal operating position. Some other valves, such as subsidiary drain valves, or other low level equipment, should also be locked in their normal mode as a deterrent to misuse. All locking arrangements should be a leather strap and padlock. This allows the strap to be cut in an emergency.

Whilst the operating and maintenance instructions will identify all the equipment installed on the premises, it is a good idea to identify each item on site.

The most important identification plate is the one on the outside of the building showing the location of the main control valves. This will enable any Fire Officer who is unfamiliar with the site to locate the valves quickly, which will minimize the time taken to turn the system off if the fire has been extinguished by the time the fire brigade arrive. It is also useful to have labels on all equipment itemized in the manual, which will allow ease of identification and speed of operation in an emergency. An emergency is not just fire conditions, but it could be a forklift truck knocking into, and breaking a pipe joint. The quicker the reaction to a situation such as this, the less the water damage.

9.14 The fire service

With complex sites and those with a high fire load, the local Fire Service will want to have details and should be invited to visit the site, if not at the commissioning, then as soon after as possible. In an emergency they must have access to all the control equipment as soon as possible after they arrive, so prior knowledge of the site will enable them to achieve this.

It is advisable to inform the Fire Service whenever a sprinkler system is installed and offer them an open invitation to come and inspect, at their convenience.

All main control valves should be situated by an outside wall adjacent to a door at ground floor level. If they are going to be any less accessible than that, the Fire Service must be consulted before the actual location is decided, as they will be the ones to require access in fire conditions.

9.15 Seeking advice

For advice on sprinkler systems/installations any contractor named in section 5 parts 1A and 1B should be able to help. If independent advice is preferred, the insurance company covering the buildings or the contents should have a surveyor who is capable of providing all the information necessary and possibly a specification.

The Loss Prevention Certification Board (LPCB), who manage the LPS 1048 scheme for sprinkler installers, should also be able to provide a contact, but they are not permitted to give advice themselves.

An independent fire engineering consultant competent in sprinkler systems could also be used. By doing this, not only would advice on the type, hazard classification etc. of an automatic sprinkler installation be available, but he could also provide tender drawings, a full and comprehensive specification and a tender review facility. The fire engineering consultant should also be able to address the related fire engineering matters. These could include fire exits, extinguishers, compartmentation, construction specialist fire protection systems etc. The fire engineer would also be able to help select the correct contractor and manage the project on the owner/occupier's behalf. Although there is no national list of this type of engineer, the Institution of Plant Engineers or the Society of Operators Engineers will be able to provide some contacts.

9.16 Codes of practice for contractors

It has been mentioned previously in this article, but the UK standard for the design, installation and maintenance of automatic sprinkler installations is the Loss Prevention Council Rules for Automatic Sprinkler Installations incorporating BS5306:Part 2:1990. The standard is stated in this format as the Loss Prevention Council (LPC) have produced many Technical Bulletins (No 33 being the latest) which have enhanced the requirements of BS5306:Part 2:1990. If the BS only were to be used in a specification all the recommendations and requirements of the Technical Bulletins would be ignored, and this would have a detrimental effect on the system installed.

In the USA there are several codes available, dependent upon which aspect of sprinkler protection is being considered, but the basic one is the National Fire Protection Association Code 13.

9.17 Recognition and acceptability

The LPCB, as mentioned previously, operate the LPS 1048 scheme and, if a contractor operating within this scheme installs a sprinkler system entirely to the LPC Rules for Automatic Sprinkler Installations incorporating BS 5306:Part 2:1990, then that contractor can issue, or can have issued on his behalf, an LPS 1048 Certificate of Conformity. Other than all authorities having jurisdiction accepting the system in writing, this is the only means of certification. If there are any minor deviations to the standard, and assuming the authority having jurisdiction has accepted these, they must be stated on a separate sheet issued with the LPS1048 Certificate of Conformity. Should a major deviation exist, no LPS1048 certification will be permitted. A major deviation being defined as one which could have a detrimental effect on the operation of the sprinkler system.

9.18 Value for money

In real monetary terms it is difficult to quantify "value for money". A great deal depends on the type of system required, the water supply available and the discount the insurance company is prepared to give.

The only time value for money can be quantified is in the event of fire.

If a sprinkler system were installed which had been designed, installed and maintained correctly, a fire would be controlled within a few minutes, whether the premises are occupied or not, with the minimum amount of water. Thus, very little water and fire damage and business can resume, if not in hours, then certainly within days.

If a sprinkler system were not installed, no water would be applied for probably 10 minutes. After this, several fire hoses would apply 250 gallons of water per minute for probably a few hours. At best there would be a major fire with and severe fire and water damage, at worst, a total loss of the building. Business resumed after many, many weeks – if at all!!!

PEACE OF MIND AND SECURITY OF BUSINESS ARE BEYOND VALUE.

10 Industrial boilers

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and
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10.1 Terminology

The following explain some of the more fundamental terms encountered when considering boilers.

10.1.1 Shell boiler

This is a boiler in which the products of combustion or hot gases pass through a series of tubes surrounded by water. All are contained in an outer shell.

10.1.2 Watertube boiler

In a watertube boiler water circulates through small-bore tubes constructed in banks and connected to drums or headers. The external surfaces of the tubes are exposed to the products of combustion or hot gases.

10.1.3 Dryback boiler

This is a horizontal shell boiler where the gas-reversal chamber from the combustion tube to the first pass of tubes is external to the rear tube plate and is formed by a refractory lined steel chamber.

10.1.4 Wetback boiler

A wetback boiler is a horizontal shell boiler where the gas-reversal chamber from the combustion tube to the first pass of tubes is integral within the boiler shell and surrounded by water.

10.1.5 Economic boiler

This is a term applied to the early free-standing shell boilers of two- and three-pass construction. Originally, they were dry back and later wet back. These boilers superseded the brickset Cornish and Lancashire boilers. The earliest economic boilers were also brickset. The gases from the front smokebox returning across the lower external part of the shell were contained within the brick setting to form a third pass.

10.1.6 Packaged boiler

A packaged boiler is a concept of a factory-built and assembled shell boiler complete with its combustion appliance, feedwater pump and controls, valves, base frame and insulation. Before this, the economic boiler was delivered to site as a bare shell and assembled *in situ*.

Originally, in the early 1960s package boilers were designed to make them as compact as possible, resulting in some inherent faults. Since then, design criteria have greatly improved and the present packaged boiler is constructed to acceptable commercial standards.

10.1.7 Evaporation

This is the quantity of steam produced by the boiler at temperature and pressure. It may be quoted as 'actual evaporation' or 'evaporation from and at 100°C'. Actual evaporation is the quantity of steam passing through the crown valve of the boiler.

Evaporation from and at 100°C is a figure taken for design purposes, and is based on the actual evaporation per pound of fuel multiplied by the factor of evaporation.

10.1.8 Factor of evaporation

This is the figure obtained by dividing the total heat of steam at working condition by the latent heat of steam at atmospheric condition (i.e. 2256 kJ/kg). Then

$$\text{factor of evaporation} = \frac{H - T}{2256}$$

where H = Total heat in 1 kg of steam at working pressure above 0°C taken from steam tables in kJ/kg.
T = Heat in feedwater (kJ/kg).
2256 = The latent heat of steam at atmospheric conditions.

10.1.9 Availability

This is the period of time that a boiler may be expected or required to operate before being shut down for cleaning or maintenance. This will vary with the type of boiler, the fuel being used and the operating load on the boiler.

10.1.10 Priming

This is when the water surface in the boiler shell becomes unstable. Vigorous surging will occur and this may cause the boiler to go to low water and cut out or possibly lock out. This, in turn, will exacerbate the condition.

There are two possible causes. The first could be incorrect control of water treatment and blowdown. This can result in excessive levels of suspended solids in the boiler water, organic matter in the boiler water or high alkalinity. The second can be mechanical. If the boiler is operated below its designed working pressure it will increase the efflux velocity of the steam leaving the water surface area to a point where it may lift the water surface and drop the water level. It is important therefore to give due consideration to the steam load required from the boiler.

10.1.11 Thermal storage

Thermal storage is a method of supplying a steam load in excess of the maximum continuous rating of the boiler for short periods. The boiler shell diameter is increased to provide a greater height of water than normal above the top line of heating surface to the normal working water level. When an excess load is then imposed on the boiler it allows this extra water to flash to steam while lowering the working pressure in the boiler. Safety-level controls protect the boiler against an excessive draw-off of steam. As the load decreases, the boiler maintains its maximum firing rate and allows the extra water to return to the normal (higher) working water level and the higher working pressure regained.

10.1.12 Accumulator

This may be likened to an unfired boiler. Steam is generated in the boilers at a pressure higher than that required

for the process and fed to the process through pressure-reducing valves. This higher-pressure steam is also supplied to the accumulator, where it heats and pressurizes the water in the accumulator. When a steam load in excess of the boiler maximum firing rate occurs, steam may be supplied from the accumulator until such time as the load may be met from the boilers. As the steam load falls away the accumulator will recharge from the boilers. This system enables boilers to be installed with ratings to match an average load while the peaks will be met from the accumulator.

10.1.13 Cavitation

This is a condition which occurs when the feedwater pump is unable to deliver feedwater to the boiler although the feed tank has water available. The temperature of the feedwater coupled with the possible suction effect from the feedwater pump in the line between the feed tank and the pump effectively drops the pressure, causing the feedwater to flash to steam. The pump then loses its water supply.

In most cases this condition may be avoided by arranging a sufficient head of water and by correct sizing of the feedwater pipework. Clean filters must also be maintained.

10.2 Heat transfer in industrial boilers

Heat is transferred from the hot products of combustion to the boiler heating surfaces through the plate and tube walls and to the water by various mechanisms which involve conduction, radiation and convection.

10.2.1 Conduction

The rate at which heat is transferred by conduction through a substance without mass transfer is given by the Fourier Law. This states that the heat flow rate per unit area, or heat flux, is proportional to the temperature gradient in the direction of heat flow. The relationship between heat flux and temperature gradient is characterized by the thermal conductivity which is a property of the substance. It is temperature dependent and is determined experimentally.

For a plate of area A (m^2), thickness e (m) and with hot and cold face temperatures of T_1 and T_2 (°C), respectively, the normal heat flux ϕ and heat transfer rate Q are given by:

$$\phi = \frac{Q}{A} = \frac{k(T_1 - T_2)}{e} (W/m^2)$$

where K = thermal conductivity (W/mK).

10.2.2 Radiation

Thermal radiation takes place by the emission of electromagnetic waves, at the velocity of light, from all bodies at temperatures above absolute zero. The heat flux from an ideal or 'black body' radiating surface is proportional to the fourth power of the absolute temperature of the surface. The constant of proportionality is the Stefan–Boltzmann constant, which has a value of 5.6696×10^8 ($W/m^2 K^4$).

The heat flux radiated from a real surface is less than that from an ideal 'black body' surface at the same temperature. The ratio of real to 'black body' flux is the normal total emissivity. Emissivity, like thermal conductivity, is a property which must be determined experimentally.

Although the rate of emission from a surface is independent of the condition of the surroundings, the net overall exchange of radiant heat between surfaces at different temperatures depends on a number of factors. The continuous interchange of energy is a result of the reciprocal processes of radiation and absorption, and these are dependent on geometrical relationships, emissivity differences and the presence of any absorbing and emitting gases in the intervening space.

10.2.3 Convection

Convective heat transmission occurs within a fluid, and between a fluid and a surface, by virtue of relative movement of the fluid particles (that is, by mass transfer). Heat exchange between fluid particles in mixing and between fluid particles and a surface is by conduction. The overall rate of heat transfer in convection is, however, also dependent on the capacity of the fluid for energy storage and on its resistance to flow in mixing. The fluid properties which characterize convective heat transfer are thus thermal conductivity, specific heat capacity and dynamic viscosity.

Convection is classified according to the motivating flow. When the flow takes place as a result of density variations caused by temperature gradients, the motion is called natural convection. When it is caused by an external agency such as a pump or a fan the process is called forced convection.

At a convection heat transfer surface the heat flux (heat transfer rate per unit area) is related to the temperature difference between fluid and surface by a heat transfer coefficient. This is defined by Newton's law of cooling:

$$\phi = \frac{Q}{A} = h_c \Delta T_m$$

where ϕ = heat flux (W/m^2),
Q = heat transfer rate (W),
A = surface area (m^2),
ΔT_m = mean temperature difference between fluid and surface (K),
h_c = convective heat transfer coefficient ($W/m^2 K$).

The heat transfer coefficient is correlated experimentally with the fluid transport properties (specific heat, viscosity, thermal conductivity and density), fluid velocity and the geometrical relationship between surface and fluid flow.

10.2.4 Furnace heat transfer

Heat transfer in the furnace is mainly by radiation, from the incandescent particles in the flame and from hot radiating gases such as carbon dioxide and water vapour. The detailed theoretical prediction of overall radiation exchange is complicated by a number of factors such

as carbon particle and dust distributions, and temperature variations in three-dimensional mixing. This is overcome by the use of simplified mathematical models or empirical relationships in various fields of application.

For industrial boilers the mean gas temperature at the furnace exit, or at the entrance to the convection section of the boiler, may be calculated using the relationship:

$$T = k(H/A)^{0.25}$$

where T = gas temperature (°C),
H = heat input rate (W) based on the net calorific value of the fuel,
A = effective (projected) water-cooled absorption surface area (m^2),
K = a constant which depends on the fuel and the excess air in the combustion products.

The value of k is determined experimentally by gas temperature measurement. The measurement error of a simple pyrometer can be 250–300 K, due to re-radiation to water-cooled surroundings, and the values given below are based on measurement by a 'Land' multi-shielded high-velocity suction pyrometer. Typical values for normal excess air at or near full boiler load are:

Natural gas	$k = 52.4$
Gas oil	$k = 49.1$
Heavy fuel oil	$k = 48.3$
Coal	$k = 40.3$

In calculating the smoke tube inlet gas temperature of a shell boiler, A includes the effective water-cooled surface in the reversal chamber. In coal-fired boilers any water-cooled surface below the grate is excluded from A.

The total furnace heat absorption may be estimated by using the calculated furnace exit gas temperature and analysis to determine the enthalpy (excluding the latent heat of water vapour) and thus deducting the heat rejection rate from the net heat input rate.

10.2.5 Boiler tube convection heat transfer

The radiant section of an industrial boiler may typically contain only 10% of the total heating surface, yet, because of the large temperature difference, it can absorb 30–50% of the total heat exchange. The mean temperature difference available for heat transfer in the convective section is much smaller. To achieve a thermally efficient yet commercially viable design it is necessary to make full use of forced convection within the constraint of acceptable pressure drop.

Forced convection heat transfer has been measured under widely differing conditions, and correlation of the experimental results is made by using the dimensionless groups:

Nusselt number $$Nu = \frac{h_c D}{k}$$

Reynolds number $$Re = \frac{GD}{\mu}$$

Prandtl number $$Pr = \frac{C_p \mu}{k}$$

where h_c = heat transfer coefficient ($W/m^2 K$),
D = characteristic dimension (m),
K = thermal conductivity (W/m K),
G = gas mass velocity ($kg/m^2 s$),
μ = dynamic viscosity (kg/m s),
C_p = specific heat at constant pressure (J/kg K).

In applying the correlations use is made of the concept of logarithmic mean temperature difference across the boundary layer. For a boiler section, or pass, this is given by:

$$\Delta T_m = \frac{(T_1 - T_w) - (T_2 - T_w)}{\log_n((T_1 - T_w)/(T_2 - T_w))} (K)$$

where T_1 = inlet gas temperature (°C),
T_2 = outlet gas temperature (°C),
T_w = tube wall temperature (°C).

The difference in temperature between the tube wall and the water is small, typically less than 10 K in the convection section. Therefore little error is introduced by using the water temperature as T_w in the evaluation of the gas transport properties.

The representative gas temperatures used in the correlations are the bulk temperature and the film temperature. These are defined as:

Bulk temperature $$T_b = T_w + \Delta T_m$$

Film temperature $$T_f = (T_b + T_w)/2$$

For longitudinal flow in the tubes of shell boilers the mean heat transfer coefficient may be determined from:

$$Nu = 0.023 Re^{0.8} Pr^{0.4} (1 + (D/L)^{0.7})$$

where D/L is the tube inside diameter-to-length ratio and the characteristic dimension in Nu and Re is the tube inside diameter. Gas properties are evaluated at the film temperature.

Correlations for forced convection over tubes in cross-flow are complicated by the effect of the tube bank arrangement. For the range of Reynolds numbers likely to be encountered in industrial boilers the following equations may be used:

In-line arrays $$Nu = 0.211 Re^{0.651} Pr^{0.34} F_1 F_2$$

Staggered arrays $$Nu = 0.273 Re^{0.635} Pr^{0.34} F_1 F_2$$

In these cases gas properties are evaluated at the bulk temperature, the characteristic dimension in Nu and Re is the tube outside diameter, and the Reynolds number is based on the mass velocity through the minimum area for flow between tubes. F_1 is a correction factor for wall to bulk property variation which can be calculated from the relationship:

$$F_1 = \frac{(Pr_b)^{0.26}}{(Pr_w)}$$

where Pr_b and Pr_f are Prandtl numbers at the bulk and wall temperatures, respectively. F_2 is a correction factor for the depth of the tube bank in the direction of flow.

Table 10.1 Transport properties: natural gas products of combustion

Temp. (°C)	*Spec. heat* (J/kg K)	*Viscosity* (kg/m s × 10^6)	*Conductivity* (W/m K × 10^3)	*Sp. vol.* (m^3/kg)
100	1098	20.01	27.27	1.1
200	1133	23.97	34.45	1.395
300	1166	27.55	41.34	1.69
400	1198	30.83	47.94	1.985
500	1227	33.89	54.25	2.28
600	1255	36.74	60.29	2.575
700	1281	39.44	66.09	2.87
800	1305	41.99	71.61	3.164
900	1328	44.43	76.86	3.459
1000	1348	46.75	81.86	3.754
1100	1367	48.98	86.6	4.049
1200	1384	51.13	91.08	4.344
1300	1400	53.2	95.31	4.639
1400	1413	55.2	99.25	4.934

Table 10.2 Transport properties: gas oil products of combustion

Temp. (°C)	*Spec. heat* (J/kg K)	*Viscosity* (kg/m s × 10^6)	*Conductivity* (W/m K × 10^3)	*Sp. vol.* (m^3/kg)
100	1061	20.32	27.24	1.058
200	1096	24.29	34.4	1.342
300	1128	27.88	41.22	1.625
400	1159	31.16	47.73	1.909
500	1188	34.2	53.92	2.192
600	1215	37.05	59.81	2.476
700	1240	39.72	65.42	2.76
800	1263	42.26	70.71	3.043
900	1284	44.67	75.73	3.327
1000	1303	46.98	80.46	3.61
1100	1320	49.19	84.89	3.894
1200	1336	51.32	89.02	4.177
1300	1349	53.37	92.88	4.461
1400	1361	55.35	96.43	4.745

For bank depths of 10 rows or more, $F_2 = 1$. For smaller bank depths the following values of F_2 may be used:

No. of rows	1	2	3	4	5
In-line tubes	0.64	0.8	0.87	0.9	0.92
Staggered tubes	0.68	0.75	0.83	0.89	0.92
No. of rows	6	7	8	9	
In-line tubes	0.94	0.96	0.98	0.99	
Staggered tubes	0.95	0.97	0.98	0.99	

Gas transport properties for the products of combustion of the common fuels, fired at normal excess air at or near-full boiler load, may be obtained from Tables 10.1–10.4. Non-luminous gas radiation has a small overall effect in the convective section, typically 2–5% of total convection. It may therefore be neglected for a conservative calculation.

10.2.6 Water-side conditions

In the radiant section of a boiler the fourth power of the wall temperature is typically less than 2% of the fourth power of the mean flame and gas temperature. The effect of water-side conditions and wall thickness on the heat transfer rate are therefore negligible.

Table 10.3 Transport properties: heavy fuel oil products of combustion

Temp. (°C)	*Spec. heat* (J/kg K)	*Viscosity* (kg/m s × 10^6)	*Conductivity* (W/m K × 10^3)	*Sp. vol.* (m^3/kg)
100	1054	20.37	27.22	1.05
200	1088	24.34	34.37	1.332
300	1121	27.93	41.17	1.613
400	1152	31.21	47.66	1.895
500	1181	34.25	53.82	2.176
600	1207	37.09	59.69	2.458
700	1232	39.44	66.09	2.87
800	1255	42.3	70.51	3.02
900	1276	44.71	75.47	3.302
1000	1294	47.01	80.15	3.583
1100	1311	49.22	84.51	3.865
1200	1326	51.35	88.59	4.146
1300	1339	53.40	92.38	4.428
1400	1351	55.38	95.86	4.709

Table 10.4 Transport properties: bit coal products of combustion

Temp. (°C)	*Spec. heat* (J/kg K)	*Viscosity* (kg/m s × 10^6)	*Conductivity* (W/m K × 10^3)	*Sp. vol.* (m^3/kg)
100	1031	20.82	27.43	1.034
200	1065	24.83	34.63	1.312
300	1096	28.44	41.39	1.589
400	1125	31.73	47.78	1.866
500	1152	34.78	53.8	2.143
600	1177	37.63	59.5	2.421
700	1201	40.3	64.88	2.698
800	1222	42.83	69.93	2.975
900	1242	45.24	74.68	3.252
1000	1259	47.55	79.11	3.53
1100	1275	49.75	83.23	3.807
1200	1289	51.87	87.05	4.084
1300	1301	53.92	90.56	4.361
1400	1311	55.89	93.77	4.638

Even the presence of a dangerous layer of water-side scale reduces the heat flux only by a few per cent. Although this means that scale has little effect on radiant section performance, it also indicates that the metal temperature escalation due to the presence of scale is not self-limiting but is almost proportional to scale thickness.

The thermal conductivity of an average boiler scale is 2.2 (W/m K) and that of complex silicate scales is 0.2–0.7 (W/m K). Since the furnace peak wall flux can be over 300 000 (W/m^2) it may readily be seen that a small thickness of scale can raise the metal temperature into the creep region, resulting in very expensive repairs.

In the convective section the gas-side heat transfer coefficient controls the heat flux distribution since the water-side coefficient and the thermal conductance of the tube walls are very large in comparison. For this reason, it is usually satisfactory to make an allowance by adding 10 K to the water temperature in steam boilers. In hot

water generators the allowance should be about 20 K, because sub-cooled nucleate boiling generally takes place only on the radiant walls and in shell boilers on the reversal chamber tubeplate. Water-side heat transfer on the major part of the convective heating surface in these units is by convection without boiling.

10.2.7 Further reading

A good introduction to the extensive literature on the science and technology of heat transfer, with 87 further references, is given in Rose, J. W. and Cooper, J. R., *Technical Data on Fuel*, 7th edition, British National Committee, World Energy Conference, London, p. 48 (1977).

10.3 Types of boiler

As this covers industrial boilers, only units of 500 kg/h of steam, or equivalent hot water, and above will be considered. There are nine categories of boiler available. In order of evaporation these are:

Cast iron sectional boilers
Steel boilers
Electrode boilers
Steam generators
Vertical shell boilers
Horizontal shell boilers
Watertube boilers
Waste heat boilers
Fluid bed boilers

10.3.1 Cast iron sectional boilers

These are used for hot water services with a maximum operating pressure of 5 bar and a maximum output in the order of 1500 kW. Site assembly of the unit is necessary and will consist of a bank of cast iron sections. Each section has internal waterways.

The sections are assembled with screwed or taper nipples at top and bottom for water circulation and sealing between the sections to contain the products of combustion. Tie rods compress the sections together. A standard section may be used to give a range of outputs dependent upon the number of sections used. After assembly of the sections, the mountings, insulation and combustion appliance are fitted. This system makes them suitable for locations where it is impractical to deliver a package unit, e.g. basements where inadequate access is available or rooftop plant rooms where sections may be taken up using the elevator shafts. Models available use liquid, gaseous and solid fuel.

10.3.2 Steel boilers

These are similar in rated outputs to the cast iron sectional boiler. Construction is of rolled steel annular drums for the pressure vessel. They may be of either vertical or horizontal configuration, depending upon the manufacturer. In their vertical pattern they may be supplied for steam raising.

10.3.3 Electrode boilers

These are available for steam raising up to 3600 kg/h and manufacture is to two designs. The smaller units are element boilers with evaporation less than 500 kg/h. In these, an immersed electric element heats the water and a set of water-level probes positioned above the element controls the water level being interconnected to the feedwater pump and the element electrical supply.

Larger units are electrode boilers. Normal working pressure would be 10 bar but higher pressures are available. Construction is a vertical pattern pressure shell containing the electrodes (Figure 10.1). The lengths of the electrodes control the maximum and minimum water level. The electrical resistance of the water allows a current to flow through the water which, in turn, boils and

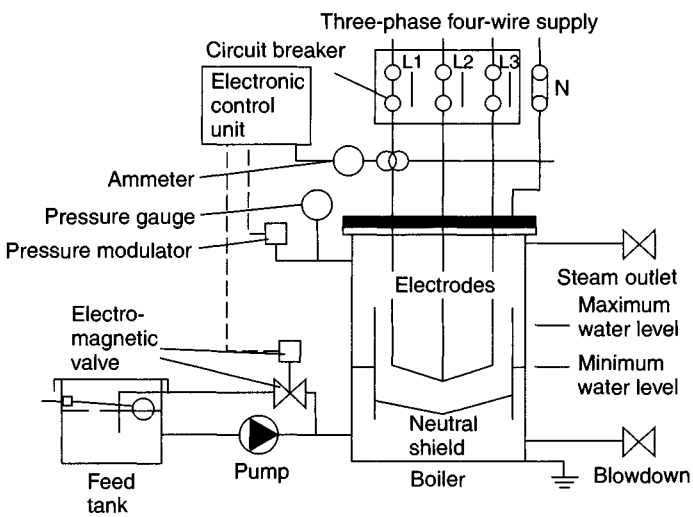


Figure 10.1 Diagrammatic layout of electrode boiler

releases steam. Since water has to be present within the electrode system, lack of water cannot burn out the boiler. The main advantage with these units is that they may be located at the point where steam is required and, as no combustion fumes are produced, no chimney is required. Steam may also be raised relatively quickly, as there is little thermal stressing to consider.

10.3.4 Steam generators

While the term 'steam generator' may apply to any vessel raising steam, this section is intended to cover coil type boilers in the evaporative range up to 3600 kg/h of steam. Because of the steam pressure being contained within the tubular coil, pressures of 35 bar and above are available, although the majority are supplied to operate at up to 10 bar. They are suitable for firing with liquid and gaseous fuels, although the use of heavy fuel oil is unusual.

The coiled tube is contained within a pressurized combustion chamber and receives both radiant and convected heat. A control system matches the burner firing rate proportional to the steam demand. Feedwater is pumped through the coil and partially flashed to steam in a separator. The remaining water is recirculated to a feedwater heat exchanger before being run to waste. Because there is no stored water in this type of unit they are lighter in weight and therefore suitable for siting on mezzanine or upper floors adjacent to the plant requiring steam. Also, as the water content is minimal, steam raising can be achieved very quickly and can respond to fluctuating demand within the capacity of the generator. It must be noted that close control of suitable water treatment is essential to protect the coil against any build-up of deposits.

10.3.5 Vertical shell boilers

This is a cylindrical boiler where the shell axis is vertical to the firing floor. Originally it comprised a chamber at the lower end of the shell which contained the combustion appliance. The gases rose vertically through a flue surrounded by water. Large-diameter (100 mm) cross tubes were fitted across this flue to help extract heat from the gases which then proceeded to the chimney. Later versions had the vertical flue replaced by one or two banks of small-bore tubes running horizontally before the gases discharged to the chimney. The steam was contained in a hemispherical chamber forming the top of the shell.

The present vertical boiler is generally used for heat recovery from exhaust gases from power generation or marine applications. The gases pass through small-bore vertical tube banks. The same shell may also contain an independently fired section to produce steam at such times as there is insufficient or no exhaust gas available.

10.3.6 Horizontal shell boilers

This is the most widely used type of boiler in industry. The construction of a single-flue three-pass wetback shell is illustrated in Figure 10.2. As a single-flue design boiler evaporation rates of up to 16 300 kg/h F and A 100°C are normal on oil and gas and 9000 kg/h F and A 100°C on coal.

In twin-flue design these figures are approximately double. Normal working pressures of 10–17 bar are available with a maximum working pressure for a shell boiler at 27 bar. The outputs of larger boilers will be limited if high pressures are required.

The boilers are normally despatched to site as a packaged unit with the shell and smokeboxes fully insulated and painted and mounted on a base frame. The combustion appliance and control panel will be fitted together with the feedwater pump, water-level controls and gauges and a full complement of boiler valves. Additional equipment may be specified and incorporated during construction. Larger boilers may have to have certain items fitted at site due to site restriction or weight.

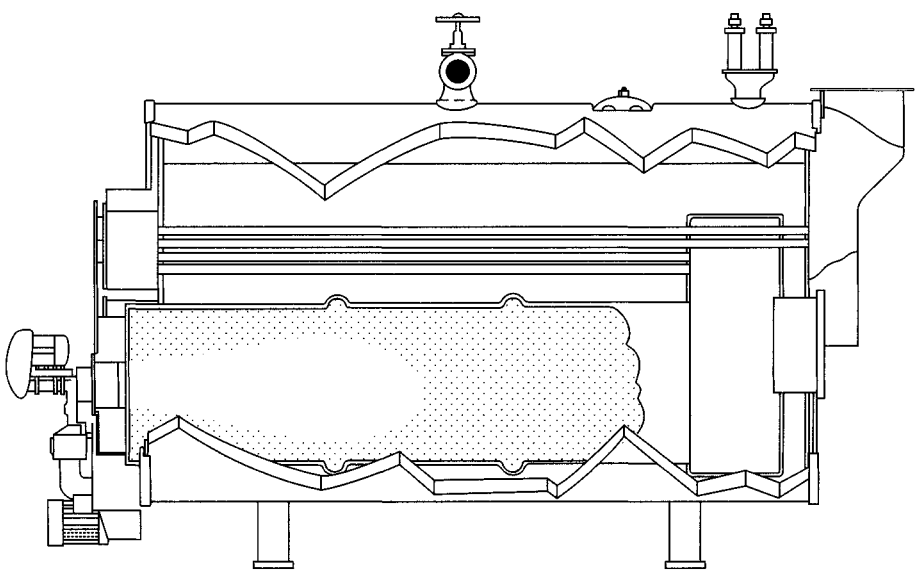


Figure 10.2 A three-pass wetback shell

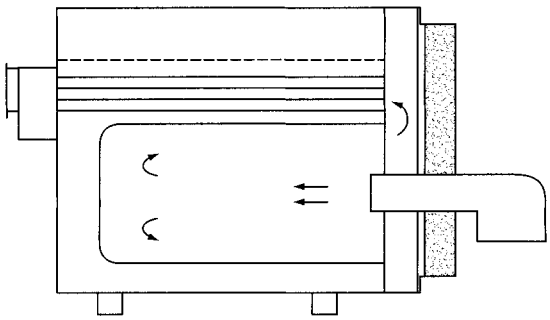


Figure 10.3 A reverse flame shell

Some variations of the three-pass wetback design exist. The most common is the reverse flame boiler, and Figure 10.3 illustrates this shell. In this design the combustion appliance fires into a thimble-shaped chamber in which the gases reverse back to the front of the boiler around the flame core. The gases are then turned in a front smokebox to travel along a single pass of smoketubes to the rear of the boiler and then to the chimney. In order to extract heat from these gases, turbulators or retarders are fitted into these tubes to agitate the gases and help produce the required flue gas outlet temperature. Evaporative outputs up to 4500 kg/h F and A 100°C on liquid and gaseous fuels are available.

Other variations of the three-pass wetback design are the two-pass, where only one pass of smoketubes follows the combustion tube, and the four-pass, where three passes of smoketubes follow the combustion tube. Neither of these are as widely used as the three-pass design.

Dryback boilers are still occasionally used when a high degree of superheat is required, necessitating a rear chamber to house the superheater too large for a semi-wetback chamber. A water-cooled membrane wall chamber would be an alternative to this.

With twin-flue design boilers it is usual to have completely separate gas passes through the boiler with twin wetback chambers. It is then possible to operate the boiler on one flue only, which effectively doubles its turndown ratio. For example, a boiler rated at 20 000 kg/h F and A 100°C may reasonably be expected to operate down to 2500 kg/h F and A 100°C on oil or gas providing suitable combustion equipment and control is incorporated. It would be good practice to alternate on a planned time scale which flue takes the single-flue load if prolonged periods of single-flue operation occur.

Shell boilers are supplied with controls making them suitable for unattended operation, although certain operations such as blowdown of controls are called for by the insurance companies to comply with safety recommendations.

Oil-, gas- and dual-fired boilers are available with a range of combustion appliances. The smaller units have pressure jet-type burners with a turndown of about 2:1 while larger boilers may have rotary cup, medium pressure air (MPA) or steam-atomizing burners producing a turndown ratio of between 3:1 and 5:1, depending upon size and fuel. The majority have rotary cup-type burners, while steam- or air-atomizing burners are used where it is essential that the burner firing is not interrupted even for the shortest period.

For coal-fired boilers, chain grate stokers, coking stokers and underfeed stokers are supplied. An alternative to these is the fixed-grate and tipping-grate boiler with coal being fed through a drop tube in the crown of the boiler (Figure 10.4). With the fixed grate, de-ashing is manual while with the tipping grate a micro-sequence controller signals sections of the grate to tip, depositing the ash below the grate, where it is removed to the front by a drag-link chain conveyor and then to a suitable ash-disposal system.

It is possible to have boilers supplied to operate on liquid, gaseous and solid fuels, although there may be a

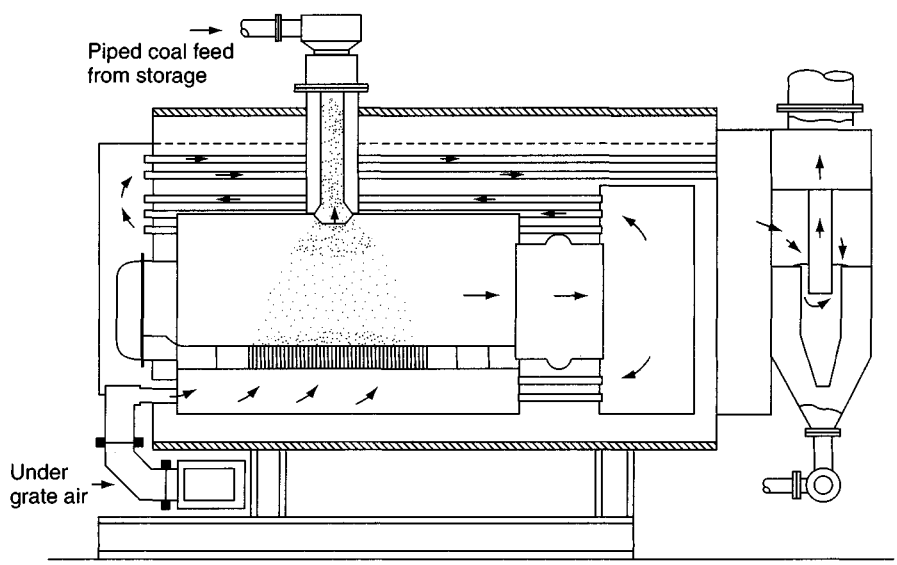


Figure 10.4 A fixed-grate coal-fired boiler

time penalty of two or three days when converting from solid to liquid and gaseous fuels and vice versa.

Access to both waterside and fireside surfaces of the boiler is important. All boilers will have an inspection opening or manway on the top of the shell with inspection openings in the lower part. Some larger boilers will have a manway in the lower part of the shell or end plate. With a three-pass wetback boiler all tube cleaning and maintenance is carried out from the front. The front smokebox doors will be hinged or fitted with davits. On most sizes of boilers bolted-on access panels are sufficient on the real smokebox. As the majority of shell boilers operate under forced-draught pressurized combustion, steam raising is relatively quick. While good practice could require a cold boiler to come up to pressure over a period of several hours once it is hot, it may be brought up to pressure in minutes, not hours.

For hot water shell boilers the above still applies. The shells would be slightly smaller for equivalent duties due to the absence of steam space. There are three accepted operated bands for hot water boilers. Low-temperature hot water (LTHW) refers to boilers having a mean water temperature (between flow and return) of below 95°C; medium-temperature hot water (MTHW) would cover the range 95–150°C; high-temperature hot water (HTHW) covers applications above 150°C.

The flow and return connections will be designed to suit the flow rates and temperature differentials required. The water-return connection will be fitted with either an internal diffuser or a venturi nozzle to assist mixing of the water circulating within the shell and prevent water stratification. The flow connection will incorporate the temperature control stat to signal control of the firing rate for the burner.

Hot water boilers are potentially more susceptible to gas-side corrosion than steam boilers due to the lower temperatures and pressures encountered on low- and medium-temperature hot water boilers. With low-temperature hot water especially, the water-return temperature may drop below the water dewpoint of 50°C, causing vapour in the products of combustion to condense. This, in turn, leads to corrosion if it persists for long periods of time. The remedy is to ensure that adequate mixing of the return water maintains the water in the shell above 65°C at all times. Also, if medium or heavy fuel oil is to be used for low- or medium-temperature applications it is desirable to keep the heat transfer surfaces above 130°C, this being the approximate acid dewpoint temperature of the combustion gases. It may be seen, therefore, how important it is to match the unit or range of unit sizes to the expected load.

10.3.7 Watertube boilers

Originally, watertube boilers would have been installed for evaporation of 10 000 kg/h of steam with pressures as low as 10 bar. At that time this would have been the maximum evaporation expected from a shell-type boiler. Now shell boilers are available at much greater duties and pressures as described in Section 10.3.6. It may be appreciated that there will be an overlap of types of boiler in this area, with watertube covering first for high-pressure applications and ultimately the larger duties. Figure 10.5 illustrates *an oil/gas fired* unit.

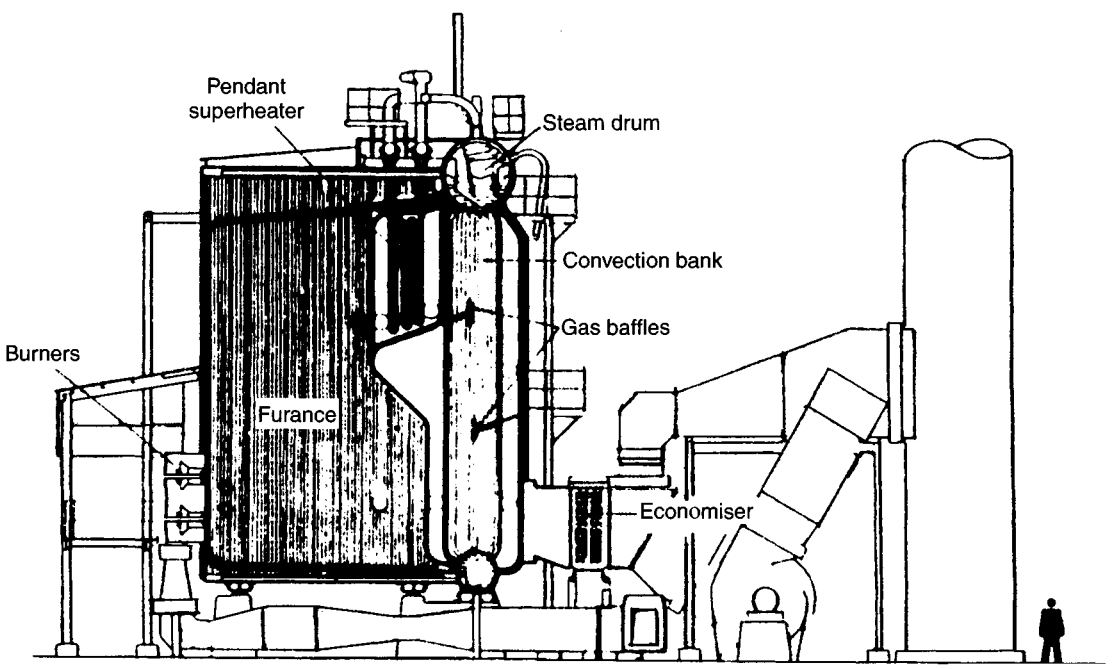


Figure 10.5 An oil/gas fired two drum water tube boiler with water cooled walls. Reproduced with kind permission from Pearson Education Limited from "Industrial Boilers" by Gunn and Horton (1989).

Generally, outputs up to 60 MW from a single unit may be considered for industrial installations. Higher duties are available if required. Watertube boilers supplied for national power generation will have outputs up to 900 MW, pressures of 140 bar and final steam temperatures of 500°C. For the smaller industrial unit we are considering, the maximum pressure would be 65 bar with final steam temperature up to 500°C. This is the maximum temperature and pressure likely to be required for small turbine-driven generating units, although turbines are available to operate at much lower pressures of, say, 17 bar.

Construction is a water-cooled wall combustion chamber connected to a steam drum at high level. The bottoms of the walls are connected to headers. Sometimes a bottom or mud drum is incorporated, but improved water treatment now available does not always necessitate this.

The chamber is externally insulated and clad. Combustion equipment for solid fuel may be spreader or travelling-grate stokers or by pulverized fuel or fluid bed. Oil and gas burners may be fitted either as main or auxiliary firing equipment. The boilers will incorporate superheaters, economizers and, where necessary, air preheaters and grit arresters and gas-cleaning equipment to meet clean air legislation.

Where watertube boilers are used to recover waste heat (for example, exhaust gases from reciprocating engines) lower gas temperatures may be involved, and this, in turn, could obviate the need for water-cooled walls. In this case, tube banks may be contained within a gas-tight insulated chamber.

There are two basic types of watertube boilers: assisted and natural circulation. Assisted circulation might apply where heat is from a convection rather than a radiation source such as a waste heat application. Natural circulation is more suited where radiant heat and high gas temperatures are present.

Depending upon the required duty and the site, units may be shop assembled or of modular construction. Site-erected units may be designed to have their main components arranged to fit in with the space available.

10.3.8 Waste-heat boilers

These may be horizontal or vertical shell boilers or watertube boilers. They would be designed to suit individual applications ranging through gases from furnaces, incinerators, gas turbines and diesel exhausts. The prime requirement is that the waste gases must contain sufficient usable heat to produce steam or hot water at the condition required.

Supplementary firing equipment may also be included if a standby heat load is to be met and the waste-gas source is intermittent. Waste-heat boilers may be designed to use either radiant or convected heat sources. In some cases, problems may arise due to the source of waste heat, and due consideration must be taken of this, with examples being plastic content in waste being burned in incinerators, carry-over from some type of furnaces causing strongly bonded deposits and carbon from heavy oil fired engines. Some may be dealt with by maintaining gas-exit temperatures at a predetermined level to prevent dewpoint being reached and others by sootblowing. Currently, there is a strong interest in small combined heat and power (CHP) stations, and these will normally incorporate a waste-heat boiler.

10.3.9 Fluid-bed boilers

The name derives from the firebed produced by containing a mixture of silica sand and ash through which air is blown to maintain the particles in suspension. The beds are in three categories, shallow bed, deep bed and recirculating bed. Shallow beds are mostly used and are about 150–250 mm in depth in their slumped condition and around twice that when fluidized. Heat is applied to this bed to raise its temperature to around 600°C by auxiliary oil or gas burners. At this temperature coal and/or waste is fed into the bed, which is controlled to operate at 800–900°C. Water-cooling surfaces are incorporated into this bed connected to the water system of the boiler.

The deep bed, as its name implies, is similar to the shallow bed but in this case may be up to 3 m deep in its fluidized state, making it suitable only for large boilers. Similarly, the recirculating fluid bed is only applicable to large watertube boilers.

Several applications of the shallow-bed system are available for industrial boilers, the two most used being the open-bottom shell boiler and the composite boiler. With the open-bottom shell the combustor is sited below the shell and the gases then pass through two banks of horizontal tubes.

In the composite boiler the combustion space housing the fluid bed is formed by a watertube chamber directly connected to a single-pass shell boiler. In order to fluidize the bed the fan power required will be greater than that with other forms of firing equipment.

To its advantage, the fluid bed may utilize fuels with high ash contents which affect the availability of other systems. It is also possible to control the acid emissions by additions to the bed during combustion. They are also less selective in fuels and can cope with a wide range of solid-fuel characteristics.

10.4 Application and selection

Figure 10.6 illustrates the selective bands for various types of boilers. The operating pressure will govern the steam temperature except where superheaters are used. For hot water units the required flow temperature will dictate the operating pressure. It is important that when arriving at the operating pressure for hot water units due allowance is made for the head of the system, an anti-flash steam margin of 17°C and a safety-valve margin of 1.5 bar.

In arriving at a decision to install one or more boilers the following should be considered. The first choice (providing the load is within the duty range of the boiler) will be a single unit. This is economically the most attractive in capital cost, providing account is taken of the following:

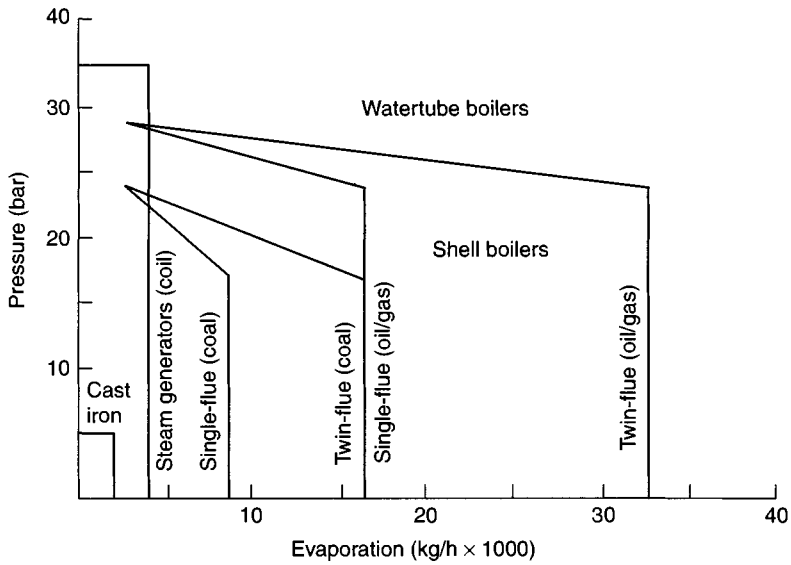


Figure 10.6 Guide to boiler capacities

1. If there is a breakdown on the boiler will production be seriously affected immediately?
2. Will adequate spare parts for the boiler be held in stock or available within an acceptable time, and will labour be available to carry out the repair work?
3. Will time be available to service the boiler?
4. The duty will preferably fall within the modulating firing rate of the burner.
5. Prolonged periods of intermittent operation are avoided.
6. Is there an existing standby unit?

If any or all of these points are not accepted, then the next consideration for a shell boiler could be a twin-flue unit suitable for single-flue operation. This has the advantage of using less space than two smaller boilers and having only one set of services.

Moving now to two boilers, the heat load may comprise two elements. One may be a production process whose interruption would cause problems and the other, say, a heating load where any interruption would not be noticed immediately. Assuming the two elements were of equal duty, it would be reasonable to install two boilers each 50–50% of the total load. One boiler would then be able to cover the process load.

An extension to this is to install two boilers, each capable of handling the total combined load. Depending upon the boiler size, there may be only a relatively small difference in total capital cost between the above two schemes.

Further options involving three or more boilers must take into account minimum and maximum loads in order to run the plant efficiently. When considering hot water it may be advantageous to consider units in a range of outputs. This will help in operation, so that a unit may be brought into duty to match the load and thus avoid low-load conditions and consequent danger of dewpoints. Also if the plant is fired on solid fuel it will help in maintaining a more even firing rate and a clean stack.

10.5 Superheaters

Steam produced from a boiler is referred to as dry saturated, and its temperature will correspond with the working pressure of the boiler. In some instances, particularly with shell boilers, this is perfectly acceptable. There are occasions, however, where it is desirable to increase the temperature of the steam without increasing the pressure. This function is performed by a superheater. Steam from the drum or shell of the boiler is passed through a bank of tubes whose external surfaces are exposed to the combustion gases, thus heating the steam while not increasing the pressure.

Where a superheater is fitted the boiler working pressure must be increased to allow for the pressure drop through the elements. This will be between 0.3 and 1.0 bar.

In a watertube boiler the superheater is a separate bank of tubes or elements installed in the area at the rear or outlet of the combustion chamber. Saturated steam temperature may be increased by 200°C with a final steam temperature of up to 540°C.

For shell boilers, superheaters may be one of three types, depending upon the degree of superheat required. The first and simplest is the pendant superheater installed in the front smokebox (Figure 10.7). The maximum degree of superheat available from this would be around 45°C. The second pattern is again installed in the front smokebox but with this the elements are horizontal 'U' tubes which extend into the boiler smoketubes. The degree of superheat from this pattern is around 80°C. Third, a superheater may be installed in the reversal chamber of the boiler. A wetback chamber presents problems with lack

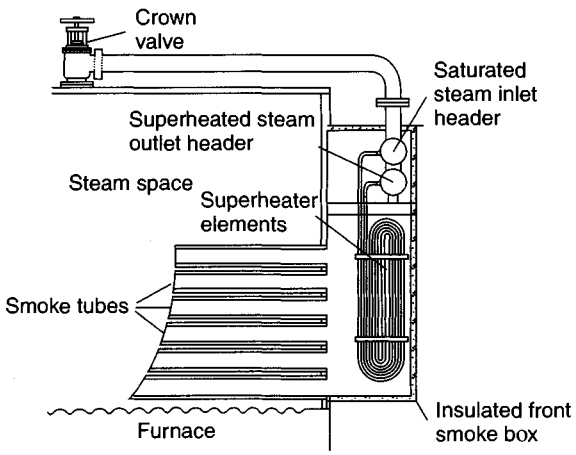


Figure 10.7 Front smokebox pendant superheater (with permission of Senior Thermal Engineering Ltd)

of space, and therefore either a semi-wetback, dryback or water-cooled wall chamber may be considered. Maximum degree of superheat would be around 100°C.

Superheater elements are connected to inlet and outlet headers. The inlet header receives dry saturated steam from the steam drum of a watertube boiler or the shell of a horizontal boiler. This steam passes through the elements where its temperature is raised and to the outlet header which is connected to the services. A thermometer or temperature recorder is fitted to the outlet header.

It should be appreciated that a steam flow must be maintained through the elements at all times to prevent them burning away. If a single boiler is used then provision to flood the superheater during start-up periods may be required.

Superheated steam may be needed where steam distribution pipework in a plant is over extended distances, resulting in a loss of heat and increase in wetness of the steam. Another case may be where a process requires a temperature above the working pressure of the plant. The third case is where steam is used for turbines. Here it improves the performance of the turbine, where for every 6°C increase in steam temperature it can produce a saving of about 1% reduction in steam consumption. Superheaters may also be supplied as independently fired units. These may be used when either the amount of superheated steam required is much less than the boiler evaporation or is only needed on an intermittent basis.

10.6 Economizers

Economizers are installed in the exhaust gas flow from the boiler. They take heat from the flue gases which they transfer via extended surface elements to the feedwater immediately prior to the water entering the boiler. They therefore increase the efficiency of the boiler and have the added advantage of reducing thermal shock. In watertube boilers they may be incorporated within the structure of the boiler or supplied as a free-standing unit. With shell boilers they will be a separate unit fitted between the boiler flue gas outlet and the chimney.

Figure 10.8 is a schematic illustration of such a unit. It is desirable for each boiler to have its own economizer. Where one economizer is installed to take the exhaust gases from more than one boiler special considerations must be taken into account. These will include gas-tight isolation dampers. Consideration must be made of flue-gas pressures at varying loads and maximum and minimum combined heat load to match economizer and a pumped feedwater ringmain. Economizers may be used for both forced-draught and induced-draught boilers, and in both cases the pressure drop through the economizer must be taken into account when sizing the fans.

Economizers are fitted to most watertube boilers. An exception is on a waste-heat application, where it may be desirable, due to the nature of the products being burned, to maintain a relatively high gas outlet temperature to prevent corrosive damage to the boiler outlet, ductwork and chimney.

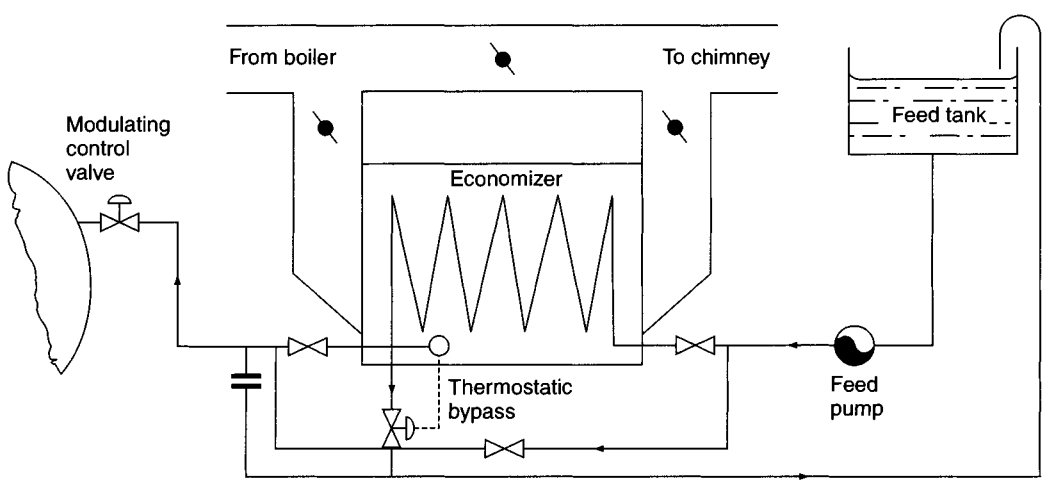


Figure 10.8 Schematic illustration of an installed economizer

With watertube boilers economizers may be used when burning coal, oil or gas. The material for the economizer will depend on the fuel, and they may be all steel, all cast iron or cast iron protected steel. All steel would be used for non-corrosive flue gases from burning natural gas, light oil and coal. Cast iron may be used where the feedwater condition is uncertain and may attack the tube bore. Fuels may be heavy fuel oil or coal, and there is a likelihood of metal temperatures falling below acid dewpoint. Cast iron protected steel is used when heavy fuel oil or solid fuel firing is required and feedwater conditions are suitably controlled. As cast iron can withstand a degree of acid attack, these units have the advantage of being able to operate without a gas bypass, where interruptible natural gas supplies are used with oil as standby.

With shell boilers, economizers will generally only be fitted to boilers using natural gas as the main fuel and then only on larger units. It would be unlikely that a reasonable economic case could be made for boilers of less than 4000 kg/h *F* and *A* 100°C evaporative capacity. The economizer will incorporate a flue gas bypass with isolating dampers to cover for periods when oil is used and for maintenance. The dampers require electric interlocks to the selected fuel.

As the majority of shell boilers operate in the pressure range 7–10 bar, the flue gas outlet temperature will be in the range of 190–250°C. It may be appreciated from this that the boiler needs to operate at 50–100% of its maximum continuous rating for most of the working day to produce an economic return.

Where an economizer is installed it is essential to have water passing through the unit at all times when the burners are firing to prevent boiling. Therefore boilers fitted with economizers will have modulating feedwater control. Even then, it is possible that the water flow requirement can become out of phase with the burner firing rate. To prevent damage, a temperature-controlled valve allows a spillage of water back to the feedwater tank, thus maintaining a flow of water through the unit. Each economizer will be fitted with a pressure-relief safety valve.

Due to the amount of water vapour produced when natural gas is burned, it is important not to allow the exhaust gas temperature to fall below 80°C, otherwise the water dewpoint will be reached. Not only the economizer but also the ductwork and chimney must be considered and provision incorporated for drainage.

In the event of a separate use for low-grade hot water being available, it is sometimes practical to install a secondary condensing economizer. With this, the material of which the economizer is constructed allows for condensate to form and drain away without excessive attack from corrosion.

A recent development in heat recovery has been the heat tube. This is a sealed metal tube which has been evacuated of air and contains a small quantity of liquid which, for boiler applications, could be water. When heat from the flue gases is applied to one end of the heat pipes the water in the tube boils, turning to steam and absorbing the latent heat of evaporation. The steam travels to the opposite end of the tube which is surrounded by water, where it gives up its latent heat, condenses and returns to the heated end of the tube. Batteries of these tubes can be arranged to form units, usually as a water jacket around a section of a flue.

10.7 Water-level control

Water-level controls continuously monitor the level of water in a steam boiler in order to control the flow of feedwater into the boiler and to protect against a low water condition which may expose the heating surfaces with consequent damage. The control may be float operated but modern plant will have conductivity probes. The probes will be fitted in pads or standpipes on the crown of the shell or drum and enclosed in a protection tube which will extend to below the lowest water level. The open bottom of the protection tube shall be so designed that ebullition within the boiler does not give rise to a false alarm or lock out situation.

With watertube boilers the control of the water level needs to be precise and sensitive to fluctuating loads due to the high evaporative rates and relatively small steam drums and small water content. Control will be within ±10 mm on the working water level and will be two- or three-element control. Two-element control will comprise modulating feedwater control with first low water alarm and high–low control with low-water cut-out and alarm. The second element will be monitoring of the steam flow to give early indication of any increase in steam demand. This signal may then be linked to the firing rate of the burners and the feedwater modulating valve. The third element senses a drop in feedwater demand, which would signal the firing rate of the burners to modulate down.

Shell boilers will have two sets of independent controls. Boilers up to about 9000 kg/h *F* and *A* 100°C will have a dual control and either a single or high–low control. The dual control instigates the feedwater pump, which operates on an on–off cycle over a water level band of ±15 mm and also operates the first low-water alarm. The single or high–low control will incorporate a second low-water alarm with burner lockout and with the high–low control also an indication of high water, which may be linked to shut down the feedwater pump with automatic restart when the water level drops to normal.

Boilers of larger evaporations will have modulating and high–low control. The modulating level control monitors the working water level in the shell and operates a control valve in the feedwater line, allowing water to enter the boiler from a continuously running feed pump. It will also incorporate the first low-water alarm. The high–low control operates as before.

The advantage of modulating control is that it maintains a constant working water level and therefore the boiler is always in its best condition to supply steam for peak loading. These controls may also be fitted to boilers below 9000 kg/h *F* and *A* 100°C particularly if severe loads are present or when the working pressure is above 10 bar.

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With water level controls it is important to check they are functioning correctly. External controls will be operated daily to simulate low water conditions. On shell boilers this is normally a manual operation but may

be motorized on water tube boilers. Where conductivity probes are fitted these can be supplied for self monitoring operation.

10.8 Efficiency

This is the ratio of heat input to the useful heat output of the boiler, taking account of heat losses in the flue gases, blowdown and radiation. It is covered in BS 845: Part 1, which fully details the concise or losses method of determining the efficiency of a boiler.

10.9 Boiler installation

Figure 10.9 illustrates the services required for a boiler. The individual items are covered separately in other sections and only the general concept is being considered here.

If boilers are being replaced it is reasonable to expect that existing services will be available, apart from possible upgrading in some areas. For new installations a new building is likely to be required, and it will first be necessary to determine the overall size and type of construction.

Starting with the boiler(s), these will be set out giving due consideration to space between boilers and other items of plant in order to give adequate access to all equipment, valves and controls for operation and maintenance. For small- to medium-sized boilers 1 m may be considered a reasonable space between items of plant where access is required. With large boilers (including watertube) this may be increased up to 3 m. The width of firing aisle will be dependent upon the size and type of boiler.

Having now established the space requirement for the boilers, we must consider the other items of plant to be housed in the same structure. These may include water-treatment plant, heat-recovery system, tanks and pump, instrument and controls. With oil- and gas-fired installations there is little additional plant to consider within the boiler house. With solid fuel then the handling, distribution and perhaps storage could also form part of the building with provision for ash handling and removal.

Access for air into the boiler house must be considered. Air for combustion will be drawn in through purpose-made louvres and care should be taken that this air does not create a hostile environment to personnel in the building. Also, passage of air across cold water pipes should be avoided, as in cold weather this may aggravate freezing in the pipes.

Ventilation will also be required. With gas-fired installations this is mandatory, and specified free areas must be provided.

The fabric of the building may range from a basic frame and clad structure offering minimum weather protection to a brick and concrete construction. While it is possible to weatherproof boilers for outside installation, it should be remembered that the occasion will arise when someone is going to carry out maintenance or service work, and if weather conditions are inclement, this may prove impractical. Two instances where outdoor installation may be considered are where the climatic conditions of the country permit and in the case of waste-heat boilers where controls are minimal.

Foundations and trenches will be formed prior to boiler delivery. The boiler house structure may be erected before or after delivery of the boilers, dependent upon site conditions and the type of boiler. Due consideration will be given to access openings and doorways and provision for lifting any items of plant once the boiler house is complete.

Noise may be considered in two areas, one being an unacceptable level of noise to adjacent areas and the other an excessive noise level for personnel inside the boiler house. With the first, the type of construction of the building together with position of openings and the fitting of acoustic louvres for air ingress will all help to reduce external noise. As an extension to this and to also reduce noise for personnel within the building, all items of plant generating noise may be considered. These will generally be forced-draught fans and feedwater pumps. Various degrees of silencing are available for combustion appliances and feed pumps may be housed in a separate enclosure within the building.

External to the boiler house, provision for the storage and handling of solid and liquid fuel is required with access for delivery vehicles. With some small boilers such as electrode or steam-coil generators, where the

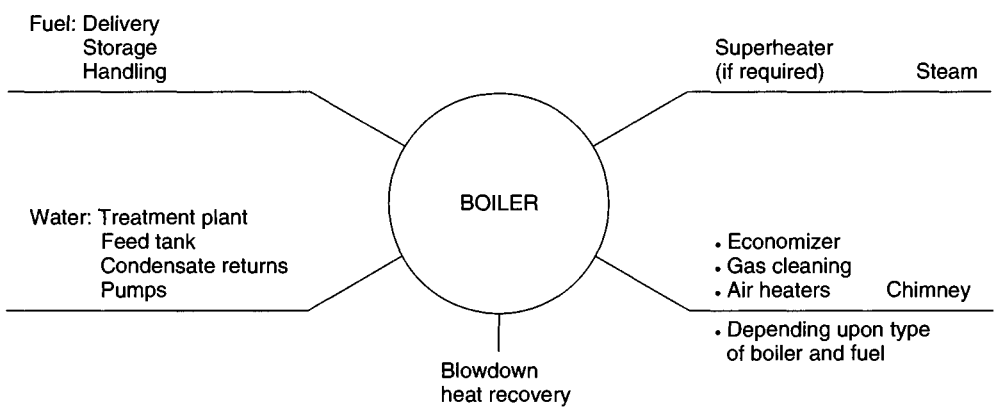


Figure 10.9 Boiler services

boiler only serves a single item of plant or process, it is practical to install them immediately adjacent to that process. The electrode boiler is eminently suitable here as no combustion gases are produced.

10.10 Boiler house pipework

Pipework layout should be designed so that it does not restrict access to the plant or building. Walkways and gantries should be considered when deciding on pipe service routes.

Where pipework is subject to temperature such as steam and hot water mains a means for expansion must be included to prevent undue stresses to valves and building structure. Balancing the steam flow from a range of boilers is important, particularly if the load may include peaks of more than one boiler capacity. To achieve this balance, the pressure drop in each steam line from the boiler crown valve to the distribution manifold should be the same, so that any imposed load will be shared between all on-line boilers. Failure to provide balanced steam headers may give rise to the lead boiler losing pressure, priming and locking out, thus aggravating the situation for the remaining on-line boilers.

Steam lines from the boiler should always drain away from the boiler crown value to prevent condensate building up against the valve. Careless opening of this valve to allow steam to pass when the line is flooded can result in splitting the valve and pipework. If the steam line rises from the crown valve a tee trap must be installed and fitted with a steam trap and drain valve. The drain valve must be operated to check that the steam line is clear of water before the crown valve is opened.

Safety-valve vent pipework should be run on the shortest possible route. Where bends or long runs occur, the pipe size may have to be increased to prevent back pressure on the safety valve during operation.

Feedwater pipework will normally be gravity head suction from the hotwell or feed tanks to the pumps and at a pressure in excess of the boiler working pressure from the pumps to the boiler. Few problems occur on the pipework between pumps and boilers. However, inadequately sized suction lines can give rise to cavitation at the feed pump with subsequent boiler shutdown. The feed tank should always be positioned to suit the temperature of the feedwater and the pipework sized to give free flow at that head, taking account of bends, valves and filters.

Fuel lines should be run where they will not be subject to high temperatures and must include protection with automatic and manual shut-off fire valves at the perimeter of the boiler house. Individual boilers should also be capable of isolation from this supply. Local requirements may vary on fuel supply systems, and these should be ascertained before installation.

Blowdown and drains may be taken to either a sump or blowdown tank prior to discharging into the drains. The purpose of this is to reduce the temperature by dilution and dissipate the pressure to prevent damage to the drains. This is covered in greater detail in Section 10.13.

All pipework must be installed to the appropriate standard and codes of practice. The degree of insulation will be suitable for the temperature of the pipework, although the finish may vary, depending upon site preferences. Valve boxes are recommended, although on some low-pressure installations these are not always included.

10.11 Feedwater requirements

Poor or unsuitable water can be a major factor where failure in a boiler occurs. There are four problem areas for which feedwater needs suitable treatment and control. These are sludge, foam, scale and corrosion.

Boiler feedwater may be from various supplies. If it is from a mains water supply, further filtering prior to treatment is unlikely, but for other supplies such as borehole, lakes, rivers and canals, filters may be required. Impurities in water may be classed as dissolved solids, dissolved gases and suspended matter and suitable treatment is required.

Table 10.5 shows the recommended water characteristics for shell boilers and Table 10.6 the water quality guidelines for industrial watertube boilers. Due to the wide parameters encountered in the quality of feedwater it is not possible to be specific and to define which treatment suits a particular type and size of boiler. The quality of make-up and percentage of condense returns in a system will both have to be taken into consideration.

Table 10.5 Recommended water characteristics for shell boilers

For pressures up to 25 bar[a]			
Total hardness in feedwater, mg/l in terms of $CaCO_3$ max.	2	20	40
Feedwater			
pH value	7.5–9.5	7.5–9.5	7.5–9.5
Oxygen	[b]	[b]	[b]
Total solids, alkalinity, silica	[b]	[b]	[b]
Organic matter	[b]	[b]	[b]
Boiler water			
Total hardness, mg/l in terms of $CaCO_3$ max.	ND	ND	ND
Sodium phosphate, mg/l as $Na_3PO_4^c$	50–100	50–100	50–100
Caustic alkalinity, mg/l in terms of $CaCO_3$ min.	350	300	200
Total alkalinity, mg/l in terms of $CaCO_3$ max.	1200	700	700
Silica, mg/l as SiO_2 max.	Less than 0.4 of the caustic alkalinity		
Sodium sulphite, mg/l as Na_2SO_3	30–70	30–70	30–70
or			
Hydrazine, mg/l as N_2H_4	0.1–1.0	0.1–1.0	0.1–1.0
Suspended solids, mg/l max.	50	200	300
Dissolved solids, mg/l max.	3500	3000	2000

–: Not applicable.
ND: Not detectable.
[a]1 bar=105 N m^2 = 100 kPa = 14.5 lb/in^2.
[b]Numerical values depend upon circumstances but the comments are relevant.
[c]Phosphate is usually added as sodium phosphate but determined as phosphate (PO_4^3); $Na_3PO_4 = 1.73 \times PO_4^3$.
Based on Table 2 of BS 2486:1978, by permission of BSI.

Table 10.6 Water-quality guidelines recommended for reliable, continuous operation of modern industrial watertube boilers

Boiler feedwater

Drum pressure (lb/in^2 g)	*Iron (ppm Fe)*	*Copper (ppm Cu)*	*Total hardness (ppm $CaCO_3$)*
0–300	0.100	0.050	0.300
301–450	0.050	0.025	0.300
451–800	0.030	0.020	0.200
601–750	0.025	0.020	0.200
751–900	0.020	0.015	0.100
901–1000	0.020	0.015	0.050
1001–1500	0.010	0.010	ND[d]
1501–2000	0.010	0.010	ND[d]

Boiler water

Drum pressure (lb/in^2 g)	*Silica (ppm SiO_2)*	*Total alkalinity[a] (ppm $CaCO_3$)*	*Specific conductance (μmho/cm)*
0–300	150	350[b]	3500
301–450	90	300[b]	3000
451–600	40	250[b]	2500
601–750	30	200[b]	2000
751–900	20	150[b]	1500
901–1000	8	100[b]	1000
1001–1500	2	NS[c]	150
1501–2000	1	NS[c]	100

[a]Minimum level of hydroxide alkalinity in boilers below 1000 lb/in^2 must be individually specified with regard to silica solubility and other components of internal treatment.
[b]Maximum total alkalinity consistent with acceptable steam purity. If necessary, the limitation on total alkalinity should override conductance as the control parameter. If make-up is demineralized water at 600–1000 lb/in^2 g, boiler water alkalinity and conductance should be shown in the table for the 1001–1500 lb/in^2 g range.
[c]NS (not specified) in these cases refers to free sodium- or potassium-hydroxide alkalinity. Some small variable amount of total alkalinity will be present and measurable with the assumed congruent control or volatile treatment employed at these high-pressure ranges.
[d]None detectable.

For some small boilers it may be possible to supply internal dosing subject to a suitable water supply and other conditions being favourable. However, for anything other than very small installations, external treatment is recommended.

For shell boiler installations a simplex or duplex base exchange system with suitable dosing is usual, although on larger installations or if the water is excessively hard and there is little condense return then a de-alkalization plant may be used.

For watertube boilers base exchange or de-alkalization may be used providing the water quality is suitable and the boilers are not operating at pressures in excess of 30–35 bar. With modern watertube boilers demineralized water is recommended. Where boilers are operating at high pressures or are used for power generation it is essential to use demineralized water in order to prevent build-up of deposits, particularly silica, on turbine blades.

With hot water installations it is equally important that water suitably treated for hardness and corrosion should be used. Even when cleaning or flushing a new or modified system, care must be taken to prevent premature corrosion occurring by the addition of a suitable treatment. Few (if any) hot water systems are completely sealed, and provision should be designed into the system to treat all make-up water. Draw off of hot water directly from the system should never be done and a calorifier must always be used. Analysis of the water in the boiler and system should be carried out at least monthly and more frequently during the commissioning period of a new installation or where an existing system has been refilled.

Where steam or hot water boilers are not required to operate for a period of time it is important that suitable measures are taken to prevent water-side corrosion. For periods of a few days the water may be left at its normal level but daily testing should be carried out as if the boiler were in use and corrective treatment added as necessary. If the period is for several months then the boiler should be fully flooded to exclude all air and the water treated. Regular testing of this water should be carried out and corrective treatment used. For longer periods, boilers should be drained completely and thoroughly dried out. The boiler may then either be left vented with the addition of a small electric heater inside or sealed and trays of moisture-absorbing chemicals such as hydrated lime or silica gel laid inside. In potentially damp atmospheres such as near coasts the dry method is preferred, as keeping the boiler full of cold water will cause condensation to be continuously present on the fire-side, giving rise to surface corrosion.

10.12 Feedwater supply and tanks

The design, size and siting of the boiler feed tank or hotwell must be compatible with the boiler duty capacity and system temperatures. They should be installed giving sufficient space for access to controls, valves and manways.

The tank will normally be of fully welded construction from either stainless steel or mild steel suitably braced and stiffened. In the case of mild steel tanks the internal surfaces should be shot blasted and a protective plastic coating applied. It is important that any possible future connections are incorporated before application of the lining. The tank should have a sealed top with adequate bolt-on access covers. This will keep out foreign bodies and also protect the water surface from the atmosphere, where it would absorb oxygen. Adequate venting must be included to prevent any build-up of pressure from either heating or condense returns.

Sectional tanks may be installed for convenience in restricted places, but great care must be taken if they are subject to temperature variations which can give rise to joint problems.

The following connections will be required in addition to the vent already referred to:

1. Feedwater take-off. This will be from the bottom of the tank and preferably from the base with a weir pipe

extending 50–100 mm up into the tank. If the take-off is from the side of the tank the bottom of the pipe bore must be a similar dimension up from the base. This allows sludge to remain in the tank which should be inspected and cleaned as required.
2. Drain pipework will be directly from the bottom of the tank.
3. Overflow pipework should be sized to meet the supply quantity to the tank and run so that visible evidence is obvious of an overflow condition.
4. Condense returns. Where returns arrive at the feed tank from several sources it is desirable to bring them together with a collection manifold at the top of the tank. The manifold then has a dip pipe extending down into the tank terminating in a sparge pipe. This method reduces the risk of entraining air in the returns and also helps to promote mixing of the water in the tank. Alternatively a de-aerator head may be installed to the tank. Here condense return and make up water may mix before discharging into the tank through the low level sparge.
5. Make up water in most installations will be supplied through a suitable treatment plant. Depending upon its source a break tank and pump set may be required. Control of supply to the feed tank will be through a flow control valve which in turn is controlled by conductivity probes or level switches. This method permits a positive flow through the treatment plant and avoids slippage.
6. Chemical dosing. This is a connection into the tank with an internal diffuser for any corrective treatment required for the water.
7. Level indicator. This may be either visual or electrical or both.

Additional connections may also be required for the following:

8. Flash steam. This will result from the blowdown heat recovery referred to in Section 10.13. Flash steam is introduced into the tank through a dip pipe terminating in a distribution manifold near the bottom of the tank.
9. Tank heating. This is referred to in detail later in this section.
10. Thermometer.

Connections should be arranged to avoid short circuiting between the tank supply and take-off to the boiler feed. Also, adequate mixing within the tank is required to prevent stratification.

With the capacity of the feed tank, assuming that there is an adequate supply of water either from mains or local storage, a 1 h supply should be considered a minimum. This would be based on a continuous supply of make-up water being available such as from a duplex treatment plant. If the supply of make-up is not continuous then the tank capacity must be increased. For example, a base exchange plant will take about 75 min to regenerate, and in that case the tank capacity should be able to sustain a supply of water to the boiler for 90 min in order to give a safety margin. The treatment plant then has to supply a quantity of water in excess of the boiler demand rate in order to replenish the tank. On top of this capacity a volume has to be allowed for condense returns when the system starts in order to prevent wastage of heat and water. As steam capacities increase, the feed tank becomes correspondingly larger, and it may be considered that on steam outputs in excess of 20 000 kg/h a duplex treatment plant should be installed in order to keep the feed tank to a reasonable size.

In areas where the water demand of the plant may exceed the supply capacity of the local mains it will be necessary to install additional storage tanks. It is likely that if the local supply is subject to low flow rates additional storage is already available for services such as fire protection.

Feedwater to the boiler should not be cold, as this can cause harmful thermal stresses to the boiler. A minimum feedwater temperature of 70–80°C should be designed into the system. This increased temperature has the added advantage that it accelerates some water-treatment reactions and also helps to remove oxygen and other gases from the feedwater. Once the system is working, this higher temperature may be achieved from the condense returns, but this condition is not effective until the plant has been running for some time. A tank heating system should therefore be installed. This is best achieved by direct steam injection into the feed tank. Steam is taken from the boiler and reduced in pressure to 1–5 bar to reduce noise in the tank. Passing through a thermostatic control valve, the steam mixes with the water in the tank through a sparge pipe or steam nozzle.

With watertube boilers economizers are normally used, therefore the situation of cold feed to the boiler would not apply. However, the feed to the economizer should be treated similarly to that to a boiler to reduce thermal shock.

With the feedwater being raised in temperature it is necessary to avoid cavitation at the inlet to the boiler feed pump. One method of reducing this problem is to elevate the feed tank to give an adequate positive head at the pump. The following are recommended heights to the minimum water level in the tank at various temperatures:

88°C–1.6 m
93°C–3.1 m
99°C–4.6 m
100°C–5.2 m

The feed tank should always be insulated to reduce heat loss to a minimum. Figure 10.10 illustrates typical heat losses from a feed tank operating at 93°C in an ambient temperature of 21°C with and without 50 mm of insulation.

10.13 Blowdown requirements, control and tanks

In order to maintain the level of dissolved and suspended solids within the boiler as recommended in Section 10.11 it is necessary for the boiler to be blown down. This is an operation where a quantity of water is drained from the

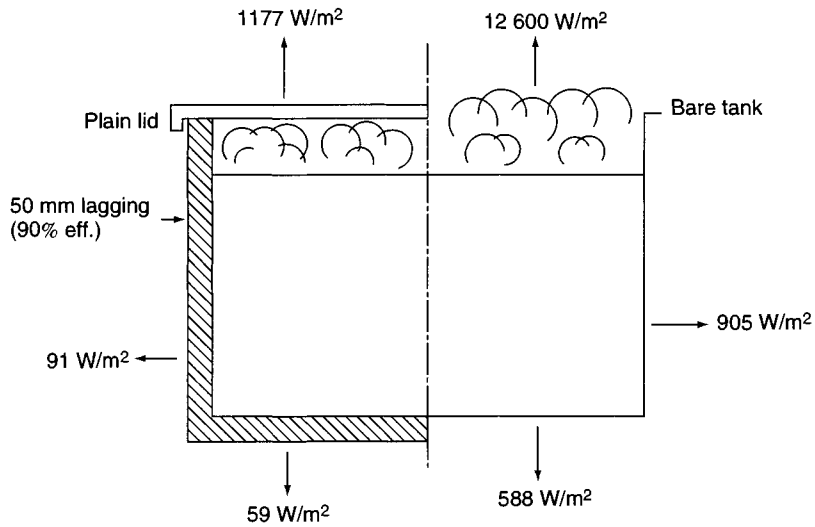


Figure 10.10 Heat losses from a feedwater tank operating at 93°C with ambient 21°C

boiler while the boiler is operating at pressure and may be achieved by various methods.

The simplest and that applied to small boilers is for the main bottom blowdown valve to be opened for a set period of time at regular intervals (e.g. 20 s every 8 h). This method may also extend to larger boilers where conditions are such that there is little build-up of solids. Such conditions could be high condense returns and good-quality make-up feedwater.

The second method could be automatic intermittent blowdown. With this, a timer-controlled valve is installed at the bottom of the boiler prior to the main blowdown valve. A programme is then designed to operate this valve in short bursts which disperses any sludge and controls the levels of solids. This method is preferred for boilers having internal treatment.

The third method would be continuous blowdown through a regulating or micrometer valve. The take-off position for this should preferably be about 250 mm below the working water level and may either be on the side of the shell or on the crown with a dip pipe down to the correct level. If a connection is not available it is possible to install the valve on the bottom connection prior to the main blowdown valve.

All these methods will require careful monitoring initially to set up and determine the correct rate of blowdown once the plant is operating. In order to take the necessary sample from the boiler the boiler(s) should be fitted with a sample cooler. To automate the continuous blowdown a conductivity-controlled system may be installed. Here a controller continuously compares the boiler water electrical conductivity with a value set in the controller. Depending on whether this is above or below the set rate, it will automatically adjust the blowdown flowrate.

While the above methods control the level of dissolved and suspended solids in the boiler, it will still be an insurance requirement to operate the main blowdown valve periodically.

The minimum amount of blowdown may be calculated as a percentage of the evaporation rate by:

$$\text{Blowdown rate} = \frac{F}{B - F} \times 100\%$$

where F = the total dissolved solids content of the feed in parts per million allowing for the mixture of make-up and condensate plus any chemical treatment and B = the maximum recommended solids content for boiler water in parts per million.

While vitally necessary, blowdown can be expensive in terms of lost heat. Therefore a point will be reached when it is economical to install a blowdown heat recovery system. Generally, the heat content in the blowdown water for a shell boiler will represent only about 25% of the heat content in the same percentage of steam. Therefore if a blowdown rate of 10% is required this represents an approximate heat loss of 2.5% from the boiler capacity. This differential reduces and eventually becomes insignificant on high-pressure watertube boilers.

The blowdown from the boiler(s) will be run to a flash-steam vessel mounted adjacent to the feed tank. Flash steam will be introduced into the feed tank through a dip pipe terminating in a distribution manifold. The drain from the flash vessel may then be taken to a residual blowdown heat exchanger. Any remaining heat is then transferred to the make-up water to the tank before the blowdown runs to drain.

Blowdown from the boiler(s) should always be taken to either a blowdown sump or blowdown vessel before discharging into drains. Both should be adequately sized to give cooling by dilution and be fitted with vent pipes to dissipate pressure safely. Each boiler shall have independent drain lines for main, auxillary and water level controls/gauges blowdown. Where these connect to the manifold of a blowdown vessel each line shall be fitted with an isolating and non return valve.

Blowdown sumps will be constructed from brick and/or concrete and the blowdown lines will drain under gravity. Where the blowdown lines enter the sump they will turn to discharge downwards and the bottom of the sump will be protected below this area with a cast iron tray to prevent erosion. The drain or overflow from the pit will be at such a level to produce a weir effect, thus holding water for dilution.

With a blowdown vessel these may be installed at ground level, and thus the water in them can be above the boiler blowdown valve. In this case, a drain valve for maintenance purposes must be installed at the lowest point in the line between the boiler and the vessel. The vessel may also be fitted with a cooling water dilution system to control the exit water temperature to the drains.

10.14 Clean Air Act requirement for chimneys and flue designs

10.14.1 Introduction

The function of a chimney is to discharge in a manner to give adequate dispersal to the products of combustion in accordance with the third edition of the 1956 Clean Air Act Memorandum on Chimney Heights. The scope of the memorandum is as follows:

1. The publication provides for the use of local authorities, industry and others who may need to determine the height appropriate for certain new chimneys a relatively simple method of calculating the appropriate height desirable in normal circumstances.
2. Heights determined by these methods should be regarded as a guide rather than as a mathematically precise decision. The conclusions may need to be modified in the light of particular local circumstances such as valleys, hills and other topographical features.
3. The advice given is applicable only to chimneys of fuel burning plant with a gross heat input of between 0.15 MW and 150 MW, including stationary diesel generators. It does not deal with direct-fired heating systems which discharge into the space being heated, gas turbines or incinerators (which require separate treatment, depending on the pollutants emitted).
4. The main changes from the second edition are the inclusion of a method dealing with very low sulphur fuel and extensions of the methods for taking into account the height of nearby buildings and of the range of the size of furnace included.

10.14.2 Gas velocity

In order to maximize the chimney height, the efflux velocity of the gases leaving the chimney should be designed on 12 m/s at Maximum Continuous Rating (MCR) of the boiler. On some very small boilers this may be impractical to achieve, but a target velocity of not less than 6 m/s at MCR should be aimed for. With boilers at the top end of the range a velocity of 15 m/s at MCR is required. Some inner-city authorities may stipulate higher efflux velocities and some plants have been installed with gas velocities of 22 m/s.

10.14.3 Chimney height

Originally, the height of the chimney was designed to produce a draught sufficient to produce induced-draught air for combustion. With modern boiler plant forced-draught and/or induced-draught fans are used. This allows for the greater degree of control of the air to be designed into the combustion appliance. The chimney is therefore only required to disperse the gases.

When using gaseous fuel it is normally sufficient to terminate the chimney 3 m above the boiler house roof level, subject to there being no higher buildings adjacent to the boiler house. In such cases these buildings may need to be considered.

On medium-sized boiler plant where gas is to be the main fuel it may have oil as a secondary standby fuel. In this case, the chimney height must be based on the grade of fuel oil capable of being burned.

The methods of calculating proposed chimney height are clearly laid out in the Clean Air Act Memorandum, and will be based on:

1. Quantity of fuel burned;
2. Sulphur content of fuel burned;
3. District category;
4. Adjacent buildings;
5. Any adjacent existing emissions.

Application for approval of the proposed chimney height should be made to the appropriate authority at an early stage of a project in order to ascertain their approval or other height they may require. Failure to do this can result in an embarrassing situation where insufficient finance has been allocated due to their requiring a larger chimney than was included in the planned costings.

Where waste products are being incinerated special consideration may have to be given to the resulting flue gases. This may involve having to arrive at a chimney height in conjunction with HM Inspectorate of Factories for Pollution.

10.14.4 Type and combustion

Where a multi-boiler installation is being considered a multi-flue chimney is preferred. This is where the required number and size of flues are enclosed in a single windshield. It is preferred by planning offices and has the advantage of a greater plume rise than from separate stacks.

Several boilers discharging into a single-core chimney are to be avoided. At times of low load the efflux velocity will be very low, which, in turn, will allow the chimney to cool. This may then drop to dewpoint temperatures and, where sulphur is present in the fuel, acid will form. If the chimney is unprotected steel it will suffer rapid corrosion. Even worse, as the boilers increase their load the efflux velocity will increase and start to discharge the acid droplets, which quickly fall out and cause damage to surrounding property.

Construction of chimneys for industrial boilers will mainly be of steel, being either single or multi-flue. A single-core chimney should be suitably insulated in

order to maintain a maximum temperature at the chimney outlet to prevent corrosion and will be finish clad with aluminium sheet. A multi-flue chimney will have each flue suitably insulated and enclosed in an outer windshield. Provision for drainage should be incorporated at the base of each flue. Large watertube boilers may have concrete windshields containing internal flues.

10.14.5 Connecting ducts

The duct between the boiler outlet and the chimney connection should be designed to have a gas velocity no greater than the chimney flue and be complete with insulation and cladding, access openings and expansion joints. It should have the least number of bends and changes of section possible and should preferably not fall between the boiler outlet and the chimney connection.

With the use of multi-flue chimneys, dampers are not required in each flue as they were for boiler isolation when several boilers discharge into a common duct or chimney. This should not be confused with the fitting of dampers for heat conservation in a boiler during off-load periods.

10.14.6 Grit and dust emissions

Solids emissions from solid and liquid fuel fired plant are covered in the HMSO publication *Grit and dust – The measurement of emissions from boiler and furnace chimneys*. This states levels of emissions which should be achieved in existing plant and specified for new plant. Suitable sampling connections should be incorporated into the flue ducting for the use of test equipment if permanent monitoring is not included.

10.15 Steam storage

Most boilers built now, together with their combustion equipment, are quick to respond to local fluctuations. Occasionally, where very rapid load changes occur, the firing rate of a gas or oil burner can be virtually instantaneous by the use of special control equipment. This control will have to work in conjunction with the boiler, and therefore the boiler should have adequate steam space and water surface area to help accommodate the rapid changes in steam demand. Good water treatment is especially important here in order to reduce the risk of priming during peak draw-off periods. A boiler with a large shell will have an advantage over one with a smaller shell, assuming equal heating surfaces, but it will give no more than a slight buffer against severe loads.

Most boiler plants can be installed using one or more boilers which can accommodate minimum to maximum loads. Occasionally, heavy peak loads occur for only relatively short periods, and here there may be an advantage on economic running grounds to install boilers whose firing rate will not meet these peaks. In these cases, there are two methods which may be used: one is thermal storage and the other is with an accumulator.

10.15.1 Thermal storage

This is briefly described in Section 10.1.11. Its principle is based on a special feedwater control system which allows the water level in the shell to fall during periods of steam demand in excess of the maximum firing rate. Conversely, during periods of low steam demand the control system allows the water level to re-establish itself. This is achieved using a constant burner firing rate which should match the average steam demand, thus allowing maximum efficiency. It is claimed it is possible with this system to control the limits of boiler working pressure to within ±0.07 bar.

10.15.2 The accumulator

This was briefly described in Section 10.1.12. Unlike thermal storage, it depends upon differential pressures, and it is suited to a situation where both high- and low-pressure steam systems are required (for example, 17 bar and 7 bar). Alternatively, if no high-pressure steam is required then the boilers must be designed to operate at a higher pressure with all steam supplies going to process through a pressure-reducing station. Any high-pressure surplus then goes to the accumulator to help meet peak loads. Figure 10.11 shows the layout of an accumulator.

The storage vessel is filled to around 90% of its volume with water and the overflow valve is controlled by the pressure of the boilers. On rising steam pressure (indicating that the boilers are producing more steam than the process requires) a signal to the overflow valve allows all surplus high-pressure steam to flow into the accumulator via a non-return valve and internal distribution header. Here it is condensed and its thermal energy stored. If a peak load develops on the high-pressure system, controls will close the overflow valve and allow steam to discharge from the accumulator through the pressure-reducing valve set to meet the low-pressure steam requirement. Similarly, if the peak develops on the low-pressure system, then high-pressure steam may pass directly to the pressure-reducing set to supplement steam from the accumulator.

Every accumulator will be designed to meet its specified duty. It will be appreciated that the greater the differential pressure, the smaller the vessel will need to be.

10.16 Automatic controls on boilers

Whether the boiler is fired on oil, gas or solid fuel, it may be expected that it will operate automatically. When boiler plant is not run continuously initial start-up may be manual, time clock or through an energy-management system. Manual attendance may be limited to maintenance functions dictated by the type and size of plant. Automatic controls will cover three areas:

1. Combustion appliance
2. Water level
3. Blowdown

10.16.1 Combustion appliance

When using oil or gas this may operate in one of three modes. On/off, high/low/off or modulating. Only small units will have on/off operation and usually all units of 4000 kg/h evaporation and above will have modulating

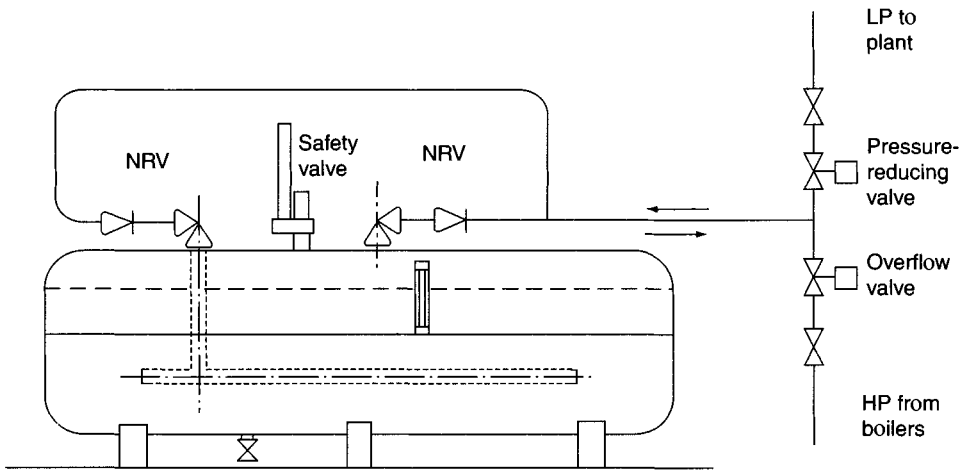


Figure 10.11 Diagrammatic layout of a steam accumulator

control. The burners will have safety systems incorporated to prove satisfactory fuel supply before ignition takes place, flame proving at point of ignition and continuous flame monitoring thereafter.

High/low burners will have between 2:1 and 3:1 turndown on the maximum firing rate while a modulating burner will give between 3:1 and 5:1, depending upon the unit size and the fuel used. A higher turndown ratio is available from some burners, but if the above-mentioned ratios are exceeded care must be taken to consider the effect on the final gas temperature leaving the boiler. Dewpoint temperatures are to be avoided. Coal-fired units by nature of the fuel will have modulating control whether chain or travelling grate, underfeed or fixed/tipping grate.

10.16.2 Water level

The control of feedwater into the boiler is automatic. Feedwater will be delivered from a pump with on–off operation or from a continuously running pump delivering water through a modulating feed control valve. In both cases the water requirement is continuously monitored by level controls directly connected to the shell or drum of the boiler.

In addition to controlling the feedwater, the level controls will also monitor low- and high-water conditions. It is essential that all heated surfaces are always fully immersed, therefore two stages of low-water alarms are fitted on two independently mounted controls. The first low water will give audible and visual indication and shut down the combustion appliance. If normal water level is automatically restored it will allow the boiler to go back to firing mode. If the second low water is reached again, audible and visual alarms are instigated, but now the boiler will go to lock-out condition, requiring manual restart after the problem has been resolved. Watertube boilers may have additional monitoring controls to give early indication of load changes as referred to in Section 10.7.

10.16.3 Blowdown

Blowdown on a boiler is mandatory. On small boilers the required operation of the main blowdown valve may be sufficient to control the quality of water within the boiler. On medium and large plants additional systems are employed.

The simplest is a preset continuous blowdown valve to maintain a suitable water quality in the boiler. It is necessary for water quality to be checked frequently and the rate of continuous blowdown adjusted as may be found necessary.

A second method is a time-controlled valve allowing regular intermittent blowdown of the boiler. Again, regular checks need to be carried out to monitor the quality of water in the boiler.

The third and most automatic system is the conductivity-controlled blowdown. This constantly measures the level of solids in the water and instigates an automatic variable blowdown on a continuous or intermittent basis.

10.17 Automatic boiler start

In order to control the operating times of a boiler it is a simple matter to fit each with time clock control. Alternatively, they may be controlled through a central energy management system. Either way, a boiler or boilers may be shut down at the end of each day and programmed to restart the following day or when required. Special considerations need to be made if standing periods are extended, allowing a boiler to go cold.

With hot water units time clock control can operate satisfactorily as automatic bypass valves built into the distribution system will help the heater to achieve its working temperature quickly. With steam boilers it is important that the boiler reaches a reasonable working pressure before steam is allowed into the distribution system. For example, if boilers are left open to a system for an extended length of time while not firing they will quickly lose their pressure. This is not only wasteful of

energy but eventually creates a problem on start-up. To start a boiler on a zero-pressure system with all valves open will undoubtedly cause the boiler to prime and go to lock-out condition, but not before condensate has at least partly flooded the system.

Therefore where a time clock is incorporated it is recommended that the crown valve(s) be closed at the end of each working day and only opened after the boiler has reached working pressure the next time it is required. This operation can be automated by the use of motorized or similar valves. These valves may be fitted to each steam, supply line from a manifold adjacent to the boilers and, provided adequate safeguards are incorporated to protect the boilers, the on-line boiler(s) may be left open to the manifold. Alternatively, each boiler may have its own automatic motorized start-up valve. Figure 10.12 illustrates a valve suitable for either system.

Each valve would have a control panel incorporating a timer. This may initially be set to a 'crack' position timed to open after the boiler has started to fire and is already building up pressure. This will allow gentle warm-up of the system while enabling the boiler to achieve working pressure. After this, the valve may be set to open in timed adjustable steps to its fully open position. At the end of a timed period, coinciding with the time clock fitted to the boiler, the valve automatically closes at the end of the working cycle. Where multiple valves are used their control may be incorporated into a single panel or, alternatively, become part of an energy-management system.

10.18 The automatic boiler house

As described in Section 10.16, the boiler will operate automatically and we saw in Section 10.17 that it can be programmed to operate to suit various cycles. There are, however, other areas within the boiler house which still require a degree of attendance.

The first of these is blowdown control. Assuming that control of the water quality within the boiler is being carried out by a separate system, we are left with the main blowdown, blowdown of the water level gauges and blowdown of external water level controls if fitted. Conductity level controls fitted within the shell can be self monitoring. It is possible to automate these valves but it is unusual. Before proceeding, the advice of the insurance company must be sought and agreement reached on the operation of the valves. When blowing down the level controls it should take the boiler to lock-out. If this, in turn, is overridden, a further proving system will need to be incorporated to prove correct functioning of the level control. In addition to the above, it will still be necessary to carry out an evaporation test on the boiler to prove correct operation of the level controls at defined periods.

The second area will be feedwater pumps. It is normal to have a duplicate standby feedwater pump. Sometimes this may be two for each boiler or one duplicate pump to serve any selected boiler. These will usually require manual changeover in the event of failure of the duty pump. It is practical to automate this changeover by using pressure sensors and motorized valves. The same can apply to

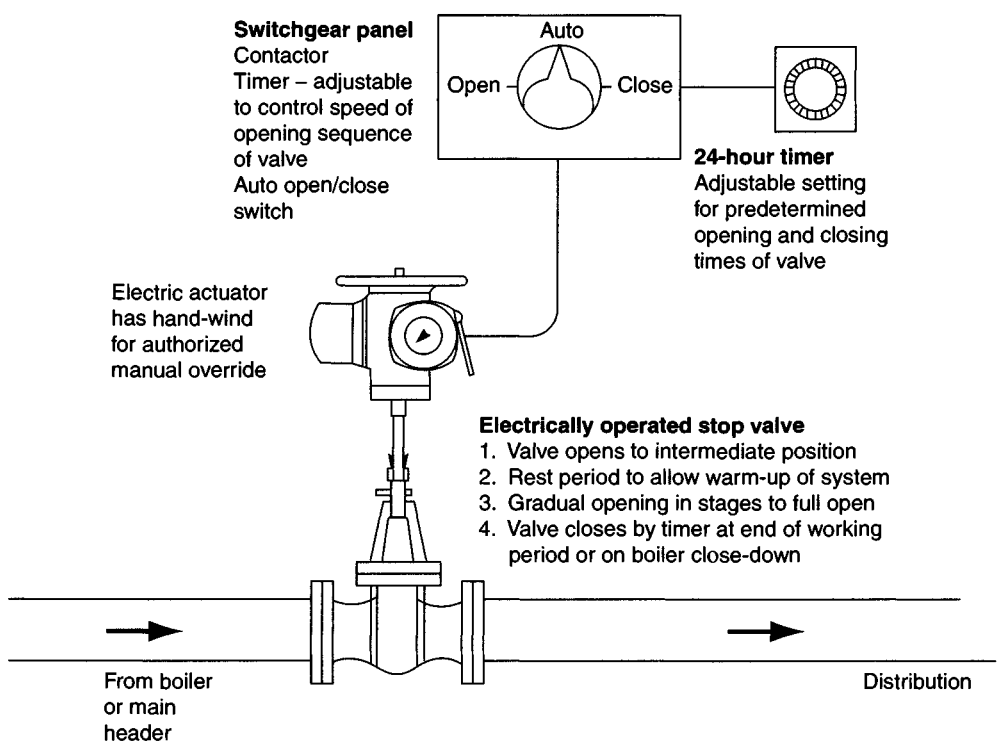


Figure 10.12 Diagram of electrically operated automatic steam stop valve (with permission of Hopkinsons Valves Ltd, Huddersfield)

oil-circulating pumps, gas boosters, water-treatment plant and any other valves and motors. It is possible to do most things, but in the end there is the cost to be considered. An energy-management system coupled to a suitable maintenance programme can still prove the best option for the great majority of installations. Should an energy management system be installed in an unattended boiler house then should a fault occur on a boiler then independent fuel shut off valves will isolate the fuel supply to that boiler and require manual re-setting when fault has been cleared.

10.19 Safe operation of automatic boiler plant

The most frequent cause of damage and even explosion in boilers is a low-water condition. This will expose the heating surfaces which ultimately overheat and rupture under the operating pressure. Experience has shown that since the introduction of controls for unattended automatic operation of boilers the accident rate has increased. Investigation invariably shows that lack of maintenance has been the main contributing factor. It is therefore imperative that personnel responsible for the running of the boiler plant be fully trained and conversant with its safe operation.

The minimum recommended requirements for automatic controls for boilers not under continuous supervision are:

1. Automatic water-level controls arranged to positively control the flow of water into the boiler and maintain a set level between predetermined limits;
2. Automatic firing controls arranged to control the supply of fuel and air to the combustion appliance. A shutdown will occur in the event of one or more of the following occurring:
   (a) Flame/pilot flame failure on oil- or gas-fired boilers. The control should be of the lock-out type requiring manual reset;
   (b) Failure to ignite fuel on oil- or gas-fired boilers within a set time. Again, lock-out type with manual reset;
   (c) At a preset high pressure (or temperature in the case of hot water) at or below the safety valve setting;
   (d) When the water level falls to a preset point below the normal working water level. This control will operate on audible alarm but will automatically go back to firing mode once the water level is re-established;
   (e) Failure of combustion air fans or automatic flue dampers;
3. An independent overriding second low-water control. This will be set below the level control in (2). It will give an audible alarm on shutting off the fuel and air supply and require manual reset before the boiler may be brought back into operation;
4. All electrical equipment for the water-level and firing controls should be designed so that any fault will cause the boiler to shut down and require manual resetting before the boiler may be restarted.

For hot water boilers the burner controls will be similar but controlled by a combination of pressure and temperature signals. A single overriding level control will be fitted to the flooded boiler to protect against any accidental low-water condition.

In order to monitor the safe operation of the boiler a daily and weekly programme of tests should be drawn up and log sheets completed as verification of the tests being carried out. Items checked should include:

Boiler pressure;
Water level gauges – visual and blowdown;
Sequence valves operated where external level controls are fitted. Conductivity level controls checked if these are not self monitoring.
Feedwater pump operating;
Operate main blowdown valve;
First low-water alarm and burner off;
Second low-water alarm and burner lock-out.

When a boiler may not be shut down for maintenance then self monitoring conductivity level controls are best suited. Alternatively isolating valves may be fitted between the external water level control chamber and the steam space. In this instance, the valves must be capable of being locked in the open position and the key retained by a responsible person. When these valves are closed during maintenance periods the boiler must be under manual attendance. Fitting of these valves should only be with the agreement of the insurance company responsible for the boiler. Drains from the water-level controls and level gauges should be collected at a manifold or sealed tundish before running to the blowdown vessel.

As the boilers are designed for unattended operation, it follows that if a fault occurs and an alarm activated this alarm may need to be duplicated at a secondary location where it will be intercepted and acted upon.

Safety valves should be trouble-free. No attempt should be made to alter the set relief pressure without reference to the insurance company and the boiler manufacturer.

With waste-heat boilers fitted to incinerators care must be taken not to overfire. It is possible to introduce additional heat either by increasing the quantity of waste or by a change in the composition of the waste. The resultant increase in gas volume and/or temperature is then capable of imparting more heat to the waste-heat boiler. As the boiler will have been designed for a specified duty it could be possible to raise an amount of steam in excess of that which may be safely controlled.

Sometimes it is not practical to blowdown the level controls and shut down the incinerator. In this case, the situation should be discussed with the insurance company and the boiler supplier. It is possible to include for an extra high working water level giving a safety margin above the heating surfaces. The controls may then be blown down and checked for satisfactory operation with a predetermined time delay before it shuts down the incinerator or operates a bypass in the event of a fault.

10.20 Energy conservation

Energy conservation in the boiler house can be considered in two areas. One is the selection and installation of

suitable equipment and the other is good operation and management.

10.20.1 Plant installation

The boiler, flues and chimney, pipework and hotwell, where installed, should all be insulated to adequate standards and finish. Valves should be enclosed in insulated boxes, although on small installations this can prove disproportionately expensive. The boilers may be fitted with either inlet or outlet air-sealing dampers. These will prevent the flow of ambient air through the boiler during off-load and standby periods, thus helping to maintain the heat already in the boiler.

Economizers may be installed, particularly if gas is the main fuel. It is unlikely that an economic case can be made for a single boiler if there is less than 4000 kg/h evaporation. An economizer can produce fuel savings of 4–5%, but it must be remembered that this will be at MCR, and if the load factor of the installation is lower, the savings will also be proportionately lower.

Combustion controls such as oxygen trim help to maintain optimum operating conditions, especially on gaseous fuels. Instrumentation can give continuous visual and recorded information of selected boiler and plant functions. To be effective, it must be maintained and the data assessed and any required action taken before the information is stored.

Energy-management systems will form an important part of a multi-boiler installation, whether on steam or hot water. Boiler(s) for base load will be selected and further boilers brought on- or taken off-line as required. The important feature of these systems is that the selection of boilers coming either on- or off-line will be ahead of the load and programmed to anticipate rising or falling demands.

Computer monitoring and control systems have recently been introduced. These are designed to operate in place of conventional instrumentation. Using intelligent interface outstations connected to a desktop computer, many plant functions may be programmed into the computer and controlled centrally.

10.20.2 Operation and maintenance

As most boiler plants installed today are designed for unattended operation it is even more important that early action is taken in the event of the boiler requiring adjustment of combustion or other maintenance. If full instrumentation is not installed then a portable test kit should be used and the plant checked and logged daily or weekly. Perhaps the most obvious waste to look for after steam leaks is a rise in the flue-gas outlet temperature. The boiler will progressively have deposits adhering to its heating surfaces, but at an increase in temperature of no more than 16°C above its design outlet temperature it should be cleaned. The time period between cleaning will vary according to the type of fuel and operational load.

Comparatively small air leaks into the combustion spaces of a boiler can produce localized problems. All access opening seals and sight glasses and seals must be monitored to prevent this.

10.21 Noise and the boiler house

Noise can constitute a danger to health, and therefore adequate precautions must be taken to protect personnel who are required to be in such an environment. The Health and Safety at Work, etc. Act 1974 has the power to control noise emissions, but the subject is complex. If it is anticipated that noise will exceed acceptable levels then specialist knowledge should be employed at an early stage in the design and layout of the plant.

As a guide, Figure 10.13 shows a noise-rating curve for everyday noises. At the lower sound levels these may be considered acceptable, and it will be found that to produce overall sound levels below this will prove costly. Alternatively, sound levels exceeding the upper figures need careful consideration if personnel are required to be in that environment. For some machinery, such as reciprocating engines, turbines and compressors, it is not practical to contain the noise at source and then ear protection has to be utilized. Generally, however, industrial boilers and their associated plant can be designed to meet acceptable noise levels.

It is generally the case that small boiler plants will create less noise than large ones. Nevertheless, due to the practice of siting small boilers close to working areas, the matter of noise must not be overlooked. Noise sources within the boiler house will be from the following:

Combustion appliance, including forced- and induced-draught fans;
Feedwater pumps;
Oil pumps;
Gas boosters;
Water-treatment plant;
Steam lines and PRV stations;
Safety valve vent pipes;
Gas lines;
Flue ducting.

Small oil and gas burners are generally supplied without any form of silencing. Some may be enclosed within an acoustic hood and air inlet silencers are normally available if specified. Oil and gas burners fitted to boilers of outputs above 3000 kg/h evaporation can be supplied with progressive degrees of silencing equipment. Figure 10.14 illustrates sound-pressure levels of one burner manufacturer when fitting three basic types of silencing. The use of variable-speed motor drive for the combustion air fan can also reduce the overall noise level, specifically when the unit is not operating at maximum continuous rating. Coal-fired plant will normally be quieter than oil- or gas-fired plant, although, where fixed grate boilers are employed, the same criteria will apply to the forced-draught fans as for oil and gas.

Feedwater pumps will not normally constitute a noise problem unless the area is particularly sensitive. Two alternatives are then available. One is to install reduced-speed pumps and the other is to site the pumps in a separate acoustic enclosure within the boiler house. Oil-circulating pumps are usually low speed and, as such, do not cause a noise problem.

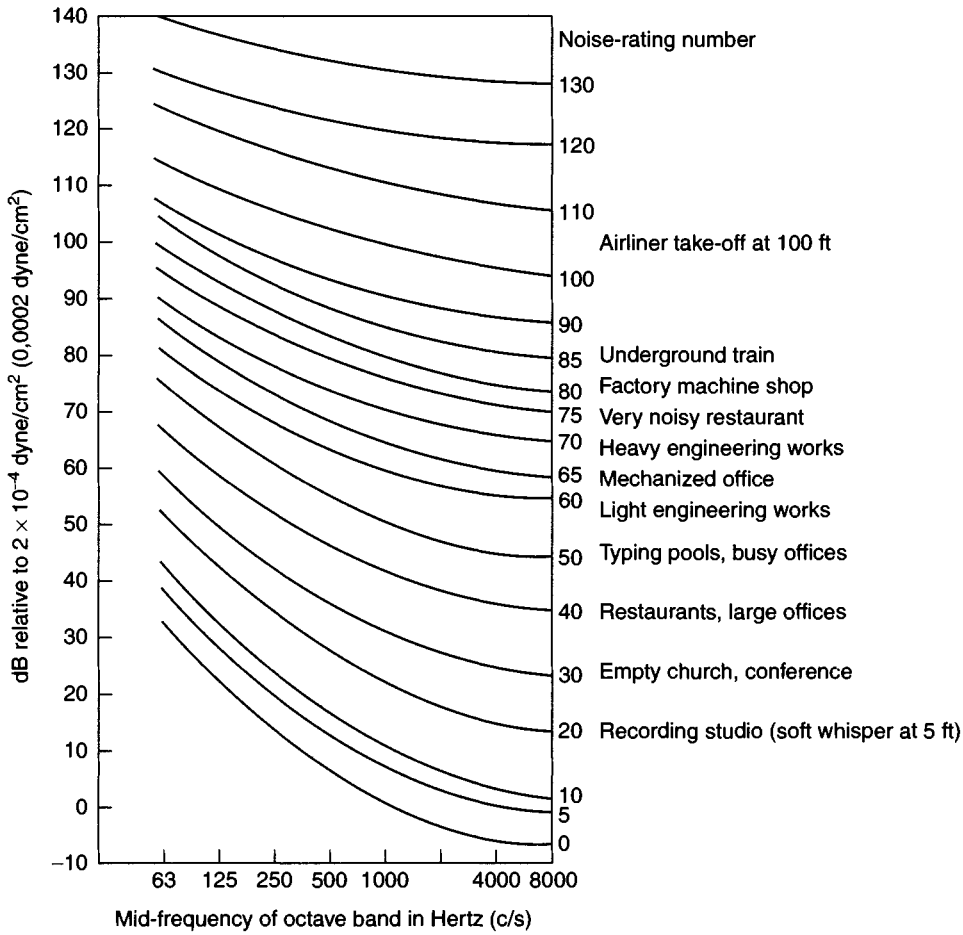


Figure 10.13 Noise-rating curves for some everyday sounds (with permission of Saacke Ltd, Portsmouth)

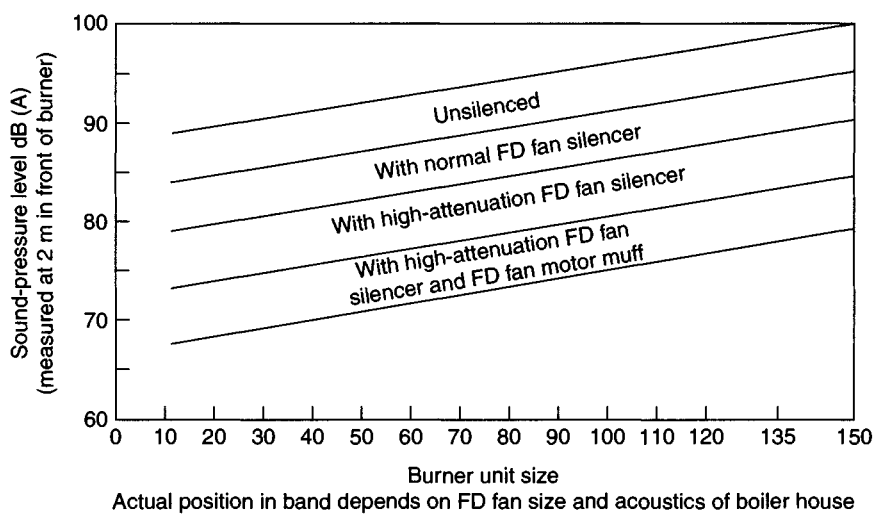


Figure 10.14 Sound-pressure levels for Saacke rotary cup burners (with permission of Saacke Ltd, Portsmouth)

Gas boosters may be fitted with motor enclosures or designed to operate at lower rotating speeds. Alternatively, they may be housed in an acoustic enclosure within the boiler house. The booster and drive unit can be supplied with anti-vibration mountings to isolate it from the floor or steelwork and flexible bellows fitted to the gas inlet and outlet connections.

Water-treatment plant may include one or more electric motors driving feedwater pumps or dosing pumps. Dosing pumps are usually very small and will not cause noise problems. Water pumps may be considered as for the feedwater pumps already described.

Steam transmission will produce noise. Low steam velocity will help to reduce this. One specific noise area will be if a pressure-reducing valve set is employed. Therefore it is desirable to have this within the boiler house or other building and not outside. Some types of pressure-reducing valves operate at lower sound levels than others, and therefore if environmental noise could be a problem then this should be investigated. Insulated valve boxes will also help to contain any noise.

Safety valve venting is noisy. It should only happen infrequently and therefore may be acceptable. If the location is near to offices or housing it may be advisable to fit silencer heads. Noise levels from gas lines and meters should not normally prove a problem on industrial premises.

Flue gas ductwork will be insulated, which helps to reduce any transmitted combustion noise. Where large rectangular flue ductwork is used it must be adequately stiffened and insulated to reduce any risk of reverberation being set up from the combustion system.

Finally, if the boiler house is to be within an industrial complex and there is no adjacent residential development, the building need only be suitable for adequate weatherproofing of the plant and for maintenance. Alternatively, if it is sited adjacent or near to housing or offices then the building structure should take account of this.

Ideally, the walls should be of brick or concrete with an insulated roof. Large areas of glass should be avoided. It is desirable that all routine maintenance and operating functions can be carried out without having to open doorways. Openings and access to the boilerhouse should be away from sensitive areas. Free areas for air for both combustion and ventilation should be through acoustic louvre panels and preferably again away from sensitive areas. Discharge points for vehicles delivering fuel should be carefully considered so as to cause the minimum nuisance.

10.22 Running costs

With the wide range of boiler types and outputs being considered together with the ever-changing costs for fuel it is difficult to arrive at a specific figure which can relate running costs to the installed plant. In order to arrive at a guide in this area several case studies were carried out. It quickly became apparent that few operators maintain separate costs relating to the boiler plant and only keep overall factory maintenance costs. Fortunately, sufficient information was obtainable to arrive at an overall pattern of costs.

On an annual basis, with running costs covering fuel, operation, electricity, water treatment and maintenance, fuel can account for 90% on a plant operating 168 h per week and 80% on a plant running 40–80 h per week, the remaining 10–20% covering the other items. These proportions were consistent for modern plant burning coal, oil or natural gas. With the recent increase in natural gas tariffs (1989) for large consumers it will now mean that natural gas will account for a larger percentage of the annual figure.

An alternative cost also became apparent from the case studies. If the mean hourly steaming rate in kilograms is multiplied by 2.25 it produces a figure roughly equivalent to the annual operating costs in pounds, excluding the cost of fuel.

10.23 Management and operation

The boiler plant, regardless of its size, is an essential part of the plant otherwise it would not be there. Having established this, it should be covered by a planned maintenance schedule to produce maximum availability. Most boiler plant is supplied for unattended operation, but certain procedures still need to be carried out. The extent of this programme will depend upon the size of the plant and the fuel used.

Table 10.7 outlines briefly the extent of operations which need to be undertaken. This is intended only as a guide, as in the majority of installations a programme will be evolved to suit individual cases. In certain instances (for example, where electrical power generation is involved) the boilers may not shut down on a daily, weekly or monthly basis, and all controls are then fully automated. Also, watertube boilers may operate for longer periods before fire-side shutdown is necessary.

Boiler plant operation will normally be undertaken by internal personnel. Maintenance work may be by either

Table 10.7 Recommended maintenance procedure

Operation	*Fuel*		
	Oil	*Gas*	*Coal*
Blowdown			
Main	1	1	1
Water-level controls	1	1	1
Water-level gauges	1	1	1
Visual check	1	1	1
Check/clean burner	1	3	1
Water-treatment check	2	2	2
Combustion check	2	2	2
Water-level control operational check	2	2	2
Inspect refractories	3	3	3
Open fire side and clean	3	4	3
Open water side for inspection	4	4	4

1: Daily.
2: Weekly.
3: 6–12 weeks.
4: Annually.

internal personnel or outside contractors. Service contracts will be available from equipment suppliers covering all items of the boiler plant.

Recently, companies have started offering contract energy-management schemes. These may be designed to suit individual applications and will be tailored to customer requirements. They may take over the operation of an existing plant or, if necessary, include for a new replacement plant. They will usually operate over a 3–10-year contract period. Dependent upon the terms of contract, all fuels, electricity, repairs and replacements may be covered.

10.24 Fuel conversion of boilers

This will normally be to convert a boiler from solid fuel firing to gaseous, liquid or dual fuel firing. The majority of boilers can be converted and for an example the shell boiler will be considered.

A boiler designed for solid fuel will have a greater heat transfer surface than one designed for gaseous or liquid fuels so there is no problem in retaining the design output. An increase in the boiler output may appear possible but would require the changing of crown valve, safety valves and feed water pumps. Furthermore the design of the boiler shall be in compliance with BS 2790 Appendix C calculations for acceptable tube entry gas temperatures.

After the removal of solid fuel firing equipment the fire side of the boiler shall be thoroughly cleaned prior to the fitting of new combustion equipment. Any connections into the combustion space such as coal or ash drop tubes shall be sealed and refractory plugs fitted where necessary. The grit arrester may be left in position but the cells or internals should be removed to reduce pressure loss.

Chimney height should be checked if liquid fuel is to be used either as primary or standby and approval of height and gas efflux velocity obtained from the appropriate authority.

To convert a shell boiler from gaseous or liquid fuel firing to solid fuel is not a practical option. It would reduce the rated output of the boiler by 30 –50%. In addition the smoke tubes will be smaller in diameter than those in a boiler designed for solid fuel firing and therefore the availability will be seriously affected.

11 Combustion equipment

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11.1 Introduction

A burner is a device for liberating heat by the combustion of fuel. Fuels are predominantly hydrocarbons, which release their heat exothermically when oxidized in a controlled manner. The most freely available oxidant is air, which contains only 21% oxygen, the remaining 79% being nitrogen which does not contribute to the process. The nitrogen, because it is heated at the same time, reduces the maximum flame temperature that would have been possible with a pure oxidant. Similarly, the combustion products, when discharged from the process, contain the inert nitrogen, which increases the volume of the gases and hence the sensible heat loss.

A burner, then, comprises a means to inject the fuel, a fan to provide the air for the combustion reaction, a register or flame stabilizer assembly which provides for the mixing of air and fuel and the stability of the flame, and a means for controlling the air-fuel ratio and fuel input. In addition, on automatic burners, a burner management system is necessary to ensure programmed start up and shut down together with supervision while firing via a flame detection system and interlocks to prove that certain parameters are maintained such as air and fuel pressure. An almost infinite number of types of burner have developed over the years, but broad categories exist characterized by the type of fuel being burnt, the principle of the fuel injection and mixing system, and often the application for which they were designed. The most common applications are for hot water heating, steam production and thermal oil heating. Some integration has taken place where the burner has become part of the boiler particularly in the case of gas firing. In general the market is serviced by combustion equipment suppliers who supply both the appliance manufacturers as well as the retrofit market where a change of fuel, enhanced emissions performance or perhaps more sophisticated control provide the motivation. Various specialized process uses exist which require special shaped flames, very high temperatures, controlled atmospheres etc. which are beyond the scope of this chapter. These might include kilns, steel and glass melting, drying of materials, etc. Burners for these purposes are built to BS EN 748.

Combustion equipment manufacturers are frequently called upon to provide all the auxiliary services necessary for the safe and efficient operation of the burner. This can include gas supply and control trains and governing stations and pumping, heating and filtration for liquid fuels.

11.2 Aspects of selection

Assuming that the plant requirements do not embrace a heat and power study resulting in a combined heat and power system, we can confine ourselves to assessing the heat loading alone. Having determined a total steam and/or hot water requirement in terms of MW this will determine how many boilers are required. Nowadays, financing requirements together with very high reliability do not tend to accept much capability over and above the maximum load, unless of course the outage requirements for annual inspections conflict with 365 day operation. Unless this calculation yields a multiple boiler operation, so allowing for a spare boiler, one is looking at a one, two or three boiler situation. Invariably a single burner is fitted to a single boiler with the exception of a small range of 6 to 20 MW where a twin flue shell boiler could be considered. Rangeability of load may then become a factor in burner selection with the exception that proves the rule of the twin flue boiler aforementioned. Modern twin flue boilers have the ability to operate independently of each flue, so doubling the range capability.

Unless one is planning a green field site the choice may be whether to retain the existing boilers or fit new ones. Modern combustion equipment together with sophisticated controls provides the opportunity to improve the reliability, control, flexibility and emission enhancements which may be the driving force in the consideration of new combustion equipment. The life of boilers is of the order of two or three times the life of the combustion equipment, especially with the current pace of electronic and computer control development. The retrofitting of new combustion equipment may be provoked by a need to integrate the heat generation plant with the process control of the whole site operation. This can be accomplished by the specification of a SCADA (Supervisory, control and data acquisition) system, which manages the whole boiler house as well as providing operational functions such as boiler sequencing and banking, hours run and data on running costs, efficiencies and so on.

Whilst gas generally offers greater burner turndown ratios larger oil burners may be capable of almost double figure turndown ratios. On-off operation where boiler load swings exceed burner turn down may be offset by the common fitment of a damper to prevent cold airflow through the boiler generated by chimney draught. It is better to prevent this airflow by sealing the air inlet rather than the exhaust exit on the grounds of the cleaner cooler position.

Presently in Europe one is restricted in practical terms to a choice between gas and diesel oil with perhaps heavy oil in certain load ranges and specific regions. Solid fuel has eliminated itself from the market not only by the difficulties raised by the storage and handling of the coal but also the handling and disposal of the ash. Of greater impact is the inability to meet emissions requirements without the fitment of very expensive and sophisticated clean up systems which also have high maintenance and efficiency penalties. A section on solid fuel burners is retained in this edition for reference purposes and operators in developing countries or where indigenous coal is still economic.

Within Europe another factor in the decision process is Type Approval and Directives. Burners up around 3 MW which are intended for low temperature hot water generation (<105°C) in domestic and commercial applications must have CE certification to comply with the Gas Appliances Directive. This lays down the essential requirements regarding the level of safety and specification necessary to obtain Type Approval. The submission of the equipment for CE acceptance testing by a "Notified Body" also includes measurement of the field of operation (boiler resistance versus heat output) and emissions of NO_X and

CO. Sizes above 3 MW will need to be tested on the actual hot water boiler because the Notified Body does not have a test firing capability which is large enough. In parallel with this similar CE approval is being adopted for oil burners and an Efficiency Directive also exists to ensure that the accompanying new boiler meets certain efficiency requirements. Above 3 MW heavy oil can be added to the fuel selection choice with the caveat that boilers in the 20–50 MW individual size have to meet emission limits. Plant exceeding 50 MW combined aggregated output on one site is also subject to emission limits together with continuous monitoring of emissions. In conjunction with the Pressure Equipment Directive burners will shortly have to meet the design and safety standards laid down for the boiler under codes for the auxiliary equipment which includes the firing equipment as well as all of the other peripheral parts of the basic heat generation pressure vessel. These Standards are as follows:-

PrEN 12953 Shell Boilers
Part 7 Firing Equipment for Liquid and Gaseous Fuels
PrEN 12953 Water Tube Boilers
Part 8 Firing Equipment for Liquid and Gaseous Fuels
Part 9 Firing Equipment for Pulverized Fuels
Part 16 Firing Equipment for Grates and Fluidized Beds

Basic Standards for burners which are associated with other Directives comprise:-

BS:EN 676 Gas Burners with Fans
BS:EN 267 Oil Burners with Fans

Emissions are becoming a major element in the selection of combustion equipment, not only to meet Local Authority and Environment Agency requirements but the Climate Change Levy, which will mitigate against poor plant efficiency and the carbon/hydrogen ratio of the fuel. In ascending order or merit is coal, heavy oil, diesel oil and gases with natural gas being the most attractive, apart from hydrogen, which is only found in one or two special chemical processes and refineries.

Fuel selection choice may be coloured by emission considerations but primarily depends on fuel price.

Sizes in the 3–20 MW individual size classification, especially where fitted in a multi-boiler layout, are prime candidates for interruptible gas operation with a back up of diesel fuel. It is inadvisable to use heavy oil as the back up for natural gas supplied under an interruptible contract, as the heavy oil does deteriorate when not used by the agglomeration of the long chain molecules forming asphaltenes which are very slow burning. This can cause boiler fouling and increased particulate emissions. Similarly, circulating heavy oil for long periods without burning the fuel can also lead to fuel degradation and combustion problems.

Smaller applications especially of a non-industrial nature primarily burn natural gas, not only for its simplicity and convenience, but also to minimize space requirements by the avoidance of tankage.

11.3 Air pollution and emissions

Over the last decade emission performance of combustion equipment has become a topic of unavoidable importance. It is incumbent upon the plant engineer to do all in his power to select, utilize and maintain the best standards and technology to minimize the total production of exhaust gases by maximizing overall efficiency. In addition, specific gaseous species which contribute to atmospheric pollution need careful control and monitoring to abrogate their effects. The main pollutants and effects are shown in Figure 11.1.

11.3.1 Carbon dioxide and water vapour

The combustion of hydrocarbon fuels yields Carbon Dioxide (CO_2) from the combustion of the carbon and Water Vapour (H_2O) from the Hydrogen content. Carbon Dioxide is a greenhouse gas, therefore, the mass flow of exhaust gases must be minimized by high production and utilization efficiency.

Macro effect	Combustion Emmission	Comments
Global warming via greenhouse gases	CO_2 Carbon dioxide UHC's Unburnt hydrocarbons N_2O Nitrous oxide O_3 Ozone	High overal efficiency thrugh good selection, control and management ie. Low excees air using low emission burners, computer control. Pessimists predict average temps increasing by 1.5–4.5°C by 2050. Sea levels 3.0 meters higher by 2100.
Ozone layer depletion	NO, NO_2, N_2O Nitric oxides	Photodissociation causes loss of UV filtration leading to more skin cancer and further global warming.
Acid rain deposition	H_2O Water vapour NO_x Nitric oxides CO Carbon monoxide SO_x Sulphur oxides	NO_x and SO_x are the most important. Widely accepted that 20 countries are badly effected the most obvious being the Scandanavian group.
General pollution	Smoke UHC's Unburnt hydrocarbons SO_x Sulphur oxides Particulates NO_x Nitric oxides CO Carbon monoxide	Photochemical smog formed in reaction with sunlight. Over 1 billion people suffer from breathing air over agreed safety levels and hence commonly develop respiratory problems such as asthma.
The Impact on the Environment = Population × Affluence × Technology Plant Engineers have the power to contribute by choosing and using the best available technology		

Figure 11.1

11.3.2 Carbon monoxide

Evident from its name, it is the incomplete combustion of carbon. Reasons for its existence are similar to smoke. Providing the combustion chamber is of adequate volume, levels should not generally exceed:-

Gas < 100 mg/m^3

Diesel Oil < 200 mg/m^3

Heavy Oil < 400 mg/m^3

Solid Fuels < 600 mg/m^3

11.3.3 Smoke

Smoke is sub-micronic particles of carbon caused by the incomplete combustion of the fuel. This comes from either poor atomization, operation away from the optimum air/fuel ratio, chilling of the flame through poor air or fuel distribution or incorrect flame shape. No visible smoke should be seen, other than in the case of heavy oil and solid fuels and then only an insignificant haze should be discernible.

11.3.4 Particulates

Particulates in oil firing are the result of incomplete burn out of the atomized fuel droplets. In excessive amounts this may be due to bad atomization, incorrect fuel temperature, poor fuel or air distribution or chilling of the flame.

Small particles of size range 1–76 microns are classified as grit and are generally dispersed into the atmosphere, larger sizes still may result in some localized fall out in calm weather as well as fouling the heating surfaces.

Solid fuel generated particulates result from carry over from the grate or incomplete combustion in the case of pulverized fuel or fluidized bed combustion. These should be reduced to a minimum by back end clean up equipment such as dust cyclones, electrostatic precipitators or bag filters.

11.3.5 Unburnt hydrocarbons (UHC's)

These gases are the incomplete reactions of hydrocarbon fuels. Normally they only amount to a few parts per million but do contribute to global warming and can be carcinogenic. They are normally expressed as an equivalent methane value and are measured in mg/m^3 with only single figure values being acceptable.

11.3.6 Sulphur oxides (SOx)

Burning fuels containing sulphur will result in primarily in sulphur dioxide (SO_2) with a single number percentage oxidizing further to sulphur trioxide (SO_3). The combustion equipment/type has no bearing on the levels as the reaction is purely chemical and depends only on how much sulphur was present in the original fuel.

11.3.7 Nitric oxides (NO_X)

NO_X is the collective name for all nitrogen oxides; these are NO, NO_2 and N_2O. Combustion at the temperatures and pressures found in the boiler house environment generate predominantly NO with a smaller percentage (1–5%) of NO_2. N_2O is only normally encountered in solid fuel firing and gas turbines. The predominant species NO is gradually further oxidized to NO_2 in the atmosphere. For this reason nitrogen oxides are expressed as NO_2 equivalent in modern instrumentation. Similarly, legislation quotes levels as NO_2, knowing it is a foregone conclusion that it will finally oxidize. Standardized conditions of temperature, pressure and oxygen concentration are used at all times.

Three formation mechanisms result in NO_X generation:-

11.3.7.1 Thermal NO_X

First described by Zeldovich the reaction of molecular nitrogen from the combustion air with atomic oxygen and the subsequent reaction of the atomic nitrogen with the molecular oxygen. The reaction is highly dependant on temperature. In most common gases it is wholly responsible for the NO_X unless the gas contains molecules with organically bound nitrogen.

11.3.7.2 Prompt NO_X

As its name implies it is formed in the early stages of flames where highly fuel rich, substoichiometric mixtures are present. It only contributes to a small degree in gas combustion.

11.3.7.3 Fuel NO_X

In fuels containing organically bound nitrogen a degree of conversion of the nitrogen into NO_X takes place. It is essentially dependent on the local concentration of oxygen in the flame front and only to a lesser degree by temperature. For diesel oil it can add about 50 mg/m^3 to the base level of NO_X created thermally. The diesel would typically contain 0.02% nitrogen. For heavy oils and solid fuels the levels of organically bound nitrogen vary considerably from 0.2–0.6% for heavy oil and up to 1% for coal. This results in a NO_X concentration in the exhaust of 400–1000 mg/m^3 and is therefore the most prominent mechanism.

Figure 11.2 Schematically represents the formation routes to NO.

Figure 11.3 shows the strategies for reduction. Low NO_X burners utilize a combination of these techniques with the most common being fuel and air staging with lower levels being achieved in conjunction with exhaust gas recirculation. The recirculation may be induced from within the flame/furnace or by positive recycling of the products of combustion within the construction of the boiler or externally often with a separate fan. Techniques depend on which mechanism of formation predominates. Water and steam injection have been used but suffer from efficiency penalties of increased wet losses in the exhaust and is now confined to gas turbine applications where the

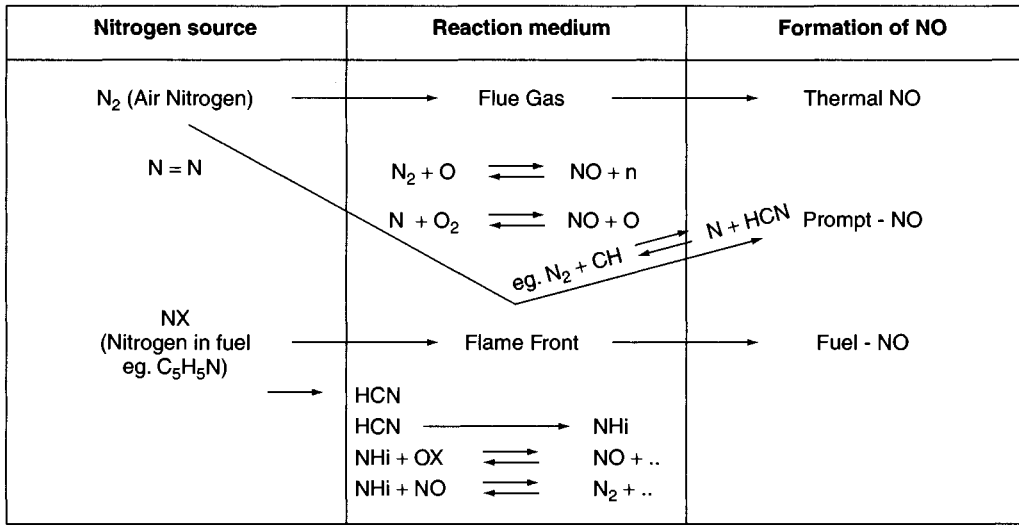


Figure 11.2 Schematic of Formation Routes to NO

Reduction in O_2 partial pressure	Reduction in combustion temperature	Reduction in residence time at high temperature
Exhaust gas recirculation	Exhaust gas recirculation	Optimization of fuel and air distribution and burner configuration
Reduced excess air	Reduced air preheat	Reduced duration in chamber
Air staging	Radiant combustion	Radiant combustion
Fuel staging	Optimization of fuel air distribution	
Water and steam injection	Optimization of combustion chamber heat absorbtion	
	Pre mix combustion	
	Water and steam injection	

Figure 11.3 Strategies for NO_X reduction

extra mass flow is beneficial in boosting the output from the turbine section. Even here it is being superseded by dry low NO_X techniques.

11.4 Gas burners

Introduction

Gas is the most common and easily controlled method of combustion. Gas and air are in the same phase, i.e. gases, as opposed to a liquid or solid fuel in two alternative phases, which obviously require greater measures to obtain mixing of the fuel and air. The process, therefore, is one of control or indeed inhibition of reaction rate. The simplest gas burners are of the non-aerated type, which utilize a small jet of gas to self inspirate the required air in order to obtain a so-called diffusion flame. Simple jets of this type are the Bray, Aeromatic or Drew types. Producing only a few KW, they find no application in sizes with which we are concerned. Commercial and industrial sizes tend to fall into three categories – Pre Mix, Radiant and Nozzle Mix all of which have been adapted for good emission performance.

11.4.1 Pre mix burners

Otherwise known as aerated or atmospheric burners, the gas ejected from the nozzle induces all the air necessary for combustion into a closed space, whereupon the mixture is emitted through a variety of slots, holes or grilles. These are sufficiently small that the flame above cannot burn back into the primary chamber because the holes are small enough to quench the combustion or are of sufficient velocity to be higher than the flame speed of the gas. The premix chamber can be made in any shape to fit the configuration of the combustion space and therefore is very suitable for small boilers where overall compactness is an important aspect. An even distribution of heat output promotes low NO_X because spacial hotspots are avoided. A typical burner of this type is illustrated in Figure 11.4.

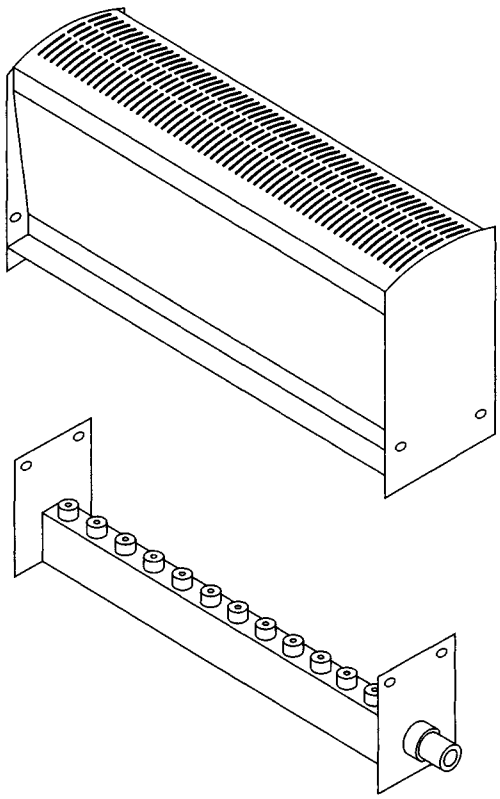


Figure 11.4 Premix bar burner

11.4.2 Radiant burners

Gas flames have the weakness that they do not liberate very much heat by radiation because of the low emmisivity of the flame. Even if the flame is fairly yellowish and at risk of incomplete combustion the emmisivity does not increase much. To overcome this weakness and hence lower the temperature of the gases as the combustion takes place a radiant burner comprises of a large ceramic or similar mantle into which the premix gases are fed. Combustion at the surface of the ceramic matrix raises its temperature to 1000°C or more so that much of the gases' energy is liberated in the form of radiant heat transfer.

By making the ceramic radiant enclosure of a similar shape to the relatively cold surfaces of the combustion chamber, very good heat transfer can be accomplished. Low average flame temperatures produce low NO_X. Sizes up to around 3 MW are available. Disadvantages are the relatively delicate nature of the matrix and its supporting framework and the inability to derive dual fuel versions. A schematic diagram is shown in Figure 11.5. The principle can also be adapted to the above mentioned smaller premix bar burners by the addition of a ceramic top surface to the flame ports. Alternatively a series of metallic rods suspended just above the ports are so arranged so that they cool the flame and radiate their heat to the combustion chamber roof.

11.4.3 Nozzle mix types

Utilizing a forced draught fan, the burner has a gas head arranged to mix the fuel and air in a blast tube which controls the stability and shape of the flame. Gas exits from holes or nozzles in the head and is mixed partly in the high velocity air stream and partly allowed to exit into an area downstream of a bluff body or a swirl stabilizer. Behind the bluff body a relatively quiescent zone forms which provides the means for stability. Alternatively the swirl stabilizer achieves its function by promoting a reverse flow zone in front of the blades so that a permanent source

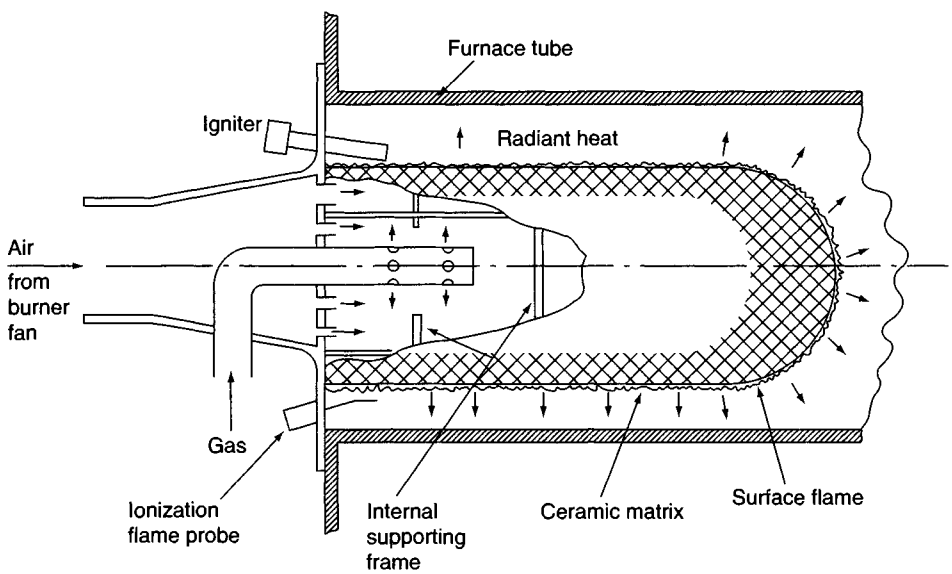


Figure 11.5 Radiant gas burner

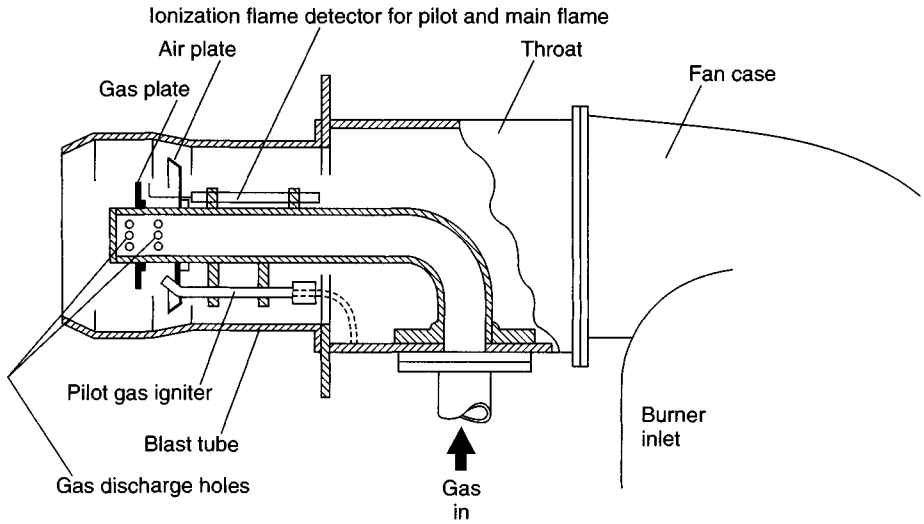


Figure 11.6 Monobloc nozzle mix gas burner

of re-ignition is facilitated. Many configurations exist, but most frequently their ancestry is a result of the adaptation of oil burners for dual fuel firing at the onset of the widespread use of gas. This can often mean that the burner is convertible to the alternative fuel or easily upgraded to dual fuel. As we have already noted, gas firing is a relatively naturally reactive process, the art being to control the combustion rate, shape, stability and emissions. A typical monobloc gas burner is shown in Figure 11.6.

Performance on gas is normally limited in dual-fuel applications to that of the oil burner, although modern electronic air fuel/ratio control permits greater turndown ratios to be set when operating on gas. Smaller burners have a turndown ratio of perhaps 4:1, whilst larger sizes can achieve 15:1. Movable sliding head parts can facilitate good performance at low loads. Low NO_X operation may be accomplished by strategic nozzle placement (fuel staging) or recirculation of the exhaust gases through the burner head or whole burner register.

Problems can occur with highly rated boilers converted to gas firing where tube end and tube plate cracking can occur due to overheating, especially if the tube/tube plate attachment is not properly "J" prepped and then welded. Boiler codes and calculation programmes are now well able to predict and avoid this eventuality. With the advent of low emission demands, boiler furnace volumetric heat release rates are now lower, although low NO_X flames can be slower burning and hence longer than their predecessors. Another phenomena that occasionally occurs is resonance or pulsation where the burner acoustically couples with the natural frequency of the combustion chamber. This is normally easily overcome by modifying the burner gas head to change the rate of mixing.

11.5 Oil burners

Oil burners are normally characterized by the method of atomizing which in itself is dependent on the grade of fuel being combusted. Three main types are found suitable for the vast majority of applications – the pressure-jet which is available as a basic nozzle and with a tip shut off, the rotary cup and the twin fluid atomizer.

11.5.1 Pressure-jet atomizers

Oil is fed at high pressure to a nozzle in which the oil passage is positioned to feed oil radially inward via a number of slots which are arranged at a tangent to the swirl chamber. The high rotational velocity given to the oil as it exits at high pressure through the central discharge hole provides the means for droplet disintegration via a conical sheet formed at discharge. Limitations of this principle include restriction to kerosene and gas oil for small sizes and poor turndown caused by a limited range of pressures over which the atomization is satisfactory. There is a choice of spray pattern, notably solid, semi-hollow and hollow cone, and a reasonable range of spray angles is available (Figure 11.7), often used in a two-nozzle head configuration to improve the turndown ratio from 1.4:1 for a single nozzle with pressue variation to 2:1 using two nozzles at constant pressure. The orthodox arrangement for the combustion head is shown in Figure 11.8 and a dual fuel low NO_X head is shown in Figure 11.9 where some partially burnt flame gases are allowed to be drawn back by the incoming air stream.

Packaged monobloc types complete with fan and all controls cover the range from a few KW up to about 6 MW. Above this the burners tend to become bespoke for the application but the principle is still valid up to power station boilers which may be firing heavy fuel oil in arrays of up to 60 burners.

11.5.2 Spill return atomizers

These partially overcome the weakness of the simplex pressure jet regarding turndown ratio by spilling back the unconsumed fuel at part load. In this way, the swirl

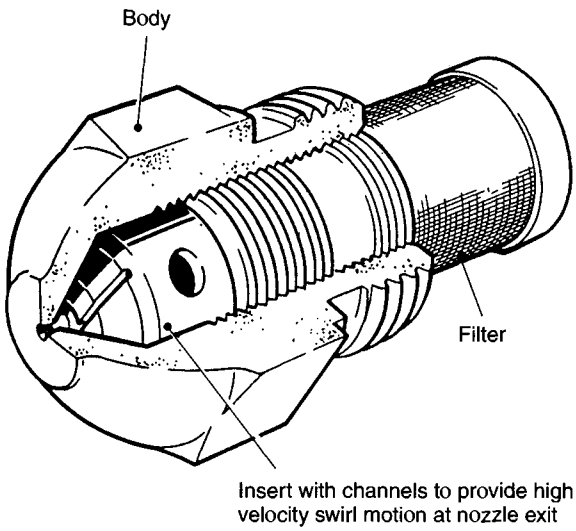


Figure 11.7 Pressure-jet Nozzle

velocity in the exit chamber is maintained constant but the diameter of the exit hole remains the same. A further advantage is that it is possible to add a central shut-off needle through the atomizer which is actuated by a servo piston using fuel pressure against the shut-off spring. This allows fuel to be circulated right up to the atomizer tip prior to starting the burner. Improved light-up results on medium and heavy fuel oils due to pre-warming of the nozzle and feed pipework. In addition, it provides a further mode of safety on shutdown acting as a shut-off valve as well as preventing dribbling of the atomizer, which could lead to poor atomization caused by nozzle fouling. This type of atomizer is shown in Figure 11.10. The combustion head configuration remains similar to simplex atomizers.

11.5.3 Twin-fluid atomizers

Atomization in these types if partly caused by fuel pressure, but this is enhanced by the kinetic energy provided by another fluid which is normally air or steam. At present, this secondary fluid is at a medium or high pressure, the low-pressure method being largely superseded. Pressures are around 1–2 bar for those categorized as medium pressure and 6–10 bar for high-pressure types. Oil pressures are also typically 6–12 bar.

Steam is the preferred atomizing medium, since it is more economic than compressed air. Steam consumption is typically less than 0.5% of the fuel burnt on a mass basis, although this rises in direct proportion to turndown ratio. On very large burners the steam flow is modulated in proportion to fuel burnt. Turndown ratios range from about 5:1 for small shell boilers to 12:1 in watertube applications, making this one of the most versatile burners. The steam condition is important in that it must be dry saturated or slightly superheated at the nozzle to avoid condensate formation. On small or non-continuously running plant where no steam is available for start up a compressed air supply must be provided until steam becomes available from the boiler.

Possibly the best-known version of this principle is the Y-jet atomizer which has between four and ten exit holes arranged circumferentially, each consisting of two converging passages arranged in a Y formation. Latterly performance has been improved by variations which use a central chamber so that the two fluids are internally mixed before being ejected in a similar pattern to the Y-jet. The advantage of this system is that the resulting jet of atomized oil is more evenly dispersed from the hole whereas with the asymmetric confluence of the two fluids at the Y junction a small amount of oil is carried down the wall of the common hole. This is due to surface

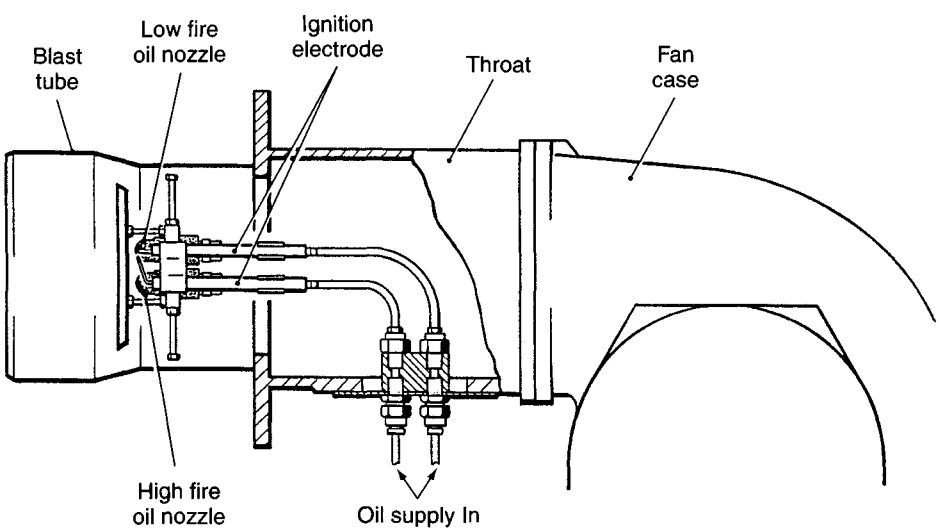


Figure 11.8 Combustion head pressure-jet burner

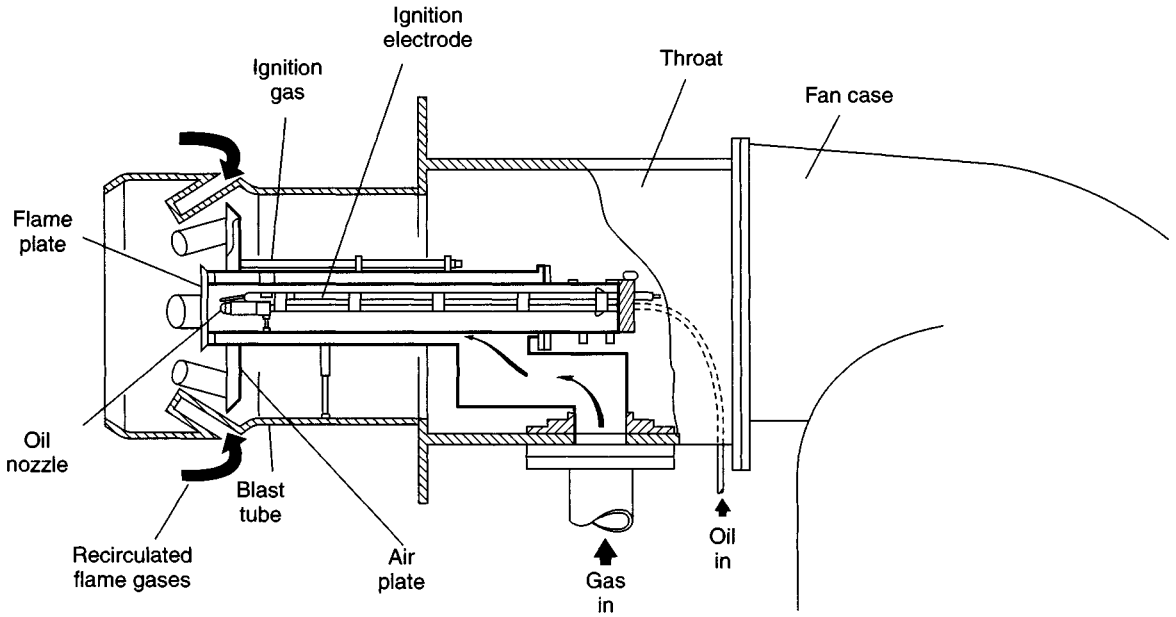


Figure 11.9 Dual fuel low NO_X head monobloc burner

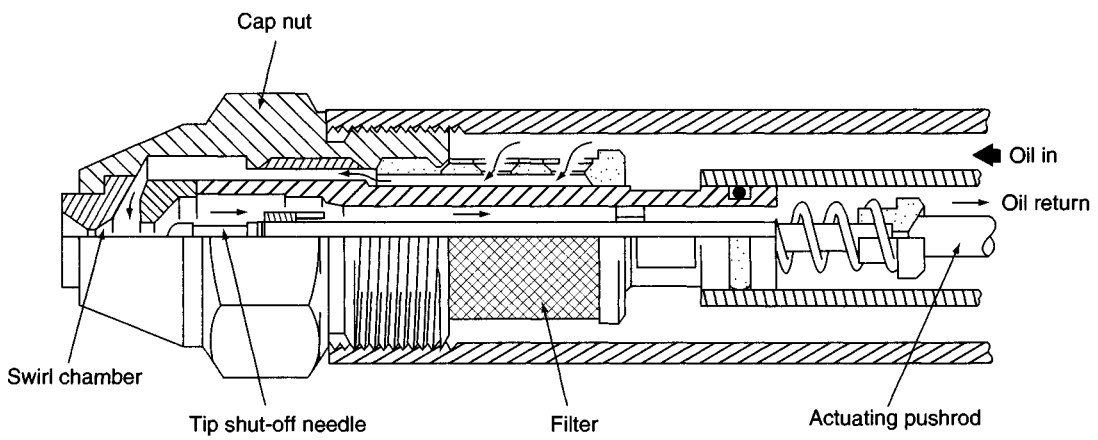


Figure 11.10 Spill return nozzle with tip shut-off needle

tension and density differences between the steam and oil. Notwithstanding this small difference both types are widely used on larger boilers especially watertube types. Cross sections of the Y-jet and the internally mixed types are shown in Figure 11.11.

Twin fluid atomisers are normally fitted into what are termed register burners the name having derived from their widespread use on watertube boilers where two or more registers or combustion heads are inserted through the front wall of the boiler and fed by a common airbox and fan. Flame stability is usually accomplished with a swirl stabiliser of 200–250 mm. diameter. In order to attain low NO_X performance the air supply is introduced in stages to the flame via several concentric passages as shown in Figure 11.12.

11.5.4 Rotary cup atomizers

A shaft rotating at 4000–6000 rev/min carries a primary air fan and an atomizing cup. The cup, typically of about 70–120 mm diameter, is tapered by a few degrees to increase in diameter at the exit. Oil is fed to the inner surface by a stationary distributor which projects oil onto the smaller-diameter end of the cup. The oil, influenced by centrifugal force, forms a thin film which passes towards the cup lip. Atomization occurs as the oil leaves this lip. In addition, a primary air supply, normally in the range of 5–12% of stoichiometric (chemically correct) air, is arranged to exit over the cup outer surface, at a velocity of about 50–90 m/s. The primary air is swirled to oppose the rotation of the cup. Droplets

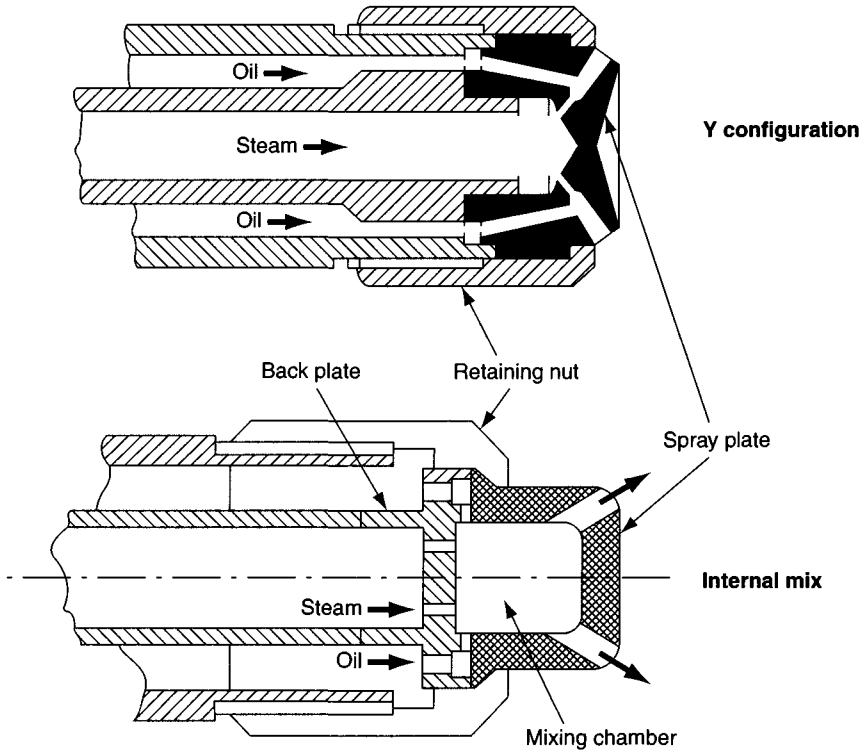


Figure 11.11 Twin fluid nozzle types

shattered by the combined centrifugal action of the cup and the primary air blast are propelled axially into the furnace.

Advantages of this type include an ability to burn all fuels from petroleum to pitch including those containing solid particles, good turndown ratio (4 to 10:1 typically) and an insensitivity to oil conditions such as pressure and temperature. It is widely used in shell boilers, and the only real limitation is that the cup surface has to be cleaned daily. A typical cross section of atomizer layout is shown in Figure 11.13. Variants include direct driven cup and separate mounting of the primary air fan.

Duel fuel versions have a gas manifold arranged around the cup and gas is emitted into the annular air exit so that the gas and air are mixed at high velocity in a highly turbulent zone. Occasionally a second gas is burnt by wrapping another gas manifold around the outside of the air exit to inject gas into the same air delivery system commonly called the quarl gap. In this manner a duel or triple fuel burner is obtained. Flame stabilization is with an aerated bluff body which uses the recirculation vortices of the flame and air spilling off the baffle. Commonly found on shell boilers they also occasionally used on watertube boilers especially where light oils are available so that the cleaning of the cup is not a problem or if gas is the prime fuel. Low NO_X versions particularly on shell boilers often use positively induced exhaust gas recirculation and are capable of excellent results. The configuration of a dual fuel rotary cup burner is shown in Figure 11.14.

11.6 Supplementary and auxiliary firing systems

Combined heat and power systems have become a major feature of the energy market over the last decade. This is not surprising when one considers the benefits of cheaper electricity, efficient generation of steam, flexibility of heat to power consumption, excellent emissions performance and avoidance of the Climate Change Levy.

11.6.1 Benefits of supplementary and auxiliary firing systems

The addition of a supplementary firing system between the gas-turbine or reciprocating engine and the waste heat boiler adds to basic attractions of CHP by:-

11.6.1.1 Improving flexibility of operation

a) Increasing the range of possible heat/power ratios from about 1.6:1 to as high as 11:1.
b) Allowing variation of steam demand by modulation of fuel input.

11.6.1.2 Improving the efficiency of scheme from 30–50% for the turbine alone to as high as 92%

a) Reducing the sensible heat losses.
b) Reducing the residual oxygen in the exhaust.

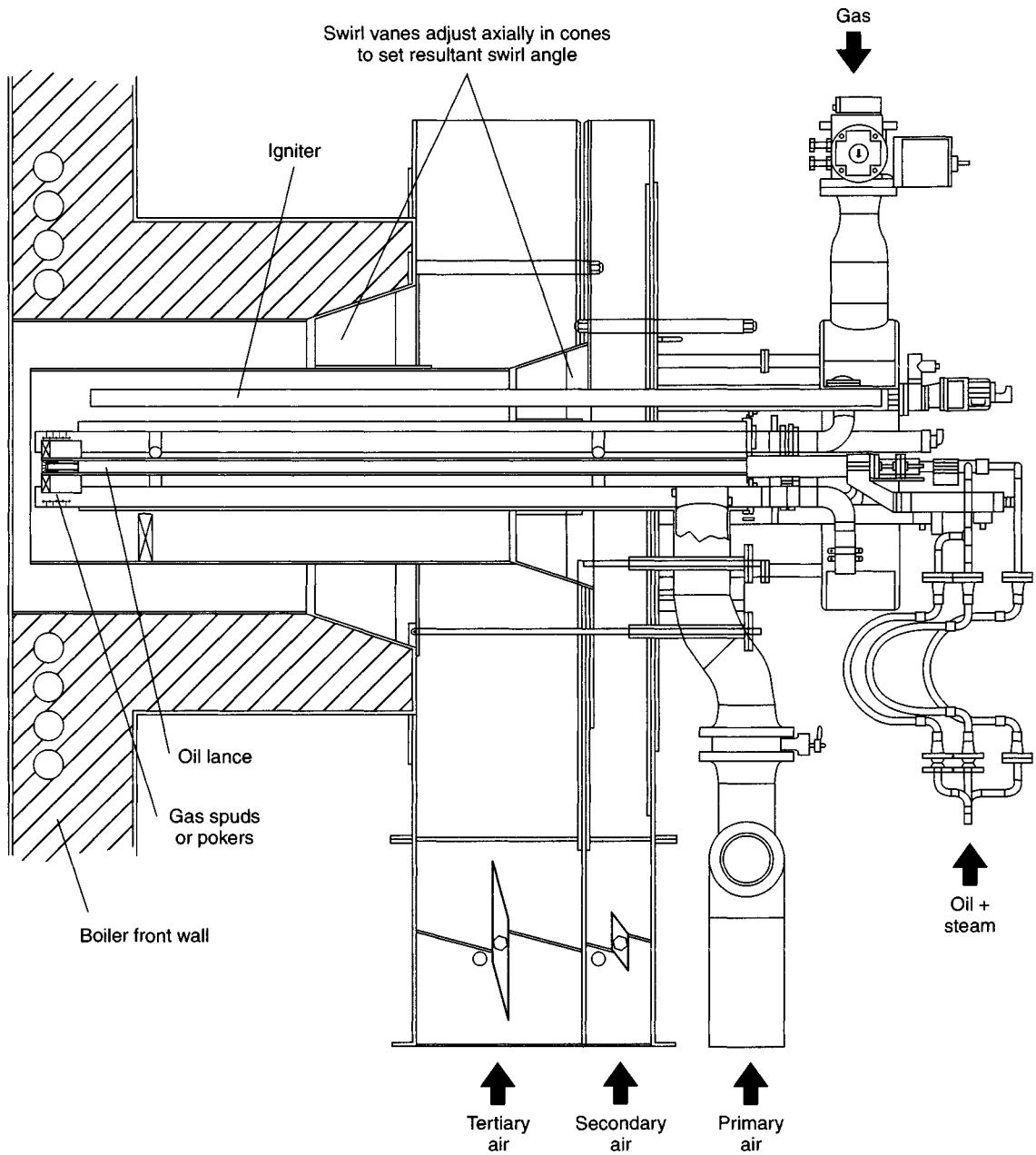


Figure 11.12 Low Nox register style burner with staging

11.6.1.3 Improving the emission performance

a) NO_X reduction from the prime mover by the technique of reburning.
b) Reduction of other pollutants, e.g. CO, particulates by combustion in a more favourable environment than in the prime mover due to higher temperatures and better flame residence times.

Specifying auxiliary operation of the burner with a forced draught fan between the prime mover exit and the burner with suitable control dampers allows:

a) Boiler operation when no significant electrical generation is required.
b) Continued boiler usage when outages occur due to breakdowns and maintenance.

There are an almost infinite number of configurations of combined heat and power layouts but only two types of burner prevail. The generic term duct burner refers to the fact that the burner is arranged to be fitted in the duct

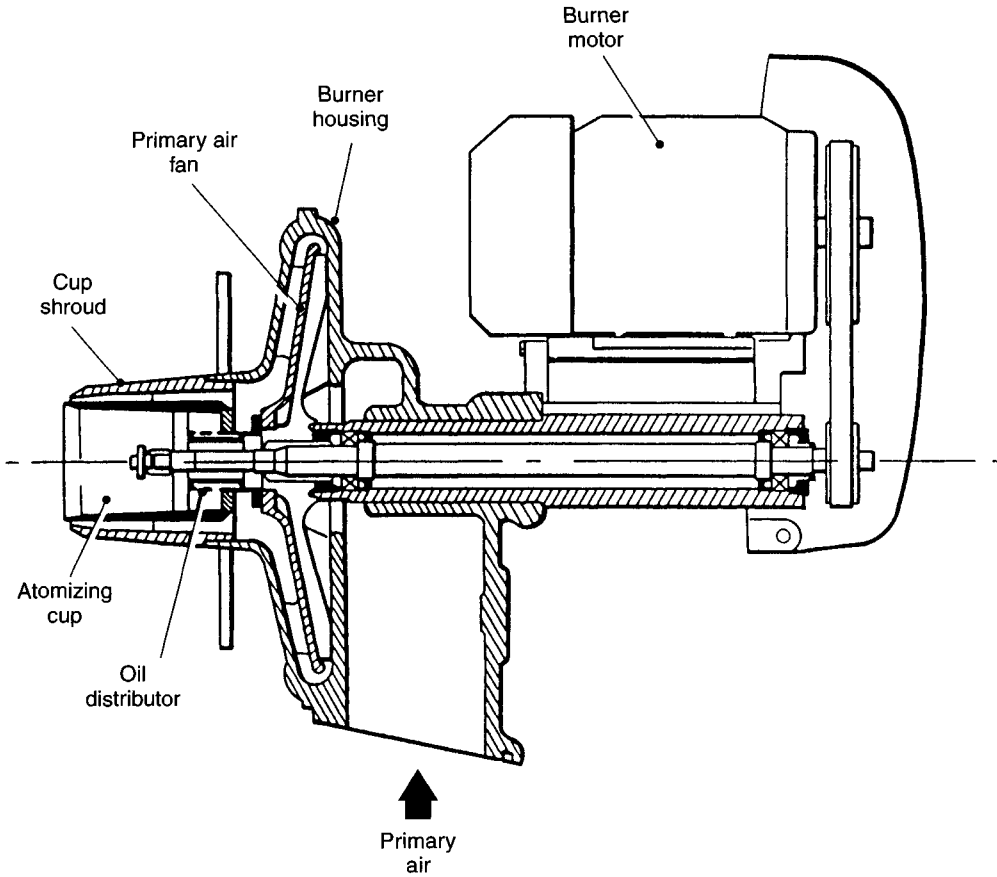


Figure 11.13 Section through rotary cup burner

between the turbine and boiler. If the fuel is to be gas the simple grid burner is adequate. However, if dual fuel operation is required, a specially adapted register burner is necessary.

11.6.2 Gas grid duct burners

Constructed in a frame for easy fitment into the ducting, they comprise of a number of bars (normally between 3 and 10), which are equi-spaced in the duct and generally all work simultaneously. The duct can be as small as 1 m^2 up to 20 m^2. Even though they only add 1–2 mbar to the back pressure on the turbine, they are capable of typically a turndown ratio of 10:1 and generally have a flame no longer than 2 metres at high fire. The boost temperature takes the turbine exit from around 500°C to a maximum of 1050°C although special linings in the duct could allow somewhat higher figures if the ceramic lining normally employed was replaced by a refractory material. Ignition is by a special cross lighting bar that brings the burner on once the turbine is firing. On the rare occasions when the steam load is between the turbine output and the low fire rate of the burner, the burner will need to go on and off as required although this is relatively unusual.

With no moving parts the grid burner is very reliable and will work on most gases such as natural gas, landfill or biogas, or refinery waste streams. Operation in auxiliary operating mode means that the pressure loss over the burner would be reduced to about a third with fresh air at 15°C instead of exhaust gas at 500°C because pressure loss is proportional to absolute temperature. This is overcome by having closing plates to restrict the cross sectional area between the gas bars either manually or automatically actuated. The method of stabilization of the flame is illustrated in Figure 11.15, the stabilizers normally being made up of a number of short lengths for differential expansion reasons bearing in mind that the gas tube is kept cool by the gas whereas the stabilizer is at least turbine exit temperature. A typical burner layout is shown in Figure 11.16.

11.6.3 Gas or dual fuel duct burners

Much less common than the grid type, these find favour when there is a requirement to run both the engine or turbine on oil as well as gas, consequently the same is required from the duct burner. Burners of this nature were derived from the twin fluid register types and are arranged to sit in the duct even though the environment

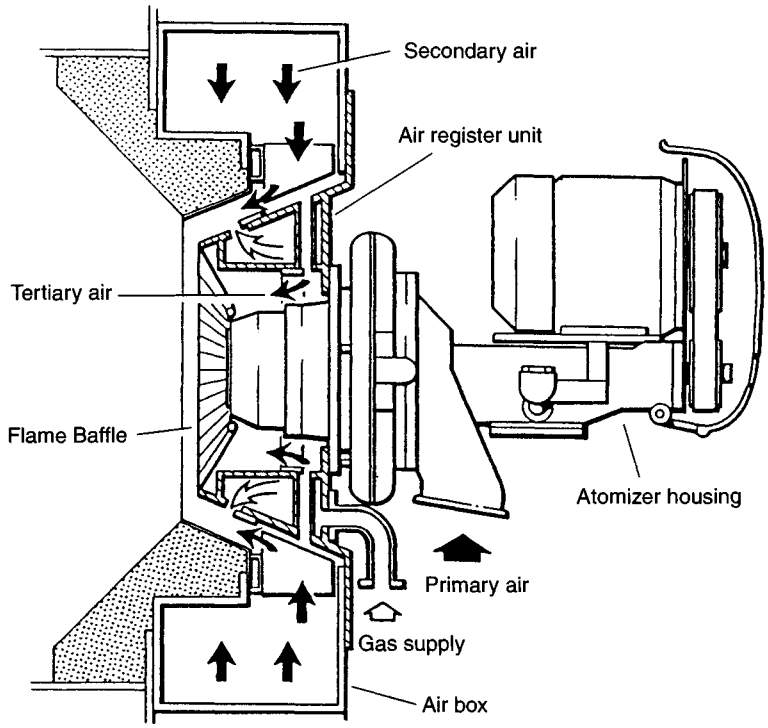


Figure 11.14 Dual fuel rotary cup burner

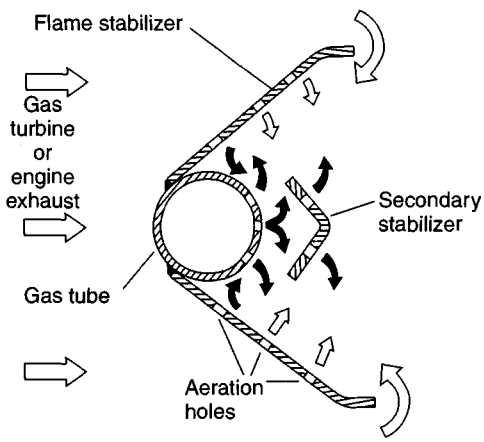


Figure 11.15 Grid burner stabilization

is rather hostile bearing in mind their extra complexity. Although capable of nearly the same turndown ratio as the grid burner, the turndown ratio on oil is more likely to be 4:1 to 6:1. Versions have been operated on heavy fuel oil, especially when in support of a heavy oil diesel engine. Burners which supplement reciprocating engines have to contend with the pulsating nature of the exhaust and a higher level of pollutants than is the case with gas turbines. In addition, the available oxygen concentration can be as low as 9%, whereas figures of 14–15% are more common with gas turbines. A dual fuel register burner is shown in Figure 11.17. It is possible to close couple this type of burner to the boiler so that the flame is not in the duct but within a boiler with its own furnace. Under these circumstances the oxygen concentration can be taken down as low as 3% with a flame temperature as high as 1600°C.

11.7 Controls

Burners require a programmed start up and shut down sequence in order that safe operation is achieved. Various interlocks need to be satisfied, e.g. that the burner is at its low fire position for light up. In addition, whilst the burner is in operation, any unsafe event must be recognized and a safe shut down, called a lock out, actioned.

For smaller burners this is done by a dedicated proprietary electronic control box. For start up the fuel supplies are checked for correct pressure and temperature and an air purge completed to ensure that the chamber is free of an explosive mixture. The air and fuel actuators are then positioned ready for start up and the ignition sequence commenced. A high voltage spark system is used for small and medium sized pressure jet style gas and oil burners with a single electrode 5000 volt spark jumping to ground on gas units. Twin electrodes producing a 10 000 volt spark which is positioned on the edge of the spray cone are used on oil burners. Larger and dual fuel burners tend to exclusively use a gas pilot, spark lit. Once the ignition is actioned and verified, the main fuel supply may be introduced. A photo cell or ionization probe

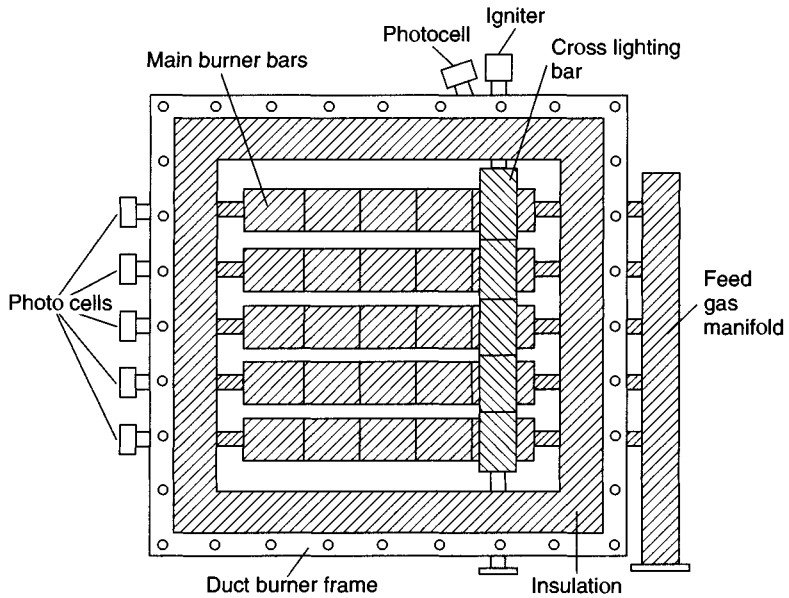


Figure 11.16 Grid burner typical bar layout

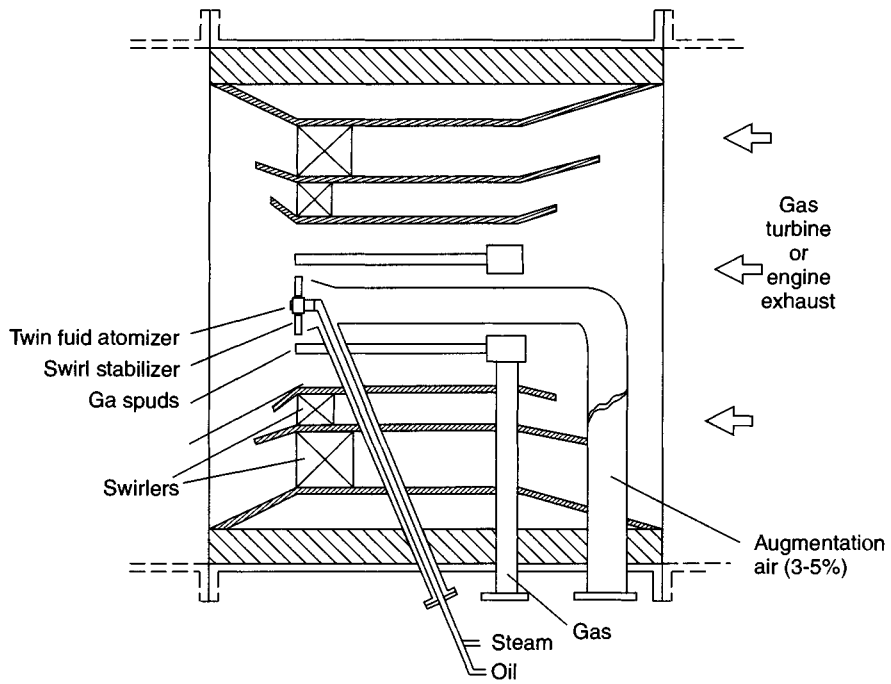


Figure 11.17 Dual fuel register duct burner

on smaller burners will then prove the pilot flame and the main fuel can be introduced and this verified. If a lock out occurs, the burner must stop, normally with a post purge to clear the incomplete products of combustion. Some codes of safety allow one re-attempt at light up but most require manual intervention to reset the trip. Safety interlocks are normally arranged to check changeover of the signal during the light up and shut down sequence, e.g. the microswitch is seen to have changed over from open to closed circuit. Burners operating continuously require self-checking of the photocell and all components should fail safe, i.e. not in a dangerous condition. Valves, pressure switches, etc. should fail in the closed or un-pressurized condition.

The management of the safety sequences on larger burners are more commonly now controlled by a PLC (programmable logic controller). However, this must have a second unit in parallel which checks that the parallel operating sequence agrees with the master controller. This is done by an approved watchdog system programmed to check for synchronized compliance. Alternatively, a second PLC can perform the watchdog duty and on some safety critical applications triple redundancy is specified. On many large industrial projects, the I/O (Input/Output) count is increased to allow communications between the burner management system and boilerhouse overall control system. Sometimes communications are required between the factory process and the heat generation equipment. Large plants often employ a SCADA (Supervisory Control and Data Acquisition) computer system to bring together operating data and control the whole process. Information on running times, efficiency of operation, emissions data etc. is made available. This may be subject to extensive computational analysis to furnish graphically presented data on a VDU and allows operators to understand and interpret complex operational information in a clear way. Using modems, the health of the whole operation may be monitored either locally or by the Contract Energy Management Company or indeed, for example, the burner maker's service department. Indeed, the burner service engineer at head office may know the burner has failed before the customer has noticed it and may already be on his way to fix it. It should be noted that SCADA systems do not replace burner management control units as this is a dedicated primary safety critical function, although the SCADA unit may re-sequence the load take-up order of the boilers and which ones remain in a banked condition. In any multiple boiler industrial plant, SCADA is becoming de rigeur. The issue of connectivity (compatibility of various instrument signals) is now virtually resolved but is nevertheless an item which needs to be addressed with new equipment.

Reverting to smaller burners, the function of air/fuel ratio control is now undertaken on modulating burners by a dedicated electronic unit which keeps the air and fuel servomotors in their pre-programmed positional relationship. Any deviation from the relationship is detected by a comparitor watchdog and trips the burner if, for example, one of the motors does not feed back the correct relationship. An extra to this function is an O_2 sensing probe which adjusts one of the motors so that the optimum air/fuel ratio is maintained throughout the modulation range. This O_2 trim function can be integrated into the digitally controlled air/fuel ratio controller. One manufacturer has now combined the burner logic sequencing controller with the air/fuel ratio controller into one compact unit. Additional printed circuit cards can be added to extend the user power to include variable speed fan drives, remote alpha-numeric message display units and touch screen control of burners and their function and operating sequence. In addition to basic burner health, information on boiler wide alarm and fault data can be conveyed in an easily understandable form.

11.8 Fuel handling systems

The foundation for a reliable and efficient combustion system is a well designed and cost effective fuel supply and regulation system

11.8.1 Gas

Smaller plant may only have a 200 mbar supply and this will normally require the use of a gas booster (specially adapted fan) to raise the pressure to 0.1 bar or so. Larger plant which is adjacent to the National grid system normally will be able to have gas at about 0.3 bar. Larger plant still may be delivered high pressure gas at several bar pressure which has to be "knocked down" to a more usable pressure with the governor station under the customers control. In these cases where the pressure reduction is more than 30% higher than the operating pressure a slam shut valve must be incorporated in the governor station to shut off the supply if the governor malfunctions giving an excessive exit pressure. Pressure relief must also be incorporated to prevent surges of pressure when the gas flow is suddenly arrested. If this was not done the governor would be "locked up", in other words it would be sensing a pressure higher than required and would therefore be trying to close off the flow when the seat was already closed. The governor should be sized so that at highest flow the pressure has not decayed by more than $7\frac{1}{2}\%$ this is know as governor droop and is caused by the increasing flow losses within the governor itself.

Most burners have a valve train packaged into the burner assembly with one of the two main safety shut off valves also fulfilling the function of a control governor. Some burners use this governor to regulate the pressure in unison with the burner air supply (detected by air pressure) which gives a rudimentary air/fuel ratio control system. Smaller units are either on/off or high/low heat control by a 2 position gas governor built into the shut off function. The more industrial sizes tend to have fixed pressure control using the multifunction governor/shut off valve and the output is controlled by a modulating gas butterfly valve or similar. A typical gas installation pipe layout is shown in Figure 11.18 but it must be remembered that there is plenty of variation dependent on pressures, number of burners and safety standards applicable to the size and type of application.

11.8.2 Oil

First and foremost comes the fuel type – if the fuel is diesel or lighter no heating is required except perhaps light tracing on external pipework where there is a risk of sub-zero temperatures. If black oil is being consumed not only must full thermostatically controlled electric or steam tracing be employed, but the oil should be kept circulating around the system so that steady state pressure and temperature is maintained. Only if the plant is to be shut down for a number of days may circulation be stopped but even then the heat tracing should be kept running. For heavy oil installations there should be an outflow heater fitted to the tank, and pumping and a line heater also is

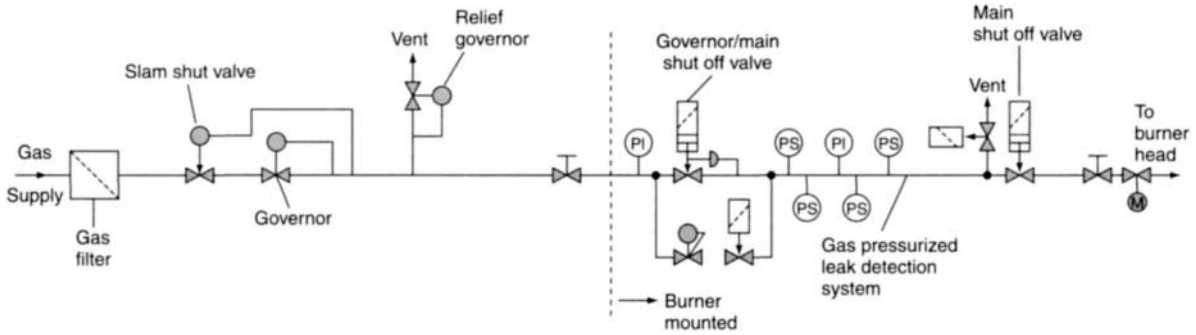


Figure 11.18 Typical installation gas pipework layout

necessary between the tank and the burner. Where high levels of availability are required the line heater, pumping and filtration should all be duplexed. Twin fluid burners normally require an atomizing temperature above the boiling point of water, which means that traces of water in the oil will boil and cause cavitation if not kept pressurized above the saturation pressure and temperature. For this reason after the oil has been heated to atomizing temperature it must be returned to a point in the pipework where there is sufficient pressure to prevent boiling. The solution to this is to incorporate two-stage pumping and return the oil between the stages of the pump. Another important consideration is to have adequately sized pipework between the tank and the pumps and ensure that there is always a positive head on the pump/s under flow conditions and bear in mind to keep the filter before the pumps sufficiently clean. Good instrumentation i.e. pressure and temperature gauges at all strategic points are essential. So often, the fuel delivery, preparation and transport to the burner is inadequate with gross examples of bad practice, for example running the ring main in a trench which also acts as a wash down reservoir and is therefore full of water.

Diesel oil burner systems have the advantage of no line and tank heaters but good filtration and pumping preferably duplexed is desirable. Diesel oil does not normally require a ring main system although in large systems it is not uncommon with a so called dead leg (single pipe) to each burner. For small burners there will only be a pump on the burner with its own pressure controller within the pump, in this case it is important that the pump inlet is fully pressurized from the tank head and pipework is sufficiently large enough to cope with all burners firing. Ring main systems have an upstream pressure controller fitted at the end of the outgoing run, this should be capable of isolation and bypassing so that flow can be re-established in the event of a restart where highly viscous oil is present which may risk diaphragm failure of the controller. Pump sizing capacity should allow a 15% margin over the total oil burnt for diesel oil and single pipe systems and 30% excess for ring main systems so that wear and other forms of deterioration are catered for.

As with gas burners the burner oil fuel controls are normally packaged onto the burner and obviously designed to suit the particular operation and fuel of the application. Two shut off valves are essential for both the ignition and main flame supplies. Small burners have a supply to each nozzle, each line having one valve with another valve in the common line. Spill return burners normally have a shut off valve incorporated by the action of the cut-off needle and secondary valves in the supply and spill lines. Fully modulating burners utilize a control valve which can be adjusted for overall throughput as well as low and high fire settings so that the linearity of flow to opening position is not compromised.

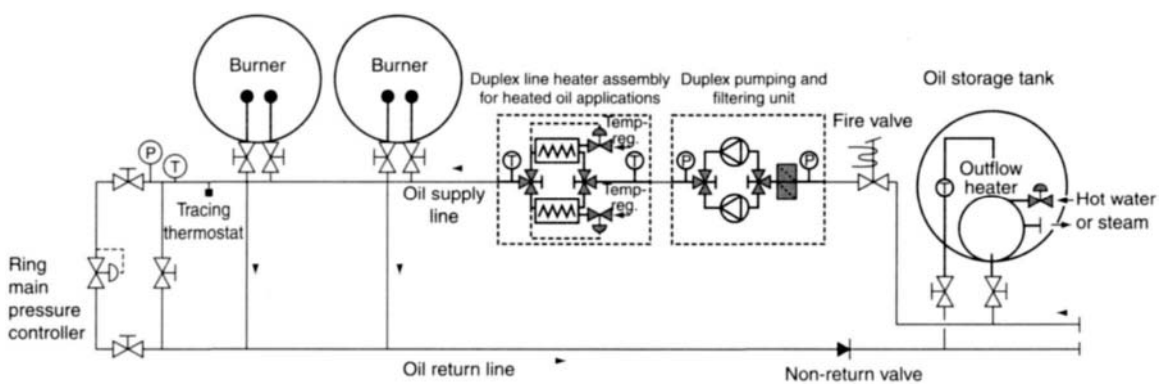


Figure 11.19 Typical installation oil pipework layout

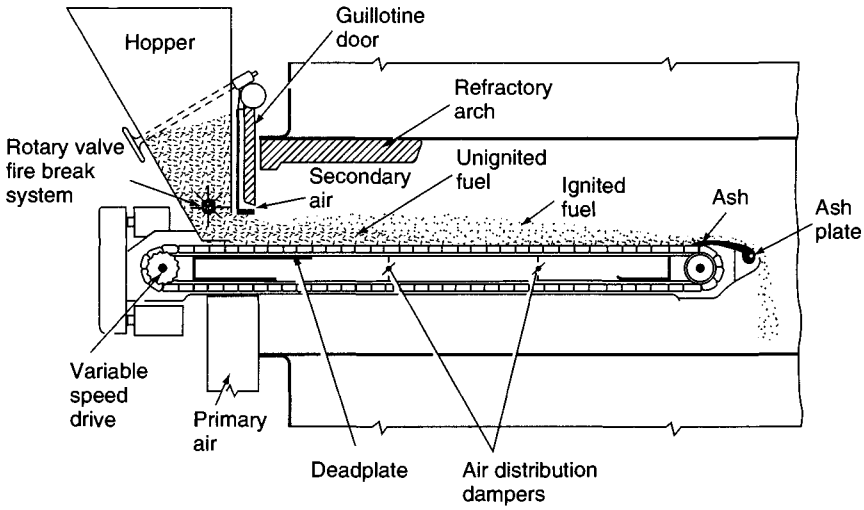


Figure 11.20 Chain grate stoker

11.8.3 Accessories

Essential accessories for both gas and oil are fuel usage meters both for commissioning and set-up purposes as well as energy monitoring. Equally important for a completely different reason – that of safety – is a fire isolating valve to isolate the fuel system in the event of a fire in the boiler house. This must be self closing on loss of signal and not require any electrical power supply to rapidly isolate the fuel delivery system.

11.9 Solid fuel firing

Within the European Union, coal firing has virtually disappeared largely as a result of emission issues. Other factors facilitating its demise have been uneconomic fuel prices, the cost of ash disposal and high labour and maintenance costs.

Only where these factors are significantly different will solid fuel equipment be found. Developing countries, especially those having cheap coal from surface deposits, still use what was the technology that fuelled the Industrial Revolution. Stokers are the eponymous underfeed and fixed grate types with the coking stoker (which uses reciprocating bars) and the chain grate being the main other types. Due to the high ash content likely in the third world, the latter two are the most likely survivors. A chain grate stoker is shown in Figure 11.20. The pulverized fuel burner which uses milled fine coal dust can still be found, especially where a requirement exists for dual or triple fuel operation. The configuration of this burner is in the form of a register not dissimilar to gas and oil register burners. A pulverized coal and gas dual fuel burner is shown in Figure 11.21.

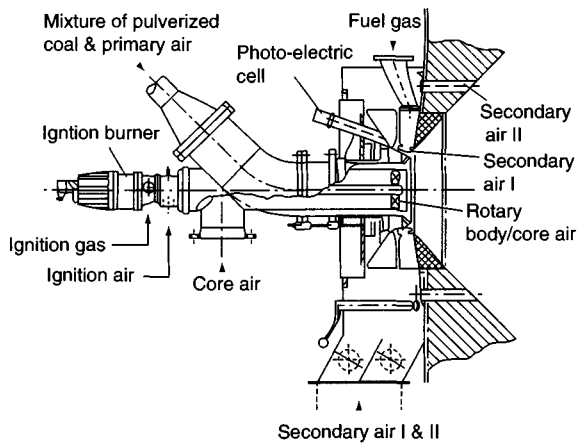


Figure 11.21 Pulverized coal and gas dual fuel burner

Circulating fluidized bed combustion is the only other type which has the potential to burn poor quality fuels. Combustion of the coal in a fluidized or bubbling bed of sand or similar inert material energized by the upward flow of air prompts rapid burn out of the solid fuel. Although capable of operation using a blend of coal and domestic and industrial waste, the high maintenance costs of corrosion and erosion both in the bed and in the auxiliary systems have made it a rarity even though much money and effort has been spent on progressing the technology. Clean up costs from the exhaust also weigh heavily against its further use.

Waste incineration plant has specially developed grate systems such as the stepped or roller grate.

12 Oil

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12.1 Distribution and delivery

Crude oil is processed at oil refineries, generally located around coastal areas, and then transferred to a nationwide network of oil fuel terminals, from where it is distributed to customers. Fuel supplies to the customer can be made by road delivery vehicle, rail tank wagon or coastal tanker, depending on the location of the customer's storage installation.

12.1.1 Road delivery vehicles

Deliveries of oil fuels by road are made by vehicles with capacities ranging from 11 800 to 28 700 l (2600 to 6300 gal). The vehicles discharge fuel into customers' storage by pump or compressed air at rates up to 1050 l (230 gal) per minute, and can deliver to a height of 10.7 m (35 ft) above the vehicle.

There are occasions where the noise of vehicle discharge needs to be minimized, examples being night discharge at hospitals, hotels and adjacent to residential areas where there are parking restrictions on daytime deliveries or where a customer agrees to a 24-hour delivery service. In such cases, the customer can install a offtake suction pump as part of his storage facilities, thus eliminating the use of the vehicle engine for vehicle pump operation.

There must, in all cases, be safe road access to sites where tanks are situated and suitable hard standing provided for the vehicle during delivery.

12.1.2 Rail tank cars

The capacities of rail tank cars are generally 45 t gross laden weight (approx. 30 t payload) or 100 t gross laden weight (approximately. 70 t payload). Cars for carrying heated fuel oil are insulated with fibreglass lagging covered with galvanized sheeting, and are equipped with finned tubes for steam heating.

A customer's steam supply must be capable of providing an adequate amount of heat to discharge a full trainload of oil. Considering individual rail tank cars, a 100 t *gross laden weight* (glw) car requires 385 kg/h (850 lb/h) and a 45 t glw car requires 154 kg/h (350 lb/h) of steam. Because of the risk of contamination by oil, the condensate should be drained from the outlet connection and run to waste.

Rail tank cars have bottom outlets terminating in a quick-acting coupling, and are designed for pump offloading only. A flow indicator should be inserted between the terminal outlet and the fill line. Flexible connections for steam and oil lines should be provided for the maximum number of cars that will be discharged simultaneously.

A block train consists of a series of rail tank cars of either 45 t glw or 100 t glw (or a mixture of both) coupled for movement from source to destination and back as a unit. The size of the trains will be determined by contractual agreement, but will never be less than 300 t payload, and will normally be 500 t.

12.1.3 River and coastal tankers

Where a customer has suitable berthing facilities and satisfactory arrangements can be made, deliveries can be by either river or coastal tanker. River tankers currently in use are of 960 t capacity but may be larger if conditions permit. The customer is responsible for supplying oil hose and/or discharge arms capable of discharging the full contents of the barge under low-water conditions.

Coastal tankers are available up to 2000 t capacity, equipped with pumps for discharging into customer's storage. The size of the vessels to be used will depend upon local conditions and the depth of water in the approaches.

12.2 Storage tanks

12.2.1 Type of tanks

There are four main types of storage tank available for industrial and commercial fuel oils, namely:

Mild steel welded
Mild steel sectional
Cast iron sectional
Reinforced concrete

Of these four, the mild steel welded tank is the most popular and is widely used for every type of application.

The majority of storage tanks are of the horizontal cylindrical type, as shown in Figure 12.1. Where ground space is a limiting factor, vertical cylindrical tanks may be used.

12.2.2 Construction

The principal British Standard used for the design and construction of oil storage tanks and associated fittings is BS 799, Part 5. Other relevant standards are:

BS 1564, Pressed steel sectional rectangular tanks
BS 2594, CS welded horizontal cylindrical tanks
BS 2654, Vertical steel welded tanks for the petroleum industry

Limitations on the tanks covered by the above-mentioned codes are as follows:

1. *BS 799, Part 5*
   Integral tanks, which form part of a complete oil-fired unit, having a capacity not exceeding 25 l;
   Service tanks, which isolate the main storage tanks from the burner installation, having a capacity not exceeding 1000 l;
   Storage tanks of unlimited capacity but with a maximum height of 10 m;
   Design pressure not exceeding the equivalent head of water acting at the bottom of the tank, i.e. height of tank, plus full height of vent pipe.
2. *BS 1564*
   Constructed of pressed steel plates 1220 mm square;
   Design pressure not exceeding the static head corresponding to the depth of the tank;
   Maximum depth of 4880 mm.

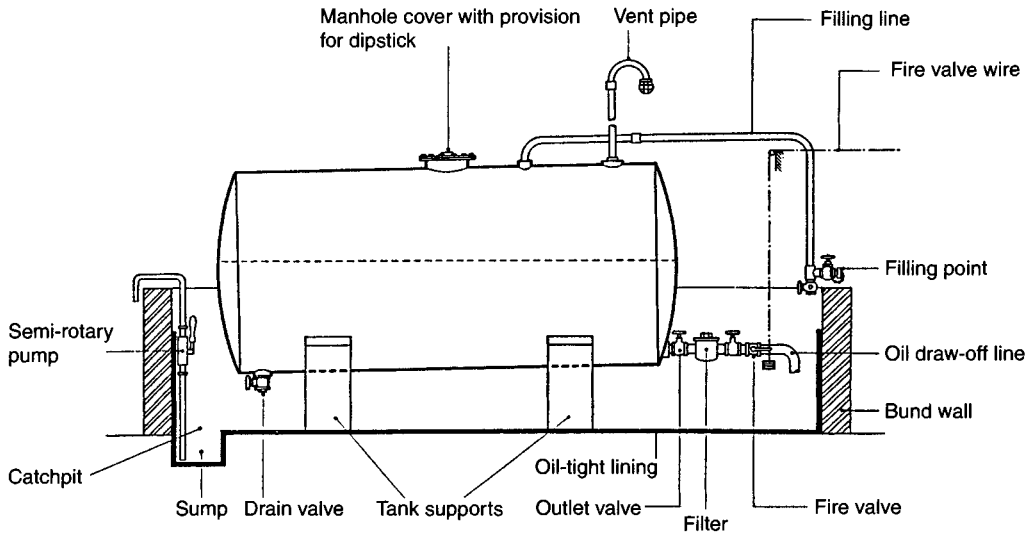


Figure 12.1 Typical storage tank for a distillate fuel oil

3. *BS 2594*
   Maximum internal working pressure not exceeding 0.4 bar at top of tank and maximum internal vacuum not exceeding 10 mbar.
4. *BS 2654*
   Design pressure and vacuum pressure not exceeding 56 mbar and 6 mbar, respectively;
   Design metal temperature not lower than −10°C.

When using mild steel rectangular welded tanks, internal bracing is required. Great care is necessary in the design and installation of supports for sectional steel tanks to prevent distortion under load.

12.2.2.1 Design Criteria

Basic design criteria which need to be taken into consideration when designing a storage tank will include:

1. Geographical location of tank (e.g. indoors/outdoors, height above ground level, available space, accessibility, etc.);
2. Principal dimensions or capacity;
3. Type of roof (e.g. fixed or floating, cone, dome, membrane, pontoon, etc.);
4. Properties of fluid;
5. Minimum and maximum design temperatures;
6. Requirement for heating elements;
7. Design vapour pressure and/or vacuum conditions;
8. Minimum depth of fluid;
9. Maximum filling/emptying rates;
10. Venting arrangements;
11. Connections/manhole requirements;
12. Access ladders;
13. Corrosion allowance;
14. Number and type of openings;
15. Type of support or foundation;
16. Internal/external coating or lagging.

12.2.3 Capacities

The capacity of storage tanks for oil-fired installations is an important consideration. BS 779: Part 5 recommends that the minimum net storage capacity should be calculated either by taking:

1. Three weeks' supply of oil at the maximum rate of consumption; or
2. Two weeks' supply at the maximum rate of consumption, plus the usual capacity ordered for one delivery, whichever is the larger.

Where the maximum weekly offtake is less than 200 gal (910 l) the capacity should still not be less than 650 gal (2950 l) in order to accept a standard 500-gal (2270-l) tanker delivery. In some circumstances, it may be desirable to provide more than one tank, each of sufficient capacity to accept at least a full delivery.

12.2.4 Tank supports

Horizontal cylindrical tanks should be installed on brick or reinforced concrete cradles with a downward slope of 1 in 50 from the draw-off end towards the drain valve, as shown in Figure 12.1. Cradles should be constructed on foundations adequate for the load being supported and the type of soil. A reinforced concrete raft equal to the plan area of the tank, and of adequate thickness to bear the load, is normally suitable for all but the weakest soils. Cradles should not be placed under joints or seams of the tank plates and a layer of bituminized felt should be interposed between the cradle and tank. The height of the tank supports should provide at least 450 mm space between the drain valve and ground level to allow access for painting or draining the tank.

12.2.5 Tank fittings

12.2.5.1 Oil-level indicators

A brass dipstick is recommended as a cheap and reliable means of determining the contents of a storage tank. A dipstick, when required, is usually provided ready calibrated by the tank manufacturer before installation of the tank.

In many cases it is inconvenient to use a dipstick, due to the position or location of the tank, and there are a variety of direct and remote contents gauges available, including gauge glasses, float and weight, float and swing arm, float and indicator, hydrostatic, electrical capacitance, etc.

12.2.5.2 Filling connection

Filling pipes should be as short as possible and free from sharp bends. The terminal should be in a convenient position to allow easy coupling of the vehicle hose connection, wherever possible within 5 m (15 ft) of the hard standing for vehicle delivery. The most suitable height for a filling pipe is about 1 m (3 ft) above ground level and clear of all obstructions.

A non-ferrous dust cap with chain should be provided to close the end of the filling pipe and protect the thread when not in use. When the filling pipe is not self-draining into the tank a gate valve should be fitted as close as possible to the hose coupling. Where there is any possibility of damage or misuse of the terminal equipment a lockable fill cap should be fitted and, if considered necessary, the terminal enclosed in a lockable protective compartment.

All filling lines should be self-draining. Where this is not possible with residual fuel installations, trace heating and lagging should be applied, and this is particularly important in exposed positions. This will ensure that any oil fuel remaining in the filling pipe will be at pumping viscosity when delivery is made.

The filling pipe should enter at the top of most horizontal storage tanks. For vertical tanks up to 3 m (10 ft) diameter the filling pipe should be fitted at the top and then bend through 90°. This directs the incoming oil fuel down one side of the tank and minimizes air entrainment. In larger vertical storage tanks containing residual fuels, bottom inlet filling may sometimes be used. A non-return valve must be fitted in the filling line as close to the tank as possible. The entry position of the filling pipe into the tank in relation to the position of the draw-off connection must be carefully selected to avoid air entrainment into the oil-handling system.

Where delivery vehicles do not have access adjacent to the storage area a permanent extended filling pipe should be provided from the tank to a position where the vehicle can stand in safety. In cases where the length of this pipe will exceed 30 m (100 ft), careful attention should be paid to draining requirements. Where lines are not self-draining, a drain valve should be situated at the lowest point in that section. Provision should be made for lagging and tracing to be applied to extended fill lines that will carry residual grades of industrial oil fuel. Careful attention should also be paid to the use of correctly sized pipe diameters. Where the storage tank is not visible from the filling point, an overfill alarm should be fitted.

12.2.5.3 Ullage

The air space between the oil surface and the top of the tank is known as ullage; there should always be a small ullage remaining when the contents gauge registers full. This prevents the discharge of oil from the vent pipe due to any frothing and surging of the liquid during delivery. The ullage should provide not less than 100 mm (4 in) between the oil surface and the top of the tank or be equivalent to 5% of the total contents, whichever is the greater.

12.2.5.4 Vent pipes

A vent pipe must be fitted at the highest point of every storage tank. Wherever possible, it should be visible from the filling point and terminate in the open air, in a position where any oil vapour will not be objectionable and, in the event of an overflow, there will be no damage to property, fire risk of contamination of drains.

The vent pipe bore must be equal to or greater than the bore of the filling pipe, and never less than 50 mm (2 in) diameter. It should be as short as possible and free from sharp bends. It should terminate in a return bend or 'goose neck' fitted with a wire cage for protective purposes (fine gauze must never be used for this purpose).

Where, of necessity, the vent pipe rises to a considerable height, excessive internal pressure on the tank may result, due to the pressure head of oil should an overflow occur. To prevent any possible tank failure due to such an occurrence a vent pipe pressure-relief device must be provided. It should be self-draining to reduce the risk of blockage, particularly when using heavy oil fuel. BS 799 requires that these devices should not place any restriction on oil flow and must discharge within the bund area.

12.2.5.5 Draw-off connection

The draw-off connection to the oil-burning plant should be at the raised end of horizontal tanks. Where heating facilities are not provided, the lowest point of the draw-off connection should never be less than 75 mm (3 in) above the bottom of the tank. For tanks fitted with heating elements, it is essential that these and their associated thermostatic control probes should always remain below the oil surface.

To enable the contents of the tank to be isolated a screw-down gate valve should be fitted adjacent to the draw-off connection. Since stresses may be applied to valves during any tank settlement or movement of pipework, cast-iron valves should not be used for this purpose.

12.2.5.6 Drain valve

A screw-down gate valve with a bore similar to that of the draw-off connection should be installed at the lowest point on every storage tank to permit complete draining. The valve should be readily accessible with a clear space below to facilitate its use. Extension pipes to or from drain

valves should be avoided if possible, but where these are necessary, the pipe should be lagged and, if necessary, traced to ensure that residual grades of oil will flow during adverse weather conditions. Valves and extension pipes should be fitted with a plug or blank flange to prevent inadvertent discharge of the tank contents.

Tanks containing heated grades of oil fuel require regular draining. This is due to the small amount of moisture which accumulates over a period, by condensation formed on the sides of the tank. The quantity of moisture formed will be dependent upon the relative humidity conditions, the amount of 'breathing' which takes place, and the time allowed for settling. It is recommended that the tank be checked for accumulated water prior to a fuel delivery.

With storage tanks which are filled from the bottom such as large vertical tanks, the stirring action of incoming oil will carry any water (which would normally settle out) into the oil-handling system. In these circumstances, any daily service tank used in the system should receive regular inspection to ensure that water has not accumulated. Any oil/water mixtures should be drained into suitable containers and subsequently removed for disposal into a separator or interceptor.

12.2.5.7 Manhole

Every storage tank must have a manhole in an accessible position, preferably on top. It may be circular, oval or rectangular, and not less than 460 mm (18 in) diameter if circular or 460 mm (18 in) long and 410 mm (16 in) wide if oval or rectangular. The manlid must be securely fixed by bolts, studs or setscrews, and have a liquid and vapor-tight joint. Close-woven proofed asbestos, graphited on both sides, is a suitable jointing compound for this purpose.

Vertical tanks over 3.65 m (12 ft) high should have a further manhole fitted near the bottom to provide access for cleaning and maintenance of any storage-heating facilities.

12.2.6 Heating requirements

Distillate grades of oil fuel may be stored, handled and atomized at ambient temperatures, and do not require heating facilities to be provided in storage tanks and handling systems. However, exposure to extreme cold for long periods should be avoided, since oil flow from the tank may become slightly restricted. This is particularly important for storage serving stand-by diesel generating plant where summer cloud point specification fuel may be in both storage and oil feed lines during the most severe winter weather. In very exceptional conditions, even winter cloud point specification fuel may present occasional problems in unlagged storage and handling systems. Such systems should be lagged and, if necessary, traced to ensure faultless starting.

Heating facilities are required for all residual grades of oil fuels, such as Light Fuel Oil, Medium Fuel Oil, and Heavy Fuel Oil. Table 12.1 gives the recommended minimum storage and handling temperatures for residual oil fuels (from BS 2869: 1970).

Where oil is to be maintained at minimum storage temperature, an outflow heater will be necessary to raise the temperature of the oil leaving the tank to that required for handling. It is not good practice to store oil fuel at unnecessarily high temperatures, and the temperature given under the column 'Minimum temperature at outflow from storage and for handling' should not be exceeded by more than 16.7°C (30°F). This is particularly important in relation to Light Fuel Oil. Maximum heat losses from storage tanks can be determined from Figure 12.2. These losses can be translated into maximum steam consumption rates of the heating coils from knowledge of the latent heat of steam appropriate to the steam pressure used in a given installation. The tank heating arrangements must be capable of maintaining the oil storage temperature with the appropriate rate of heat loss.

Table 12.1 Recommended storage and handling temperatures for residual fuel oils (based on BS 2869: 1970)

Grade of oil	*BS classification*	*Minimum storage temperature*	*Minimum temperature at outflow from storage and for handling*
Light Fuel Oil	Class E	10°C (50°F)	10°C (50°F)
Medium Fuel Oil	Class F	25°C (77°F)	30°C (86°F)
Heavy Fuel Oil	Class G	35°C (95°F)	45°C (113°F)

Another important point is that concerning the occasional requirement for heating the oil from ambient temperature. A heat input several times greater than that required to maintain handling temperatures will be necessary, depending on the minimum time stipulated for heat-up. Tank heating arrangements should therefore be capable of providing this heat input if the contingency is a possibility.

12.2.6.1 Heating methods

Storage tanks can be heated with thermostatically controlled steam coils, hot-water coils, electric immersion heaters or a combination of these. The elements and their thermostats should be positioned below the level of the oil draw-off line, so that they are always covered during normal operation. The temperature-sensitive element of the thermostat should always be situated above and to one side of the heating element. The heating elements should be spaced evenly over the bottom of the tank or concentrated towards the draw-off end. A combination of steam and electric heating can be used for installations where periods may occur during which steam is not available.

Where a residual oil fuel is stored in tanks with outflow heaters provision should also be made to maintain the oil at or above the minimum storage temperature shown in Table 12.1. Excessive heating is not recommended, particularly for Light Fuel Oil, and will increase running costs unnecessarily. Additional heating to outflow heaters can be provided by using a steam, hot water or electric heater running along the bottom of the tank. With electric heating, additional separate heating elements may be required.

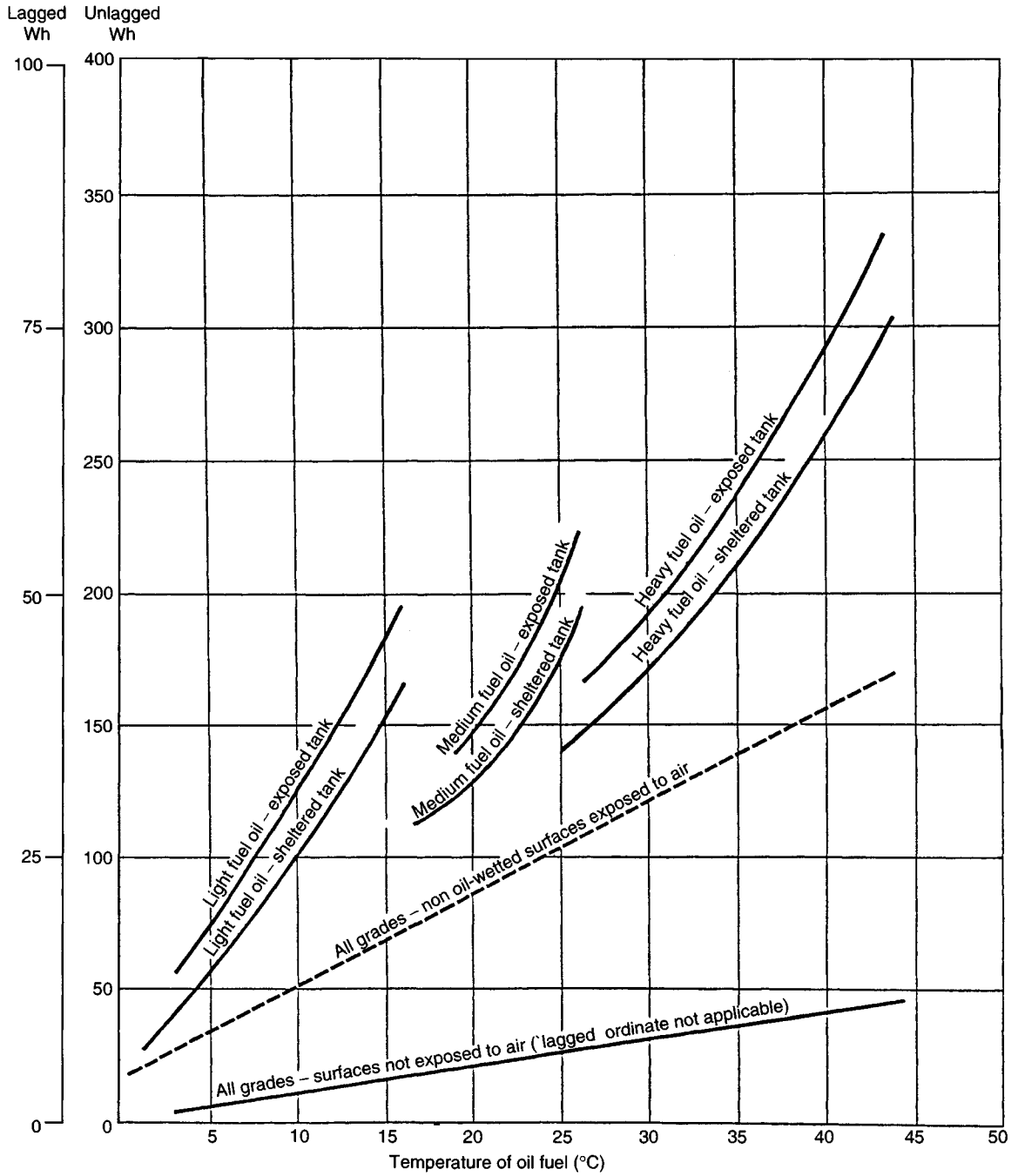


Figure 12.2 Heat losses from storage tanks plotted against oil fuel temperature

Heating elements should be readily removable for repair if necessary and consequently careful note should be taken of possible external obstructions to this operation. The steam supply to the heating coils should be dry saturated. It is not generally necessary for the pressure to exceed 3.45 bar (50 lbf/in^2). The temperature of the heating medium should not exceed 177°C (350°F), and electric element loading should not exceed 1.24 W/cm^2 (8 W/in^2).

Steam and hot-water coils should be constructed of seamless steel tube and preferably be without joints within the tank. These coils can be either plain or finned tube. However, due to their greater surface area, finned tubes generally have a higher rate of heat transfer than plain

tubes. On the basis of cost per unit surface area, finned tubes are less expensive than conventional tubes. There is also an advantage of weight saving, and complete coverage of the base area is not necessarily required to achieve specified temperatures.

Where joints are unavoidable, they should be welded. Steam coils should drain freely from inlet to outlet. Steam traps, usually of the bucket type, should also be provided. Condensate from steam coils should be drained to waste, unless adequate provision is made to drain trace quantities before return to the hotwell. Where hot-water coils are used, the water supply should be heated through a calorifier. These recommendations will avoid any risk of oil reaching the boiler plant.

Where storage facilities comprise several tanks, the contents of stand-by tanks may remain unheated. In such cases, the heating facilities should be capable of raising the contents to the required storage temperature as soon as possible from cold.

Heating requirements for warming storage tanks. The hourly heat requirement (H_r) to raise the temperature of a storage tank can be calculated from:

$$H_r = C \times h \times t_r$$

where

C = total weight of contents when full (kg (lbs)),
h = mean specific heat of fuel oil,
t_r = temperature rise required per hour (°C (°F)).

The following values should be used for the mean specific heat:

Class of fuel	*Mean specific heat* 0–100° *C (kJ/kg° C)*
D	1.99
E	1.99
F	1.97
G	1.95

The rate of temperature rise (t_r) will depend on the particular circumstances of the installation and on how quickly the contents of the tank must be brought up to temperature.

12.2.6.2 Lagging

Various types of lagging are available; the major advantage of its use is a considerable reduction in heat losses from both storage tanks and pipework. The materials most suitable for application to storage tanks are asbestos in the form of blankets or moulded sections, glass silk blankets of 85% magnesia or slagwool. When applied, these materials should provide a lagging efficiency of approximately 75%. All lagging should be reinforced with wire netting, either incorporated into the blanket or secured to anchor points on the tank surface. A weatherproof surface finish should finally be applied to the lagging. This can be either two-ply bitumen felt or, if necessary, sheets of galvanized steel or aluminium with sealed joints.

When the use of lagging is being considered, cost-benefit analysis should be made to determine the minimum running costs when either (1) fuel is stored at the minimum recommended storage temperature with an outflow heater to raise the temperature to the minimum handling temperature, or (2) fuel is stored at handling temperature, thus requiring no outflow heater.

The temperature of heated fuel when delivered into customer's storage will depend upon the length of time in transit, or the measures of preheat given to a rail tank car to assist discharge. These heat sources should not be overlooked in calculations.

12.3 Location of tanks

12.3.1 Siting

Storage tanks should, wherever possible, be installed above ground. The site selected should not be in an unduly exposed position. Clearance must be allowed for the withdrawal from the tank of fittings such as immersion heaters and steam coils. Where tanks are installed inside buildings, they should generally be located within a tank chamber, although in some industrial installations such as steelworks and foundries, a tank chamber may not be necessary. The requirements of insurance companies and local authorities should be considered when designing these installations.

12.3.2 Underground storage

Where underground installation of a storage tank is unavoidable, it should preferably be housed in a specially constructed brick or concrete chamber, allowing easy access to the drain valve and other fittings. Wherever possible, the tank chamber should be located in dry ground and the finished structure made watertight. A sump must be provided in the floor of the chamber at one end to collect any water that may enter the chamber in exceptional circumstances, and the floor should slope slightly downwards towards the sump. Water collected in the sump can be removed by using a semi-rotary pump. The lower part of the chamber should form an oil-resistant catch pit, as with the more usual aboveground storage tank.

12.3.3 Buried tanks

It is recommended that storage tanks should not be buried directly in contact with soil, since it is almost impossible to avoid corrosive attack. Where, for some reason, it is not possible to provide a tank chamber as already described, adequate corrosion protection must be applied to all exterior surfaces of the tank, fittings and pipework.

12.3.4 Bund area

Where overfilling or leakage from the tank would contribute to a fire hazard, cause damage to property or contaminate drains or sewers, a bund wall should be constructed around the tank. This should be of brick or concrete with an oil-tight lining, and sealed to the concrete base under the tank supports. The capacity of the bunded

area should be at least 10% greater than that of the storage tanks contained within it.

The bund walls must be oil proof and be capable of withstanding considerable liquid pressure in the event of an overflow or other emergency. No permanent drain must be incorporated into a bund area, but suitable facilities should be provided to remove rainwater that may accumulate. A sump and semi-rotary hand pump are suitable for this purpose.

12.4 Pipework systems

12.4.1 General

Oil fuel pipeline systems transfer oil from storage to the oil burner at specified conditions of pressure, viscosity, temperature and rate of flow. There can be considerable variety in the choice of system, but its design (particularly correct pipe sizing and temperature control) is most important if it is to function satisfactorily.

12.4.2 Handling temperatures

Distillate grades are usually handled at ambient temperatures provided these are not below the cloud point when using gas oil. Residual grades, on the other hand, are handled at temperatures above ambient. The recommendations of Table 12.1 should always be followed regarding minimum recommended handling temperatures. Residual grades can also be handled at temperatures above those recommended as minimum handling levels in order to reduce oil viscosity, improve regulation and control of oil flow, reduce friction losses in pipelines and, when necessary, provide oil at the correct atomizing temperature for the oil-burning equipment.

12.4.3 Handling equipment

Two items of equipment should always be inserted in the handling system as close to the storage tank as possible. These are a filter and a fire valve.

12.4.4 Filters

To prevent foreign matter from damaging components and choking valves or atomizer orifices, filters must be incorporated into the handling system. There are usually two stages of filtration. The first provides protection for pumps and fire valves which handle oil at temperatures below those required at the oil-burning equipment. Second-stage filtration protects the atomizer orifice and burning equipment, and is sometimes incorporated as part of the burner assembly.

For distillate grades of fuel oil, the first-stage filter should protect pumps and valves and can be placed in the draw-off line from the storage tank. Paper filters can be used where appropriate, providing filter apertures are not less than 0.1 mm (0.004 in). The paper element should be regularly replaced when necessary. For residual grades of oil, first-stage filters should be placed in the draw-off line as near to the storage tank as possible, and incorporate a filtering medium equivalent to a circular hole 2.5–0.75 mm (0.1–0.03 in) diameter. Fine filtration must not be employed at the first stage, since pressure drop across the filter may be excessive due to the higher viscosity of these grades at low temperatures. Second-stage filtration is usually incorporated into the oil burner assembly, often in the hot oil line after the preheater so that it filters the oil at atomizing temperature.

Reliable enclosed filters of ample effective filtering area should be used for both stages. The filter design should not allow the pressure drop to exceed 7 kN/m^2 (1 lbf/in^2) across second-stage fine filters in clean conditions. Filters should preferably be of the duplex or self-cleaning type, and installed so that oil spillage will not occur during operation.

They must be readily accessible for cleaning, which should be carried out as frequently as necessary to ensure that pressure drop across the filter does not affect normal oil flow rates. The filtering medium should be of corrosion-resistant material such as monel metal, phosphor-bronze or stainless steel. All first-stage filters should be provided with isolating valves.

12.4.5 Fire valves

A valve that closes in case of fire should be inserted in the oil fuel line to the oil-burning equipment and fitted as close to the tank as possible. It may be held open mechanically, pneumatically or electrically. Temperature-sensitive elements should be arranged to close the valve at a fixed maximum temperature, and sited close to the oil-fired plant and well above floor level. The operating temperature of the heat-sensitive elements should not be greater than 68°C (155°F) except where ambient temperatures in the vicinity of the plant may exceed 49°C (120°F), in which case the operating temperatures may be 93°C (200°F).

Where an electric circuit is employed the valve should close on breaking, not making, the circuit and be reset manually. A warning device should be included to indicate that resetting is necessary, to cover the eventuality of temporary electrical failure.

Where a valve is closed by the action of a falling weight, a short free fall should be allowed before the weight begins to close the valve. This assists in overcoming any tendency for the valve to stick in the open position.

Fire valves should preferably be of glandless construction. If a gland is incorporated into the system it should be of a type that cannot be tightened to an extent which would prevent the correct functioning of the valve. A manual release should be installed on all fire valves so that they may be tested regularly.

12.4.6 Types of system

There are two main types of oil-handling system in common use. These are gravity and ring main.

12.4.6.1 Gravity systems

Gravity systems are of three basic types: gravity, pump-assisted gravity and sub-gravity. A gravity system is one in which the oil flows directly from the storage or service tank through gravity feed pipeline. The static head on the feed line will vary with the depth of oil in the tank, and the system should therefore only be used for burners which will operate satisfactorily between such limits.

A pump-assisted gravity system is one in which oil flows by gravity from the storage or service tank to a pump. The pump supplies oil to the combustion equipment through a pipeline passing only the quantity required to feed the oil-firing equipment. The inclusion of a pump in this system will not reduce the static head due to the fuel supply in the tank. The working pressure required at the oil-burning equipment should therefore be greater than the maximum static head available when the storage or service tank is full.

A sub-gravity system is one in which a pump associated with the oil-burning equipment is used to suck the oil from a tank in which the level of the oil can be below the level of the pump.

Gravity systems in general will handle distillate grades at ambient temperatures, and residual oils at pumping or atomizing temperatures. Lagging and tracing will be required with residual grades to prevent cooling of the oil to below handling temperatures.

12.4.6.2 Ring main systems

A ring main system draws oil from storage and circulates it to each consuming point in turn, the balance of the oil being returned either to the suction side of the circulating pump or to storage. A diagram of a typical hot oil ring main system is shown in Figure 12.3. Each offtake point is connected to the burner it supplies by a branch line. Pressure conditions are maintained approximately constant at each offtake point by a pressure-regulating valve situated after the last offtake point, and circulating a quantity of oil one and a half to three times the maximum offtake from the circuit. By this means, stopping offtake at one consuming point will not have a marked effect on the pressure at other consuming points. Pressure conditions should be calculated at each consuming point for all conditions of operation and offtake. The bore of the ring main should be such that pressure variations are not excessive for the equipment served. If these variations at each offtake point are likely to be critical, they can be accommodated by the use of individual pressure-regulating valves on each branch.

Ring main systems are of three types: hot oil, warm oil and cold oil. Hot oil ring mains circulate oil at atomizing temperature, warm oil ring mains at a temperature between minimum pumping and atomizing temperature, and cold oil ring mains at ambient temperature.

12.4.6.3 Hot oil ring mains

This is the most important of the three types of ring main system, since it offers economies of installation and running costs. The smallest pipe sizes and fittings can be used with low-viscosity high-temperature oil, and the number of line heaters is minimized. The oil is circulated at atomizing temperatures and in consequence, the system is less liable to be affected by pressure fluctuations due to variations in viscosity, or small changes in the viscosity of the oil as delivered. The system should usually be considered as the first possibility and only discarded in favor of warm or cold oil systems where these will give some real advantage.

Where there is a large temperature difference between a hot oil line and ambient temperature conditions, particularly in the long ring main system, lagging will prevent excessive heat loss. Electric or steam tracing, in addition, will balance the heat loss from the pipeline. Residual oils should not be allowed to drop below their minimum handling temperature at any time. Where it is necessary to shut down any part of the plant, such as when servicing pumps and other equipment, a drain valve and air vent must be provided at the lowest point in the system to prevent cold oil becoming static.

With some installations, it is possible to maintain circulation during periods when the oil-firing plant is not required to operate. The oil is circulated at reduced temperature to minimize the heat loss from the ring main and, consequently, the amount of heat required to compensate for this loss. The reduced temperature should be such that the increased oil viscosity does not result in an excessive increase in pressure.

12.4.6.4 Warm oil ring mains

This system is similar to a cold oil ring main but includes provision for heaters in the circuit to maintain oil

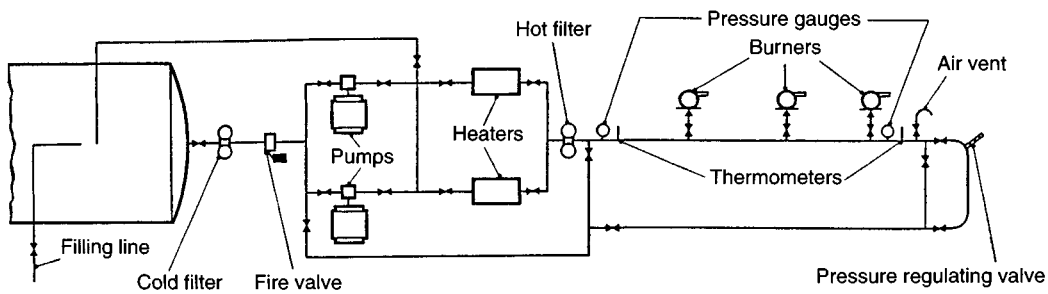


Figure 12.3 Typical hot oil ring main layout

temperature between minimum handling and atomizing levels. This provides a reduction in oil viscosity and reduces pipe friction. The circulation temperature of the oil should be chosen to give the minimum pressure drop consistent with the system design when circulating one-and-a-half to three-times the maximum offtake and using a suitable pipe diameter. This circulation temperature should allow a reasonable margin below the specified atomizing temperature to facilitate the selection of the necessary line heaters for branch lines between the ring main and the oil-burning equipment.

The volumetric capacity is adjustable to provide uniform heat transfer to the oil passing through. Heaters are flexible in operation down to about 50% of their designed temperature rise, when the quantity of oil passing through is approximately double. Where the temperature level required with a reduced throughput is outside this range, the heater manufacturer should be consulted.

12.4.6.5 Cold oil ring mains

This system is used mainly where different atomizing temperatures are required at various consuming points or where a branch line would be unacceptably long. The system should only be used where the length of pipeline involved and the quantity of oil circulated will not cause an excessive pressure drop due to friction. When designing a cold oil ring main system, care must be taken to ensure that the pressure variation between offtake points, due to changes in the oil consumption rate, do not affect burner performance. This is achieved by circulating one and a half to three times the maximum offtake required. The system is widely used with distillate grades but rarely with residual grades.

12.4.6.6 Sub-circulating loops

Where it is not possible or convenient to arrange for the ring main to be carried near the burners an alternative to using a warm oil ring main with branch heaters is hot oil ring main with sub-circulating loops. The branch line from the high-pressure leg of the ring main is extended past the burners and returned into the low-pressure or return side after the pressure-regulating valve. This ensures that circulation of hot oil is maintained past the consuming point. The amount circulated through the sub-circulating loop must be carefully regulated to avoid the pressure-regulating valve becoming inoperative by short-circuiting too high a percentage of the oil in the ring main.

The regulation of oil flow in a sub-circulating loop is controlled by a secondary pressure-regulating valve situated after the last oil burner served by the loop. Alternatively, a fixed orifice or regulating valve, either hand-controlled or of the lock shield type, may be used. With the former method, it is sometimes difficult to obtain balance between the primary and secondary regulating valves. The latter method is generally satisfactory providing the offtake rate of the burners does not fluctuate appreciably, and ample time can be allowed to establish stable pressure/temperature conditions in the sub-circulating loop after a shutdown period.

12.4.6.7 Branch lines

Branch lines transfer oil from a ring main circuit to the oil-burning equipment. Where a residual oil fuel is to be used, there will be some cooling of the oil immediately adjacent to the pipe surfaces and this will show as a small increase in viscosity. To keep this variation to a minimum and so prevent any difficulties in atomization at the oil burner, care should be taken over the length and diameter of branch lines. Provision should always be made to isolate and drain branch lines.

12.4.7 Pipe sizing

When a fluid is flowing through a pipe, resistance to flow is caused by friction. The pipe bore selected for each section must be such that under any operating conditions, the initial head, either static head of oil in the supply tank or the pump delivery pressure, will be adequate to ensure the required flow rate. Additionally, any change of flow rate and consequent variation in loss of head must not adversely affect the operation of the associated oil-burning equipment.

The following factors must be taken into account when assessing pressure drop.

12.4.7.1 Viscosity

Pressure drop is directly proportional to viscosity. The effect of heat loss from pipelines and consequent increase in viscosity should also be considered.

12.4.7.2 Flow conditions

The handling system should be designed to provide streamline flow at all times when steady and predictable pressure conditions are essential.

12.4.7.3 Flow rate

Pressure drop under streamline flow conditions is directly proportional to the quantity of oil flowing. The effect of reduced flow rate after offtake points, as compared with full flow rate throughout the full length of the pipeline when there is no offtake, should be taken into account to ensure that variation in pressure is within the specified pump output. Special consideration is necessary with gravity and ring main systems serving several offtake points.

12.4.7.4 Length of pipeline

Pressure drop is directly proportional to the length of the pipeline. All fittings used in the system should be included in the determination of 'effective pipeline length'. Table 12.2 should be used to determine the equivalent length to be added to the actual length of the pipeline for various types of fitting. The resulting figure is the total 'effective length' of the system.

The following empirical formula for estimating pressure drop under streamline flow conditions may be used:

$$H_f = \underbrace{\frac{1.2 \times 10^5 VT}{d^4}}_{\text{Metric (SI)}} = \underbrace{\frac{0.0765 VT}{d^4}}_{\text{Imperial}}$$

Table 12.2 Equivalent length of pipeline fittings

Nominal pipe bore (mm (in))	*Equivalent length of fitting*				
	Elbow (m (ft))	*Tee (m (ft))*	*Easy bend (m (ft))*	*Gate valve (m (ft))*	*Non-return valve (m (ft))*
25 (1)	0.9 (3)	1.8 (6)	0.5 (1.5)	0.3 (0.8)	0.6 (2)
32 (1.25)	1.1 (3.5)	2.1 (7)	0.6 (1.75)	0.3 (1)	0.8 (2.5)
40 (1.5)	1.2 (4)	2.4 (8)	0.6 (2)	0.4 (1.2)	0.9 (3)
50 (2)	1.5 (5)	3.0 (10)	0.9 (3)	0.5 (1.7)	1.2 (4)
65 (2.5)	1.8 (6)	3.7 (12)	1.2 (4)	0.6 (2.1)	1.5 (5)
80 (3)	2.4 (8)	4.9 (16)	1.5 (5)	0.8 (2.5)	1.8 (6)
100 (4)	3.0 (10)	6.1 (20)	1.6 (6)	1.0 (3.3)	2.4 (8)
150 (6)	4.6 (15)	9.1 (30)	2.4 (8)	1.5 (5)	3.0 (10)
200 (8)	5.5 (18)	11.0 (36)	3.0 (10)	2.1 (7)	3.7 (12)
250 (10)	6.7 (22)	13.4 (44)	3.7 (12)	2.7 (9)	4.3 (14)

where

H_f = loss of head in metres per 100 m (feet per 100 ft) effective length of pipeline ((m) (ft)),
V = oil fuel viscosity at handling temperature (Redwood I scale),
d = internal diameter of pipe (mm (in)),
T = oil flow rate (tons/hour (ton/h)).

Note: The flow is normally streamline when

$$\frac{4Q}{dV} < 2000 \qquad (30T < dV)$$

Metric (SI) Imperial

where

Q = oil flow rate (m^3/s),
d = internal diameter of pipe (m),
V = kinematic viscosity at handling temperature.

When it is necessary to estimate the pressure drop in a pipeline where turbulent flow conditions exist, the following formula will give an approximation:

$$H_f = \frac{7.89 \times 10^4 G^2}{d^5} = \frac{G^2}{6.4d^5}$$

Metric (SI) Imperial

where

H_f = loss of head in metres per 100 m (feet per 100 ft) of effective pipe run,
G = oil flow rate (l/min (gal/min)),
d = internal pipe diameter (mm (in)).

12.4.7.5 Branch lines

Branch lines transfer oil from a ring main circuit to the oil-burning equipment. Where a residual oil fuel is to be used, there will be some cooling of the oil immediately adjacent to the pipe surfaces and this will show as a small increase in viscosity. To keep this variation to a minimum and so prevent any difficulties in atomization at the oil burner, care should be taken over the length and diameter of branch lines. In general, the following empirical formula should be used when designing branch lines for hot residual oils:

$$\text{Length} = 7L < \sqrt{M} \qquad (L < \sqrt{M})$$

Metric (SI) Imperial

where

L = 'equivalent' length of branch line in m (ft) (Table 12.2),
M = minimum oil consumption (l/h (gal/h)).

Internal diameter $D < 10.4L (D < L/8)$ where D is in mm (in). Provision should always be made to isolate and drain branch lines.

The author is grateful to BP for much of the information given in this chapter.

13 Gas

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13.1 Selection and use of gas as a fuel

13.1.1 Advantages of gas

The advantages of gas can be summarized as:

1. Reliable fuel of constant composition;
2. Used as required (does not have to be ordered in advance or stored on the users' premises);
3. Clean fuel-emissions are low compared with combustion of most other fossil fuels.

13.1.2 Availability

Mains gas is widely available throughout the mainland of the United Kingdom and in the Isle of Wight. Thinly populated rural areas, particularly in Scotland, Wales, and south-west England, do not have access to mains gas although liquid petroleum gas from a central supply may be available. All major industrial areas are within the gas supply area, and less than 15% of domestic dwellings are outside this area.

13.1.3 Metering

Payment for gas consumed is made based on the consumption as registered on a meter. Meters used for billing purposes are checked for accuracy and badged by the Ofgem. These meters are known as primary meters. Those used by the user for monitoring the consumption of plant, etc. are known as check meters (often erroneously referred to as secondary meters).

Gas is metered in both cubic feet and in cubic metres. It is then billed to the gas customer in kilowatt hours. 1 therm = 105.56 MJ = 100 000 Btu's = 29.31 kWh.

The meter location should be located as close as is sensibly practicable to the site boundary adjacent to the gas main. It is generally preferable for all but small low-pressure installations to be located in a separate purpose-built structure or compound and, wherever possible, away from the main buildings. Installations should be protected from the possibility of accidental damage, hazardous substances and extremes of temperature or vibration.

With the exception of certain very large loads which may use such metering devices as orifice plates, metering will be by means of diaphragm, rotary displacement or turbine meters.

13.1.3.1 Diaphragm meters

These are the traditional gas meter which incorporates diaphragms contained within a steel case. The diaphragms are alternately inflated and then deflated by the presence of the gas. The movement of the diaphragms is linked to valves which control the passage of gas into and out of the four measuring compartments.

These meters are suitable for low pressure applications up to 75 mbar and are available in flow rates up to 160 m^3/h [5650 cfh]. It is unusual to use these meters above about 65 m^3/h due to their physical size as compared to RPD meters. This type of meter does however have a very high turndown range, possibly 200 to 1.

13.1.3.2 Rotary positive displacement meters

These meters incorporate two 'figure-of-eight' impellers rotating in opposite directions inside a casing. The impellers are made of either cast iron or aluminium. RPD meters are available with ratings from about 22 cm^3/h (800 ft^3/h) upwards but are not normally used as primary meters below about 85 m^3/h (3000 ft^3/h).

13.1.3.3 Turbine meters

These meters are normally only used for high flow loads that do not have frequent and high rates of load change. The gas flow impinges on a specially shaped turbine and is streamlined by the contour of the casing on either side of the turbine. Turbine meters are very small for their rating. Disadvantages are that 3 to 6 pipe diameters of straight pipe length or a pipe straightener are necessary upstream of the meter to ensure good flow profiles into the meter inlet. Fluctuating loads and uneven inlet profiles can cause severe meter over-registration.

13.1.3.4 Correction

Meters are accurate within close limits as legislation demands. However, gas is metered on a volume basis rather than a mass basis and is thus subject to variation with temperature and pressure. The Metric Standard Conditions are 15°C, 1013.25 mbar, saturated). Gas Tariff sales are not normally corrected, but sales on a contract basis are. Correction may be for pressure only on a 'fixed factor' basis based on Boyle's Law or, for larger loads, for both temperature and pressure using electronic (formerly mechanical) correctors. For high pressures, above say 1 to 2 barg, the compressibility factor Z may also be relevant. The current generation of correctors correct for pressure on an absolute basis taking into account barometric pressure.

13.1.4 Contracts

Most domestic and smaller loads are sold according to published tariffs. Larger loads and aggregated loads are also available on agreed Contractual terms. There are however two types of Contract and these are:

1. *Firm contract.* The gas sale is on a firm basis, that is, there is a firm commitment to supply gas under all except the most exceptional circumstances.
2. *Interruptible contract.* There is an obligation for the user to provide an alternative standby fuel to be used at the request of the gas supplier. The maximum period of 'interruption' is one of the conditions agreed in the contract. The advantage to the user is that he or she can obtain a more favourable gas price. The advantage to the supplier is that at times of peak demand, such as a cold winter, he can balance supply and demand without investing in excessive storage capacity.

13.1.5 Range of uses of gas

Gas is used for a diverse range of applications in the domestic, commercial and industrial sectors. Commercially, the main uses are space heating, water heating and

catering, together with some chilling. In larger premises such as hospitals, etc. there may be large central boiler plant. Industrially, there will be applications similar to those in commerce. In addition, there are many process applications. These may be high-temperature kilns and furnaces (ceramics, metal reheating, metal melting, glass, etc.) or low-temperature (drying, baking, paint stoving, etc.).

The theoretical flame temperature is 1930°C, but in practice this is not obtainable, and a maximum process temperature of perhaps 1300°C is realistic without recuperation. Gas is used for 'working flames' in such processes as flame hardening and glass bulb manufacture. In industrial process heating either direct or indirect heating (i.e. using a heat exchanger) may be used according to the process requirements. Gas can be used as a chemical feedstock. On a small scale this can be to produce protective atmospheres by controlled partial combustion, on a large scale as a base for ammonia production, etc. Gas is, however, sold as a source of heat and not as a chemical of constant quality. It is suitable for the production of shaft power from either reciprocating engines or turbines.

The cleanliness of the products of combustion is such that the use of heat-recovery equipment is possible without the risk of corrosion. This has led to the development of combined heat and power packages where the overall efficiency is high. CHP packages now attract the opportunity for a maximum relief of the Climate Change Levy.

Small reciprocating engines from 15 kW upwards can be used, the heat being recovered from the engine coolant and exhaust. Large reciprocating engines normally exhaust into a waste-heat boiler.

Gas turbines are available with power outputs of 100 kW upwards, and the exhaust is used to fire waste-heat boilers. The high oxygen content of the exhaust enables supplementary firing to be used to increase the heat/power ratio as desired. The current standards for CHP installations are IGE UP/3 Gas Fuelled Spark Ignition and Dual Fuel Engines, UP/6 Application of Positive Displacement Compressors to Natural Gas Fuel Systems and UP/9 Application of Natural Gas Fuel Systems to Gas Turbines and Supplementary Fired Burners.

13.2 Theoretical and practical burning and heat transfer

13.2.1 Types of burner

Efficient combustion of gas under varying conditions demands the use of a wide variety of burners. However, these can all be categorized as natural draught or forced draught.

The majority of domestic burners, together with a large number of commercial and many industrial burners, are of the natural-draught type. In these the gas passes through a jet situated in a venturi such that primary air is mixed with the gas. The resulting mixture passes through the burner nozzle where mixing with secondary (and, in some designs, tertiary) air takes place together with ignition and combustion. Such burners have the advantage of simplicity but have a limited turndown ratio and their poor mixing characteristics lead to a rather low efficiency. Indeed, to ensure that complete combustion takes place without the formation of soot or carbon monoxide it is necessary to allow a 'margin' of excess air well above that strictly needed for combustion.

The low gas pressure available at the injector (typically, 17.5 mbar) allows a primary aeration of only about 40%. The resulting flame envelope is rather large and the intensity of combustion low. It is possible to increase the degree of primary aeration, producing a more intense flame, if a higher gas pressure is used. To produce complete primary aeration a gas pressure of the order of 1 bar will be needed.

For certain processes a flame may be produced by a burner in which there is no primary aeration. These 'laminar' flames have a very low intensity of combustion and a luminous appearance.

There is however a tendency for domestic and small commercial appliances to move towards the use of premix or forced draught burners as these can improve efficiencies and reduce emissions of nitrous oxides/kWh. Such systems also give the opportunity for more compact heat exchanger design and smaller pressurized flues. On safety grounds, there is also a move towards room sealed domestic and smaller commercial appliances.

The majority of larger industrial burners, including furnace and boiler applications, are of the forced-draught type. These employ a combustion air fan to provide all the air needed for complete combustion. The burners are usually sealed into the combustion chamber so that there is no access to secondary air from the atmosphere as with natural-draught burners. Forced-draught burners may be of the premix type, where air and gas are mixed prior to the burner, or, more commonly, of the nozzle mix type, where the mixing takes place within the burner.

A refractory, or more commonly a metal quarl, is usually an integral part of forced-draught burners. Suitable design of burner and quarl can determine the flame characteristics. Long, short, pencil or even flat flames are possible.

For general purposes, including firing hot water boilers and warm air space heaters, 'package' burners are commonly used. In these the burner is ready assembled together with all its controls and air fan. To install such a burner it is only necessary to connect up to gas and electric supplies and controls (thermostats, etc.). These package burners should comply with BS EN 676. The installation of burners and appliances is detailed in IGE UP/10 Installation of Appliances in Industrial and Commercial Premises.

13.2.2 Turndown ratio

The turndown ratio is an indication of the ability of the burner to maintain a stable flame at lower firing rates, and is a ratio of the maximum and minimum firing rates. Turndown can be fairly low for average burners of both natural- and forced-draught burners, 3:1 being a typical figure with 5:1 a maximum although up to 40:1 is possible with special burners.

It is important to remember that although a burner can be fired at low rates it is probable that the efficiency at low fire will be reduced because the excess air is invariably

higher at turndown. This will affect the selection of controls (e.g. on/off or modulating).

BS EN 676 for package burners and to IGE UP/10 for the installation of flued appliances over 70 kW net input.

Oxygen trim control systems can assist with efficiency especially at low rates as it enables the excess air over the turndown range to be controlled to set parameters without the production of excessive levels of carbon monoxide.

13.2.3 Heat transfer

The carbon/hydrogen ratio of gas is considerably lower than oil or coal, which results in a flame of very low luminosity. Radiation from the flame is therefore low and furnace design must allow for heat transfer to be primarily by convection and conduction, together with re-radiation from hot surfaces.

Burners can be designed to produce a luminous flame by means of laminar mixing and partial cracking of the gas, but the radiation is still low. A typical forced-draught burner flame used for boiler firing will be essentially transparent.

13.2.4 Water vapour in products of combustion

The high hydrogen/carbon ratio of gas means that the quantity of water vapour in the products of combustion is greater than most other fossil fuels. The latent heat of this cannot be released in conventional appliances leading to a fairly low net/gross ratio of calorific value of 90%. It is now more normal practice to quote heat inputs and calorific values in *net* terms rather than *gross*. It should however be noted that condensing appliances will have efficiencies above 100% net. There is approximately 10% difference between net and gross for natural gas, i.e. 100 kW net = 110 kW gross.

The cleanliness of products of combustion from gas enable recovery of latent heat by means of condensing appliances in which the products are cooled below the dewpoint of 55°C. The condensate is only weakly acidic and a suitable choice of materials of manufacture permit it to be dealt with. Most liquid fuels produce a condensate which is too acidic to allow condensing appliances to be used.

13.3 Pressure available to user

13.3.1 Low-pressure supply

The majority of users are supplied with gas from the low pressure distribution network. The UK distribution/transmission network operates at varying pressure conditions and these are often referred to as:

Low pressure up to 75 mbarg
Intermediate pressure from 75 mbar to 2 barg
Medium pressure from 2 to 7 barg
High pressure above 7 barg up to 80+ barg.
Domestically only 20 mbar is need at the appliance.

Normal practice is to only supply direct from the highest pressure transmission mains for very large loads such as power stations due to the cost of connection to such systems.

13.3.2 Boosters and compressors

If a pressure higher than that available is wanted then a booster or compressor will be required. Boosters are normally considered as adaptions of centrifugal fans and raise pressure by typically 75 mbar for a single-stage machine. Higher pressures require a compressor which will be a positive displacement, axial or screw type. The use of a booster should not be regarded as a substitute for the correct design and engineering of pipework within a site.

Requirements for the installation of boosters and compressors up to 7 barg are detailed in IGE UP/2 Gas Installation Pipework, Boosters and Compressors in Industrial and Commercial Premises. Compressors operating above 7 barg are covered in IGE UP/6 Application of Positive Displacement Compressors to Natural Gas Fuel Systems. The most important requirement is that a low pressure cut-off switch or transducer must be fitted to the inlet connection of the machine to comply with Gas Safety legislation. It is also essential with compressors that if they could affect the accuracy or integrity of the supply or metering system, they must start up at low rate and additional safety protection may be required by the gas supplier/shipper/transporter. 28 days written notice must be provided to the gas supplier of the intention to fit any gas compressor.

13.4 Energy conservation

Energy use can be minimized by a combination of various measures. These can be categorized as those reducing energy used and those recovering heat from a process.

13.4.1 Reduction of energy used

13.4.1.1 Air/gas ratio

Any process using a fossil fuel will involve the rejection of the products of combustion following heat transfer. These flue products will contain sensible heat which is lost and represents inefficiency in the process. Unless some form of recuperation is practised, the flue products must be at a higher temperature than the process, and this cannot be reduced. The amount of excess air can, however, be controlled.

Figure 13.1 indicates the flue losses to be expected for different temperatures and excess air. It is seen that considerable savings can be made, particularly at higher temperatures, by reducing excess air levels to a practical minimum. It is also evident that a reduction in air/gas ratio to below stoichiometric will cause a rapid deterioration in efficiency caused by the energy remaining in the incomplete combustion of fuel.

The ideal air/gas ratio is that which is marginally higher than stoichiometric. It is not possible to run a burner with no excess air for various reasons (e.g. changing ambient

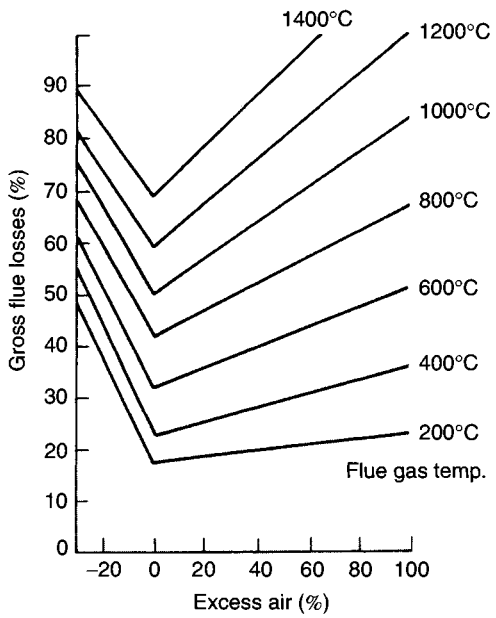


Figure 13.1 Gross flue losses versus excess air

temperature, a slight change in calorific value, variation in barometric pressure, wear of control equipment, etc.). All of these and other factors dictate that the burner is operated with sufficient excess air to avoid the production of carbon monoxide in any quantity.

Figure 13.2 shows how the production of CO can vary with excess air for two typical burners. It is seen that to limit CO to, say, 50 ppm with burner B, 3% oxygen in the flue is needed, and with burner A, which exhibits better mixing characteristics, only 0.75% excess oxygen is required. It is also seen that the 'heel' in the curve is more pronounced with burner A such that a reduction in oxygen below the heel will have a pronounced effect on CO production.

Figure 13.2 illustrates a burner at a fixed firing rate. In practice, many burners will have a varying firing rate with inferior performance at turndown, mainly because of poor mixing caused by reduced kinetic energy of both air and gas. To allow for this, the control system must provide for an increasing excess air with turndown.

To minimize flue losses it is important to keep excess air to a minimum, but the practicalities of the burner must be considered and a safe operating margin incorporated.

13.4.1.2 Maintenance

Combustion equipment can be set to give optimum efficiency at the time of commissioning but this condition will not be maintained. Wear and tear on control valves, partial blockage of filters, sooting of surfaces, etc. will all cause a fall in efficiency. To counter this, regular maintenance is desirable, and must include routine flue analysis and burner adjustment. Oxygen trim systems are now widely

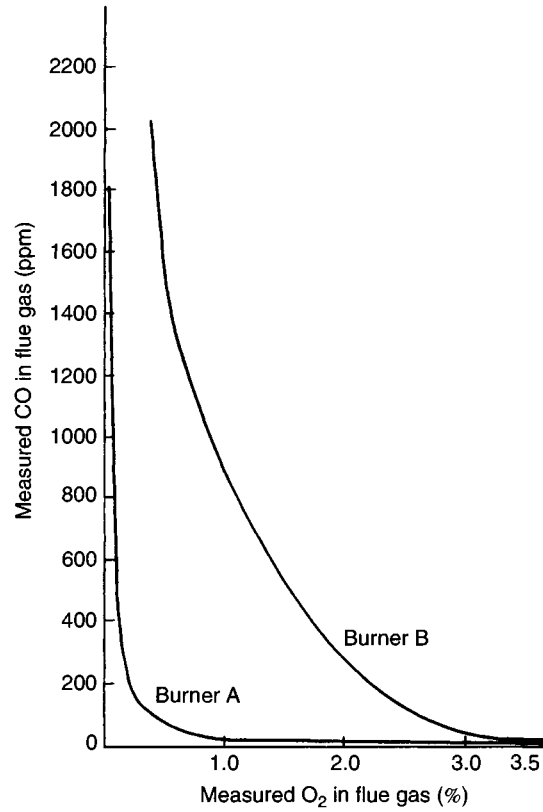


Figure 13.2 Measured percentage of O_2 in flue gas. Range of CO versus O_2 for a variety of burners

available for forced draught burner equipment to ensure or monitor the adequacy of the fuel/air ratio.

13.4.1.3 Insulation

Sensible heat losses from thermal plant should be kept to a realistic minimum by the use of correctly specified insulation. There will be a point beyond which further insulation is not economically viable. Careful analysis of the properties of insulation materials is necessary to prevent, for example, the adding of more insulation to the cold face of a furnace wall, causing the maximum service temperature of intermediate insulation to be exceeded.

Modern low-density insulation such as those based on ceramic fibres can be used to save energy in plant operating on a batch basis. The low thermal mass permits a rapid heating and cooling period which can save a substantial amount of energy. With continuously operating plant the advantages are not so pronounced.

13.4.1.4 Procedures

Energy can be conserved by operation of plant in such a way as to minimize part loading. Various practices can be adopted that can be described as 'good housekeeping'. In addition to maintenance, this will include such factors as the avoidance of plant operating in the standby mode for

long periods, operation at correct temperature, ensuring doors are closed where applicable, etc.

For production plant the energy used per unit produced is lowest when operated at design capacity. At low throughputs the energy used increases markedly because the standing losses are constant, irrespective of throughput.

For plant such as boilers operating in parallel controls should ensure that one boiler acts as a 'lead' to minimize part-load operation. As far as is possible, plant should be sized to meet the load and oversizing should be avoided.

13.4.2 Heat recovery

13.4.2.1 General points

Technology exists to recover heat from processes operating at all temperatures, from regenerators on high-temperature plant to heat pumps using low-temperature effluent as a heat source. The problem in many cases is to find a use for the heat recovered. The best solution is to recycle the heat within the same plant, as the supply will always be matched to the demand. An alternative is to use the heat recovered in associated plant (for example, the heat recovered from a melting furnace can be used to dry feedstock for the furnace).

In general, 'high grade' recovered heat is more valuable than 'low grade'. The latter can often take the form of large quantities of warm water for which there is a finite need.

13.4.2.2 Recuperation

Figure 13.1 shows the heat carried away in flue gases, particularly for high-temperature processes. For example, for a furnace operating at 800°C with no excess, air losses are 40%. Recovery of a proportion of these losses is possible by means of recuperation.

The simplest form of recuperation is load recuperation, but this is not suited to retrofit and is incorporated at the design stage. Flue products from the highest temperature zone are used to preheat incoming stock on the counter-flow heat exchanger principle. Such techniques are well established in pottery tunnel kilns, etc.

In many processes load recuperation is not practicable, and combustion air is preheated in a heat exchanger by means of the outgoing flue products. Figure 13.3 gives an indication of the savings to be made for different operating temperatures. It is not normally considered economic to operate a recuperator at flue temperatures below about 750°C.

The recuperator can be positioned in the flue of the furnace or be integral with the burner (i.e. a recuperative burner). The separate recuperator is usually less costly, particularly on a multi-burner furnace. The recuperative burners avoid the need for lagging pipework, and reduce the risks of leakage upsetting the air/gas ratio. The flow pattern of hot gases in the furnace may, however, be disturbed as the flue gases must exit through the burner.

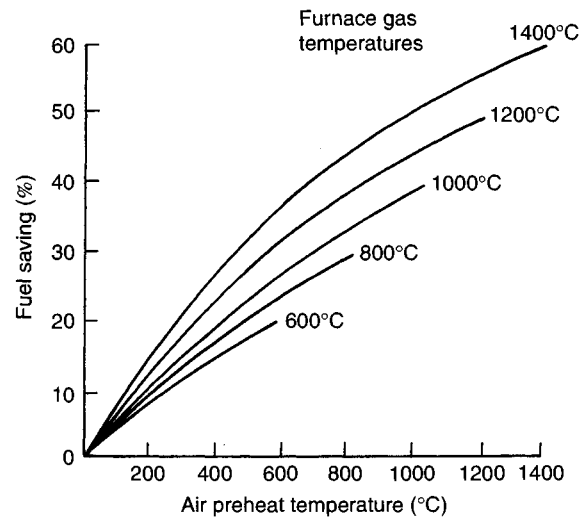


Figure 13.3 Fuel saving versus air preheat temperature (stoichiometric conditions)

13.4.2.3 Regenerators

Recuperators are limited in their performance, partly by problems with materials operating for long periods at elevated temperatures and also by the efficiency of fairly simple gas to gas heat exchangers. For high-temperature applications a regenerator has advantages.

Regenerators have long been established in such processes as steel melting in open-hearth furnaces and glass-melting tanks. They consist of checkerwork brickwork which act as a heat sink for the high-temperature flue gases. On reversing the cycle this brickwork acts as a heat source for the incoming cold air. The regenerator is thermally efficient but only suited to very large, intensively used plant.

Regenerative burners have been developed to widen the range of application of the regenerator principle. They consist of a pair of gas burners each with its own regenerator consisting of a bed packed with refractory balls. Regular cycling between the two burners, only one of which fires at a time, gives high efficiency with up to 90 percent of the heat in the flue products recoverable. Figure 13.4 shows typical performance figures for these burners.

13.4.2.4 Heat exchangers

There is a wide range of heat exchangers available to cater for most temperature ranges and for gas/gas, gas/liquid or liquid/liquid, as appropriate. High exhaust temperatures normally involve the use of a recuperator or regenerator and lower temperatures use other heat exchangers.

13.4.2.5 Gas/gas

Simple heat exchangers These can be of the parallel flow, crossflow or counterflow pattern and constructed of materials to suit the temperature.

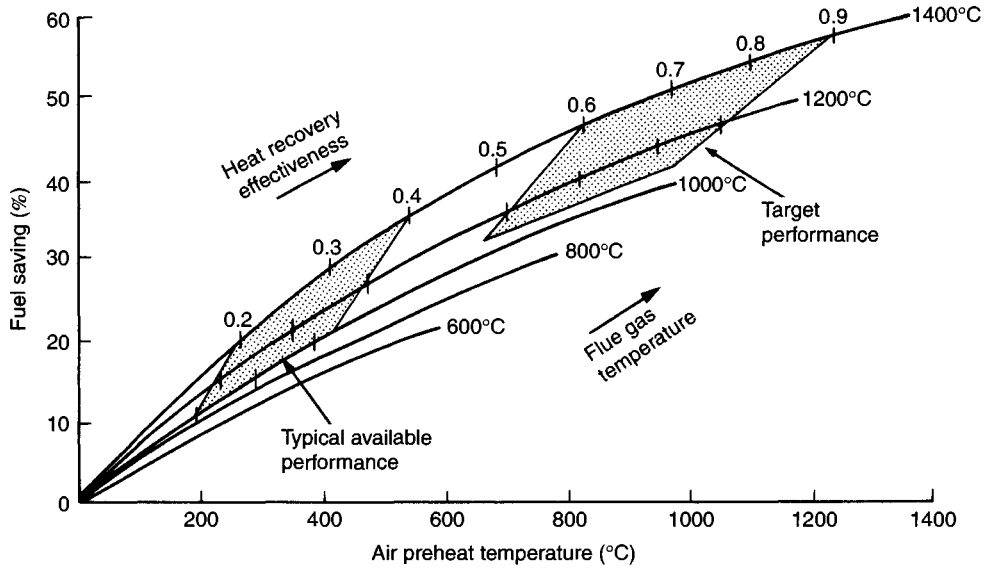


Figure 13.4 Fuel saving versus air preheat temperature

Rotary heat exchangers These consist of a slowly revolving wheel of diameter 0.6–4 m driven by an electric motor. The wheel consists of a metallic matrix which absorbs sensible heat (and, in some designs, latent heat) from the outgoing stream and transfers it to the ingoing stream. With these exchangers 75–90% efficiency is possible.

Heat pipes The use of heat pipes involves the incoming cold air stream and the outgoing warm air stream being immediately adjacent and parallel, and between the two is a battery of heat pipes. These contain a liquid and operate on the thermosyphon principle. The liquid takes in latent heat and evaporates and the vapour travels to the cold end of the tube where condensation releases the latent heat. Generally, heat pipes are restricted to 400°C, and effectiveness can be up to 70%.

Run-around coils Where the incoming and outgoing airstreams are remote it is necessary to use a run-around coil to couple them. A heat exchange coil in the warm exhaust is connected by a pumped liquid to a heat exchanger in the cold stream. The effectiveness can be up to 60%.

13.4.2.6 Gas/liquid

Economizer The economizer is a tubular heat exchanger used to recover heat from the exhaust gases from boilers or some processes. It is used in boilers to recover much of the sensible heat for use in preheating the boiler feedwater. An increase in boiler efficiency of 4–6% is typical. The design and materials of construction depend on the application.

Condensing boiler The efficiency of a hot water central heating boiler is limited in part by the latent heat of vaporization in the water vapour in the flue products. If a secondary heat exchanger is added to the boiler it is possible to cool the flue gases sufficiently to release this latent heat, provided that the return temperature is sufficiently low (i.e. below about 55°C). This is the principle of the condensing boiler. The secondary heat exchanger must be constructed of a resistant material such as anodized aluminium or austenitic stainless steel to withstand the condensate, which is weakly acidic with a pH 3.3–3.8. The condensing boiler concept is not applicable to oil or coal, which normally have a more acidic condensate. Fuel savings of from 14% to 18% can be achieved.

Spray recuperator The principle of the spray recuperator is similar to that of the condensing boiler, and again is restricted to gas firing. In this case the condensation takes place by direct contact of a water spray with the flue gases. The resultant water is at temperatures up to 50°C and is recycled through a heat exchanger. If a suitable use can be found for the low-grade heat (e.g. boiler feedwater preheating) then fuel savings of up to 17% can be made.

Waste-heat boilers Waste-heat boilers can be designed to accept any grade of waste heat to produce steam or hot water. Designs can be based on watertube boilers, shell and tube boilers, or a combination of the two.

Heat pumps Both the source and sink of heat pumps can be gas or liquid. The particular feature of the heat pump is that the source is at a lower temperature than the sink and is 'upgraded' by the heat pump. To obtain a reasonable efficiency it is essential that heat is required at a low temperature and the source and sink are fairly close in temperature. Industrial applications include dairies and maltings.

13.4.2.7 Liquid/liquid

Various designs of liquid/liquid heat exchanger are widely used. Choice is partly influenced by the cleanliness of the liquids and the need for regular cleaning. A compact and commonly used type is the plate heat exchanger.

13.5 Emissions

The combustion of gas produces little in the way of noxious substances. Ideal combustion will produce only water vapour, carbon dioxide and nitrogen. In practice, there may well be very small amounts of hydrogen, carbon monoxide and unburnt hydrocarbons, notably methane.

Environmental protection legislation refers to the following combustion products:

1. SO_2 etc
2. NOx etc
3. Carbon monoxide (CO) – CO is odour free and is formed due to incomplete combustion. This can be caused by poor burner design, by flame cooling/quenching e.g. by excessive air flow. It is often accompanied by aldehydes that have a distinctive smell. The production of CO will lower efficiency and may cause the failure of appliance heat exchangers. Unlike liquid fuel or LPG, excessive CO formation does not normally lead to the production of Soot. Where soot is observed, this indicates that there are very serious and potentially dangerous problems in the combustion system!
4. Dust – as gas is in the gaseous state and does not combust via the route of droplets or particles the formation of dust is unlikely.

13.5.1 EC Directive on emissions from large combustion plant

This legislation was formally adopted on 26 November 1988. It applies to plant for the production of energy (effectively, boiler plant and similar) and specifically excludes heating furnaces, drying plant, etc. The Directive applies to plant of thermal input 50 MW and over. If two or more separate plants are in close proximity such that they could share a common flue then if their total input is 50 MW or over then they are also subject to the Directive.

The Directive applies to new plant with provision for retrofitting existing plant.

13.5.2 UK legislation

The EC Directive on emissions from Large Combustion Plant led to the 1990 Environmental Protection Act. Under this Act a series of Regulations and Guidance Notes have been produced for a wide range of emitting processes. The breakpoints with respect to heat input vary by process but for boilers and gas turbines, Part A of the Act applies to plant over 50 MWth net input [including groups totalling over 50 MW of items above 3 MW] whilst Part B applies to individual items of plant between 20 and 50 MWth net input. The emissions criteria vary by plant and fuel and reference should be made to the appropriate Guidance Note.

One major difference between Part A and Part B is that Part A includes Integrated Pollution Control covering emissions to air, water and land whereas Part B only applies to air emissions. It should also be noted that the Clean Air Act remains on the Statute Book and that local authorities have powers to limit/control any emission if it is deemed to be a nuisance.

Information on emissions legislation can be obtained from the Environment Agency and the Combustion Engineering Association [*info@cea.org.uk*].

13.5.3 Climate Change Levy

A levy is being applied to all fuels, except oil, to encourage the take-up of energy efficient processes and equipment. Currently 0.15 p/kWh is being surcharged to natural gas and 0.43 p/kWh to electricity. The Climate Change Allowance scheme will enable certain tax advantages to be granted to companies purchasing energy efficient products. Contact should be made to *http://www.hmce.gov.uk* for more information on the Levy. The CEA also has a publication explaining the implications in plain terms. Information on emissions legislation can be obtained from the Environment Agency and the Combustion Engineering Association [*info@cea.org.uk*].

13.6 Chimney requirements: codes of practice and environmental considerations

13.6.1 Functions of a flue

Reference should be made to IGE UP/10 Installation of Gas Appliances in Industrial and Commercial Premises, the Third Edition of the 1956 Clean Air Act Memorandum on Chimney Heights and to HMSO Guidelines on Discharge Stack Heights for Polluting Emissions, Technical Guidance Note (Dispersions) D1, June 1993.

The overriding function of the flue is to remove the products of combustion. This involves the creation of sufficient draught, either mechanical or thermal, to move the flue products from the combustion chamber to the terminal of the flue. A secondary function is, by means of suitably locating the flue terminal, to ensure adequate dispersion of the products of combustion.

13.6.2 Operating principles

To operate effectively, the flue has to apply a pressure differential sufficient to overcome the system resistance and enable the products of combustion to flow from the combustion chamber to the terminal. This pressure differential can be mechanical (by forced or induced draught or a combination of the two) or thermal, possibly combined with mechanical.

The 'natural-draught' flue operates on the thermal principle. The pressure differential is caused by the difference in density between the column of hot gases within the flue and a column of air of the same height. Within limits, the

taller the flue, the greater the draught, but the upwards movement is opposed by the resistance to flow inherent in the geometry and friction of the flue.

Successful flue design involves the balancing of the draught against the resistance, possibly for a range of thermal inputs, the avoidance of condensation, and a location of the terminal which ensures unrestricted dispersion of the flue products.

13.6.2.1 Factors affecting flue performance

Flue height Raising the height of a flue increases the flue draught but also adds to the pressure loss due to friction. The net effect is that increasing height is very beneficial for short flues but has progressively less effect as the height is increased. With very tall flues there can be a reduction in flow rate due to excessive heat loss. The point where an increase in height produces no additional flow rate depends on many factors. In the case of small commercial-size appliances an increase beyond 6–9 m will normally produce no benefit.

Cross-sectional area There is a direct relationship between flue flow and the cross-sectional area. The draught is unaffected by the cross-sectional area but the frictional losses decrease as the area is increased, resulting in greater flow. Too great an area, however will lead to a low velocity with its attendant problems of downwash and possible condensation.

Thermal input The flue draught rises with temperature but the pressure losses increase because of the greater volume of the flue gases. The net result is that increased temperature leads to a greater flow rate, but only up to about 260°C, beyond which the flow is reduced.

If the heat input from a given appliance is increased both the temperature and flow rate of the gases entering the flue will rise. The net result is that an increased heat input leads to a greater flow rate, but this is more noticeable at low heat inputs. There is a limit to the rate that can be vented into a given flue before the pressure losses overcome the flue draught and 'spillage' (failure of the flue products to be satisfactorily cleared) occurs.

Flue route The only parts of the flue route that contribute to flue draught are the vertical sections. All sections, however, contribute to the pressure losses. It follows therefore that to increase the effectiveness of the flue it is important to adhere as closely as possible to a vertical route and to have a minimum of bends, changes of section, and horizontal runs.

Heat losses Heat losses through the fabric of the flue will lower the mean temperature of the flue gases, causing both the flue draught and the pressure losses to be reduced. The net effect is quite small (perhaps a 10% difference between a well-insulated and an unlagged flue).

It is, however, important to avoid condensation. Although the condensate from gas combustion is generally considered to be non-acidic, if the flue has not been designed for conditions of continual wetting condensation should be avoided. Intermittent condensation under start-up conditions can usually be tolerated.

The dewpoint for the flue products from gas is a maximum of 60°C and will, in most cases, be lower because of excess air. There is no acid dewpoint because the sulphur content is negligible. It would be thought that condensation would be most unlikely, and this is so for the bulk flue gases. However, the temperature gradient across the flue wall can be such that the 'skin temperature' at the inside wall can be considerably less than the bulk temperature, and condensation will take place.

To minimize the possibility of condensation it is desirable to:

1. Keep the flue as short as possible;
2. Avoid the use of bends and horizontal runs;
3. Insulate the flue;
4. Keep the surface area as small as possible.

These features must be consistent with the other design parameters as far as possible.

Termination A suitable design and location of the flue terminal is essential for optimum performance. This is primarily to counter adverse wind effects.

The wind effect may assist or oppose the natural-draught flue, causing increased draught up the flue, or down-draught. For this reason, it is important to minimize their effects by careful attention to the terminal position. In general, this means a position at least 0.6 to 1 m above any nearby obstacle.

For smaller appliances flue terminals are necessary. These have the main functions of:

1. Keeping the resistance as low as possible;
2. Preventing blockage;
3. Being unaffected by wind of any speed or direction.

Proprietary terminals are available up to 200 mm. For large flues, particularly forced draught, terminals are not used.

Down-draught diverters Any flue should be designed as far as possible to produce a constant draught. If the draught is insufficient then spillage of combustion products will take place, and if too great, then excess air will be induced, leading to an unnecessary loss of efficiency.

A typical down-draught diverter used with natural-draught flues is shown in Figure 13.5. This consists of a baffle plate mounted at the top of the primary flue. There are three modes of operation:

1. Normal conditions – the products of combustion mix with diluent air at the diverter and diluted products pass up the secondary flue.
2. Adverse conditions with down-draught – the down-draught mixes with the products of combustion and diluted products enter the room for the brief period that the down-draught persists. The draught in the primary flue (and hence the performance of the appliance) is unaffected.

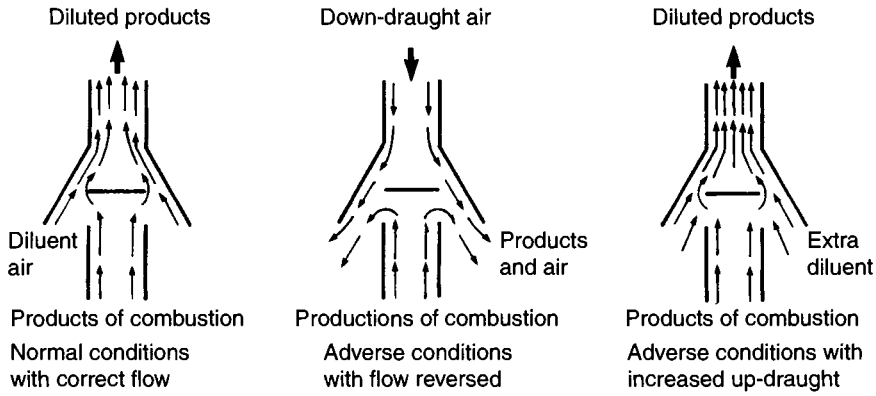


Figure 13.5 The function of the draught diverter

3. Adverse conditions with up-draught – the additional draught in the secondary flue causes excess air to be pulled through the diverter from the room. The baffle plate prevents the draught in the primary flue from being affected.

For small appliances the down-draught diverter is often incorporated into them; for larger appliances it is external.

In larger appliances the use of a down-draught diverter can be impractical if only because of size, and a draught stabilizer may then be used. This will protect against up-draught by opening to allow air to be pulled in directly from the room. If it is of the double-swing type it will protect against down-draught by opening to relieve the down-draught into the room.

Mechanically forced-draught assisted flues The above design parameters are relevant to natural-draught flues. With forced-draught flues it is possible by choice of a fan, either forced or induced draught, to overcome system resistance so that the flue will still clear the products. A crude rule-of-thumb is to allow 1 mm^2 of flue area for each 2.2–3.7 kW for natural draught or for 4.5–13.6 kW for forced draught.

13.6.3 Design procedure

The design procedure will vary with the type of flue, but the basic procedure will not change. It is necessary to consider the relevant parameters discussed above and decide on flue dimensions and materials of construction to satisfy them. The parameters to consider are:

1. Type of flue to be used;
2. Pressure needed at inlet to flue for correct operation of appliance;
3. Diameter of flue (or dimensions if rectangular);
4. Length of flue and route taken;
5. Materials of construction (this will influence both heat transfer and flow characteristics);
6. Heat input and efficiency of the appliance, together with the flue temperature and excess air. A consideration of all or some of these allows the flue gas volume to be assessed;
7. Termination position.

Design procedures are primarily given in IGE UP/10. This publication covers natural draught flues, mechanically assisted flues, room sealed appliance flues, fan diluted flues, flues on modular boiler systems for appliances and groups of appliances above 70 kW net input. For appliances below this scope, refer to BS 5440 Part 1 Installation and maintenance of flues and ventilation for gas appliances of rated input not exceeding 70 kW net.

Information on structural flues can be found in BS 5854:1996 Code of practice for flues and flue structures in buildings. This applies to larger appliances of 45 kW output and above but does not cover flues not integral to a building.

13.6.4 Chimney heights memorandum

The relevant legislation to consider when determining the termination of a flue from a larger item of plant is *Chimney Heights: Third edition of the 1956 Clean Air Act Memorandum* (this is covered in IGE UP/10). This deals mainly with the adequate dispersion of gases containing sulphur, of which there is very little in gas. However, gas is included and defined as a 'very low sulphur (<0.04%) fuel' (VLS) together with premium kerosene and LPG.

The Memorandum gives methods of calculating the uncorrected chimney height (U) based on heat input and sulphur content. The height is then corrected on the basis of the type of area in which the plant is located and the influence of nearby buildings. Important points to note are:

1. The scope of the document is for heat inputs of 150 kW to 150 MW.
2. An efflux velocity sufficient to prevent downwash is necessary. This is defined as:
   (a) For boilers up to 2.2 MW input, not less than 6 m/s at MCR (Maximum Continuous Rating);

(b) For boilers and similar plant with induced-draught fans:
Rating up to 9 MW, not less than 7.5 m/s at MCR.
Rating above 135 MW, not less than 15 m/s at MCR.
Rating 9–135 MW, pro rata.

3. Where there are several adjacent plants in the same works, the waste gases should normally be discharged from a common chimney, preferably multi-flued.
4. A chimney should terminate at least 3 m above the level of any adjacent area to which there is general access.
5. A chimney height should never be less than U.
6. A chimney should never be less than the height of any part of an attached building within a distance of $5U$.
7. Fan-diluted systems are covered.

13.6.5 New flue systems

Various flue systems have been developed to overcome the need for a conventional flue, the provision for which can be both difficult and expensive in some locations.

13.6.5.1 Balanced flue or room sealed appliances

Room sealed appliances can have natural draught or fan assisted (forced draught or premix) burners. The flue outlet and air supply inlets are separately ducted to outside, normally at the same point on a wall for natural draught burners. As the external wind conditions are at a balance for the natural draught burner, the combustion system is relatively unaffected by changes in wind. The forced draught burner types of room sealed appliance may have enough fan-power to overcome varying wind conditions to permit the terminal to be remote from the air inlet duct. No provision for ventilation is required for the supply of air to the combustion system.

Room sealed appliances are available up to about 150 kW input. Flue termination locations are restricted according to other openings and obstructions, see BS 5440 Part 1 or IGE UP/10 for detailed information.

13.6.5.2 Balanced compartment

This can be regarded as an extension of the balanced flue principle to larger plant. A conventional chimney is used for clearing flue products, and the air inlet to the boilerhouse is integral with this so that the inlet and outlet are balanced. It is important for correct operation that there is no additional ventilation and that the room is sealed with all doors closed. However, in the case of LPG, low level ventilation direct to outside must be fitted.

13.6.5.3 Fan-diluted flues

If the products of combustion can be diluted so that the carbon dioxide content is not greater than 1% it is permissible to discharge them at low level. This is the principle of the system shown in Figure 13.6, in which fresh air is drawn in to dilute the flue products which are discharged, preferably on the same wall as the inlet to balance against wind effects. It is essential to interlock the air flow switch with the burner controls.

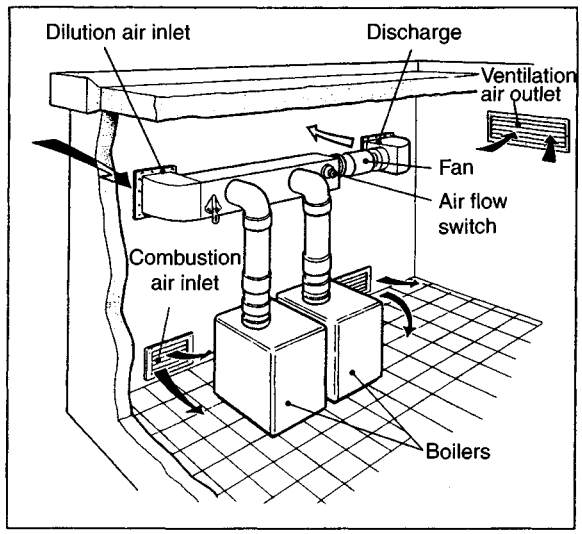


Figure 13.6 A typical arrangement of a fan-diluted flue system

The volume flow rate of the fan (Q) is given by:

$Q = 9.7\times$ (Rated input of appliance in kW gross of natural gas)/ 3600 m^3/s

Additional points to note are:

1. The rating of the plant must not exceed 6 MW.
2. The emission velocity must be at least $75F$ m/s. (F is the fan dilution factor, defined as $F = V/V_0$, where V is the actual flue gas volume and V_0 is the stoichiometric combustion volume, $0.26Q$ m^3/s for gas.)
3. The outlet must not be within $50U/F$ of a fan-assisted intake (except for intakes for combustion air or fan dilution air).
4. The outlet must not be within $20U/F$ of an operable window.
5. The distance to the nearest building must be at least $60U/F$.
6. The outlet must be at least 3 m above the ground, except if the input is less than 1 MW, where 2 m is permissible.
7. The outlet must be directed at an angle above the horizontal (preferably at 30°) and not under a canopy.
8. The outlet should not discharge into an enclosed (or almost totally enclosed) 'well' or courtyard.
9. UP/10 also suggests that the NO_x level from the fan diluted flue exhaust should not exceed 5 ppm. This may affect the choice of appliance.

13.6.5.4 Enclosures

These are defined in UP/10 as spaces for the containment of appliances that are so small as not to be large enough for a person to enter in order to perform work. In essence, this means a cupboard with opening outward doors.

13.6.5.5 Flues for condensing systems

Boilers and air heaters can be designed to operate in the condensing mode, that is, the outlet temperature of the products entering the flue can be at or close to the dewpoint. The usual design criteria for flues, which attempt to avoid condensation, are no longer applicable and it is necessary to incorporate additional features. These will include:

1. Provision must be made to drain off and dispose of the condensate, which is produced at a rate of up to 0.15 l/h for every kilowatt Gross of input. This is slightly acidic, and plastic is the most suitable for the pipework.
2. The flue will be wetted by the condensate, and should be constructed of a suitable material such as twin wall stainless steel.
3. All sockets in the flue should face upwards and the joints sealed.
4. The low temperature of the flue products will contribute little flue draught.
5. The flue gases will readily form a plume at the flue terminal. The termination should not lead to nuisance complaints e.g. concern about the condensing plume being smoke or fire.

13.6.6 Dual-fuel installations

In a dual-fuel installation the alternative fuel will usually have a higher sulphur content than gas, and it is the alternative fuel which will usually dictate the chimney height, materials of construction, etc. In a changeover situation, that is, where plant previously fired by another fuel is changed over to gas, chimneys or flues that have been satisfactory on oil or solid fuel will also be satisfactory on gas firing, unless condensing or direct contact boilers are to be fitted. The chimney should be checked to ensure that there is no restriction, that no leakage is occurring, and that on the previous fuel draught was adequate. In some cases it may be necessary to reduce an excessive draught with double-swing draught stabilizers, etc.

It is permissible to fire with other fuels into the same chimney provided that:

1. The other fuel is not solid fuel;
2. The common flue is of adequate size and construction;
3. The burner system of the gas- and oil-burning boilers are operating under similar draught conditions and preferably in the same room;
4. The burner-control equipment for both oil and gas is to the current standard for this type of equipment.

13.6.7 Automatic flue dampers

The use of flue dampers may be considered as a means of energy conservation by preventing ventilation of the boiler in the non-firing state. There is a possible safety hazard if the damper remains closed when the burner ignites and fires. Safe application of flue dampers is covered in UP/10. An assessment of the fuel savings to be expected from the use of flue dampers has been made by Dann, R. G., Lovelace, D. E. and Page, M. W., 'The effect of flue dampers on natural ventilation heat losses from boilers', *The Heating and Air Conditioning Journal* (May 1984).

13.7 Health and safety in the use of gas

13.7.1 Legislation

13.7.1.1 Health and Safety at Work etc. Act 1974

This has relevance to the supply of gas and plant burning gas, in particular section 6, as amended by the Consumer Protection Act 1987.

13.7.1.2 Gas Act 1995

Together with the Gas (Safety) Management Regulations 2001, this forms the major legislation concerning the safe supply of gas. The Gas Act does not have great relevance to safety aspects of gas utilization but it is an enabling Act under which specific regulations can be published.

An exception is Schedule 5, Public Gas Supply Code, which deals with meter installation, use of antifluctuators and valves, reconnection of gas supplies, escapes of gas, etc. This is now repeated in other gas safety regulations.

13.7.1.3 Gas Safety (Installation and Use) Regulations 1998 (SI 1998 No 2451)

These Regulations cover the safe use of gas in users' premises. They apply to domestic and commercial premises but not to industrial, although it is practice to apply the intent of the Regulations to such premises. The whole subject of gas safety legislation and training is under review (2001) within the HSE. The Regulations cover most aspects of installation and safety, including gas fittings, meters, installation pipes, gas appliances, ventilation, flueing, gas escapes and non-return valves. The term 'competent person' is a requirement of much safety legislation. To be 'competent' in the gas industry, the engineer needs to be trained, experienced and assessed by a third party organization. In addition, in non-factory or process environments, the engineer and his employer must be registered with CORGI. Training is detailed in HSE Approved Code of Practice on Standards of Training in Safe Gas Installation. Information on assessment requirements are available from CORGI *www.corgi-gas.com.*

13.7.1.4 Gas Safety Regulations 1972 (SI 1972, No. 1178)

These Regulations were largely repealed by the later 1984 Regulations. Certain sections were retained, however, notably Part II, which deals with service pipes (i.e. the pipes to carry gas from the main to the user's property). See also IGE/TD/4 Gas Services.

13.7.1.5 The Building Regulations 1991

The Regulations are accompanied by a series of guidance publications called Approved Documents. These are constantly under review to take account of modern

building practices, safety matters and building thermal efficiency. Document J on Heat Producing Appliances is primarily domestic and covers flues and ventilation. Document L covers Conservation of Fuel and Power whilst Document F covers Means of Ventilation in a range of buildings.

13.7.2 Potential hazards in the use of gas

13.7.2.1 Properties

Natural gas is a colourless gas to which has been added a distinctive odour. It is composed principally of methane (88–95%) together with small proportions of higher hydrocarbons (ethane, propane, butane), and nitrogen and/or carbon dioxide. It has a calorific value generally in the range 38–39 MJ/m^3 and is lighter than air with a specific gravity (with regard to air) of 0.59– 0.64.

13.7.2.2 Health hazard data

Natural gas does not in itself constitute a hazard to health. However, exposure to concentrations in excess of approximately 10% in air may cause dizziness and nausea. Higher concentrations may lead to asphyxiation.

Exposure to carbon monoxide resulting from inadequate ventilation and/or leakage of combustion products may cause headaches, chronic tiredness or muscular weakness. High concentrations or long-term exposure may be fatal. Personnel suffering from these effects should be treated by normal resuscitation methods and medical advice sought.

13.7.2.3 Safety hazard data

Natural gas forms flammable mixtures with air in the concentration range 5–15% in air. In the event of a natural gas fire, steps should be taken to shut off the gas supply, and the local fire brigade and the gas supplier notified.

13.7.2.4 Handling

Natural gas must always be contained in appropriate pipes or vessels and precautions taken to ensure that leakage cannot occur. If a gas leak does occur, the main gas supply should be shut off, the area ventilated and the gas supplier informed. Electrical switches should not be turned on or off, portable electrical appliances including hand-held torches should not be operated and all other possible sources of ignition removed or rendered inoperable and the affected area ventilated. In circumstances of excessive leakage the building should be evacuated.

13.7.2.5 Application

Appliances and other equipment intended to be used with natural gas should be purpose designed and built to recognize safety standards, installed in properly ventilated locations and supplied with the necessary flueing systems or other means of disposal of combustion products. Lack of adequate ventilation and/or leakage of combustion products into the work space may give rise to carbon monoxide poisoning. In this event, affected personnel should be evacuated from the area, the gas supply shut off, the supplier informed and medical advice sought. Attention is drawn to the Gas Safety (Installation and Use) Regulations, relevant British Standards and appropriate relevant BSI codes of practice or standards and IGE Recommendations, all of which deal with the design, application and safe use of gas and gas-fired equipment.

13.7.2.6 Hazardous Areas

High pressure flammable gases and flammable liquids require consideration, e.g. risk assessment, with respect to the hazardous area that may develop around potential leakage sources. The physical space around each joint is dependent upon the ventilation rate and operating pressure. Spaces around pressure relief valve vents pose particular problems and the dimensions of the hazardous area become quite extensive. Guidance is given in IGE SR/25 and IGE UP/9 for Gas Turbines. Attention is also drawn to the requirements of the Explosive Atmospheres (ATEX) Directive. Electrical equipment located within hazardous areas will require to meet standards such as BS EN 60079:10. Information on Risk Assessment is given in IGE SR/24.

13.7.3 Safety procedures

These have been partly covered in Section 13.7.2. All gas-fired equipment should be designed to be ignited, operated and shut down in a safe manner. Instructions to this effect should be clearly displayed. This is a requirement of the Health and Safety at Work etc. Act 1974. In addition, such plant should comply with all relevant standards, e.g. BS EN 676, BS EN 746 and IGE IM/30 Code of Practice for Gas-fired Process Plant.

In the event of an incident occurring it is essential in the first instance to shut off the gas supply. This is recognized in the Gas Safety (Installation and Use) Regulations by the need for an 'emergency control valve' sited close to the entry to a building. In smaller premises this may be the meter control valve. In larger premises it is a requirement of the Regulations that for every building with a gas supply of 50 mm or more and more than one self-contained area then a valve must be installed at the position where the gas enters the building. In such premises a line diagram of the pipe layout should also be prominently displayed, at least close to the primary meter. Such a diagram, indicating all emergency control valves and all pipework of internal diameter 25 mm or more, can be used to locate areas to be isolated in an emergency.

It is additionally recommended in UP/10 that for buildings containing pipework at pressures above 1 barg, a means of automatically isolating the supply to the building is fitted. Ideally, this should be a quick closing type valve meeting BS EN 161. In some cases a system dump valve may also be needed. Provision for remote operation of the valve should be considered. See 13.12.2.

13.7.4 Maintenance

Safe operation of all plant is improved by means of regular maintenance by competent personnel in conjunction with

the manufacturer's maintenance instructions. This should always be followed by IGE UP/4 for plant recommissioning in a safe manner. It is particularly important that valves such as safety shut-off valves, non-return valves, etc. are regularly checked for soundness.

13.8 Pressure control

13.8.1 Governors

Constant-pressure governors are required at various stages of the gas supply within the user's premises from the first pressure reduction from distribution pressure to supply pressure at the meter installation to the appliance governor. The complexity and design of the governor installation depends on pressure, throughput, duty, etc. In addition to governors, pressure-relief, slam-shut and non-return valves may be relevant in some installations.

BS EN 88 applies to governors [also referred to as regulators] with an inlet pressure up to 200 mbar. For pressure between 200 and 5000 mbar, refer to BS EN 334.

13.8.1.1 Pressure-regulating installations

Detailed requirements for pressure-regulating stations are contained in two Institution of Gas Engineering publications:

TD/9: Offtakes and Pressure-regulating Installations for Inlet Pressures between 7 and 100 bar
TD/10: Pressure-regulating Installations for Inlet Pressures between 75 mbar and 7 bar
IGE TD/13 will eventually replace TD9 and 10.

These references give details of the requirements for safely maintaining a constant pressure outlet over a wide range of flow rates. It should be noted that 'governor' and 'regulator' are largely interchangeable terms.

Requirements become more demanding as the pressure at the inlet rises. A governor alone has its characteristics which include a pressure 'droop' at high throughputs and an increase above set point at very low throughputs. In many cases there must additionally be protection against the failure of a governor. This can be provided by:

1. 'Active and monitor' governors (defined as two governors in series whose settings are stepped so as to allow the active governor to control the outlet pressure and the monitor governor to assume control in the event of failure of the active governor to the open position);
2. Pressure-relief valve (this will vent to atmosphere when a predetermined maximum pressure is attained);
3. Slam-shut valve, this will close quickly in the event of an abnormal pressure (usually excess) being detected.

All regulator or governor installations must be designed to work over the range of inlet pressures including any fault condition. At the same time, they must provide a safe and secure outlet pressure at such a level as will not cause danger to the pipework system including its controls and any appliances. It is therefore essential to know the maximum design pressure rating of the appliance control system. In those cases where the failure of a single regulator could lead to a hazard, it is generally required that an additional safety device is fitted, e.g. a pressure creep relief valve and an over pressure cut-off valve. In some larger systems, such a means of protection may also be required at the appliance/burner to cope with high internal installation pressures. It should be noted that most appliances are designed to operate on low pressure systems requiring at least 17.5 mbar and not more than about 30 mbar.

1. *Inlet pressure not exceeding 75 mbar.* The only requirement is for a single governor and a single stream, although twin streams will be advantageous for larger loads.
2. *Inlet pressures 75 mbar to 2 bar.* A single or multi-stream installation including:
   (a) Single-stage governor with internal valves open at rest;
   (b) Relief valve with capacity not more than 1% of the stream fault capacity;
   (c) Slam-shut valve.
3. *Inlet pressures 2–7 bar, governor of 50 mm bore or less and stream fault flow rates less than 300 m^3/h.* As in (2) above *or* duplicate streams, each having two-stage governing and a slam-shut valve;
   (a) A monitor override pilot governor to be fitted to the first-stage governor impulsed from the outlet of the second-stage governor;
   (b) A relief valve of capacity not more than 1% the fault stream capacity to be included in each stream.
4. *Inlet pressures 2–7 bar, larger flow rates.* Duplicate streams with two-stage governing as in (3) above *or* duplicate streams each having monitor and active governors and a slam-shut valve;
   (a) The monitor governor to be upstream of the active governor;
   (b) A relief valve of capacity not more than 1%, the fault stream capacity to be included in each stream.

13.8.1.2 Legal requirements

The Gas Safety (Installation and Use) Regulations require that the gas supply to the meter be governed in all premises other than mines, quarries and factories (Regulation 13). It is practice to govern all premises, but exceptions may be made in categories where it is permissible, and there is advantage in so doing.

13.8.2 Pressure-relief valve

The pressure-relief valve has the physical appearance of a pressure governor. It operates in the reverse manner to a governor, that is, on exceeding the set pressure the valve lifts off its seat, rather than being forced onto its seat, as in a governor. Gas is therefore allowed to flow through the valve.

The main function of the relief valve is to act as a back-up to a pressure governor to prevent the pre-set downstream pressure being exceeded. In particular, it will

the manufacturer's maintenance instructions. This should always be followed by IGE UP/4 for plant recommissioning in a safe manner. It is particularly important that valves such as safety shut-off valves, non-return valves, etc. are regularly checked for soundness.

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The main function of the relief valve is to act as a back-up to a pressure governor to prevent the pre-set downstream pressure being exceeded. In particular, it will

relieve the small amount of 'creep' that will occur by slippage past the valve seating in a governor.

Safe venting of the gas relieved is of great importance. Breather and instrument vents must be terminated in a safe location, preferably above roof level, and away from potential sources of ignition. They should not be manifolded together if back flow into other control or safety systems could lead to danger. The termination point should minimize the ingress of rain, dust, etc but should not normally be fitted with a flame arrestor. The size of vent pipework needs to take account of the flow and longer lengths, e.g. those over 20 m may well require enlargement.

Vents from pressure relief valves must be terminated vertically upwards to achieve good dispersion and require further attention with respect to hazardous areas see IGE UP/9 or SR25. The fitting of flame arrestors is not recommended or normally necessary.

13.8.3 Slam-shut valves

The slam-shut valve cuts off the gas supply in the event of predetermined pressure criteria being exceeded. It must be manually reset, having made safe the downstream pipework and the cause of the abnormal pressure removed.

It consists of a spring-loaded cut-off valve which is held open in the open position under normal conditions. Should the pressure deviate sufficiently, the diaphragm will move and disengage the trigger mechanism, releasing the latch on the valve, which will close under the force of the spring.

Slam-shut valves are usually set to operate under conditions of high downstream pressure. They can be used for low pressures, and also combined high and low. Although they normally protect the supply pressure to premises using gas, slam-shut valves are sometimes used on process plant.

13.8.4 Non-return valves

It is a requirement of the Gas Safety Legislation that where 'air at high pressure' or 'any gaseous substance not supplied by the supplier' is used, it is necessary to install an 'appliance' to prevent the admission of that gas into the supplier's gas main. This requirement is usually met by means of a non-return valve installed at the meter outlet, where it will protect the supplier's mains. There are advantages to the user in having the non-return valve installed close to the point of use so that, in the event of a gas at higher pressure entering the gas supply, it will be checked by the non-return valve at an early stage rather than diffusing throughout the user's installation pipework. A non-return valve must meet the requirements of the gas supplier.

It is important to note that the requirements of this standard are specific to gas, and include a low-pressure differential under forward-flow conditions. It is unlikely that a non-return valve suitable for compressed air, etc. will be acceptable for gas.

Reverse pressure requirements are typically:-

Up to 25 mm:	7 bar
25–150 mm:	2 bar
Over 150 mm:	1 bar

In the particular case of oxygen, valves shall be resistant to exposure for up to 12 h at all pressures up to 2 bar at 20°C. Requirements for non-return valves for oxygen are also discussed in publication *Guidance Notes on the Use of Oxygen in Industrial Gas Fired Plant and Working Flame Burners.* (IM/1) available from the IGE.

It is essential for the safe operation of a non-return valve that it be regularly checked and be shown to be resistant to reverse pressures. To enable this check to be carried out, the non-return valve should be installed with a manual isolation valve at both inlet and outlet together with inlet and outlet pressure tappings.

13.9 Gas specification and analysis

Natural gas as distributed in the UK is obtained from various sources. These comprise primarily the southern North Sea basin, northern North Sea fields (both British and Norwegian), Morecambe Bay from the Irish Sea and gas from world sources imported in small quantities as liquefied natural gas (LNG). Gas from the different fields is of general consistent quality, and further blending, conditioning, etc. allows a gas of consistent quality and specification to be distributed. The CV, RD (SG) and individual constituents do however vary and users of sensitive combustion equipment such as oxy/gas glass working burners and gas turbines will need to consider the range of variations.

13.9.1 Calorific Value

The Calorific Value is constantly monitored, and it is a condition of the Gas (Safety) Management Regulations 1996 that alterations in the declared Calorific Value (CV) are publicly made known. It is customary to quote the Gross (Upper) CV rather than the Net (Lower) CV. The difference between the two represents the heat contained in the latent heat of vaporization of the water vapour in the products of combustion which can only be recovered in condensing appliances.

The ratio of net/gross CV is about 90%, reflecting the high hydrocarbon/carbon ratio for gas. The range of declared CV (gross) is 38–39 MJ/m^3 with a typical value of 38.63 MJ/m^3. This latter figure represents a net CV of 34.88 MJ/m^3.

13.9.2 Wobbe Number

The Wobbe Number of gas is defined as 'The heat release when a gas is burned at a constant gas supply pressure'. It is represented by:

$$\text{Wobbe No.} = \frac{\text{Gross CV}}{\text{Square root of relative density of gas}}$$

The relative density (with respect to air) has no units, so that the units of the Wobbe Number are the same as Calorific Value. The value for gas is 49.79 MJ/m^3.

The Wobbe Number is of interest because it represents the heat released at a jet. A gas of varying CV but constant Wobbe Number would give a constant heat release rate.

13.9.3 Analysis of natural gas

It is not possible to give an accurate analysis of any natural gas field supplying the UK. However, Table 13.1 provides some idea of likely compositions. For more accurate information, contact the gas supplier.

13.9.4 Properties of natural gas

The main properties of gas and its combustion products are shown in Table 13.2. For comparison, the properties of propane and butane are included. It can be seen that the calorific values of these three fuels on a mass basis are very similar.

The properties of natural gas are dominated by those of methane, notably a low maximum flame speed of 0.356 m/s. This strongly influences burner design, which must ensure that the mixture velocity is sufficiently low to prevent 'blow-off'. 'Light-back', on the contrary, is very unlikely with such a low flame speed.

The range of satisfactory operation for a gas burner, defined by light-back, blow-off and incomplete combustion are limited. The variation in gas analyses, particularly higher hydrocarbons and inerts, can influence the range of operation. This has led to the definition of different groups of natural gas. A practical effect is that burners are designed to work with specific ranges of gas quality within each country. To cope with the variations from country to country, it may be necessary to change injectors or gas pressures, as recommended by the manufacturer.

13.9.5 Standard reference conditions

If properties are being accurately quoted it is important that the reference conditions are defined, as these can vary. This also has implications for metering. The main reference conditions are:

1. *Metric standard reference conditions*
   15.0°C, 1013.25 mbar, dry
   Symbols: MSC, m^3 (st)
2. *Imperial standard conditions*
   60.0°F, 30 inHg, saturated with water vapour
   Symbols: ISC, standard cubic foot, sft^3 (src in old references)
   SI equivalent: 15.56°C, 1013.7405 mbar, saturated
3. *Normal temperature and pressure*
   0°C, 760 mmHg (at 0°C and $g = 9.80665\ m/s^2$)
   Symbols: nm^3, N m^3, m^3 (n), STP, NTP
   SI equivalent: 0°C, 1013.25 mbar

   Unless otherwise specified, the gas may be assumed to be dry.
4. *US gas industry 'standard cubic foot'*
   60°F, 30 inHg (at 32°F, $g = 32.174\ ft/s^2$), saturated
   SI equivalent: 15.56°C, 1015.92 mbar, saturated
   Symbols: scf, sft^3

Table 13.1 Analysis of natural gas

	Mean North Sea	*Bacton*	*Easington*	*Theddlethorpe*	*St Fergus*
Composition (vol %)					
Nitrogen (N_2)	2.72	1.78	1.56	2.53	0.47
Helium (He)	–	0.05	–	–	–
Carbon dioxide (CO_2)	0.15	0.13	0.54	0.52	0.32
Methane (CH_4)	92.21	93.63	93.53	91.43	95.28
Ethane (C_2H_6)	3.6	3.25	3.36	4.10	3.71
Propane (C_3H_8)	0.9	0.69	0.70	0.99	0.18
Butanes (C_4H_{10})	0.25	0.27	0.24	0.33	0.03
Pentanes (C_5H_{12})	0.07	0.09	0.07	0.10	0.01
Higher hydrocarbons	0.1	0.11	–	–	–
Composition (wt %)					
Nitrogen (N_2)	4.38	2.90	2.55	4.05	0.79
Helium (He)	–	0.003	–	–	–
Carbon dioxide (CO_2)	0.38	0.33	1.39	1.31	0.84
Methane (CH_4)	84.89	87.37	87.28	83.62	91.10
Ethane (C_2H_6)	6.21	5.69	5.88	7.03	6.65
Propane (C_3H_8)	2.28	1.59	1.80	2.49	0.47
Butanes (C_4H_{10})	0.83	0.91	0.81	1.09	0.11
Pentanes (C_5H_{12})	0.29	0.38	0.29	0.41	0.04
Higher hydrocarbons	0.74	0.82	–	–	–
Ultimate composition (wt %)					
Carbon	72.16	73.23	72.93	71.98	74.38
Hydrogen	23.18	23.62	23.51	23.02	24.21
Nitrogen	4.38	2.91	2.55	4.05	0.79
Oxygen	0.28	0.24	1.01	0.95	0.61

Table 13.2 Properties of gaseous fuels and combustion products

Properties at 1013.25 mbar (15°C)	*Mean North Sea*	*Typical commercial propane*	*Typical commercial butane*
Specific gravity (air = 1)	0.602	1.523	1.941
Gross calorific value			
MJ m^{-3} (st)	38.63	93.87	117.75
Btu ft^{-3} (ISC) dry	1 036	2 500	3 270
MJ kg^{-1}	52.41	50.22	49.41
Btu lb^{-1}	22 530	21 500	21 200
Therms ton^{-1}	505	480	477
Btu $gall^{-1}$	–	110 040	124 352
Net calorific value			
MJ m^{-3} (st)	34.88	86.43	108.69
Btu ft^{-3} (ISC) dry	935	2 310	3 030
MJ kg^{-1}	47.32	46.24	45.61
Btu lb^{-1}	20 340	19 800	19 650
Liquid SG (water = 1) at 60°F	–	0.51	0.575
Volume gas/volume liquid (at 0°C)	–	274	233
Wobbe No.			
MJ m^{-3} (st)	49.79	76.06	84.52
Btu ft^{-3} (ISC) dry	1 335	2 026	2 347
Theoretical air required for combustion			
(v/v)	9.76	23.76	29.92
(w/w)	16.5	15.6	15.3
m^3 (st) kg^{-1} of fuel	13.24	12.73	12.50
f^3 (st) lb^{-1} of fuel	212.0	203.92	200.23
Theoretical stoichiometric dry flue gas CO_2%	11.86	13.8	14.1
Volumetric composition of wet theoretical flue gas			
% CO_2	9.66	11.7	12.0
% H_2O	18.63	15.4	14.9
% N_2	71.71	72.9	73.1
Dewpoint of flue gas (°C)	59	55	54
Theoretical flame temperature (°C)	1 930	2 000	2 000
Limits of flammability (% by volume to form combustible mixture)	5–15	2–10	1.8–9

NB: Calorific Value (saturated) = 0.9826 × Calorific Value (dm).

13.10 Control of efficiency

13.10.1 Monitoring of combustion

Reference to Figure 13.1 shows how efficiency can be adversely affected by deviation from the optimum air/gas ratio. By maintaining combustion close to stoichiometric, efficiency will be improved, but the practical limitations of burners discussed above must be noted.

The quality of combustion can be measured with suitable instrumentation, on either a periodic or a continual basis. If continuous analysis is practised then there may be feedback to continuously adjust the air/gas ratio and/or ratio and/or record the data derived.

13.10.1.1 Flue gases analysed

The flue gases analysed will be one or more of carbon dioxide, carbon monoxide and oxygen. If carbon dioxide alone is measured it is possible to draw erroneous conclusions, as the level will peak at stoichiometric and reduce in both the excess air and air deficiency regions. It is essential to measure another flue gas to obtain a reliable assessment of burner performance.

Oxygen does not have this disadvantage, being, in theory, zero at stoichiometry and increasing in the excess air region. Sampling of carbon monoxide additionally is advocated during initial commissioning, if not always on a routine basis.

Carbon monoxide is usually sampled as the second parameter in conjunction with carbon dioxide or oxygen. In theory, as the optimum is usually to have near-stoichiometric combustion without 'CO breakthrough' it is the most reliable gas to sample. A problem is that although small quantities of CO usually indicate the need for additional air, they can also be caused by flame chilling and careful interpretation of results is needed.

13.10.1.2 Wet and dry analysis

The relatively high hydrogen content of gas, contained in the methane, leads to a water vapour content of approximately 18% by volume in the flue products. The analysis of the other constituent gases is affected by whether or not the water vapour is included.

The 'dry' analysis is on the basis of the water being removed from the sample prior to analysis, and the maximum theoretical carbon dioxide content is 11.87%. Most flue analyses are carried out on the dry basis.

The 'wet' analysis assumes that the water vapour is present. The maximum theoretical carbon dioxide content is 9.66%. The zirconia cell method of measuring oxygen is on the wet basis.

13.10.1.3 Instruments used

A wide range of analysis instruments can be used, either of the portable or permanently installed type. The latter will frequently be recording instruments and may have control capabilities.

Various principles are employed in analysis equipment, including:

1. Wet chemical analysis;
2. Electrolytic cell;
3. Chromatography;
4. Paramagnetism – for oxygen;
5. Non-dispersive infrared absorption;
6. Thermal conductivity.

13.10.2 Control of combustion

In the great majority of installations flue gas analysis is carried out for monitoring reasons only. In some larger installations, primarily boilers, a deviation in the reading of the gas measured is used for control purposes. The safety aspects of such system must be satisfactory, in particular that the controller cannot erroneously drive the burner to fire rich under any circumstances. The controller should be capable of being set to follow the optimum curve for excess air with firing load which recognizes that more excess air is needed at lower firing rates, as shown in Figure 13.7.

Much responsibility rests with the commissioning engineer who must have an intimate knowledge of the burner, the boiler, and the combination of the two.

A decision to use an accurate method of combustion control will, in general, be based on economics. The fuel saving is unlikely to be more than about 2% and this must be balanced against the total costs of operating the control system.

In the case of larger boilers such an installation can often be justified.

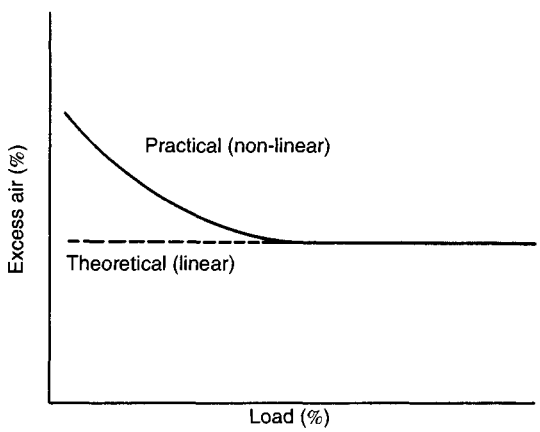


Figure 13.7 Variation of excess air with load

13.10.2.1 Oxygen trim systems

Oxygen trim systems generally operate in conjunction with variable speed drives on the combustion air fan to control the inlet air flow and to achieve further savings in power consumption. Such systems can also provide added plant safety levels, See SAFed document *Guidelines for the Operation of Steam Boilers* available from Safety Assessment Federation Ltd.

Most oxygen trim systems interpose an additional link in the air/gas ratio controller. Others use an additional valve. Most types are based on the zirconia cell installed in the flue, while others use paramagnetic or electrolytic cell methods. The zirconia type has the advantage that there is no time lag in sampling, nor is there a risk of contamination of the sample.

If the flue is operating under negative pressure, which is often the case, care should be taken that no 'tramp' air is allowed to enter the flue upstream of the sampling point, as this will give erroneous measurements. The trim system should be set to follow the practical firing curve and, in the event of a malfunction, be 'disabled' so that it ceases to have any influence on the air/gas ratio, which reverts to the normal load control only.

13.10.2.2 Carbon monoxide trim systems

There is limited application for CO trim systems which are widely used on utility and other large watertube boilers. The principle of operation is for an infrared beam to traverse the flue from emitter to sensor. The absorption of the infrared radiation is proportional to the CO content.

For gas-fired shell boilers it is difficult to justify these trim controllers on an economic basis. Equally important, the position to control based on CO in such a boiler is ideally in the reversal chamber and not the flue. However, the temperature and stratification of flue products here make it impracticable.

13.10.2.3 Control without trim systems

Most combustion equipment is not controlled by means of a feedback from flue gas analysis but is preset at the time of commissioning and preferably checked and reset at intervals as part of a planned maintenance schedule. It is difficult to set the burner for optimum efficiency at all firing rates and some compromise is necessary, depending on the control valves used and the control mode (e.g. on/off, fully modulating, etc.).

In the absence of a trim system with feedback it is likely to prove cost-effective to use a simple portable 'efficiency monitor' on a regular basis, perhaps weekly for small boilers. The change of reading is as important as the actual value of the reading. A deviation from what is known to be a good post-commissioning setting will indicate a drift from ratio and the need for remedial action.

Types of air/gas ratio control There are various types of air/gas ratio device commonly used, including:

1. *Linked butterfly valves.* This simple technique is only suited to high/low controls.
2. *Linked square port valve.* This system has a more linear relationship between flow rate and rotation than butterfly valves. There is no backlash, as the air and gas valves are on a common spindle and fine tuning is possible.
3. *Linked characterized valves.* The relationship between angular rotation of the valve spindle and open area of the valve can be adjusted over different portions of the flow range using a series of screws. In this way, the air/gas ratio can be characterized to any desired profile over the whole firing range. These valves are suited to fully modulating systems and are commonly used on steam boilers.
4. *Balanced pressure-control systems.* Various control systems are based on the balanced pressure principle in which the air pressure (or a portion of it) is applied to the diaphragm of a zero governor in the gas supply. As the air pressure is varied so is the gas pressure in proportion, as shown in Figure 13.8. The air/gas ratio is set by means of an adjustable orifice valve in the gas supply. The pressure divider system will maintain air/gas ratio over much of the turndown ratio. At very low firing rates there is a need for excess air to maintain satisfactory combustion, and this is achieved by means of tensioning the spring within the governor to give an offset (Figure 13.8). The effect of this offset is considerable at very low rates but insignificant at higher ones. The pressure divider principle is exploited in more complex multi-diaphragm controllers. In these, the pressures balanced are differential pressures across orifices, enabling the ratio to be maintained under conditions of varying back-pressure.
5. *Electronic ratio controller.* In this type of controller a proportion of both gas and air is diverted through a by-pass in which a thermistor sensor measures the flow. The air and gas flows can be compared and the ratio calculated and displayed. A deviation from the pre-set ratio will be automatically restored by a ratio control valve in the air or gas supply, depending on whether the mode of operation is gas- or air-led. The electronic controller maintains ratio over a 10:1 turndown. The principle of operation is based on mass flow, so that it can be used with preheated air in recuperative systems.

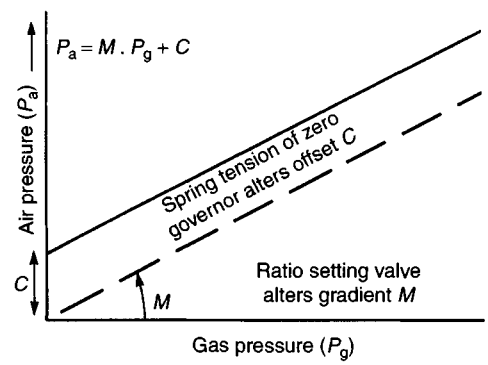


Figure 13.8 Relationship between air and gas pressures for cross-loaded governor system

13.10.3 Process controls

The choice of the mode of control of heating plant can have a considerable effect on the efficiency of the process. The process itself may dictate the controls. For example, a simple high/low temperature controller is unlikely to satisfy a process tolerance requirement of within a few degrees Celsius. Similarly, a more complex process controller cannot be coupled with a burner only capable of firing high/low.

13.10.3.1 Types of process control

High/low control This may be on/off in certain applications. Control is fairly crude, with the burner moving to high fire at a point somewhere below the nominal set point and returning to low fire somewhere above it. The result is a sinewave control pattern with a band rather than a point of control. This is, however, still an adequate control mode for many purposes.

Most burners are efficient at high fire but less so at intermediate rates and particularly at low fire. An on/off burner is therefore apparently efficient from an energy-utilization viewpoint. However, when the burner is called on to fire, in the case of forced-draught burners a purge is usually necessary which will both cool down the process and cause a delay in response, and in the case of natural draught there will be heat losses due to ventilation in the 'off' period.

In general, a fully modulating burner will be thermally more efficient, particularly if it maintains air/gas ratio accurately at intermediate rates. For natural-draught burners this may not be the case, as, in general, the air is not modulated, leading to progressively more excess air at lower rates.

Proportional-only control This avoids the cycling effect of high/low control by setting the burner rate in proportion to the deviation from the set point (i.e. the burner rate decreases as the set point is approached). In theory, this meets requirements and avoids overshoot. However, the set point is approached but not reached, leaving an off-set. This can be minimized by using a high gain in the control, but this will lead to excessive cycling or 'hunting'.

Integral mode This improves on the proportional-only control by repeating the proportional action within a unit time while a deviation from set point exists. The regulating unit is only allowed to be at rest when set point

and measured point are coincident. Integral action will move the regulating unit until the desired and measured values are coincident, even if this means moving the regulating unit to the fully open or closed position.

Derivative mode This improves on the proportional-only control by responding solely to the rate of change of the deviation but not in any way to the actual value of the deviation. Derivative action is always used with proportional control.

Proportional plus integral plus derivative action Proportional action provides a controller output proportional to the error signal. Integral action supplies a controller output which changes in the direction to reduce a constant error. Derivative action provides a controller output determined by the direction and rate of change of the deviation. When all these are combined into one controller (three-term or PID) there is an automatic control facility to correct any process changes.

13.10.3.2 Controls for space heating in buildings

The selection of controls for space heating a building shows how the overall efficiency of the process can be improved. Whether or not it is cost effective, to do this must be examined in detail. At its most basic, such a system might include one or more LPHW boilers, a single thermostat in the heated space controlling the circulating pump on/off, and domestic hot water from a calorifier.

Boiler selection Although not directly concerned with controls, the sizing of boilers is very important. There is a tendency for oversizing with consequent unnecessary cycling. Controls should ensure that if more than one boiler is installed then one boiler should act as 'lead'. Consideration should be given to a higher-efficiency boiler, possibly a condensing type.

In most cases, splitting the heating and domestic hot water loads will be advantageous. This avoids the inefficient use of a large boiler solely to heat a calorifier in the summer months.

Controls selection The selection of controls will be influenced to an extent by the characteristics of the building, particularly the insulation material and the number and disposition of windows. Control options to be considered include:

1. *Zone control valves.* In most buildings different areas will be subject to varying levels of solar gain, occupancy, etc. Dividing the building into different zones each with its own thermostat and control valve will be beneficial.
2. *Compensating controller.* The heat requirements for a building vary according to the outside conditions, particularly the outside air temperature. The compensating controller measures the outside air temperature and, together with other parameters, including the thermal response of the building, adjusts the circulating water temperature to meet the demand.
3. *Three-port mixing valves.* The valve takes hot water from the boiler and mixes it with the cooler return water to provide a circulation of mixed water of sufficiently high temperature to meet the heating demand. The system operates with a constant flow rate and variable temperature. In the case of condensing boilers the return water should pass through the condensing heat exchange of the boiler prior to flowing to the mixing valve. An alternative for condensing boilers that does not use a mixing valve is to set the boiler flow temperature, by means of an outside air temperature sensor and compensating control box, in inverse proportion to the outside air temperature. Both these alternatives cause the boiler to operate in its efficient condensing mode for the maximum period.
4. *Optimum start controller.* Any building will heat up more quickly on a warm day: to start the heating system unnecessarily early is uneconomic. The optimum start controller monitors the outside and inside temperatures and computes the start time that will just bring the temperature up to design by the start of occupancy. The controller is only used during the preheat period during which other modulating controls are not operative. Some versions are available with a self-learning capability, which corrects the initial programme until it matches the building responses, and an optimum off control, which takes account of the allowable drop in space temperature at the end of occupancy.
5. *Building management systems.* These can monitor and control most of the building services by means of sensors in the various building services plants for collecting data and carrying out control functions.

13.11 Automation

13.11.1 Requirements for automatic burners

Process or heating plant may have controls ranging from manual operation with some processes supervised by interlocks to semi-automatic and fully automatic operation. Deciding factors will include temperature of operation, frequency of ignition, degree of operator supervision, and rating of the plant. For example, boiler plant, both steam and water, will invariably have automatic control whereas tunnel kilns operated continuously at high temperature are unlikely to require it.

The definition of an automatic burner is: 'A burner where, when starting from the completely shut-down condition, the start-gas flame is established and the main gas safety shut-off valves are activated without manual intervention.' This means that a burner is only automatic if it is ignited by means of a remote interlock (e.g. thermostat, timeswitch, etc.) closing. A burner is not automatic if it has a pilot burner that remains ignited in the 'off' condition. Nor is a burner strictly automatic if a start button needs to be pushed, even though the controls may comply with all requirements for automatic burners.

13.11.2 Automatic burner sequence

The sequence of operation for automatic burners is based on that which a knowledgeable, conscientious and alert operator would perform. This involves checks at stages to ensure that no hazard has developed. This sequence can be summarized as:

1. Check that the flame detector (ultraviolet or flame rectification) is not giving a spurious signal. This is continuous throughout the purge period.
2. Check that the safety shut-off valves are in the closed position (where applicable).
3. Check that the air flow detector is not giving a false indication.
4. Start the combustion air fan.
5. Prove the combustion air flow (at high rate, if variable).
6. Purge for a predetermined period (sufficient to give five volume changes of the combustion chamber and associated flueways).
7. Modulate the combustion air flow to the low fire rate (where applicable).
8. Prove the burner throughput control valves to be in the low fire position (where applicable).
9. Energize the ignition source.
10. Energize the start gas safety shut-off valve(s).
11. De-energize the ignition source.
12. Check that the flame detector is registering the presence of a flame.
13. Energize the main gas safety shut-off valves.
14. In the case of an interrupted pilot, de-energize the safety shut-off valves.
15. Check that the flame detector is registering the presence of a flame. This is continuous until the burner is shut down.
16. Release the burner controls to modulation so that the burner can be driven to high fire, according to demand.

In the event of any of the checks not being satisfactory the burner is shut down or locked out, as appropriate.

13.11.3 Burner standards and codes of practice

13.11.3.1 Codes of Practice

Gas burner installations should comply with the relevant publications such as UP/10 for appliances or IM/30 for process applications. IM/30 is available from the IGE. Low-temperature plant is defined as that having a normal working temperature insufficient to ignite the fuel, that is, below 750°C at the working temperature walls.

13.11.3.2 Automatic Burner Standards

Standards for forced draught automatic burners are now mostly covered by BS EN 676. However, the UK has retained BS 5885 Automatic Gas Burners parts 1 and 2 for process applications if needed by the designer.

The number and quality of the automatic safety shut off valves is laid down in the Standards. These are usually Class A or B according to BS EN 161. EN 161 specifies the closing times and closing forces for the two Classes. Burners to EN 676 will have valves on the main supply as follows:

Heat input kW	*Main gas with pre-purge*	*Start gas up to 10%*	*Start gas over 10%*
Up to 70 kW	2 × Class B	1 × Class B	2 × Class B
Above 70 up to 1200 kW	2 × Class A	2 × Class A	2 × Class A
Over 1200 kW	2 × Class A plus valve proving	2 × Class B	2 × Class A

In BS 5885 a different set of valve requirements exists and it is possible to apply a 'system check' to ensure valve closure rather than the more onerous 'valve proving system' in EN 676.

A 'system check' is usually satisfied by closed-position indicators on the valves. These show that the valves are nominally in the closed position but do not actually prove that there is no leakage. A 'proving system' can be met by various systems which prove the soundness of the upstream and downstream safety shut-off valves by sequential pressurization, evacuation, mechanical overtravel with limit switches and a normally open vent valve, or other means.

Valves other than electrically operated (e.g. pneumatically operated ball valves) are equally acceptable if the pressure and closing time requirements of BS 5963 are met.

13.11.4 Standards to be applied

13.11.4.1 Automatic or semi-automatic

The amount of process plant that can be defined accurately as automatic is relatively small, and manual intervention is often involved at some stage. The relevant design criteria are therefore often IM/30 from the IGE. Fully automatic burner controllers must meet BS EN 298 and be tested and fitted with a CE mark showing conformity. Although these have features which may not be applicable to non-automatic plant it may be more appropriate to use such a controller, particularly as its safety is well proven. It may also be less expensive than buying and installing separate timers, relays, etc. For some processes (for example, those that do not need and cannot tolerate a long purge) such controllers may not be appropriate.

13.11.4.2 Appliance Standards

Much work has taken place within the EU to develop appliance and component standards for most domestic and commercial appliances. These are always shown as BS ENXXXX and should always display a CE mark of conformity. As they are published within the EU, they replace the old British Standards. Examples of European boiler standards are BS EN 297 and BS EN 677.

13.12 Fire and explosion hazards

13.12.1 Limits of flammability

Gas will form a flammable and explosive mixture with air or oxygen and the band within which this will happen will vary with pressure and temperature. At atmospheric pressure and 15°C the properties are:

	Lower explosive limit (LEL) (% gas)	*Upper explosive limit* (HEL) (% gas)
In air	5	15
In oxygen	5	61

In the combustion chamber it is essential to purge down to below the LEL before initiating the ignition source. The usual criterion is 25% LEL.

Outside the combustion chamber there should be no gas under any circumstances. Such a presence will indicate an uncontrolled leakage into the building. A gas level of 20% LEL is normally sufficient grounds for evacuating the building.

The human nose is often considered to be the best gas sensor, as the odorant contained in the gas permits detection at levels as low as 100 ppm or 0.01% in air. Gas detectors are, however, sometimes used to give additional warnings of any leaks. The following points should be borne in mind when considering such an application:

1. Location is of the greatest importance. It is not known from where a gas leak will emanate and such a leak will disperse rapidly. In general, a high-level location should be chosen, as gas is lighter than air. More than one detector will usually be advisable.
2. Gas detectors should comply with BS 50057, Instruments for the detection of combustible gas, specifically Parts 4 and 5.
3. Detectors may respond to other gases and vapours giving a false reading.
4. Detectors will require frequent maintenance and calibration to perform accurately.
5. The use of gas detectors should not be regarded as a substitute for proper ventilation.

13.12.2 Flame speed and flame traps

The flame speed of gas in air is 0.356 m/s. This is lower than most common flammable gases and is an indication of the low propensity for light-back of natural gas.

In certain applications a flame trap may be required, and further guidance is given in HSE publication HS(G)11, *Flame Arrestors and Explosion Reliefs*. Flame arrestors should comply with BS 7244. The flame trap is constructed of strips of corrugated and flat steel ribbon wound in a spiral. It breaks up a flame in the very small passages between the corrugations where the flame is quenched and extinguished.

A flame trap is employed where premixed air and gas is used in combustion equipment and prevents the flame passing upstream into the pipe system. Flame traps should be situated as near as possible to the gas burner. This is so that the flame does not have a long pipe run in which it might accelerate to such a speed as to form a detonation wave and make the trap useless.

Thermocouple elements can be incorporated into the flame trap so that a flame that has lit back to the flame trap element and continued to burn there without being quenched can be detected. This sensor can be used to close an upstream safety shut-off valve. Flame traps will be the cause of a significant pressure drop for which allowances must be made in low-pressure systems.

Typical applications for flame traps include:

1. The outlet pipework from premix machines, but not fan-type mixers as they may adversely affect the operation of such machines;
2. Vents from pressure-relief systems and governor vents;
3. Purge outlet pipes.

13.12.3 Automatic isolation valves

Unlike oil burners, there is no requirement to install a fire valve. With oil burners this is usually met by having a fusible link sited over the burner and connected in a tensioned wire which holds open a weighted valve in the oil supply so that the valve closes if the link melts.

The use of automatically closing valves operated from gas-, fire- or smoke-detection systems is not normally required for gas installations. The reasons for this are:

1. There are very few recorded instances of fire caused by gas in installations such as boilerhouses;
2. A leak in the oil supply will cause oil to collect on the floor fuelling a fire in a predictable location, most probably at the burner itself. With gas a leak is possible at any joint, but such a leak will rapidly disperse. A predictable location is not possible, and a fire is not likely.
3. Gas can feed a fire caused by other sources. The integrity of pipework should withstand an external fire for sufficient time for an external emergency control valve to be operated.
4. Gas does not have the lubricant qualities of fuel oil. Consequently whereas a dropweight valve in the oil supply can be expected to close when called upon, this is not the case with a relatively large-bore gas ball valve or plug valve used for gas.

However, IGE UP/9 and UP/10 recognize that for high pressure plant it is sensible to consider the inclusion into the system of an automatic isolation valve. This is normally closed from a 'Panic Button' close to the exit doors from the plant room although it can also be closed by smoke, fire or gas detection systems. The valve is typically a solenoid type or drop handle type valve meeting BS EN 161 or BS 5963. Automatic isolation valves are also required in catering establishments and school laboratories.

If an automatic isolation valve is specified, the selection of the valve and its operating system must be carefully considered, particularly with respect to the design and methods of restoring the gas supply in those cases where appliances do not incorporate automatic flame safeguards. Further information is given in IM/20 available from the IGE.

13.12.4 Explosion reliefs

HSE publication HS(G) 16, *Evaporating and Other Ovens*, gives guidance on the use of explosion reliefs in plant where flammable solvent is present as a potential source of explosion. Consideration should also be given to utilizing explosion reliefs in other plant, particularly low-temperature ones and where recirculation is practised. Correctly designed controls will minimize the risk of an explosion but explosion reliefs will reduce to a minimum adverse effects from such an incident. Further guidance on the use of explosion reliefs is given in the HSE publication HS(G) 11, *Flame Arrestors and Explosion Reliefs*.

The main requirements of a relief are:

1. If obstructions exist in the plant the relief should be located in a plane which allows an unobstructed flow of gases to the relief vent (e.g. if there are horizontal shelves the relief should be in a side, not the roof).
2. The relief size should be as large as possible, ideally occupying the whole of one side, and minimum vent area = 60 × area of side/P_{max} (m^2) (where P_{max} is the pressure that the plant can withstand without damage – if unknown, assume 140 mbar).
3. The relief should be as light as possible (the weight per unit area should not exceed 24 kg/m^3).
4. The relief should be held in position with the minimum of force.
5. There must be sufficient space around the plant to allow gases to vent freely and not impair the effectiveness of the relief.
6. Reliefs must not form dangerous missiles when called upon to operate.
7. The thermal resistance of the structure should not be significantly altered by the relief.

13.13 Maintenance

13.13.1 Need for maintenance

It is desirable that plant is regularly maintained to ensure that:

1. Thermal efficiency remains at an optimum.
2. Availability and reliability is at a maximum, with no avoidable unplanned downtime.
3. Safety devices are reliable.

The time intervals for maintenance will obviously vary widely. In all cases the work should be part of a clearly determined schedule.

13.13.2 Thermal efficiency

Combustion equipment, when first commissioned, can be set to operate at its optimum efficiency. With time, however, there will be a deterioration due to blockage of air filters and breather holes, wear in valve linkages, etc. Such changes may have safety implications if gas-rich firing is a consequence.

Regular checking of measured parameters and comparison with commissioning data will enable adjustments to be made to optimize efficiency. Replacement of items subject to wear, filters, etc. and items subject to thermal distortion such as some burner components will be necessary.

13.13.3 Reliability

To ensure that plant is not subject to breakdown it is important that there are no unnecessary 'failures to safety', that is, that correctly operating safety equipment only operates because of exceptional circumstances, not avoidable faults. Safety shut-down will occur for various reasons, i.e.:

1. No flame or shrinkage of flame during operation;
2. Failure to ignite flame initially;
3. Failure of any interlock, leading to (1) or (2).

Preventative maintenance that can be carried out that will minimize the chance of nuisance shutdowns includes:

1. Attention to air filters;
2. Cleaning of all burner ports liable to blockage;
3. Replacement of mechanical and electrical components known to have a finite life. For example, the average service life of an ultraviolet flame detector may be 10 000 h, and much less if used above its recommended temperature.

After any maintenance work involving replacement or adjustment of components it is essential that the plant be recommissioned in a safe way, including 'dry runs' with the gas turned off to ensure that flame failure devices operate correctly and pilot turndown tests to ensure that if the pilot can energize the flame detector then it can also smoothly ignite the main burner.

13.13.4 Safety

When initially commissioned all safety devices should be proved to be operating correctly. At intervals these should be checked to ensure that no undetected failure has taken place. Checks that are necessary include:

1. Visual examination of ignition of pilot burner and main burner;
2. All interlocks checked for correct setting and operation. These will include thermostats, pressurestats, limit switches, pressure switches, process interlocks, etc.;
3. Condition of flame sensor and its location with relation to pilot burner and main burner;
4. Soundness of non-return valve with regard to reverse flow;
5. Soundness of safety shut-off valves in the closed position for both forward and reverse flow. Note that this

should be done with the valve *in situ* and without dismantling it, by means of a bubble leak detector, etc. The valve should not be dismantled to check for swarf on the seat, etc.

After modifying the controls in any way during maintenance it is essential to carry out a recommissioning of the plant as outlined in Section 13.15.3 above.

13.13.5 Training of maintenance staff

All staff involved with maintaining gas-fired equipment should be capable of doing so in a safe and responsible manner. The term 'competent' has not yet been defined in this context, but personnel should be qualified by both training and experience to carry out work on any plant which they are to maintain.

A code of practice outlining the training programme that should be undergone by persons carrying out work on gas-fired plant is Approved Code of Practice on Standards of Training in Safe Gas Installation. The Code offers guidance on the standards of training to produce competence in gas installation.

In addition those working on gas systems in domestic and commercial locations must be CORGI registered.

13.13.6 Manufacturer's instructions

For much plant the manufacturers will provide detailed maintenance schedules which should be followed at all times. This may necessitate the use of spares and tools specific to that appliance. Attention is drawn to Regulation 25(7) of the Gas Safety (Installation and Use) Regulations, which states that 'No person shall carry out any work in relation to a gas appliance which bears an indication that it conforms to a type approved by any person as complying with safety standards in such a manner that the appliance ceases to comply with those standards'.

13.14 Statutory requirements

The most important statutory requirements concerning gas distribution and utilization are:

HASWA etc Act
Gas Act 1995, Gas Safety I & U Regs 1998
Building Regulations 1991
RIDDOR Regs 1995

13.15 Testing

13.15.1 Soundness testing

It is essential that gas is not admitted to an installation pipe which is newly installed or has had work carried out on it unless the pipe is proved to be sound. This is a requirement of the Gas Safety (Installation and Use) Regulations, specifically Regulation 21. A suitable procedure is set out in IGE UP/1 or 1A. This recognizes that there is a difference between new installations, which must be sound within practical limitations of measurement, and existing installations which may have inherent small leakages at, for example, valve glands.

The test procedure differs from new to existing installations and the acceptable leakage (or pressure drop over a period of time) will vary depending on the location of the pipework. Testing nowadays is usually with an electronic gauge or a simple water gauge, for low pressures. Test pressures can be at line pressure for existing pipework and not less than 1.5 times working pressure for new systems.

High pressure systems will normally require hydrostatic testing using water and the procedures for this are currently set out in UP/9. The important differences with water as a test medium is that it has to be disposed of safely after the test, the weight of water will require additional supports and finally, the water has to be fully removed from the system. The removal process can be by methanol filling and draining but is more easily performed using a vacuum pump.

An allowance has to be made for temperature, as an increase in temperature will cause a rise in pressure of an enclosed volume of pipework. In practice, this will mean avoiding the effects of direct sunlight and allowing an adequate time for stabilization.

13.15.1.1 Soundness testing procedure

For both new and existing installation the soundness testing procedure would normally consist of:

1. Estimation of the system volume;
2. Establishment of the test procedure;
3. Selection of a pressure gauge. The sensitivity of the pressure gauge will determine the minimum leak rate detectable;
4. Determination of the permitted leak;
5. Determination of test period;
6. Carrying out the test.

13.15.1.2 New installations and new extensions

1. There should be no perceptible drop in pressure as shown by the test gauge, although a small leakage rate is defined which allows for testing technique limitations.
2. Air or inert gas should be used and not fuel gas.
3. The test pressure should be 50 mbar or 1.5 times the working pressure or the maximum pressure likely to occur under fault conditions, whichever is the greater.

It is assumed that the pipework has been designed and installed to withstand the test pressure to which it is to be subjected.

4. Decide on the permitted leak rate. This is taken to be 0.0014 dm^3/h.
5. Calculate the test period. On large installations it may be necessary to section the system.

13.15.1.3 Existing installations

1. Existing installations may be tested with fuel gas or inert gas. Air may also be used subject to correct purging procedures.
2. The test pressure is as with new installations.
3. Existing installations may not meet the requirements laid down for new installations because of minor leaks that have developed. It is necessary to relate such leak rates to the pipe environment.
4. Permitted leak rates are determined by installation location:
   (a) Potentially hazardous areas: no leakage is permitted; all joints in the area must be tested.
   (b) Occupied areas: permitted leakage rate is 0.75 dm^3/h per cubic metre of space. But in no case shall the permitted leak rate be taken as greater than 30 dm^3/h.
   (c) Large open work areas and exposed pipes outside: leak rates in excess of those in (b) may be acceptable from the safety point of view.
   (d) Buried pipes: The measured leak rate must be assessed in the light of ground conditions. In particular, special consideration shall be given to the proximity of cellars, ducts, cable runs, sewers, etc.

13.15.2 Purging procedures

After testing for soundness it will be necessary to safely introduce gas into the pipework displacing the air or inert gas that is in it. Similarly, if pipework is decommissioned for any reason fuel gas must be displaced by air or inert gas. This is a requirement of the Gas Safety (Installation and Use) Regulations, Regulation 21. Guidance on recommended procedures is given in IGE UP/1 or 1A.

Purging can be defined as:

1. The displacement of air or inert gas by fuel gas;
2. The displacement of fuel gas by air or inert gas;
3. The displacement of one fuel gas by another fuel gas.

Important requirements for purging include:

1. A full knowledge of the pipework layout;
2. Adequate provision of vent points and their termination in a safe location;
3. Preferably a written procedure, appropriate to the installation, should be prepared and followed;
4. Ignition sources should be prohibited from within 3 m of vents and test points.

13.15.2.1 Purge volumes

These procedures are aimed at pipework purging using the principle of achieving an optimum forward velocity. This minimizes the amount of natural gas needed for the purge and thus reduces the environmental impact of natural gas emissions. The target velocity is 0.6 m/s for all pipes up to 150 mm, above this size the velocity increases. There is also a limit of 500 m of length for the larger sizes. Due to the difficulty of determining the gas velocity by timing the flow through a gas meter a unique system [shown below Figure 13.9] has been designed giving direct gas flow rates by pipe size. It is also essential that the purge gases are discharged at a safe height at least 2.5 m above ground level. Contact *admin@globalenergy.co.uk.*

13.15.2.2 Purging methods

Purging may be by either the direct or slug method, and may involve the use of an intermediate inert gas purge. At all stages the vent point is sampled and the purge is deemed to be satisfactory when certain criteria are met.

Direct purge This refers to the displacement of an air/gas mixture with fuel gas. The purge is complete with:

Oxygen less than 4%
Combustibles levels greater than 90%

Inert purging This refers to the displacement of fuel gas or air with inert gas (complete displacement) or the formation of a barrier of inert gas (less than 4% oxygen) between fuel gas and air during purging (slug purging):

Gas to inert, purge complete with: combustibles levels less than 7%.
Inert to air, purge complete with: oxygen level greater than 16%.

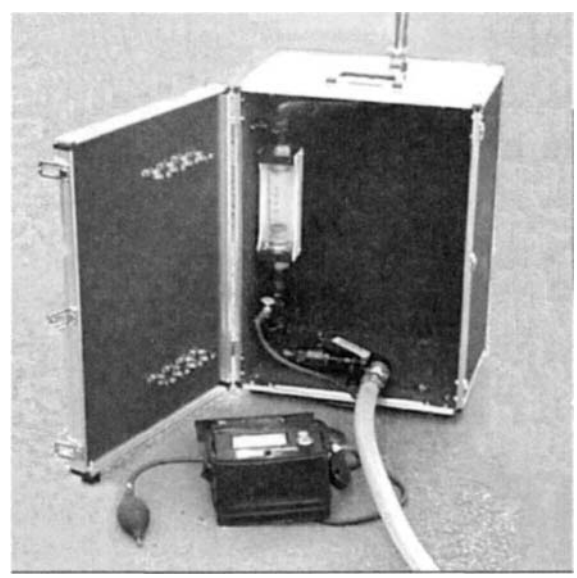


Figure 13.9

Air to inert, purge complete with: oxygen level less than 4%.
Inert to gas, purge complete with: combustible levels greater than 90%.

Slug purging Slug purging is appropriate only for long pipe runs. It should not be used to purge installations with branches unless each one can be (and is) valved off and purged separately.

Air purging This refers to the displacement of gas or gas/air mixture with air. The purge is complete with:

Oxygen level greater than 20.5%
Combustibles levels less than 40% LEL.

Fuel gas to fuel gas purging The purge may be carried out by burning the gas under supervision on an appliance or appliances. If the two fuel gases have different burning characteristics and Wobbe Numbers, correct burner selection is important.

13.15.3 Commissioning

After soundness testing and purging, the item of plant must be commissioned by a competent person. It is a requirement of the Gas Safety (Installation and Use) Regulations, Regulation 33, that an appliance is fully commissioned at the time that gas is made available to it or that it is isolated in such a manner that it cannot be used.

Detailed procedures for plant commissioning are given in IGE UP/4 Commissioning of Gas-fixed plant on Industrial and Commercial Premises. It is important to note that before a purge can take place, that the pipework passes a soundness test; and that immediately after purging has been completed, plant commissioning must occur. In larger sites the commissioning process may not always be possible immediately after the purge and in such cases the plant must not only be physically isolated from all power sources but that the manual isolating valve is locked in the OFF position. This recognizes that it is generally impossible to disconnect the gas supply system from such large items.

Large items of plant also often require the services of several commissioning experts to deal with the different parts of the process, e.g. burners, steam controls, water treatment, chimneys, BMS systems.

13.15.4 *In-situ* testing

Regular *in-situ* testing of various parameters can be an aid to maintaining plant in an optimum condition regarding both efficiency and safety. Commissioning data, which should be on record, must be compared with measurements made on a regular basis for such parameters as gas and air pressures, pressure switch settings, limit switch settings, timer settings, flue gas analyses, etc. Adjustments should be made as necessary.

The period between such tests will depend on the maintenance schedule for the plant, which should also include the *in-situ* soundness testing of non-return valves and safety shut-off valves by bubble leak detectors, etc.

13.16 The gas grid system and distribution networks

13.16.1 The national transmission system

The majority of gas consumed in the United Kingdom originates in the North Sea, both northern and southern basins, and is brought ashore at four terminals, St Fergus, Easington, Theddlethorpe and Bacton. At these terminals the gas is metered, odorized and conditioned (i.e. condensates are removed, it is blended to give a constant calorific value, etc.). Gas can also be brought ashore in the form of liquefied natural gas (LNG) to the Canvey Island terminal, where it can be stored, vaporized and conditioned.

The gas of constant quality is passed into the National Transmission System (NTS) which conveys the gas to all areas of the country where it is passed to regional transmission systems operating at somewhat lower pressures. The length of the NTS is approximately 5000 km with diameters up to 900 mm and operating pressures up to 70 bar. To maintain pressure and to allow for frictional losses, compressor stations, powered by gas turbines, are positioned approximately every 65 km. The National Transmission System is shown in Figure 13.10.

13.16.2 Storage of gas

The rate of use of gas varies considerably both on a seasonal and on a diurnal basis. The gas supplier must ensure that the supply meets the demand under all foreseeable conditions. To an extent, this is achieved by the rates at which gas is taken into the NTS which is determined by contracts specifying daily consumptions throughout the year. Additional fluctuations must be taken up by storage.

13.16.2.1 Methods of storage

Low-pressure holders These are the conventional cylindrical multi-stage gas holders. They operate at low pressure and are usually water-sealed. The storage capacity is low for the large physical size and fewer of these holders are used now as their storage capacity can be met by other means.

High-pressure holders A relatively small number of high-pressure holders are in use. These 'bullets' operate at pressures of up to 30 bar and consequently have a higher storage capacity for their size.

Liquefied natural gas LNG is stored at certain locations as a means of 'peak-shaving'. Advantages are that the liquid gas occupies a volume equal to 600 volumes of gas under standard conditions. The main disadvantage is that it is necessary to lower the temperature to −162°C to liquefy the gas. It is also necessary to maintain the gas at this low temperature, usually in insulated aluminium vessels.

Salt cavities Where the geological formation is favourable it is possible to leach out salt to create underground impermeable cavities in which gas can be

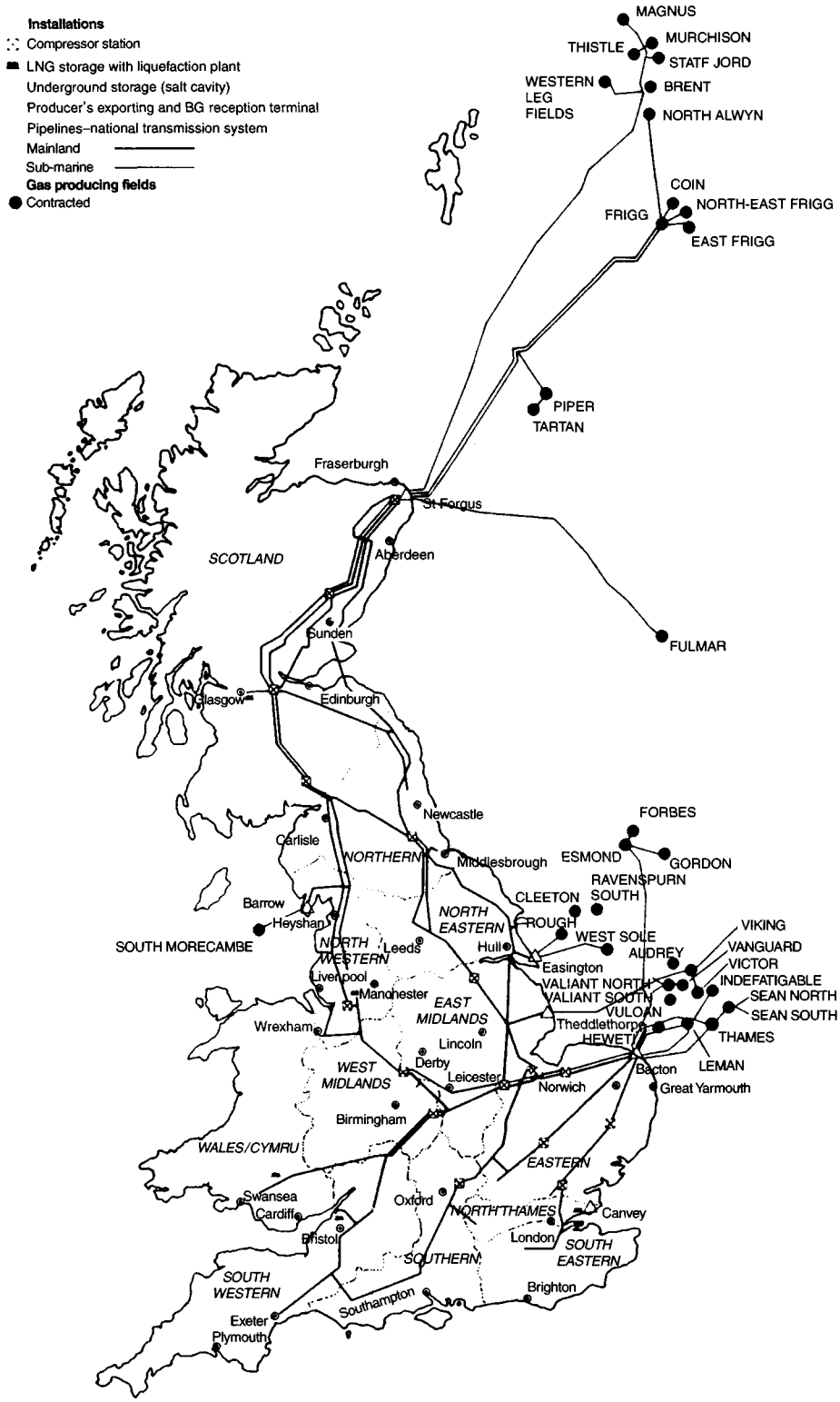


Figure 13.10 Gas supply and transmission

stored at high pressure. These can be likened to large underground high-pressure holders.

Rough storage The Rough gas field is a largely depleted field in the southern North Sea basin which is now used as a storage facility. Gas from other fields is re-injected into the Rough field during the summer period of low demand and drawn on during periods of peak demand.

Morecambe Bay The Morecambe Bay field is a recently developed gas field in the Irish Sea connected to the NTS by means of a gas pipeline to Barrow terminal. While it is possible to operate this field throughout the year it is currently being drawn on only in the winter months as a form of peak-shaving.

Interruptibles As outlined in Section 13.1.4, some users are offered interruptible contracts. A condition of these is that the user must provide a standby fuel and that, when requested, he or she must switch to this fuel. Under peak demand conditions the large quantity of gas that would be burnt (typically, for steam raising) is available for use by firm contract and tariff users.

Line packing The NTS, together with the regional transmission systems, constitute a considerable length of pipework operating at pressures of up to 70 bar. Maximum pressures are set by design and minimum pressures by operational constraints. Between these two the pressure can be permitted to fluctuate.

When it is considered that the volume of 1 km of 900 mm pipe is 636 m^3, and if the pressure is allowed to fall from 42 bar to 19 bar, the equivalent volume of gas at standard conditions is 14 628 m^3, then this should be compared to the capacity of a low-pressure gas holder of typically 28 320 m^3 (1 million ft^3). Two kilometres of pipeline operated under these conditions is therefore the equivalent of one gas holder.

Line packing is generally practised by building up the pressure during the night and reducing it during the day.

13.16.3 Distribution networks

The NTS is used for the conveyance of gas from the terminals to regions sited in different parts of the country. Regional transmission systems are used to convey gas across each region. For local conveyance of gas to the final points of use, the distribution system is used.

The primary difference between transmission and distribution systems is one of pressure. Transmission systems operate at high pressures (>7 bar) while distribution systems operate at low (<75 mbar) and medium (75 mbar to 7 bar) pressures. The functions are also different in that the transmission system is used to convey gas over distances and store it, while the distribution system is used to convey gas to the user over a local network. The pipe which conveys gas from the main of the distribution system to the meter control valve of the user is the service.

13.16.3.1 Operating pressures

Distribution systems can be operated at pressures up to 7 bar but it is practice to operate at as low a pressure as is consistent with supplying users with the agreed supply pressure, which is 21 mbar at the meter inlet in many cases. Pressure reduction takes place at offtakes from the transmission system, at 'district' governor installations serving a large number of users within a geographical area and, for many larger users, at the users' premises.

Pressure-regulating installations will incorporate regulators, pressure-relief valves, slam-shut valves, etc. as necessary and as outlined above. They should comply with the requirements of the Institution of Gas Engineers recommendations:

TD/9: *Offtakes and Pressure-Regulating Installations for Inlet Pressures between 7 and 100 bar*
TD/10: *Pressure-Regulating Installations for Inlet Pressures between 75 mbar and 7 bar*

13.16.3.2 Pipework design criteria

1. Transmission pipelines operating at high pressures are always constructed of welded steel. Recommendations are contained in the Institution of Gas Engineers publication TD/1, *Steel Pipelines for High Pressure Gas Transmission.*
2. Distribution mains may be constructed of steel, ductile iron or polyethylene depending on operating pressure, etc. Recommendations are contained in the Institution of Gas Engineers publication TD/3, *Distribution Mains.*
3. Services may be constructed of steel, ductile iron or polyethylene depending on operating pressure, etc. Recommendations are given in the Institution of Gas Engineers publication TD/4, *Gas Services.*

Requirements for gas services are also covered by the Pipelines Safety Regulations 1996.

13.17 Emergency procedures

Emergency procedures will be called upon following any abnormal occurrence such as an explosion, fire, release of unburnt gas or production and release of toxic products of combustion. It is essential to carry out an emergency shutdown procedure in a safe way that prevents the hazard continuing.

13.17.1 Emergency control valve

It is a requirement of the Gas Safety (Installation and Use) Regulations that an emergency control valve is provided to which there is adequate access. In addition, it is stipulated that for large users such a valve must be employed for every separate self-contained unit where the gas service is of 50 mm or more and that a line diagram be provided to show their location. By means of such emergency control valves it is possible to safely isolate the gas supply to any building in the event of an emergency.

In addition to the use of such manual valves, automatically operated valves may be considered see 13.12.3.

See IGE UP/2.

13.17.2 Normal shutdown procedures

All gas-fired plant should be provided with operating instructions for shutting down as well as starting up. Such instructions will ensure that the correct sequence of operations is carried out to both avoid a hazard during the shutdown and to leave the plant in a safe condition. These procedures should also contain instructions for actions to be carried out in emergencies. Such actions may differ from the normal shutdown.

13.17.3 Instruction and training

It is essential that relevant staff receive adequate training for the start-up and shutdown of plant for which they are responsible. This will include emergency procedures.

13.18 Pipework

13.18.1 Design criteria

Gas pipework in a user's premises serves the function of transporting the gas from the meter to the point of use in a safe way and without incurring an avoidable pressure loss. For low-pressure installations the permitted pressure loss is only 1 mbar from the meter to the plant manual isolating valve at maximum flow rate. The pipework must be sized adequately to allow for this. Boosters are sometimes used to overcome pressure losses, but the use of a booster should never be considered a satisfactory substitute for correct design of pipe sizes. Where gas is available at higher pressures it may be permissible to tolerate pressure losses of more than 1 mbar.

Guidance on pipework in users' premises is given in the Institution of Gas Engineers publication Gas Installation Pipework Boosters and Compressors on Industrial and Commercial Premises (UP/2) Certain Institution of Gas Engineers publications are also of relevance, particularly:

TD/3, *Distribution Mains*
TD/4, *Gas Services*

13.18.2 Materials

Materials used for gas pipework will depend on application, location, environment and operating pressure. General guidelines are as below.

13.18.2.1 Polyethylene

This is to be used only for buried pipework, as it is adversely affected by ultraviolet radiation and its use inside buildings is prohibited by the Gas Safety (Installation and Use) Regulations. PE pipe comes in two main grades and these have various pressure capabilities according to size.

13.18.2.2 Copper

Copper may be used above ground and for buried pipework at pressures up to 75 mbar and outside diameters of 67 mm. If utilized for buried pipework it must be factory sheathed and should not be attached to buried steel pipe and fittings.

13.18.2.3 Ductile iron

This may be used for buried pipework, in ducts and above ground at pressures up to 2 bar. Not to be used for plant pipework. Ductile iron is rarely used with the increasing availability of PE.

13.18.2.4 Steel

Steel may be used in all applications. The working pressure is related to the specification and grade used. However, pipe to BS 1387 heavy (up to 150 mm) and to BS 3601 (150 mm and above) is suitable for applications up to 7 bar.

13.18.3 Jointing

The method of jointing will depend on the material, the pipe size, the operating pressure and the location. General guidelines are given below.

13.18.3.1 Fusion welding

This method to be used for polyethylene pipes only by companies and persons specializing in this field.

13.18.3.2 Capillary joints

These can be used for copper in all applications and must be to BS 864, Part 2, or BS 2051, Part 1. In ducts all such joints must be accessible within the duct or chase. Not to be used within vertical ducts in high-rise buildings.

13.18.3.3 Compression joints

These can be used for copper in all applications where the joints are accessible and are not therefore recommended for underground use. In ducts all such joints must be accessible within the duct or chase. Not to be used within vertical ducts in high-rise buildings.

For polyethylene pipe compression couplings may be used provided they comply with BS 5114.

13.18.3.4 Screwed and welded jointing for steel pipework

The type of jointing may be restricted by the grade of pipe used. For example, some grades of steel pipe are not suitable for the application of screwed threads to BS 21 or ISO R7. UP/2 gives guidance on the jointing methods according to pressure and location. In buildings it is acceptable to screw joints up to 100 mm although normal good practice is to weld above 50 mm. Other points to consider include:

1. Where pipework is welded, the number of flanged joints should be kept to a minimum and such flanges shall be welded to the pipe.
2. Where pipework is welded, the minimum standard shall be: up to 2 bar: BS 2971 or BS 2640; above 2 bar

up to 5 bar: BS 2971 with 10% of welds subjected to non-destructive testing, or BS 2640 with inspection and 10% of welds subjected to non-destructive testing.
3. Jointing materials for screwed connections should comply with BS EN 751 or BS 5292. Note that there is a special grade of PTFE tape for coarse gas threads. Hemp should never be used with sealing pastes.

With screwed joints of 50 mm and above it is recognized that, in addition to a jointing paste, the use of hemp may be necessary to ensure a sound joint. However, hemp should never be used in conjunction with PTFE tape.

13.18.4 Pipes in ducts

1. It is not permissible to install an installation pipe in an unventilated shaft, void or duct (Regulation 18(5) of the Gas Safety (Installation and Use) Regulations).
2. Adequate ventilation is provided by means of openings at the top of high points and the bottom of low points. These openings shall have a free open area of 1/150 of the cross-section area of the duct or 0.05 m^2, whichever is the greater.
3. For ducts smaller than 0.05 m^2 the openings shall be not less than 3000 mm^2.
4. In exceptional circumstances if it is not possible to ventilate the duct then:
   (a) The pipe shall be continuously sleeved through the duct with the sleeve ventilated at one or both ends into a ventilated area; or
   (b) The unventilated duct or void shall be filled with a crushed inert infill to reduce to a minimum the volume of any gas which may accumulate. Suitable material is crushed slate chippings or dry washed sand, see BS 8313 Ducts for Building Services and UP/2.

13.18.5 Pipe supports

Pipe in whatever plane shall be adequately supported. Reference should be made to the relevant parts of BS 3974, Part 1. In some instances short vertical lengths in otherwise horizontal pipe runs may be self-supporting.

Pipe supports shall be provided throughout the length of the pipe and in such a way as to allow thermal movement without causing damage to any corrosion protection that may be on the pipe, see UP/2.

13.18.6 Corrosion protection and identification

Buried pipework must be protected against accidental and physical damage from sharp material, etc. and chemical action from corrosive soils, etc. It must be protected against corrosion by means of wrapping, cathodic protection, etc. for metal pipes. Above-ground pipework should be protected with suitable paint after preparation.

Pipework should be easily identifiable in accordance with BS 1710. Where the normal pressure in the pipe exceeds 75 mbar consideration should be given to labelling the pipe with the normal operating pressure. In buildings in which there are no other piped flammable gas supplies it is sufficient to paint the pipe yellow ochre or to band it with appropriately coloured adhesive tape. In large complex installations it is desirable to identify pipe contents more precisely, and in those instances the base colour should be supplemented with a secondary code band of yellow and/or its name or chemical symbol, see UP/2.

13.18.7 Flexible connections and tubes

In all instances where it is known or expected that pipework will be subjected to vibration, expansion or strain the use of flexible connections should be considered. Flexibles are essential either side of gas boosters to prevent catastrophic failure caused by plant movement.

Attention is drawn of the Gas Safety (Installation and Use) Regulations, which prohibits the use of non-metallic materials for gas pipework other than for small portable appliances such as bunsen burners and lighting torches, see UP/2.

13.18.7.1 Types of flexible connections

Various types of flexible connections are available for different purposes. Careful consideration is needed for suitability for purpose. General comments on connections available can be made. All connections should:

1. Be readily available for inspection;
2. Be kept to the minimum length;
3. Be protected from mechanical damage and the effects of the environment;
4. Not pass through walls, etc.

Semi-rigid couplings and flange adaptors Restraints are needed to prevent separation of the pipes when installed above ground and to prevent angularity.

Bellows The pipework either side of a bellows joint shall be supported so that the bellows itself is not supporting any of the weight of the attached pipework.

Swivel joints The axis of rotation of the swivel must be accurately aligned on both sides of the joint and the joint should have lateral freedom and be free from side bending moments.

Quick-release couplings The coupling shall be of the type having self-sealing valves in both the plug and the body with a flexible tube fitted to the downstream connection which shall be the male plug section. A manual valve shall be fitted immediately upstream of the coupling.

Flexible tubes Metallic tubes complying with BS 669, Part 2 or BS 6501 shall be used other than with small portable appliances or with domestic-type appliances, in which case they shall comply with BS 669 Part 1. A manual valve shall be fitted on the inlet side in close proximity to the tube. The pipework shall be adequately supported such that the tube does not support the weight of the attached pipework Tubes shall be installed so that they are neither twisted nor subjected to torsional strain, have flexing in one plane only, and are not subject to sharp bends near end fittings.

13.18.8 Purge points

Purge points shall be fitted at section isolation valves, at the end of pipe runs and at other suitable positions to facilitate the correct purging of pipes. Pressure test points should be fitted at the outlet of each section-isolating valve.

13.18.9 Syphons and condensate traps

These are not normally required. Where wet gas is supplied it will be necessary to fit a vessel at low points in the installation to collect any condensate or fluid. This vessel shall be in a readily accessible position and a valve, suitably plugged or capped, shall be fitted to its drain connection. In the exceptional case where hydraulic pressure testing is to be carried out, similar provisions must be made.

13.18.10 Commissioning

After pipework has been installed it is essential that it be tested for soundness and purged, as required by the Gas Safety (Installation and Use) Regulations. Detailed procedures for these two operations are given in the IGE publication IGE UP/1 or UP/1A Testing of Industrial and Commercial Gas Installations.

13.19 Flow charts for use with gas

13.19.1 Need for flow charts

It is essential when designing the pipe layout for gas distribution that unavoidable pressure losses are not incurred. For low-pressure gas the pressure available at the meter inlet will be only 21 mbar, and the allowable pressure loss to the point of use only 1 mbar, although higher pressures may be available in some circumstances. If such a low-pressure loss is not to be exceeded it is essential that the pipework be sized correctly. It is preferable to oversize pipework rather than undersize, particularly as this allows scope for future expansion. For routine purposes, the use of flow charts or rotary calculations is much to be preferred to formulae based on first principles.

13.19.2 Theory of pressure loss

The theory of pressure losses can be established by developing Bernoulli's theorem for the case of a pipe in which the work done in overcoming frictional losses is derived from the pressure available. For a fluid flowing in a pipe the pressure loss will depend on various parameters. If

L = length of pipe,
D = diameter of pipe,
S = specific gravity of gas,
Q = flow rate of gas,
f = friction factor,
P = pressure loss

then P is proportional to L
$1/D^5$
S
Q^2
f

For a particular material of pipeline construction the friction factor can be assumed. This allows a fairly simple formula to be derived:

$$P = kQ^2SL/D^5$$

where k is a constant taking into account the friction factor, units of length, units of pressure, etc. This is the Pole equation, and is frequently expressed in the form:

$$Q = k\sqrt{(PD^5/SL)}$$

Forms of this equation have been drawn up for use with different units (SI or Imperial). Typical assumptions are:

1. Flow is fully turbulent with $Re > 3500$ (the transition from laminar flow starts at about $Re = 2000$);
2. Viscosity is known and allowed for in k;
3. Pressure is <25 mbar;
4. If SG is known this can be incorporated into k;
5. Pipe is assumed to be to BS 1387. This determines f, which can be incorporated into k.

For uniform circular pipe the Fanning equation can be used:

$$P = (4fL/D)U^2/2g$$

where U = linear velocity,
g = gravitational constant.

The Fanning Friction factor (f in the above equation) varies with Reynolds number and relative roughness of the internal surface of the pipe. This variation is plotted in the Moody diagram.

The relative roughness is expressed as E/D, where E = the surface roughness and D = the internal pipe diameter. Typical values of E/D are 0.0015 for drawn tubing, 0.046 for commercial steel and 0.12 for asphalted cast iron.

13.19.3 Practical methods of sizing pipework

The use of formulae derived from first principles is time consuming and cannot normally be justified in comparison with approximate methods, which have a sufficient degree of accuracy. It is necessary to know:

1. Flow rate;
2. Pressure loss;
3. Pipe diameter;
4. Pipe length;
5. Pipe material (if this is not known, an assumption that it is steel will normally be sufficiently accurate).

Using these parameters, there are three main ways of expressing the relationships between them:

Table 13.3 Gas flow through pipes and fittings

Flow in a straight horizontal steel pipe (to BS 1387, Table 2, Medium) with 1.0 mbar differential pressure between the ends, for gas of relative density 0.6 (air = 1)

Nominal size mm (in)	*Length of pipe (m)*									
	3	*6*	*9*	*12*	*15*	*20*	*25*	*30*	*40*	*50*
	Discharge (m^3/h)									
6 ($\frac{1}{8}$)	0.29	0.14	0.09	0.07	0.05	–	–	–	–	–
8 ($\frac{1}{4}$)	0.80	0.53	0.49	0.36	0.29	0.22	0.17	0.14	0.11	0.08
10 ($\frac{3}{8}$)	2.1	1.4	1.1	0.93	0.81	0.70	0.69	0.57	0.43	0.34
15 ($\frac{1}{2}$)	4.3	2.9	2.3	2.0	1.7	1.5	1.4	1.3	1.2	1.0
20 ($\frac{3}{4}$)	9.7	6.6	5.3	4.5	3.9	3.3	2.9	2.6	2.2	1.9
25 (1)	18	12	10	8.5	7.5	6.3	5.6	5.0	4.3	3.7
32 (1 $\frac{1}{4}$)	39	27	21	18	16	14	12	11	9.2	8.1
40 (1 $\frac{1}{2}$)	59	40	32	27	24	21	18	16	14	12
50 (2)	110	76	61	52	46	39	34	31	26	23
65 (2 $\frac{1}{2}$)	220	150	120	100	92	79	70	63	54	47
80 (3)	340	230	190	160	140	120	110	97	83	73
100 (4)	690	470	380	330	290	250	220	200	170	150

Flow in a straight horizontal copper tube (to BS 2871, Part 1, Table X) with 1.0 mbar differential pressure between the ends, for gas of relative density 0.6 (air = 1). Tube sizes given below are outside diameters

Nominal size mm (in)	*Length of pipe (m)*									
	3	*6*	*9*	*12*	*15*	*20*	*25*	*30*	*40*	*50*
	Discharge (m^3/h)									
6	0.12	0.06	–	–	–	–	–	–	–	–
8	0.52	0.26	0.17	0.13	0.10	0.02	0.06	0.05	–	–
12	1.5	1.0	0.85	0.82	0.69	0.52	0.41	0.34	0.26	0.20
15	2.9	1.9	1.5	1.3	1.1	0.95	0.92	0.88	0.66	0.52
22	8.7	5.8	4.6	3.9	3.4	2.9	2.5	2.3	1.9	1.7
28	18	12	9.4	8.0	7.0	5.9	5.2	4.7	3.9	3.5
35	32	22	17	15	13	11	9.5	8.5	7.2	6.3
42	54	37	29	25	22	18	16	15	12	11
54	110	75	60	51	45	38	33	30	26	23
76	280	190	150	130	120	98	86	78	66	58
108	750	510	410	350	310	260	230	210	180	160

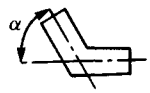
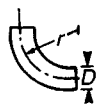
Note: 1 m^3/h = 1000 dm^3/h. For smaller rates of flow it may be more convenient to use dm^3/h.

The effects of elbows, tees or bends inserted in a run of pipe (expressed as the approximate additional lengths to be allowed)

Nominal size				
Cast iron or mild steel	Up to 25 mm (1 in)	32 mm to 40 mm (1 $\frac{1}{4}$ in to 1 $\frac{1}{2}$ in)	50 mm (2 in)	80 mm (3 in)
Stainless steel or copper	Up to 28 mm (1 in)	35 mm to 42 mm (1 $\frac{1}{4}$ in to 1 $\frac{1}{2}$ in)	54 mm (2 in)	76 mm (3 in)
Elbows	0.5 m (2 ft)	1.0 m (3 ft)	1.5 m (5 ft)	2.5 m (8 ft)
Tees	0.5 m (2 ft)	1.0 m (3 ft)	1.5 m (5 ft)	2.5 m (8 ft)
90° bends	0.3 m (1 ft)	0.3 m (1 ft)	0.5 m (2 ft)	1.0 m (3 ft)

1. A tabulated form as in Table 13.3. This shows flows versus pipe length and diameter for both copper and steel. Such tables are included in IGE UP/2 and British Standard BS 6891. Note that Table 13.3 includes allowances for elbows, tees and bends. Allowances, equivalent to numbers of pipe diameters, must be made for all pipe fittings which cause an additional pressure loss. Further details for allowances to be made for pipe fittings, including valves and non-return valves, are given in Table 13.4.
2. Flow calculators are available with scales for steel, copper and PE pipes.

Table 13.4 Allowances for fittings and entrance and exit losses in pipes

Fitting		*S Additional velocity heads*	*Additional length pipe diameters $f = 0.025$*
Elbows of various angles 	$\alpha = 90°$	1.0	40
	60	0.36	14
	45	0.18	7
	30	0.07	3
	15	0.02	1
90° bends 	$r/D = 0.5$	1.0	40
	1.0	0.6	24
	2.0	0.4	16
	4.1	0.3	12
Standard tee 90°, equal areas:			
From barrel to branch		1.2	48
From branch to barrel		1.5	60
Through barrel (third leg stagnant in each case)		0.25	10
Close return bend, 180°	$r/D = 1.0$	2.0	80
Globe valve, full open		10	400
Angle valve, 45° open		5	200
Flap non-return valve		2	80
Gate valve, full open		0.15	6
$\frac{3}{4}$ open by area		0.8	32
$\frac{1}{2}$ open by area		4.5	180
$\frac{1}{4}$ open by area		28	1120
Square entrance from a tank		0.5	20
Bell mouth entrance from a tank		0.05	2
Re-entrant (Borda) mouthpiece		0.8	32
Pipe discharge into a tank		1.0	40

The parameters of pipe bore, flow, length of pipe, and specific gravity can be used to determine pressure loss. The calculators are versatile in that they can be used for pressure losses of under 1 mbar and also for up to 50 bar. Scales for both cast iron and steel pipe are available for greater accuracy.

13.19.4 Discharge through orifices

The Bernoulli theorem can be used as the basis for a means of determining the flow through an orifice. The equation will be of the form:

$$Q = kC_d D^2 \sqrt{\frac{P}{S}}$$

where

C_d = coefficient of discharge,

D = diameter of the orifice

This equation can be used for an orifice plate introduced into pipework as a measuring, throttling or balancing device, and for a jet discharging gas into the injector of a burner at atmospheric or sub-atmospheric pressure.

The major unknown is the value of the coefficient of discharge. In the case of the orifice plate this will be of the order of 0.6. With the jet this may be as low as 0.6 but can be up to 0.9 for jets with profiled entries.

Tables are available for discharges from jets for different diameters and pressures, both on a general basis and for proprietary jets.

13.20 Conversion factors

SI units are widely used in the gas industry. Imperial units are also employed, particularly for measuring gas and for its calorific value. In some areas SI and Imperial units can co-exist, particularly thermal ratings, which can equally be expressed in kW and MW or in Btu/h and therm/h.

American combustion equipment is frequently used. This tends to use Imperial units as well as degrees Fahrenheit and ounces per square inch pressure.

European combustion equipment utilizes metric units but these are frequently non-SI. For example, heat and power ratings often use calories and kilocalories/h instead of joules and watts.

It is not intended to include a comprehensive set of conversion factors, but rather those which are frequently to be found in the energy industries.

Pressure

Non-SI unit	*Conversion factor to N/m^2*
bar	100 000
inch of Hg	3386.39
inch of water	249.089
Pascal	1
millibar	100

pound-force/in^2 (psi)	6894.76
ton-force/in^2	15 444.3
torr	133.322
ounce-force/in^2	430.922 5

Linear

Non-SI unit	*Conversion factor*
foot	0.3048 m
inch	25.4 mm
yard	0.9144 m
mile	1.60934 km

Volume and capacity

Non-SI unit	*Conversion factor*
cubic foot	0.028 3168 m^3
gallon	4.54 609 dm^3
gallon (US)	3.785 41 dm^3

Heat and energy

Non-SI unit	*Conversion factor*
British thermal unit	1.05506 kJ
calorie	4.1868 J
therm	105.506 MJ
thermie	4.1855 MJ

Power

Non-SI unit	*Conversion factor*
Btu/h	0.293 071 W
therm/h	29.307 1 kW
kilocalorie/h	1.163 W
horse power	745.700 W
ton of refrigeration	3516.85 W
frigorie	1.162 6 W
cal/s	4.186 8 W

Calorific value

Non-SI unit	*Conversion factor*
Btu/ft^3	37.258 9 kJ/m^3
Btu/lb	2326 J/kg
therm/gal	23.208 GJ/m^3

Temperature

Non-SI unit	*Conversion factor*
degree Fahrenheit	$(T - 32)5/9$°C
degree Rankine	5/9 K
degree Celsius	$(T + 273.15)$K

Thermal conductivity

Non-SI unit	*Conversion factor*
Btu in/ft^{2}h°F	0.144 228 W/mK
Btu in/ft^{2}s°F	519.220 W/mK
Btu/ft^{2}h	3.154 59 W/m^2
Btu/ft^{2}h°F	5.678 26 W/m^{2}K
Btu ft/ft^{2}h°F	1.730 73 W/mK

Thermal resistivity

Non-SI unit	*Conversion factor*
ft^{2}h°F/Btu in	6.933 47 m K/W
ft^{2}h°F/Btu ft	0.577 89 m K/W

14 Liquefied petroleum gas

R H Shipman MBE, MIMechE, MIGasE, MInstE
Liquefied Petroleum Gas Association

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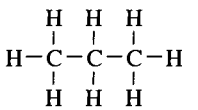
14.1 Introduction

Liquefied petroleum gases (often referred to as LPG or LPGas) are a constituent of crude oil or the condensate of natural gas fields (NGL). They are the C_3 and C_4 hydrocarbons, propane and butane, respectively, which have the property of being gases at normal ambient temperature but can be liquefied and kept in the liquid state by quite moderate pressure. Gases released from crude oil are called 'associated gases' while those found without heavier hydrocarbons are known as 'unassociated gases'. The North Sea gas wells are good examples of the latter.

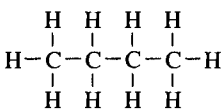
Methane is the major constituent of both associated and unassociated gas at source. There will be higher (heavier) hydrocarbons in varying amounts present in the gas, associated gas having more than unassociated gas.

When crude oil is refined some of the processes yield additional gaseous products. The C_3 and C_4 constituents differ from those released from crude oil or from NGLs, which are 'saturated' hydrocarbons. Refinery gases are high in 'unsaturates', e.g. propene (propylene) and butene (butylene). These unsaturated hydrocarbons are a valuable source of chemical process intermediates and enjoy a large market alongside naphtha.

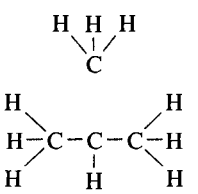
The major constituents of LPG can be shown by the following molecular diagrams:



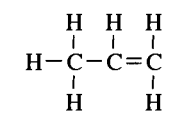
C_3H_8 Propane — Saturated



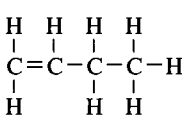
C_4H_{10} Butane — Saturated



C_4H_{10} ISO Butane — Saturated



C_3H_6 Propene (Propylene) — Unsaturated



C_4H_8 Butene (Butylene) — Unsaturated

No doubt the most successful exploitation of the peculiar properties of LPG has been its use as a fuel gas. Originally used predominantly in refineries for process heating, its value as a fuel was first realized before the Second World War, when it was sold in small portable containers. From primarily domestic use this spread after the war to commercial and industrial utilization and the introduction of bulk storage on-site. In order to develop such a market it was necessary to refine the product to an agreed standard. Today, LPG sold into the UK commercial fuel gas market meets the British Standard BS 4250:1997. The Standard sets the limits of the constituents for commercial propane and commercial butane since they are always mixtures of C_3 and C_4 with one or the other predominating. Paragraphs 14.2 and 14.3 are derived from BS 4250 for illustration purposes but for full specification purposes the latest issue of the standard at the time needs to be consulted.

14.2 Composition

Commercial butane. This product shall consist of a hydrocarbon mixture containing predominantly butanes and/or butenes.

Commercial propane. This product shall consist of a hydrocarbon mixture containing predominantly propane and/or propene.

14.3 Requirements

14.3.1 General

When tested in accordance with the methods given in Table 14.1 the properties of the commercial butane and commercial propane shall be in accordance with the limiting requirements given in that table. For gauge vapour pressure either the direct measurements method described in BS 3324 or the calculation procedure described in Appendix C of this standard shall be used. The method described in BS 3324 is the referee method and shall be used in cases of dispute.

14.3.2 Water content

Commercial butane and commercial propane shall not contain free or suspended water on visual inspection. Additionally, for commercial propane, the content of dissolved water shall not be such as to cause failure when tested in accordance with the valve freeze method to BS EN ISO 13758.

Note: The addition of up to 0.125% (v/v) of methanol to commercial propane will normally ensure that it complies with the specified limit for water content.

14.3.3 Odour

When tested in accordance with the procedure described in Appendix B, the odour of the gas shall be distinctive and unpleasant, and the odour in a gas/air mixture shall be such that it is detectable down to a concentration of 20% of the concentration corresponding to the lower limit of flammability for the hydrocarbon mixture concerned.

Note: Odorants such as ethanediol, tetrahydrothiophene or dimethyl sulphide may be added so that the gas complies with the specified requirements for odour.

Table 14.1 Limiting requirements for commercial butane and commercial propane

Property	*Limit*		*Test method*
	Commercial butane	*Commercial propane*	
Gauge vapour pressure, at 40°C (measured or calculated) (kPa), max. (see D.1)	505	1550	BS EN ISO 4256 or annex A (see 5.1)
Total sulphur content (mg/kg), max.	200	200	BS EN 24260[a]
Mercaptan sulphur content (mg/kg), max.[b]	50	50	BS 2000: Part 272
Hydrogen sulphide content (mg/m^3), max. (see D.2)	0.75	0.75	Annex C
Ammonia content (mg/m^3 in the vapour phase), max.	2.3	2.3	Absorption tube[c]
Copper corrosion, 1 h at 40°C	Class I	Class I	BS EN ISO 6251
Tendency to freeze in valves	–	Pass	BS EN ISO 13758
Dienes content[d], mole percent, max.	0.5	0.5	BS EN 27941[e]
Ethylene content, mole percent, max.	–	1.0	BS 3156: Part 4[e]
Alkynes content, mole percent, max.	0.5	0.5	BS 3156: Part 4[e]
C_4 and higher hydrocarbons content, mole percent, max.	–	10.0	BS EN 27941[e]
C_5 and higher hydrocarbons content[f], mole percent, max.	2.0	2.0	BS 3156: Subsection 14.1.1
R number[g]	10 max.	10 max.	BS 2000: Part 317
O number	33 max.	33 max.	BS 2000: Part 317

[a] ASTM D 3246 [4] may be used, provided the total sulfur content is less than 100 mg/kg.
[b] The result, expressed in accordance with BS 2000: Part 272 as x mg/m^3, may be converted to y mg/kg by applying $y = 0.39x$ for commercial butane and $y = 0.51x$ for commercial propane.
[c] Absorption tubes for ammonia should be capable of detecting ammonia down to approximately 0.4 mg/m^3 (0.5 ppm). GASTEC 3L is a suitable tube. This test is sensitive to volatile amine compounds. These materials, like ammonia, are corrosive towards metals that may be used in LPG equipment. Therefore, a reading above the limit specified for ammonia should be regarded as failure to conform with this standard, even though the level of ammonia present may be below the specified limit.
[d] EC Directives 67/548/EEC [1] (substances) and 88/379/EEC [5] (preparations) classify commercial propane and commercial butane according to their hazardous properties. LPG containing more than 0.1%(*m*/*m*) of any substance classified as carcinogenic is also required to be classified as carcinogenic. Users of this standard should be aware of this requirement when making contractual arrangements, since commercial propane and commercial butane may contain the substance 1,3 butadiene which is classified as a Class II carcinogen.
[e] For components of commercial butane or commercial propane not described in BS EN 27941 or BS 3156: Part 4, gas chromatographic equipment such as that described in BS 5443 may be employed for the compositional measurement. Suitable columns should be used and various types are available commercially. The equipment should be calibrated with appropriate reference gas mixtures from a specialist supplier and the analyst should ensure that the equipment is capable of resolving satisfactorily components at the concentration limits required by this standard.
[f] For information on residue see the foreword.
[g] This test should be carried out prior to the addition of methanol since liquefied petroleum gases which contain alcohols may give erroneous results when tested by this method.
NOTE. Annex D provides some explanatory notes on properties and test methods.

Further guidance in BS4250 provides information on the concentrations required, and cautionary comments *on the exposure of personnel conducting odour tests.*

14.4 Typical properties of commercial LPG

Typical properties are shown in Table 14.2. These are important in setting the requirements for the storage, handling and use of LPG and require further elaboration.

14.4.1 Vapour pressure

This is one of the most important properties of LPG since it determines the pressure that will be exerted by the gas at ambient temperature, and therefore affects the requirements for handling and the design working pressures of storage vessels. It constitutes the main difference in physical characteristics between commercial propane and butane. The vapour pressure is the pressure at which a liquid and its vapour are in equilibrium at any given temperature. The boiling point of a liquid is, in fact, the temperature at which the vapour pressure is equal to the external ambient pressure.

Commercial propane and butane often contain substantial proportions of the corresponding unsaturated analogues and smaller amounts of near-related hydrocarbons, as well as these hydrocarbons themselves. Figure 14.1 shows vapour pressure/temperature curves for commercial propane and commercial butane. Due to its lower boiling point, higher rates of vaporization for substantial periods

Table 14.2 Properties of commercial propane and butane

	Propane	*Butane*
Relative density of liquid at 15°C (60°F)	0.50–0.51	0.57–0.58
Imperial gallons/ton at 60°F	439–448	385–393
Litre/tonne at 15°C	1965–2019	1723–1760
Relative density of gas compared with air at 15°C (60°F) and 1016 mbar (30 in Hg)	1.40–1.55	1.90–2.10
Volume of gas (ft^3) per lb of liquid at 60°C and 30 inHg	8.6–8.7	6.5–6.9
Volume of gas (litres) per kg of liquid at 15°C and 1016 mbar	537–543	406–431
Ratio of gas volume to liquid volume at 15°C (60°F) and 1016 mbar (30 inHg)	274	233
Boiling point at atmospheric pressure		
°C (approx.)	−45	−2
°F (approx.)	−49	28
Latent heat of vaporization (Btu/lb) at 60°F	154	160
Latent heat of vaporization (kJ/kg) at 15°C	358	372
Specific heat of liquid at 60°F (Btu/lb°F)	0.60	0.57
Specific heat of liquid at 15°C (kJ/kg°C)	2.512	2.386
Sulphur content, % weight	Negligible to 0.02	Negligible to 0.02
Limits of flammability (percentage of volume of gas in a gas-air mixture to form a combustible mixture)	Upper 10.0 Lower 2.2	Upper 9.0 Lower 1.8
Calorific values		
Gross		
Btu/s ft^3 dry	2500	3270
MJ/s m^3 dry	93.1	121.8
Btu/lb	21 500	21 200
MJ/kg	50.0	49.3
Net		
Btu/s ft^3 dry	2310	3030
MJ/s m^3 dry	86.1	112.9
Btu/lb	19 900	19 700
MJ/kg	46.3	45.8
Therm/ton (gross CV)	482	475
GJ/tonne	50.0	49.3
Air required for combustion		
ft^3 to burn 1 ft^3 of gas at STP	24	30
m^3 to burn 1 m^3 of gas at STP	24	30

are obtainable from propane than from butane, and at the same time appreciable pressures are maintained even at low ambient temperatures.

14.4.2 Gross calorific value

This is defined as the amount of heat liberated when unit volume (or unit mass) of the gas is burned at a standard temperature and pressure. It is usually expressed in terms of megajoules per cubic metre at 15°C and 1016 mbar, i.e. MJ/s m^3 dry or megajoules per kilogram. Typical calorific values of LPG and other gaseous fuels are shown in Table 14.3 and allow a comparison of their heating values to be made.

The great advantage of LPGs is that they are stored as a liquid. However, they are almost always used as a gas. One volume of liquid propane when released at STP gives about 274 volumes (233 for butane) of high calorific value fuel gas.

14.4.3 Sulphur content

Compared to most other widely available fuels, with the exception of natural gas, LPG has a very low sulphur content which is strictly controlled within tight specification limits. This makes LPG a particularly useful fuel where the products of combustion are intended to be released directly into living accommodation.

14.4.4 Relative density – liquid

The density of liquid butane and propane is about half that of water, and as such is much lower than other liquid fuels.

14.4.5 Relative density – vapour

This is the one major property where there is an important difference between LPG vapour and natural gas. Natural gas is lighter than air; propane and butane vapour are,

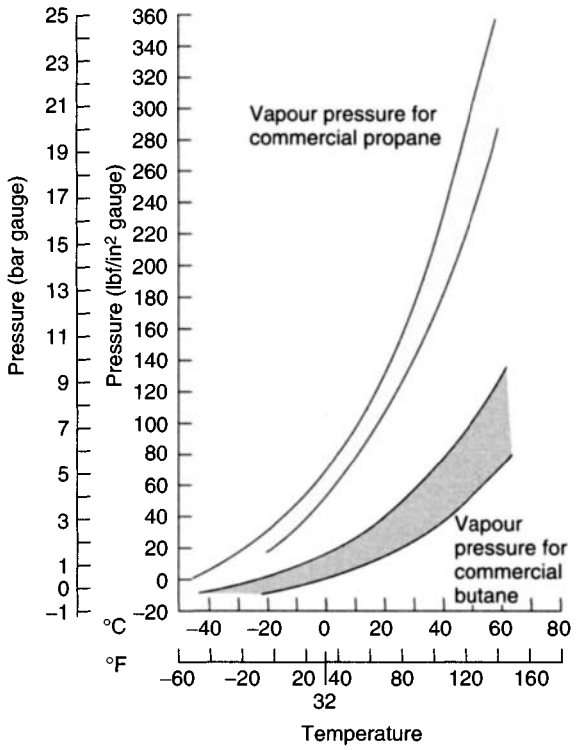


Figure 14.1 Vapour pressure/temperature curves for commercial propane and commercial butane

Table 14.3 Typical gross calorific values of fuel gases

Gas	*MJ/s m³ dry*	*Btu/s ft³ dry*	*MJ/kg*	*Btu/lb*
Commercial propane	93.1	2500	50.0	21 500
Commercial butane	121.8	3270	49.3	21 200
Producer gas (cold)	4.7–6.1	125–165	–	–
Town gas	14–20.5	375–550	–	–
Natural gas	31.6–46.6	850–1250	–	–
Acetylene	56	1500	49.9	21 460

respectively, one and a half times and twice as heavy as air. This is of importance in two areas. First, when converting equipment running on natural gas to run on propane or butane the amount of gas which issues from a fixed orifice at a fixed pressure is inversely proportional to the square root of its density. Second, if there is a leak of LPG vapour it will collect at ground level or in depressions, drains or cellars if appropriate precautions are not taken. This is a major safety consideration when designing or installing LPG systems.

14.4.6 Limits of flammability

When mixed with air, LPG can form a flammable mixture. The flammable range at ambient temperature and pressure extends between approximately 2% of the vapour in air at its lower limit and approximately 10% of the vapour in air at its upper limit. Outside this range any mixture is either too weak or too rich to propagate flame. However, over-rich mixtures resulting from accidental releases can become hazardous when diluted with air. At pressures greater than atmospheric, the upper limit of flammability is increased but the increase with pressure is not linear.

The limits of flammability for propane and butane are much narrower than most other gaseous fuels, making LPG safer in this respect.

14.4.7 Coefficient of expansion

This is defined as the increase in volume of unit volume of a substance when its temperature is raised by one degree. It is important in that the coefficient of expansion of LPG in its liquid form is relatively high, so that when filling a storage vessel adequate space must always be provided to allow for possible thermal expansion of the liquid.

14.4.8 Other physical characteristics

LPG is both colourless and odourless. However, a distinctive odour is added to aid detection of the vapour in the case of leakage. BS 4250 requires sufficient stench to be added so that the odour of the gas can be detected in air at concentrations down to one-fifth of the lower limit of flammability, i.e. about 0.4% gas in air.

Neither propane nor butane is toxic, but they do possess anaesthetic properties. There is a threshold limiting value for LPG at 1000 ppm given as an occupational exposure standard in the Health and Safety Executive Guidance Note EH40/00 X, for an 8-hour time-weighted average. This calls for consideration in particular by LPG cylinder-filling plant operators of the requirements of the COSHH Regulations (Control of Substances Hazardous to Health).

Liquid propane and butane will vaporize rapidly if released into the open air, and if they come into contact with bare skin will cause painful freeze burns. Therefore gloves and goggles should always be worn if there is a danger of liquid LPG being released or spilt.

14.5 Transport and storage

The great advantage of LPG is that for use it can be regarded as a gas but for conveyance it can be treated as a liquid. It is therefore transported by road or rail in a manner similar to liquid fuels. Thus the most usual method is by road tanker (up to 17 tonnes of product) or rail tank wagon (from 20 tonnes to 100 tonnes per wagon). Figure 14.2 shows a typical 15-tonne capacity propane road tanker. In order to maintain the product in its liquid state, however, it has to be kept under pressure and the tanks are therefore pressure vessels. This pressure must be maintained during all activities, from storage at the refinery, to transfer into the road tanker or rail tank wagon, and then in the storage vessel at the users' premises.

In addition to the modes of distribution described above there is also the transportable container which is now a familiar feature in all kinds of activity. These vary from tiny disposable cartridges of less than 100 g to the larger



Figure 14.2 LPG road tanker. (Courtesy of BP Oil Ltd)

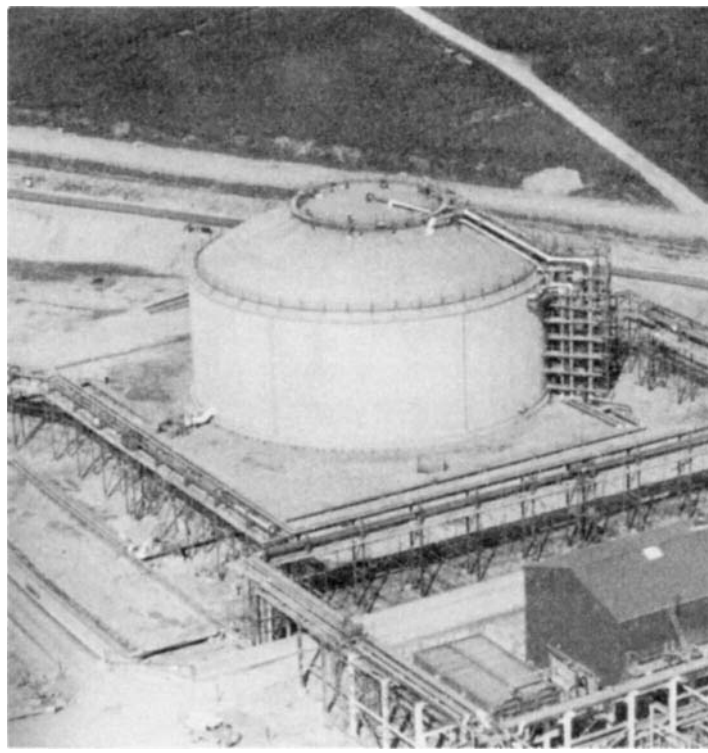


Figure 14.3 Refrigerated LPG storage at 'Flotta'. (Courtesy of the Motherwell Bridge Group)

refillable steel or aluminium alloy cylinders ranging up to around 50 kg of product. These are filled at purpose-designed filling plants and distributed by road or rail transport to the retail outlet.

At the other end of the scale there is also the transport and storage of LPG in a refrigerated state. Large international sea transport cargoes are usually refrigerated, while refrigerated land storage is only economically justified for storage measured in thousands of tonnes and for import/export terminals, as illustrated by Figure 14.3. For design, construction and installation of refrigerated storage, references are given to the Institute of Petroleum,

and the Engineering Equipment and Materials Users Association (EEUMA) at the end of this chapter.

Thus for most inland transport and storage the liquid is held at ambient temperature under pressure. The pressure is simply created by the natural vapour pressure of the product which varies with its temperature. Butane has a lower vapour pressure than propane. The carrying vessels, whether road tankers, static storage, cylinders or cartridges, must be designed to accept the highest pressure likely to occur in service. A knowledge of the highest ambient temperature and the grade of product is thus essential.

This illustrates the need for an agreed national standard for product specification which provides assurance of the highest pressure likely to be attained in service from a knowledge of ambient conditions. Against this knowledge, Codes of Practice can safely recommend the pressures which should be used for the design of storage vessels both for static use and for road/rail tankers. Guidance on the design parameters is given in the LPGA (UK) Code of Practice No. 1, Installation and Maintenance of Bulk LPG Storage at Consumer's Premises and Code of Practice No. 2, Safe Handling and Transport of LPG in Bulk by Road.

Storage vessels for LPG range from those for major industrial users and refineries of 1000 tonnes capacity or more down to small industrial or commercial users of 1 tonne. Even smaller vessels down to 380 litres designed for on-site refilling are used for domestic purposes, i.e. heating and cooking. Similar vessels are used for permanent caravan sites and holiday homes. Figures 14.4 and 14.5 illustrate a storage installation for industrial and domestic use, respectively.

Deliveries to these installations are usually by road tanker. The tanker carries is own off-loading pump driven by the vehicle engine and the transfer is by a flexible hose which is connected to the receiving vessel by a gas-tight coupling.

LPG storage vessels have to be designed as pressure vessels to a recognized standard. In the UK the currently

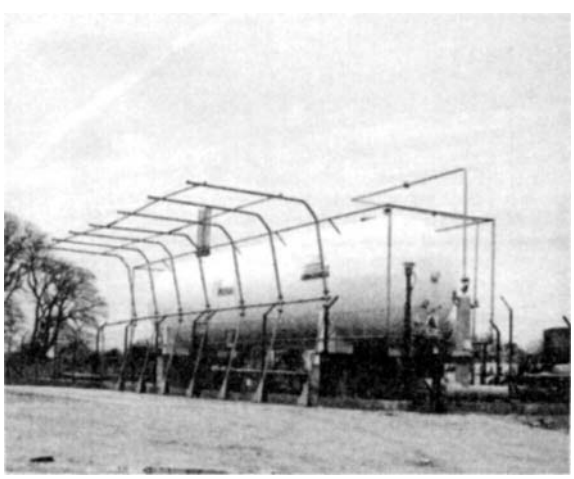


Figure 14.4 Typical industrial LPG storage installation. (Courtesy of Esso Petroleum Co. Ltd)



Figure 14.5 LPG storage vessel for a domestic installation. (Courtesy of the Calor Group Plc)

used standards are BS 5500 for static storage and BS 7122 for transport storage (i.e. for road tankers). The design limits for static storage are based on a maximum product temperature in service of 38°C, which gives a design pressure for propane of not less than 14.5 bar gauge. Those for transport storage are defined in BS 5355 which, for barrels greater than 5 m^3, sets a temperature of 42.5°C, giving a design pressure for propane of 16.75 bar gauge.

The Carriage of Dangerous Goods by Road Regulations 1996 has introduced requirements for new road tankers built after the 31st December 1996 as a result of the so-called ADR Directive enacted by the EU. (ADR refers to the ECE International rules for the transport of dangerous goods across Europe)

The design of carrying tanks will be specified in "Approved Tank Requirements" under these Regulations and come into force in 2001. They will supersede the design standards referred to above. A European standard will be published to take their place.

It is apparent from the vapour pressure curves that to obtain a gas supply from a storage vessel, or from a cylinder, it is only necessary to release it from the top vapour space. Propane can usually be supplied from storage to the plant by this natural vaporization, without any pumps or compressors, throughout the year in the UK.

The bulk storage of commercial butane for end-use has been confined to industrial heating processes. This has reduced considerably in the UK as a result of the spread of natural gas. Unlike commercial propane, the vapour pressure of commercial butane is usually too low to provide adequate continuous gas supply by natural vaporization and recourse is made to a liquid feed from the bottom of the storage vessel to a vaporizer. A vaporizer is simply a heat exchanger using hot water, steam, or even



Figure 14.6 Hot-water heated LPG vaporizers. (Courtesy of Esso Petroleum Co. Ltd)

direct flame as the source of heat. Figure 14.6 shows a typical vaporizer.

A glance at the vapour pressure curves will reveal that in winter there is a possibility that butane vapour in the pipeline after the vaporizer may re-liquefy if the temperature is allowed to fall even at relatively low pressures. For this reason such pipework is usually trace heated, either by electrical tapes or, if available by parallel steam or hot water pipes. An alternative is to lower the dew-point of the vapour by diluting it with air. Special air-gas mixers are available which will ensure that the pre-set ratio is maintained at all demand rates. The ratio must of course be well outside the flammable limits i.e. not enough air.

Another use for an LPG-air supply is to simulate the physical properties of another gas e.g. natural gas or manufactured town gas, using either propane or butane. Such a simulated gas will produce the same heat release through a burner if the supply pressure is the same. This is characterized by the term known as the Wobbe Number (W):

$$W = \frac{\text{Calorific value}}{\sqrt{\text{specific gravity of the gas(air} = 1)}}$$

The gas-air ratio is therefore chosen to achieve an equivalent Wobbe Number. However, the use of a simulated gas may not duplicate all the properties, for example flame speed and aeration requirements usually call for further adjustment to burners depending on the gas being simulated. Nevertheless LPG-air is in use to simulate natural gas in this manner for municipal supplies where natural gas is not available since natural gas appliances can be used with only minor adjustments as described.

The vast majority of gas user installations supplied from a bulk LPG storage vessel are for neat commercial propane. Cylinder supplies on the other hand may be either propane or butane depending on the end use.

The gas supply to most appliances is governed down to 28mbar for butane or 37mbar for propane whether it is supplied from a bulk storage vessel or from a cylinder. From cylinders a single regulator is employed. For bulk propane supplies two-stage regulation is normal with both regulators mounted on the storage vessel or with the second stage at the premises. For specialist processes the flexibility of LPG allows alternative pressures to be used.

An unusual but successful alternative system has been applied for some very large high energy consuming plants. This involves using liquid phase LPG right up to the burners.

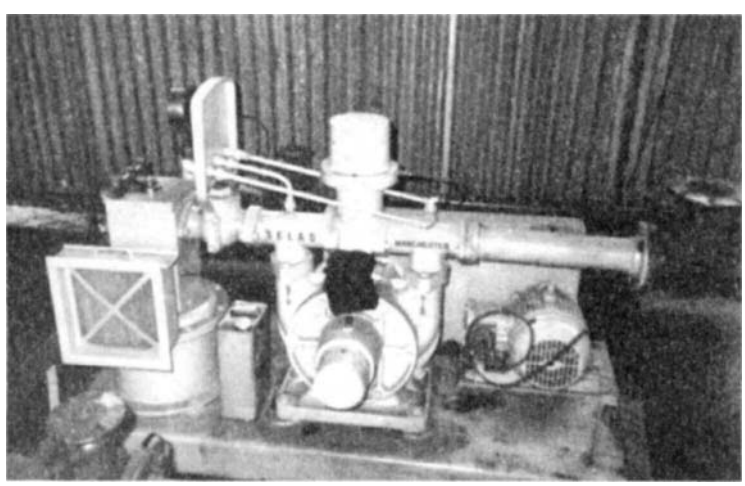


Figure 14.7 An LPG-air mixing unit. (Courtesy of John Wigfull & Co. Ltd)

14.6 Cylinder storage

The earliest market for LPG was developed by the use of small transportable cylinders filled at purpose-built filling plants and returned there for refilling. This market has grown steadily over its 50-year or more lifetime. Cylinders are available for either commercial propane or commercial butane, and in a variety of sizes from easily portable ones with a capacity of around 11 litres to the largest with a capacity of around 108 litres.

In parallel with the refillable cylinder market, the non-refillable cylinder has emerged to supply the needs of the leisure market and the DIY enthusiast, to name but two. These are broadly divided into those with a valve outlet and the pierceable cartridge. Both are designed to be disposed of when finally exhausted.

Both the refillable and non-refillable cylinders must, of course, be designed for the internal pressure conditions likely to be experienced during their lifetime. Welded steel cylinders in the UK are designed and made to BS 5045: Part 2 and for developed pressures specified in BS 5355. They are based upon a maximum liquid temperature of 55°C and the associated vapour pressure of 22.13 bar gauge for propane and 7.52 bar gauge for butane.

The Carriage of Dangerous Goods by Road, Classification Packaging and Labelling of Transportable Pressure Receptacles Regulations 1996 will amend the legal requirements for the design and national approval of LPG cylinders as a result of the EU ADR Directive and the Transportable Pressure Equipment Directive. Specific requirements will be issued for new cylinders for implementation in 2001 to align with ADR. These will also include periodic inspection and test. European standards for design (BSEN 1442) for Inspection at filling (BSEN 1439) and Periodic Inspection and test (BSEN 1440) have been published.

It is now common practice in the UK to design all refillable cylinders to propane standards. Furthermore, the use of safety relief valves has been introduced for all cylinders carrying over 3 kg of LPG.

The outlet valves of refillable butane cylinders are different from those of refillable propane cylinders. The valve for propane is a handwheel type, with a female 5/8 in BSP LEFT-HAND thread for a POL metal-to-metal connector. A compatible half-coupling must always be used to ensure a leak-free joint.

Butane cylinders, which are so widely used for domestic service, are now provided with a self-sealing clip-on valve. The pressure regulator, which is normally attached directly onto the cylinder outlet, is fitted by a simple push-on or snap-on action and is provided with a lever which will open or shut the cylinder valve.

There are a number of different clip-on valve designs used by LPG distributors and care is necessary to ensure that only the correct mating regulator is employed.

14.7 Safety in storage

Safe storage and handling of LPG is of paramount importance, whether it is in bulk or in cylinders. This is basically achieved by ensuring the mechanical integrity of the storage vessels or cylinders and by strict observance of the recommended separation distances between storage and buildings or boundaries. This passive protection has to be supplemented by rigorous observance of operational procedures. The Liquefied Petroleum Gas Association has issued a Code of Practice on bulk LPG storage at fixed installations in collaboration with and approval of the Health and Safety Executive. Part 1 deals with design, installation and operation of vessels above ground.

Perhaps the most serious hazard to LPG storage is that of accidental fire. The safety distances are intended to separate the storage from possible adjacent fires so that the risk of a fire affecting the storage is very low. However, this residual risk has to be catered for. The mechanical integrity needs to be assured under severe fire attack. For this reason, the vessels are provided with relief valves designed to cope with fire engulfment. The heat from such a fire may raise the stored pressure until the relief valve opens. The discharge capacity of the relief valve when fully open is required to meet or exceed the following:

$$Q = 10.6552A^{0.82}$$

where A is the total surface area of the vessel (m^3), and

Q is the discharge (m^3/min) of air reduced to 15°C and 1 atm.

The heat transfer to the liquid from an engulfment fire has been estimated at around 100 kW/m^2, and the above formula equates this to the vapour produced from this input as latent heat. The exponential is an area exposure factor which recognizes that large vessels are less likely to be completely exposed to flames.

The safety relief valve will protect the liquid-wetted areas of the storage vessel. The metal temperature will not significantly exceed the liquid temperature which will be absorbing the latent heat of vaporization. However, above the liquid line no such cooling will take place. The metal temperature at the top of the vessel could therefore exceed safe limits.

The usual protection for large installations is to provide a water-spray system. For small bulk storage, fire hoses or monitors are often adequate. However, for installations over 50 tonnes of storage (and all major cylinder-filling plants) it is accepted that a fixed water-spray system needs to be provided which is automatically initiated by a system capable of detecting a fire threatening the vessels and/or the adjacent tanker loading or unloading area. The deluge rate to provide protection against fire engulfment is 9.81/min/m^2 of vessel surface area, and this should be capable of being sustained for at least 60 min. The spray pattern adopted for a fixed installation normally includes four longitudinal spray bars, two at the upper quadrants and two at the lower quadrants of horizontal cylindrical vessels, with nozzles spaced to give uniform coverage.

An alternative means of avoiding the hazard from fire is to bury the vessels or to employ the increasingly popular method of mounding. In either case acknowledgment of the reduced hazard is indicated by the reduced separation distances (see Table 14.4). Since both burial or mounding

Table 14.4 Location and spacing for vessels

Maximum water capacity					*Minimum separation distances*					
Of any single vessel in a group			*Of all vessels in a group*		*Above-ground vessels*			*Buried or mounded vessels*		
Liters	*Gallons*	*Nominal LPG capacity (tonnes)*	*Liters*	*Gallons*	*From buildings boundary, property line or fixed source of ignition (a)*	*With firewall (b)*	*Between vessels (c)*	*From buildings, etc. to*		*Between vessels (f)*
								Valve assembly (d)	*Vessel (e)*	
					m (ft)	m	m	m	m	m
150–500	28–100	0.05–0.25	1 500	330	2.5 (8)	0.3	1	2.5	0.3	0.3
>500–2500	100–500	0.25–1.1	7 500	1 650	3 (10)	1.5	1	3	1	1.5
>2500–9000	500–2000	1.1–4	27 000	6 000	7.5 (25)	4	1	7.5	3	1.5
>9000–135 000	2000–30 000	4–60	450 000	100 000	15 (50)	7.5	1.5	7.5	3	1.5
>135 000–337 500	30 000–75 000	60–150	1 012 500	225 000	22.5 (75)	11	$\frac{1}{4}$ of sum of the dia. of two adjacent vessels	11	3	–
>337 500	>75 000	>150	2 250 000	500 000	30 (100)	15	–	15	3	–

preclude the possibility to monitor continuously the external condition of the vessels, very high-quality corrosion protection needs to be applied, normally supplemented by cathodic protection, depending on soil conditions. Guidance approved by the H.S.E. is published by the LPGA in their Code of Practice 1 part 4.

The use of burial or mounding is sometimes employed to overcome visual environmental objections since the mounding, for instance, can be grassed over. Indeed, this is the method often adopted to prevent erosion of the mounding material. A typical mounded storage is seen in Figure 14.8.

Codes of Practice also provide guidance on the storage of LPG in cylinders. Again, it is based on the adequate separation of stacks of cylinders from buildings and boundaries. These distances depend on the total tonnage stored or the tonnage in the largest stack in the storage area. The Codes also provide guidance on width of gangways, height of stacks and storage within buildings.

14.8 Uses of gaseous fuels

LPG has many advantages over the alternative liquid fuels, and is regarded as a 'premium fuel'. Some of the premium characteristics are:

Very low sulphur
Easy ignition

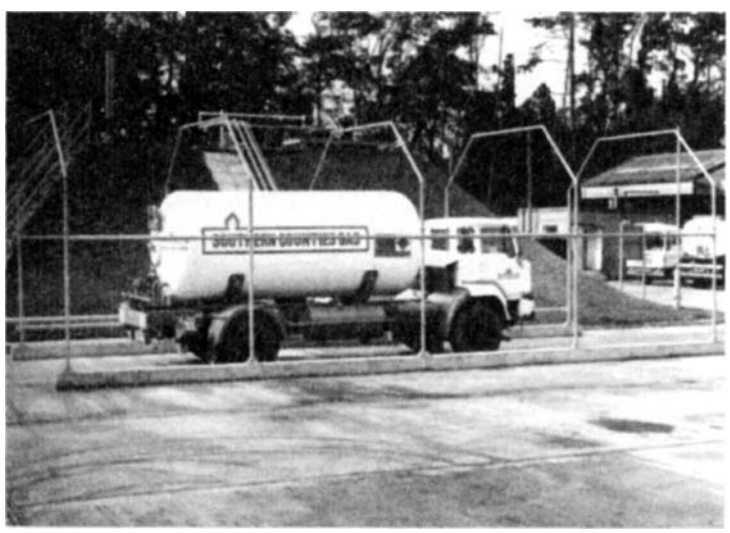


Figure 14.8 Mounded LPG storage. (Courtesy of Southern Counties Gas)

Simplicity of burner design
Versatility (e.g. very small flames, localized heating)
Wide turndown of burners
Clean combustion gases
Ease of control

These properties apply equally to natural gas as for LPG. However, since LPG can be used anywhere in the country which is accessible by road or rail it is not subject to the geographic limitations of a piped supply. The versatility of gaseous fuels has resulted in much development work in the design of burners for a wide range of applications. Some are highly specialized. Much of this development has been primarily for natural gas since its introduction to the UK in the late 1960s. The properties of LPG and natural gas are different, which means that LPG cannot be used in an appliance or burner designed for natural gas. However, a key property, flame speed, is of the same order, unlike the very high flame speed of coal gas. This similarity means that most natural gas appliances or burners can be adapted for use with LPG with minor modifications to allow for the much higher calorific value and higher gas density. Aeration needs attention, but for a given heat input rate the majority of gaseous fuels require approximately the same amount of air for combustion. Of course, appliances have been developed specifically for LPG particularly those for use with cylinder supplies where portability or mobility is essential. Apart from the wide variety of leisure and domestic uses there are the many temporary end uses for the engineering and construction industries e.g. site hut supplies, soldering, brazing and oxy-propane metal cutting and many more.

When drawing off LPG vapour from storage, whether from bulk storage, cylinders or even non-refillable cartridges, the liquid will begin to vaporize but will need latent heat to do so. It will take this heat from itself, and the container, and both will cool. As the LPG liquid cools its pressure must fall. Equilibrium will be obtained when the heat flow from the ambient air equals the demand for latent heat.

This, together with the natural variations of vapour pressure with climatic conditions, results in a source of gas with wide variations in supply pressure. Except for some small heating appliances which are designed to attach directly to a small cylinder, the pressure is much too high and the variation has to be eliminated as far as the appliance is concerned. Hence the need for pressure regulators as already described.

LPG cylinders are filled only at purpose-designed filling plants and (if refillable) are returned there when exhausted. To provide a continuous gas supply, two, four or more cylinders are connected to a changeover valve so that empty cylinders can be exchanged without interrupting the supply. Automatic changeover devices are available which switch to the reserve supply when necessary, and indicate that they have done so. A typical wall-mounted ACD is illustrated in Figure 14.9.

Codes of Practice restrict the use of LPG cylinders indoors for commercial and domestic use to commercial butane. Propane cylinders should always be located outside the premises except for special industrial purposes.

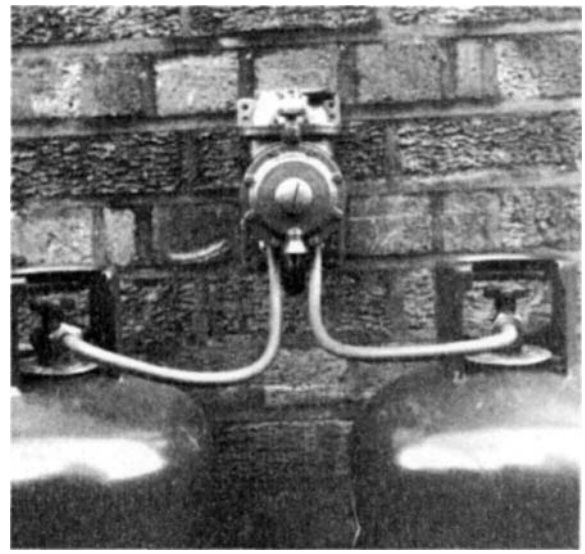


Figure 14.9 Wall-mounted automatic changeover device. (Courtesy of Sperryn & Co. Ltd)



Figure 14.10 A 2 × 2 LPG cylinder pack supply domestic premises. (Courtesy of the Calor Group Plc)

A typical four-cylinder pack is shown in Figure 14.10. LPGA Codes of Practice 24 parts 1 and 2 cover the use of LPG cylinders in residential premises.

The use of propane as a motor vehicle fuel has been highly developed in some overseas countries, particularly in the USA, Holland and Italy. It is, of course, entirely lead-free. It is now rapidly gaining popularity both for private and commercial use in the UK because of fuel tax incentives which make it economical as well as environmentally desirable. Very high efficiencies can be obtained in spark ignition engines particularly when the latest computer controlled fuel injection equipment is used and this results in considerable reductions in exhaust emissions of CO, CO_2 and hydrocarbons. The LPGA operates an approval scheme for companies specializing in vehicle conversions.

At this time there are insufficient re-fuelling locations for country-wide use although their numbers are growing fast. Therefore vehicles are usually dual-fuel, retaining their petrol system. Vehicle fleet owners, however, serving a restricted area can have an on-site bulk propane storage vessel installed complete with dispensing equipment. This is an attractive proposition for taxis, ambulances, local authority fleets, etc.

Since virtually any spark ignition engine can be supplied or converted to run on propane it can be considered for any engine driven machinery and is often supplied for portable or mobile electricity generators.

The low level of harmful exhaust emissions has, of course, been one of the spurs to the wide use of LPG as a forklift truck engine fuel in all countries because of their wide use inside buildings such as warehouses, railway station forecourts, etc. Another advantage is the high power continuously available compared with electric battery-driven equivalents. Similar arguments favour its use for other engine-driven workhorses such as mechanical sweepers, in large warehouses, railway stations, etc.

14.9 Safety and legislation

Safety in the storage, supply and use of LPG, as with all forms of energy supply, is of paramount importance. Safety for industrial plants is maximized by paying strict attention to plant design, system design, operational procedures, maintenance and periodical inspection procedures, and management control. The LPGA has produced a series of Codes of Practice, which provide the basis for safe storage, handling and use of LPG in the UK and which are recognized by the Health and Safety Executive. Those on bulk storage and cylinder storage now replace earlier guidance issued by the HSE following extensive review.

There are many statutory requirements which impose on the design, installation and operation of LPG plants some of which are increasingly being brought about by European Commission Directives. There is the need to comply with the general duties under the Health and Safety at Work Act of course but there are many other Regulations which will apply particularly to industrial plants. These are reflected in the LPGA Codes of Practice. Control is placed on the design and construction of storage vessels, on cylinders, on their national approval, and on their periodic inspection. For large storage sites holding 25 tonnes or more of LPG in cylinders or in bulk storage or in combination, the HSE have to be notified and there is a need to hold or to obtain Hazardous Substance Consent from the Local Authority. Between 50 and 200 tonnes of storage the Control of Major Accident Hazards Regulations usually referred to as COMAH require a "Major Accident Prevention Policy" (MAPP), to be drawn up. For storage of 200 tonnes and above these Regulations require a full Safety Report to be submitted to the HSE before construction and periodically updated after commissioning.

Since so many new Regulations are pending, engineers involved with the design or construction of plant involving LPG are well advised to seek guidance on the legal requirements from the relevant local authorities, the HSE, or technical bodies such as the LPGA. Apart from the changing legal duties it will also be found that relevant standards including those referred to in this chapter, will increasingly be replaced by European (EN) standards in the future.

14.10 British standards

BS 4250	Liquefied Petroleum Gas – Specification for commercial butane and propane.
BS 5500	Unfired fusion welded pressure vessels.
BS 7122	Welded steel tanks for the road transport of liquefiable gases. Will be superseded for new road tankers by BSEN 12493.
BSEN 12493	Design and manufacture of welded steel tanks for LPG road tankers.
BS 5355	Filling ratios and developed pressures for liquefiable and permanent gases.
BS 5045	Transportable gas containers Part 2: Steel containers up to 450 litres capacity with welded seams. Superseded for new cylinders by BSEN 1442
BSEN 1439	Transportable refillable welded steel cylinders for LPG. Procedure for checking before, during and after filling.
BSEN 1440	Transportable refillable welded steel cylinders for LPG. Periodic requalification.
BSEN 1442	Transportable refillable welded steel cylinders for LPG. Design and construction.
BSEN 417	Non-refillable metallic gas cartridges for LPG.

14.11 Codes of practice and guidance notes

14.11.1 Health and Safety Executive

Control of Major Accident Hazards 1999	HS(G)25
Major Accident Prevention Polices for the COMAH Regulations.	CS3
A Guide to The Control of Major Accident Hazards Regulations 1999	L.111
Carriage of Dangerous Goods by Road.	HS(G)160–164
Gas Safety (Installation and Use) Regulations 1994	L.64

14.11.2 Liquefied Petroleum Gas Association

Code of Practice 1	Bulk LPG storage at fixed installations:
	Part 1. Design and installation of vessels above ground.
	Part 2. Small bulk installations for domestic purposes.
	Part 3. Examination and inspection
	Part 4. Buried/mounded LPG storage vessels.

Code of Practice 2 Safe handling and transport of LPG in bulk in road tankers and tank containers.
Code of Practice 3 Prevention or control of fire involving LPG.
Code of Practice 4 Safe and satisfactory operation of thermoplastic and bitumen boiler, mastic asphalt cauldrons and mixers, hand tools and similar equipment.
Code of Practice 5 Withdrawn-see COP 11
Code of Practice 6 Injector jets. Withdrawn.
Code of Practice 7 Storage of full and empty LPG cylinders and cartridges.
Code of Practice 8 Withdrawn-see COP 1 Part4.
Code of Practice 9 LPG-Air plants
Code of Practice 10 Containers attached to mobile gas fired equipment.
Code of Practice 11 Autogas installations.
Code of Practice 12 Safe filling of LPG cylinders at depots.
Code of Practice 13 Not issued.
Code of Practice 14 Hoses for the transfer of LPG in bulk: Installation, inspection, testing and maintenance.
Code of Practice 15 Valves and Fittings for LPG service.
Part 1. Safety valves.
Part 2. Valves for transportable LPG cylinders.
Code of Practice 16 Not issued.
Code of Practice 17 Purging LPG vessels and systems.
Code of Practice 18 Safe use of LPG as a propulsion fuel for boats, yachts and other craft.
Code of Practice 19 Liquid measuring systems for LPG.
Code of Practice 20 Automotive LPG refuelling facilities.
Code of Practice 21 Guidance for caravan ventilation and flueing checks.
Code of Practice 22 LPG piping systems: Design and installation.
Code of Practice 23 Not issued.
Code of Practice 24 The use of LPG cylinders:
Part 1. The use of propane cylinders in residential premises.
Part 2. The use of Butane cylinders in residential premises.
Part 3. The use of LPG cylinders in mobile catering vehicles and similar vehicles.
Part 4. The use of LPG for catering and outdoor functions.
Part 5. The storage and use of LPG on construction sites.
Part 6. The use of propane in cylinders at commercial and industrial premises.
Code of Practice 25 LPG central storage and distribution systems for multiple consumers.
Code of Practice 26 Uplifting of bulk vessels from site and their carriage to and from site by road.
Code of Practice 27 The carriage of LPG cylinders by road.
Code of Practice 28 Not issued.
Code of Practice 29 The labelling requirements for commercial LPG cylinders.
Code of Practice 30 Gas installations for motive power on mechanical handling and maintenance equipment.

LPGA Guidance Notes

GN1. Withdrawn.
GN2. A guide to servicing LPG cabinet heaters.
GN3. A guide to the preparation of Major Accident Prevention Policies.
LPG Fundamentals.

LPGA Product Data

LPGA publications on sale from:
LPGA, Pavilion 16, Headlands Business Park, Salisbury Road, Ringwood, Hampshire, BH24 3PB
Tel. 01425 461612, Fax. 01425 471131
e-mail: lpga@btintnet.com
web page: www.lpga.co.uk

14.11.3 Institute of Petroleum

Model Code of Safe Practice Part 9. Large bulk pressure storage and refrigerated storage of LPG.

14.11.4 Engineering Equipment and Materials Users Association. (EEMUA)

Recommendations for the design and construction of refrigerated liquefied gas storage tanks.

15 Steam utilization

Paul Mayoh
Spirax Sarco Ltd

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15.1 Introduction

The use of steam provides an ideal way to deliver just the right amount of heat energy to a point of use, to help with product manufacture or to provide an acceptable environment. The story of steam efficiency begins at the boiler (which is discussed in Chapter 10) but it does not end until the energy carried by the steam is transferred appropriately and the resulting hot condensate is returned to the boiler. Control of steam is necessary throughout the plant if the performance designed into the system is to be achieved and maintained. However, the natural laws which steam obeys are few in number and are easy to understand. Following them allows efficiencies to be achieved which would be envied with most other energy-distribution systems.

Two of the laws of thermodynamics and two of the laws of motion will cover almost all needs. In the simplest terms, it can be said that:

1. Energy is not destructible. It can always be accounted for, and if it disappears at point A then it reappears in equal amount at point B. This ensures that the world is a consistent place, that energy does not mysteriously appear from or disappear to nowhere, and that the Steam Tables can be relied on always to provide information on the properties of steam.
2. Heat flows from higher-temperature to lower-temperature objects without any help. It follows that the rate of flow will vary directly with temperature differences, and inversely with any resistances to this flow. A temperature difference is necessary for heat to flow!
3. Any matter tends to move in the direction in which it is pushed, and, in particular, because of the effects of friction, any fluid will only flow from high-pressure to lower-pressure regions. Again, the rate of flow will vary directly with pressure differences, and inversely with any resistances to this flow.
4. Gravity acts downwards! The denser constituents in a mixture often tend to move to the bottom of a space, unless other forces acting on them oppose such motion.

If these basic laws can be accepted it is easy to build up an understanding of steam systems and the way that steam behaves. The ground rules for an effective (and efficient) steam system then quickly become apparent. Specific heats and weights for various solids, liquids, gases and vapours, as well as pipeline capacities, are shown in Tables 15.1–15.4.

15.2 What is steam?

The datum point, when considering the steam/water substance, is usually taken as water at the temperature of melting ice, at normal atmospheric pressure and so at a temperature of 0°C. Adding heat energy raises its temperature; some 419.04 kJ will raise 1 kg to 100°C, when any further addition of heat evaporates some of the water. If 2257 kJ are added to each kg of water, then all the water becomes the dry gas, steam. Equally, if only part of this extra energy is added – say, 90% – then 90% of the water evaporates and the other 10% remains liquid.

Table 15.1 Specific heats and weights of various solids

Material	*Relative Density*	*SHC kJ/kg Deg C*
Aluminium	2.55–2.8	0.92
Andalusite		0.71
Antimony		0.2
Apatite		0.83
Asbestos	2.1–2.8	0.83
Augite		0.79
Bakelite, wood filler	1.38	
Bakelite, asbestos filler		1.59
Barite	4.5	0.46
Barium	3.5	2.93
Basalt rock	2.7–3.2	0.83
Beryl		0.83
Bismuth	9.8	0.12
Borax	1.7–1.8	1
Boron	2.32	1.29
Cadmium	8.65	0.25
Calcite 0–37°C		0.79
Calcite 0–100°C		0.83
Calcium	4.58	0.62
Carbon	1.8–2.1	0.71
Carborundum		0.66
Cassiterite		0.37
Cement, dry		1.54
Cement, powder		0.83
Charcoal		1
Chalcopyrite		0.54
Chromium	7.1	0.5
Clay	1.8–2.6	0.92
Coal	0.64–0.93	1.08–1.54
Cobalt	8.9	0.46
Concrete, stone		0.79
Concrete, cinder		0.75
Copper	8.8–8.95	0.37
Corundum		0.41
Diamond	3.51	0.62
Dolomite rock	2.9	0.92
Fluorite		0.92
Fluorspar		0.87
Galena		0.2
Garnet		0.75
Glass, common	2.4–2.8	0.83
Glass, crystal	2.9–3.0	0.5
Glass, plate	2.45–2.72	0.5
Glass, wool		0.66
Gold	19.25–19.35	0.12
Granite	2.4–2.7	0.79
Haematite	5.2	0.66
Hornblende	3	0.83
Hypersthene		0.79
Ice, −79°C		1.46
Ice, −40°C		1.79
Ice, −20°C		1.96
Ice, 0°F		2.05
Iridium	21.78–22.42	0.12
Iron, cast	7.03–7.13	0.5
Iron, wrought	7.6–7.9	0.5
Labradorite		0.79
Lava		0.83
Lead	11.34	0.12
Limestone	2.1–2.86	0.92

(*continued overleaf*)

Table 15.1 *(continued)*

Material	*Relative Density*	*SHC kJ/kg Deg C*
Magnetite	3.2	0.66
Magnesium	1.74	1.04
Malachite		0.75
Manganese	7.42	0.46
Marble	2.6–2.86	0.79
Mercury	13.6	0.12
Mica		0.87
Molybdenum	10.2	0.25
Nickel	8.9	0.46
Oligloclose		0.87
Orthoclose		0.79
Plaster of Paris		4.77
Platinum	21.45	0.12
Porcelain		1.08
Potassium	0.86	0.54
Pyrexglass		0.83
Pyrolusite		0.66
Pyroxylin plastics		1.42–1.59
Quartz, 12.8–100°C	2.5–2.8	0.79
Quartz, 0°C		0.71
Rock salt		0.92
Rubber		2
Sandstone	2.0–2.6	0.92
Serpentine	2.7–2.8	1.08
Silk		1.38
Silver	10.4–10.6	0.25
Sodium	0.97	1.25
Steel	7.8	0.5
Stone		0.83
Stoneware		0.79
Talc	2.6–2.8	0.87
Tar	1.2	1.46
Tellurium	6.0–6.24	0.2
Tin	7.2–7.5	0.2
Tile, hollow		0.62
Titanium	4.5	0.58
Topaz		0.87
Tungsten	19.22	0.16
Vanadium	5.96	0.5
Vulcanite		1.38
Wood	0.35–0.99	1.33–2.0
Wool	1.32	1.38
Zinc blend	3.9–4.2	0.46
Zinc	6.9–7.2	0.37

Table 15.2 Specific heats and weights of various liquids

Liquid	*Relative Density*	*SHC kJ/kg°C*
Acetone	0.79	2.13
Alcohol, ethyl, 0°C	0.789	2.3
Alcohol, ethyl, 40°C	0.789	2.72
Alcohol,methyl, 4–10°C	0.796	2.46
Alcohol,methyl, 15–21°C	0.796	2.51
Ammonia 0°C	0.62	4.6
Ammonia 40°C		4.85
Ammonia 80°C		5.39
Ammonia 100°C		6.19
Ammonia 114°C		6.73
Anilin	1.02	2.17
Benzol		1.75
Calcium chloride	1.2	3.05
Castor oil		1.79
Citron oil		1.84
Diphenylamine	1.16	1.92
Ethyl ether		2.21
Ethylene Glycol		2.21
Fuel oil	0.96	1.67
Fuel oil	0.91	1.84
Fuel oil	0.86	1.88
Fuel oil	0.81	2.09
Gasoline		2.21
Glycerine	1.26	2.42
Kerosene		2
Mercury	19.6	1.38
Naphthalene	1.14	1.71
Nitrobenzole		1.5
Olive oil	0.91–0.94	1.96
Petroleum		2.13
Potassium hydrate	1.24	3.68
Sea water	1.0235	3.93
Sesame oil		1.63
Sodium chloride	1.19	3.3
Sodium hydrate	1.27	3.93
Soybean oil		1.96
Toluol	0.866	1.5
Turpentine	0.87	1.71
Water	1	4.18
Xylene	0.861–0.881	1.71

The specific volume of steam at atmospheric pressure is 1.673 m^3/kg, so the mixture of 90% steam and 10% water would occupy a volume of $(0.9 \times 1.673)\ m^3$ plus $(0.1 \times 0.001)\ m^3$. Clearly, almost all the volume of this 1 kg of steam and water is occupied by the steam, at 1.5057 m^3, and the mixture would be described as steam with a Dryness Fraction of 0.9.

If the water is kept at a pressure above atmospheric, its temperature can be raised above 100°C before boiling begins. At 10 bar gauge, for example, boiling point is at about 184.1°C. The extra energy needed to convert water at this pressure and temperature into steam (the enthalpy of evaporation) is now rather less at 2000.1 kJ/kg, while the volume of 1 kg of pure steam is only 0.177 m^3. These figures are all recorded in the Steam Tables at the end of this chapter.

When steam at the saturation temperature contacts a surface at a lower temperature, and heat flows to the cooler surface, some of the steam condenses to supply the energy. With a sufficient supply of steam moving into the volume which had been occupied by the steam now condensed, the pressure and temperature of the steam will remain constant. Of course, if the condensate flows to a zone where it is no longer in contact with the steam it can cool below steam temperature while supplying heat to a cooler surface.

Equally, if steam at the saturation temperature were to contact a surface at a higher temperature, as in some boilers, its temperature could be increased above the evaporating temperature and the steam would be described as superheated. Superheated steam is very desirable in turbines, where its use allows higher efficiencies to be reached, but it is much less satisfactory than saturated

Table 15.3 Gases and vapours

Gas or Vapour	*Specific heat capacity kJ/kg°C (constant pressure)*
Acetone	1.31
Air, dry, 10°C	0.71
Air, dry, 0–199°C	0.72
Air, dry, 20–440°C	0.74
Air, dry, 20–461°C	0.77
Air, dry, 20–798°C	0.78
Alcohol, $C_2 H_5 OH$	1.66
Alcohol, $CH_3 OH$	1.53
Ammonia	1.76
Argon	0.3
Benzene, $C_6 H_6$	0.98
Bromine	0.19
Carbon dioxide	0.62
Carbon monoxide	0.71
Carbon disulphide	0.55
Chlorine	3.43
Chloroform	0.54
Ether	1.95
Hydrochloric acid	0.56
Hydrogen	10
Hydrogen sulphide	0.79
Methane	1.86
Nitrogen	0.71
Nitric oxide	0.69
Nitrogen tetroxide	4.59
Nitrous oxide	0.69
Oxygen	0.65
Steam, 0.68 bar 49–315°C	1.46
Steam, 1 bar 104–315°C	1.5
10 bar 182–315°C	1.76
Sulphur dioxide	0.49

steam in heat exchangers. It behaves as a dry gas, giving up its heat content rather reluctantly as compared with saturated steam, which offers much higher heat transfer coefficients.

The condensate produced within the heat exchangers, as also within the steam lines, is initially at the saturation temperature and carries the same amount of energy as would boiler water at the same pressure. If it is discharged to a lower pressure, through a manual or automatic drain valve (steam trap) or even through a leak, it then contains more energy than water is able to hold at the lower pressure if it is to remain liquid. If the excess of energy amounted to, say, 5% of the enthalpy of evaporation at the lower pressure, then 5% of the water would be evaporated. The steam released by this drop in pressure experienced by high-temperature water is usually called flash steam. Recovery and use of this low-pressure steam, released by flashing, is one of the easiest ways of improving the efficiency of steam-utilization systems.

It is equally true that condensate, even if it has been released to atmospheric pressure, carries the same 419.04 kJ/kg of heat energy that any other water at the same temperature would hold. Allowing condensate to drain to waste, instead of returning it to the boiler feed tank or de-aerator, makes no economic sense. Condensate is a form of distilled water, requiring little chemical feed treatment or softening, and it already holds energy which may amount to 15% of the energy which would have to be supplied to cold make-up feedwater, even in relatively low-pressure systems. An installation which makes good use of both flash steam and condensate will see the benefits on the bottom line! To summarize:

1. Saturated steam provides a heat source at a temperature which is readily controlled, by the control of pressure;
2. It carries very large amounts of heat as enthalpy of evaporation or latent heat in relatively small weights of steam;
3. It supplies heat, by condensing, at a constant temperature and with high heat transfer coefficients, so it maximizes the effectiveness of heat exchangers;
4. Recovery and re-use of the condensate and its heat content is usually simple and effective.

15.2.1 The working pressure in the boiler and mains

Where steam is generated as a source of energy for turbines or engines the boiler pressure is usually high and often the steam is superheated. Steam for process use or for heating may then be supplied through pressure-reducing valves or be available at pass-out pressures from the engine or at the exhaust pressure. In other cases where steam is wanted for process or heating use only, use of a packaged boiler, or sometimes a single-pass watertube steam generator is almost universal. The most suitable operating pressure for the boiler has then to be decided. It should be said that steam of the best quality is provided by boilers operating at or close to their designed working pressure. When the steam is to be used at a lower pressure, then pressure-reducing valves or other control valves may be utilized, close to the steam-using points.

The reason for this becomes clear when the specific volume of steam at varying pressures is noted from the steam tables and Figure 15.1 is considered. This shows a boiler operating at either high or lower pressure while producing the same weight of steam from the same energy input. Energy flows through the outer surface of the tubes into the boiler water, and when this water is at saturation temperature any addition of energy means the formation of steam bubbles. These bubbles rise to the surface and break, releasing steam into the steam space.

The volume of a given weight of steam contained in these bubbles is inversely related to the pressure at which the boiler operates. If this pressure is lower than the design pressure, the volume in the bubbles is increased. This raises the apparent water level in the boiler, reducing the volume of the steam space. The greater volume of the bubbles enlarges the turbulence at the surface, and as the bubbles burst, splashing of droplets into the steam space increases. The larger volume of steam, flowing towards the boiler crown valve through the reduced steam

Table 15.4 Pipeline capacities at specific velocities (metric SI units)

Pressure (bar)	*Velocity (m/s)*	*kg/h*										
		15 mm	*20 mm*	*25 mm*	*32 mm*	*40 mm*	*50 mm*	*65 mm*	*80 mm*	*100 mm*	*125 mm*	*150 mm*
0.4	15	7	14	24	37	52	99	145	213	394	648	917
	25	10	25	40	62	92	162	265	384	675	972	1457
	40	17	35	64	102	142	265	403	576	1037	1670	2303
0.7	15	7	16	25	40	59	109	166	250	431	680	1006
	25	12	25	45	72	100	182	287	430	716	1145	1575
	40	18	37	68	106	167	298	428	630	1108	1712	2417
1.0	15	8	17	29	43	65	112	182	260	470	694	1020
	25	12	26	48	72	100	193	300	445	730	1160	1660
	40	19	39	71	112	172	311	465	640	1150	1800	2500
2.0	15	12	25	45	70	100	182	280	410	715	1125	1580
	25	19	43	70	112	162	295	428	656	1215	1755	2520
	40	30	64	115	178	275	475	745	1010	1895	2925	4175
3.0	15	16	37	60	93	127	245	385	535	925	1505	2040
	25	26	56	100	152	225	425	632	910	1580	2480	3440
	40	41	87	157	250	357	595	1025	1460	2540	4050	5940
4.0	15	19	42	70	108	156	281	432	635	1166	1685	2460
	25	30	63	115	180	270	450	742	1080	1980	2925	4225
	40	49	116	197	295	456	796	1247	1825	3120	4940	7050
5.0	15	22	49	87	128	187	352	526	770	1295	2105	2835
	25	36	81	135	211	308	548	885	1265	2110	3540	5150
	40	59	131	225	338	495	855	1350	1890	3510	5400	7870
6.0	15	26	59	105	153	225	425	632	925	1555	2525	3400
	25	43	97	162	253	370	658	1065	1520	2530	4250	6175
	40	71	157	270	405	595	1025	1620	2270	4210	6475	9445
7.0	15	29	63	110	165	260	445	705	952	1815	2765	3990
	25	49	114	190	288	450	785	1205	1750	3025	4815	6900
	40	76	177	303	455	690	1210	1865	2520	4585	7560	10880
8.0	15	32	70	126	190	285	475	800	1125	1990	3025	4540
	25	54	122	205	320	465	810	1260	1870	3240	5220	7120
	40	84	192	327	510	730	1370	2065	3120	5135	8395	12470
10.0	15	41	95	155	250	372	626	1012	1465	2495	3995	5860
	25	66	145	257	405	562	990	1530	2205	3825	6295	8995
	40	104	216	408	615	910	1635	2545	3600	6230	9880	14390
14.0	15	50	121	205	310	465	810	1270	1870	3220	5215	7390
	25	85	195	331	520	740	1375	2080	3120	5200	8500	12560
	40	126	305	555	825	1210	2195	3425	4735	8510	13050	18630

space volume, moves at higher velocity. All these factors increase the carry-over of water droplets with the steam into the distribution system.

There is much to be said in favour of carrying the steam to the points where it is to be used, at a pressure close to that of the boiler. The use of a high-distribution pressure means that the size of the steam mains is minimized. The smaller mains have lower heat losses, so that better-quality steam at the usage points is more readily achieved and the smaller pipes are often much lower in capital cost.

Pressure reduction to the levels needed by the steam-using equipment can then be achieved by the use of pressure-reducing stations located close to the steam users themselves. The individual reducing valves will tend to be smaller in size than would valves at the supply end, will give closer control of the reduced pressures and emit less noise. Problems which may arise if a whole section of a plant were dependent on a single reducing valve are avoided. The effects on the steam-using equipment of pressure drops in the pipework, varying in amount at different loads, are eliminated.

15.3 The steam load

Before selecting the size of a steam-control valve, a supply main or even a steam boiler it is necessary to know at least approximately (or better) how much steam is to be supplied. Where steam is to be used as the energy source for heat exchangers this is the same as knowing the heat load which is to be met.

Almost all heat loads fall into one of two categories. Either some material is to be heated from a lower temperature to a higher one or it is to be maintained at a high temperature while heat is supplied at a rate sufficient to balance the heat losses. In the first case the amount of heat needed to produce the change in temperature is given by

$$Q = W \times Sp \times \delta t$$

where Q = heat load (kJ),
W = weight of material (kg),

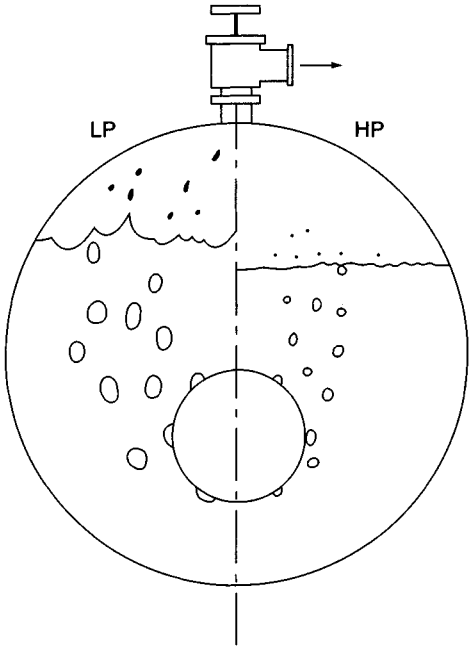


Figure 15.1 Boiler operation at low or high pressure

Sp = specific heat (kJ/kg°C),
δt = temperature rise (°C).

More usefully, since the steam flow rate is sought rather than the weight of steam,

$$q = \frac{Q}{h} = \frac{W \cdot Sp \cdot \delta t}{h}$$

where q = heat flow (kJ/h),
h = time available (h).

Then if hfg = enthalpy of evaporation of the steam at the pressure involved,

$$Ws = \frac{W \cdot Sp \cdot \delta t}{hfg \cdot h} \qquad (15.1)$$

where Ws = flow rate of steam (kg/h),
hfg= enthalpy of evaporation (kJ/kg).

The second case is the supply of heat at a rate which balances the heat losses, and here the heat load is given by

$$q_l = U \cdot A \cdot \Delta t \qquad (15.2)$$

where q_l = heat flow (kJ/h),
U = heat transfer coefficient for heat flow through the surface involved (kJ/m²°C · h),
Δt = temperature difference across surface involved (°C),
A = area of surface involved (m^2).

It must be said that heat transfer coefficients are affected by so many variables that they are best regarded as approximations, unless measurements have been made on identical equipment under similar conditions. Further,

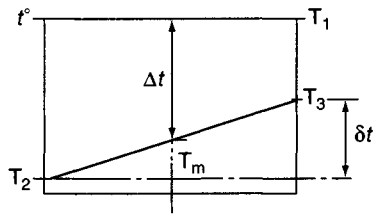


Figure 15.2

it will be noticed that equations (15.1) and (15.2) each include a temperature difference term, Δt or δt, but two different quantities are meant. To avoid confusion, it is useful to construct a diagram of the temperatures around the heat exchanger, as shown in Figure 15.2. At temperature T_1 a horizontal line represents the temperature of steam within the exchanger. Points T_2 and T_3 are the inlet and outlet temperatures of the heated material (or initial and final temperatures). A line is drawn from T_2 to T_3, and the difference between T_2 and T_3 is the temperature increase of the material, δt in equation (15.1). The midpoint of the line T_2 to T_3 gives the arithmetic mean of the material temperatures, T_m, and the difference between T_m and T_1 is then the arithmetic mean temperature difference Δt in equation (15.2). Note that although theoretical considerations lead to the use of logarithmic means in heat transfer calculations, arithmetic means are usually sufficiently accurate when sizing steam supply equipment.

Some typical specific heats are listed in the tables, and a few examples of heat load calculations may be useful.

1. An air heater battery raises 2 m³/s of air from −5°C to 30°C using steam at a gauge pressure of 6 bar. What is the hourly steam load?

$$2\,m^3/s = 2 \times 3600\,m^3/h = 2 \times 3600/0.76\,kg/h$$
$$= 9474\,kg/h$$

(0.76 m³ of air at −5°C weighs approx 1 kg)

$$Ws = \frac{9474 \times 1.0 \times (30 + 5)}{2066 \times 1} \quad \text{(from equation (15.1))}$$
$$= 160.5\,kg/h$$

(1 kg of air is heated through 1°C by 1.0 kJ).

2. A calorifier holding 2000 l is heated from 10°C to 60°C in 2 h using steam at a gauge pressure of 3 bar. What is the hourly steam load?

$$Ws = \frac{W \cdot Sp \cdot \delta t}{hfg \cdot h} = \frac{2000 \times 4.186 \times (60 - 10)}{2133.4 \times 2}$$
$$= 98.1\,kg/h$$

3. A calorifier has a heating surface area of 2 m² and is required to heat a flow of water from 65°C to 80°C. The U value has been found to be 1250 W/m²°C, and steam can be supplied at a gauge pressure of 2 bar in

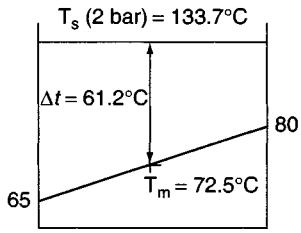


Figure 15.3

the steam chest. What rate of water flow can the calorifier handle (see Figure 15.3). From equation (15.2):

$$q = UA\Delta t$$
$$= 1250 \times 2 \times 61.2$$
$$= 153\,000W$$
$$= 550\,800 \text{ kg/h}$$

(This heat flow implies the condensing of some 550 000/2163.3 or 254.6 kg/h of steam.) From equation (15.1):

$$550\,000 = W \times 4.186 \times (80 - 65)$$
$$W = 8772 \text{ kg/h of water}$$

15.3.1 Sizing the steam lines

The appropriate size of pipe to carry the required weight of steam at the chosen pressure must be selected, remembering that undersized pipes mean high-pressure drops and high velocities, noise and erosion. Conversely, when pipe sizing is unduly generous, the lines become unnecessarily expensive to install and the heat lost from them will be greater than it need be.

Steam pipes may be sized so that the pressure drop along them is within an acceptable limit, or so that velocities along them are not too high. It is convenient and quick to size shorter mains and branch lines on a velocity basis, but the pressure drops along longer runs should also be checked to verify that sufficient pressure is available at the delivery points.

15.3.2 Sizing on velocity

In lines carrying saturated steam reasonable maxima for velocities are often taken at up to 40 m/s in larger pipes and at higher pressures. However, 25 m/s may be more appropriate in the middle ranges and even 15 m/s with small-size lines and lower pressures. Carrying capacities of pipes may be read from a table of sizes and pressures, or if the specific volume v is read from the Steam Tables, then

$$W \text{ kg/h} = \frac{0.002827D^2V}{v}$$

where D = pipe diameter (mm),
V = velocity (m/s),
v = specific volume (m^3/kg).

Velocities higher than 40 m/s may be accepted in the very large-diameter lines which some process or power industries use, especially when superheated steam is carried (up to 60 m/s or even more).

15.3.3 Sizing on pressure drop

In anything other than lines of only a very few metres in length, it is usual to choose sizes so that the pressure drop is not above, say, 0.3 bar/100 m run. Sizing with greater flow rates in a given size of pipe (and correspondingly higher velocities) will increase the pressure drop in much more than linear proportion, and can soon lead to the pipe becoming quite unable to pass the required flow.

Calculation of pressure drops in steam lines is a time-consuming task and requires the use of a number of somewhat arbitrary factors for such functions as pipe wall roughness and the resistance of fittings. To simplify the choice of pipe for given loads and steam pressures, Figure 15.4 will be found sufficiently accurate for most practical purposes.

15.4 Draining steam lines

Draining of condensate from steam mains and branch lines is probably the most common application for steam traps. It is important for reasons of safety and to help achieve greater plant efficiency that water is removed from steam lines as quickly as possible. A build-up of water can, in some cases, lead to slugs of water being picked up by the steam flow and hurled violently at pipe bends, valves or other fittings, a phenomenon described graphically as waterhammer. When carried into heat exchangers, water simply adds to the thickness of the condensate film and reduces heat transfer. Inadequate drainage leads to leaking joints, and is a prime cause of wiredrawing of control valve seating faces.

15.4.1 Waterhammer

Waterhammer may occur when water is pushed along a pipe by the steam instead of being drained away the low points and is suddenly stopped by impact on a valve, pipe tee or bend. The velocities which are achieved by such slugs of water can be very high, especially on start-up, when a pipe is being charged with steam. When these velocities are destroyed the kinetic energy of the water is converted into pressure energy and a pressure shock is applied to the obstruction. Usually, there is a banging noise, and perhaps movement of the pipe. In severe cases the fitting may fracture with an almost explosive effect and consequent loss of live steam at the fracture.

Fortunately, waterhammer may be avoided completely if steps are taken to ensure that water is drained away before it accumulates in sufficient quantity to be picked up by the steam. Avoiding waterhammer is a better alternative than attempting to contain it by choice of materials and pressure ratings of equipment.

The steam traps (used to drain water from a separator where this is fitted, perhaps to deal with carry-over from

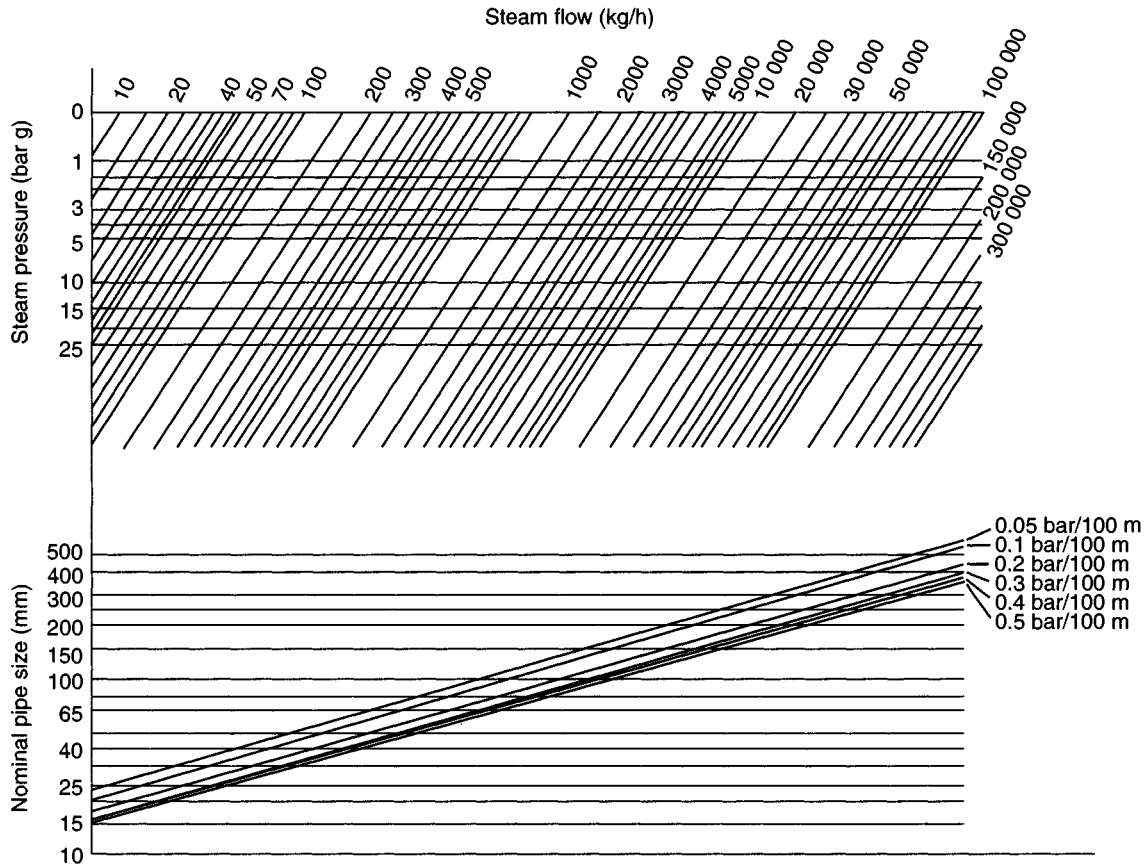


Figure 15.4 Pressure drop in steam lines

a boiler, or to drain condensate from collecting legs at intervals of not more than, say, 50 m along the steam line) clearly must have adequate capacity. For the separator at the boiler offtake or at a header supplied from the boiler(s) and itself supplying the steam mains, it may be necessary to have capacity in the trap(s) of 10% or even more of the boiler rating. On the steam lines themselves it is rare for a trap larger than 1/2 in or 15 mm size to be needed. Very often, the low-capacity versions of the 1/2 in steam trap are more than adequate.

The capacity of any steam trap will depend on the difference in pressure between its inlet and outlet connections. Under system start-up conditions the steam pressure in the line will at first be only marginally above atmospheric. If the trap discharge line rises to a higher level, or delivers to a pressurized return pipe, no condensate will flow through the trap until the line pressure exceeds the back pressure. It is important that steam traps which can drain by gravity, with zero back pressure, are fitted if condensate is to be removed as the system is being heated from cold. Where this means that the start-up condensate can only be drained to waste, additional steam traps connected to the return line may also be fitted to enable recovery of the condensate to be made during normal running.

15.4.2 Steam line drainage

The use of oversized steam traps giving very generous 'safety factors' does not ensure safe and effective steam line drainage. A number of points must be considered if a satisfactory installation is to be achieved, including:

1. The heat-up method employed;
2. The provision of suitable collecting legs or reservoirs for the condensate;
3. Provision of a minimum differential pressure across the trap;
4. Choice of steam trap type and size;
5. Proper installation of the trap.

15.4.3 Heat-up method – supervised

In this case a manual drain valve is fitted at each drain point on the steam system, bypassing the trap and discharging to atmosphere. These manual drains are opened fully, either at the previous shutdown so that residual condensed steam is drained or at least before any steam is re-admitted to the system. When the 'heat-up' condensate has been discharged and the line pressure begins to increase, the manual valves are closed. The condensate

Table 15.5 Heat emission from pipes (metric SI units)

Temperature difference steam to air (°C)	*Pipe size (mm)*									
	15	*20*	*25*	*32*	*40*	*50*	*65*	*80*	*100*	*150*
	W/m									
56	54	65	79	103	108	132	155	188	233	324
67	68	82	100	122	136	168	198	326	296	410
78	83	100	122	149	166	203	241	298	360	500
89	99	120	146	179	205	246	289	346	434	601
100	116	140	169	208	234	285	337	400	501	696
111	134	164	198	241	271	334	392	469	598	816
125	139	191	233	285	321	394	464	555	698	969
139	184	224	272	333	373	458	540	622	815	1133
153	210	255	312	382	429	528	623	747	939	1305
167	241	292	357	437	489	602	713	838	1093	1492
180	274	329	408	494	556	676	808	959	1190	1660
194	309	372	461	566	634	758	909	1080	1303	1852

Heat emission from bare horizontal pipes with ambient temperature between 10°C and 21°C and still air conditions.

formed under operating conditions is then discharged through the steam traps. These need to be sized only to handle the loads corresponding to the losses from the lines under operating conditions as indicated in Table 15.5.

This heat-up procedure is most often adopted in large installations where start-up of the system is an infrequent (perhaps only an annual) occurrence. Large heating systems and chemical processing plants are typical examples.

The procedure can be made more automatic by using a temperature-sensitive liquid expansion steam trap in place of the manual valve. Such an arrangement is a compromise between supervised start-up and the automatic start-up discussed below.

15.4.4 Heat-up method – automatic

One traditional method of achieving automatic start-up is simply to allow the steam boiler to be fired and brought up to pressure with the crown valve wide open. Thus the steam main and branch lines come up to operating pressure without supervision, and the steam traps must be arranged so that they can discharge the condensate as it is formed. This method is usually confined to the smaller installations that are regularly and frequently shut down and started up again. Typically, the boilers in many laundries and dry-cleaning plants often are shut down each night and restarted each morning.

In anything but the smallest installations the flow of steam from the boiler into the cold pipes at start-up (while the boiler pressure is still very low) will lead to excessive carry-over of boiler water with the steam. Such carry-over may be enough to overload a separator at the boiler offtake point or its steam trap (Figure 15.5). Great care (and even good fortune) are necessary if problems are to be avoided.

Modern steam practice calls for an automatic valve to be fitted in the steam supply line, arranged so that the valve remains closed until a sufficient pressure is attained in the boiler. The valve can then be made to open over a timed period, so that steam is admitted to the pipework at a controlled rate. The pressure within the boiler may be climbing quickly but the slow opening valve protects the pipework.

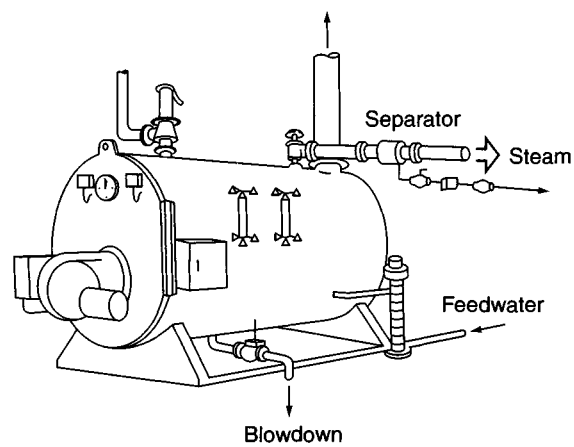


Figure 15.5 Boiler with separator at steam offtake

Where these valves are used, the time available to warm up the pipework will be known, as it is set on the valve control. In other cases, details of the start-up procedure must be known so that the time may be estimated. Thus boilers started from cold may be fired for a short time, shut off for a period while temperatures equalize, and then fired again. Boilers may be protected from undue stress by these short bursts of firing, which extend the warm-up time and reduce the rate at which the condensate in the mains must be discharged at the traps.

15.4.5 Sizing steam traps for warm-up

Whatever automatic start-up method is adopted, steam will only flow into the mains and discharge air from the air vents at a pressure at least a little above atmospheric. It then reaches the pipe and condenses on the cold metal,

and at first the condensate temperature will be well below 100°C (212°F). This means that the steam traps will have a greater capacity than their normal rating when handling saturated condensate. If the traps are fitted to a collecting leg, at about 700 mm below the main, then filling of the collecting leg will provide a hydraulic head of about 0.07 bar or 1 lb/in^2 in addition to the line pressure.

Sizing the traps requires an estimate of the condensate produced in bringing the main up to temperature and then determining the hourly rate of flow by allowing for the time available for this warm-up. Suitable traps can then be chosen to give at least this rate with a total pressure difference of, say, 0.15 bar or 2 lb/in^2 across the trap. Warm-up loads for the most common pipe sizes and pressures are listed in Table 15.6. The maximum condensation rate occurs when the mains are cold and the pressure (of the air/steam mixture) within them is still, say, 0.07 bar (1 lb/in^2). As the mains have been heated to some temperature below the corresponding saturated steam mixture, the amount of condensate formed will not have reached the values shown in Table 15.3. Further, although some of the condensate is flowing through the trap, the remainder is filling the collecting leg.

It seems reasonable to take the Table 15.6 value and to subtract the volume of the collecting leg, and to use steam traps capable of passing this nett amount in the available time with a pressure difference of 0.15 bar (2 lb/in^2). This may be clarified by an example.

A length of 150 mm (6 in) main carries steam at 17 bar (250 lb/in^2). Drain points are located at 45 m (150 ft) intervals, with collecting legs 100 mm (4 in) dia. ×700 mm (28 in) long. The main is brought up to pressure from 21°C (70°F) in 30 min.

		(Imperial)
Warm-up load to: 100°C	= approx.21.7 kg/45 m: 212°F	
	= 31.9 lb/100 ft	
	= 47.8 lb/150 ft	
Capacity of collecting	= approx. 5.7 kg	
leg	= 12.7 lb	
Nett condensate to be	= 16.0 kg	
discharged	= 35.1 lb	
Temperature rise to	= 207° − 21° = 186°C	
17 bar	= 406 − 70 = 336°F	
Temperature rise to	= 79°C	
	= 142°F	
Time to reach 100°C	$= \frac{79}{186} \times 30 \text{ min} = 12.7 \text{ min}$	
	$= \frac{142}{336} \times 30 = 12.7$	
Trap discharge rate	$= \frac{16.0 \text{ kg}}{12.7 \text{ min}} \times 60 \frac{\text{min}}{h}$	
	$= \frac{35.1}{12.7} \times 60$	

Table 15.6 Warm-up load in kg of steam per 30 m of steam main

Steam pressure (bar)	*Main size (mm)*													*−18° correction factor*
	50	*65*	*80*	*100*	*125*	*150*	*200*	*250*	*300*	*350*	*400*	*450*	*500*	
0	2.8	4.4	5.8	8.3	11.2	14.5	21.8	31	41	49	64	80	94	1.5
0.33	3.1	5.0	6.4	9.2	12.4	16.2	24.1	35	45	54	71	89	104	1.44
0.67	3.4	5.4	7.0	10.0	13.6	17.6	26.4	38	49	59	77	97	114	1.41
1.00	3.7	5.9	7.6	10.8	14.8	19.1	28.7	42	53	64	83	105	124	1.36
1.5	4.0	6.4	8.1	11.8	16	20.7	30.3	43	58	69	90	114	135	1.35
2.0	4.3	6.9	9.0	12.8	17.3	22.4	32	45	64	75	98	124	146	1.34
3.0	4.7	7.5	9.8	13.9	18.9	24.4	37	52	70	82	107	135	159	1.32
4.0	5.0	8.0	10.4	14.8	20.1	26.0	39.0	55	74	87	114	144	169	1.29
5.0	5.3	8.4	11.0	15.6	21.1	27.4	41	58	78	91	120	151	178	1.28
6.0	5.5	8.8	11.5	16.4	22.2	28.8	43	61	82	96	126	159	187	1.27
7.0	5.8	9.2	12.1	17.2	23.3	30.2	45	65	85	100	132	166	196	1.26
8.0	6.1	9.6	12.7	18.0	24.1	31.6	47	68	89	105	138	173	205	1.25
10.0	6.6	10.5	13.6	19.5	26.4	34.0	51	73	96	114	149	188	221	1.24
12.0	6.9	11.0	14.4	20.5	27.8	36.0	54	77	102	120	158	199	233	1.22
14.0	7.3	11.5	15.0	21.4	30.0	38	57	80	106	126	164	223	263	1.21
16.0	8.6	13.5	17.8	25.6	36.0	47	71	102	138	165	212	276	334	1.21
18.0	10.0	15.5	20.6	29.8	42	56	85	124	170	203	261	333	404	1.20
20.0	11.3	17.4	23.3	34.0	47	65	98	146	201	241	309	388	474	1.20
25.0	12.2	18.8	25.1	37.0	51	70	106	158	217	259	333	418	511	1.19
30.0	13.1	20.1	26.9	39.0	55	75	114	169	232	278	357	448	548	1.18
40.0	14.8	22.7	30.5	44.0	62	85	129	191	263	315	405	507	620	1.16
60.0	18.0	27.6	37	54	98	131	230	338	476	569	728	923	1120	1.145
80.0	21.3	32.5	43	63	115	154	257	378	532	638	815	1034	1255	1.14
100.0	23.5	36	48	70	127	171	284	418	588	707	902	1145	1390	1.135
125.0	28.8	44	59	86	159	208	347	510	718	863	1100	1400	1700	1.127

Ambient temperature 20°C. For outdoor temperature −18° , multiply load value in table by correction factor. Loads based on ANSI Sch. 40 pipe for pressures up to 16 bar.
Sch. 80 pipe for pressures above 16 bar, except Sch. 120 above 40 bar in sizes 125 mm and over.

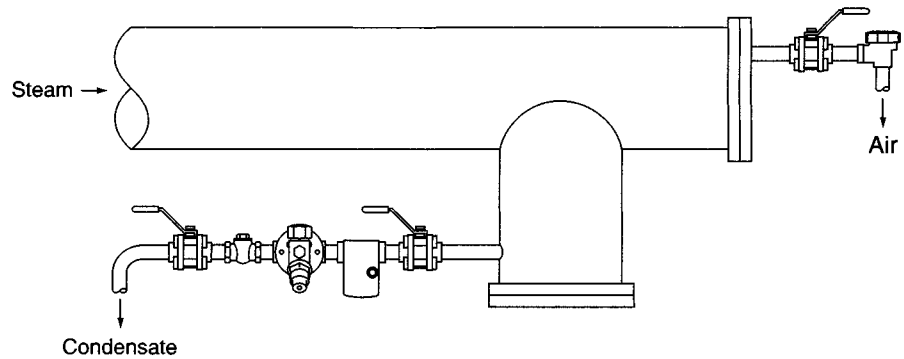


Figure 15.6 Draining and venting mains

$= 75.6\,kg/h$
$= 166\,pph$

The capacity of a 1/2 in TD trap at 0.15 bar differential (2 lb/in^2) is about 115 kg/h (255 pph) and this trap would have ample capacity.

It is clear that in most cases other than very large distribution mains, 1/2 in TD traps are sufficiently large. With shorter distances between drain points, or smaller diameters, then 1/2 in low-capacity traps more than meet even start-up loads. On very large pipes it may be worth fitting 3/4 in traps, or two 1/2 in traps in parallel. Low-pressure mains often are drained through float/thermostatic steam traps, and these traps are now available for use at much higher pressures than formerly, where it is known that waterhammer will not be present.

15.4.6 Drain point layout

Condensate-collecting legs can be of the same diameter as the main, up to, say, 100 mm (4 in) size. Larger pipes can have collecting legs two or three sizes smaller than the main but not less than 100 mm (4 in) size. The length of the collecting legs used with automatic start-up is usually 700 mm (28 in) or more, to give a hydraulic head of 0.15 bar (1 lb/in^2). With supervised start-up, the length of the legs can be 1.5 pipe diameters but not less than about 200 mm (8 in).

The spacing between the drain points often is greater than is desirable. On a long horizontal run, drain points should be provided at intervals of about 45 m (150 ft) with a maximum of, say, 60 m (200 ft). Longer lengths should be split up and additional drain points fitted. Any low points in the system, such as the foot of risers and in front of shut-off or control valves, must also be drained.

In some cases the ground contours are such that a steam main can only be run uphill. This will mean that the drain points should be closer together over the uphill section (say, 15 m (50 ft) apart) and the size of the main increased so that the steam velocity is not more than about 15 m/s (50 ft/s). The lower steam velocity may then allow condensate to drain in the direction opposite to the steam flow.

15.4.7 Air venting the steam lines

Air venting of steam mains is of paramount importance and is far too often overlooked. Air is drawn into the pipes when the steam supply is shut off and the residual steam condenses. A small amount of air is dissolved in the feedwater entering the boiler, and even if this amounts to only a few parts per billion, the gas can accumulate in the steam spaces since it is non-condensable. Further, unless the feedwater is demineralized and decarbonated, carbonates can dissociate in the boiler and release carbon dioxide into the steam supply. Automatic air vents fitted above any possible condensate level at the ends of the steam mains and branches will allow discharge of these non-condensable gases, so promoting high heat transfer rates in the exchangers and helping to minimize corrosion (Figure 15.6).

15.5 Low-pressure systems

With steam generated at or close to the boiler design pressure it is inevitable that some of the steam-using equipment will have to be supplied at a lower pressure. In some cases the plant items themselves have only been designed to withstand a relatively low pressure. Sometimes a reaction will only proceed when the steam is at a temperature below a certain level or an unwanted reaction will occur above a certain level. For these and similar reasons, steam often is distributed at a relatively high pressure which must then be lowered, close to the point of use. Pressure-reduction stations incorporating pressure-reducing valves are fitted to perform this function.

Pressure-reducing valves may be either of the simple, direct acting pattern or be pilot operated (sometimes described as relay operated) (Figures 15.7 and 15.8). In the simple type, the force produced by the pressure downstream of the valve seat acting on a diaphragm or bellows is balanced by a control spring. When this force exceeds that of the spring at a given setting the diaphragm or bellows moves, compressing the spring further until balance is regained at a higher spring load – and at the same time moving the valve disc towards its seat. At the new balance point the steam flow through the valve is lessened and the downstream pressure is a little higher

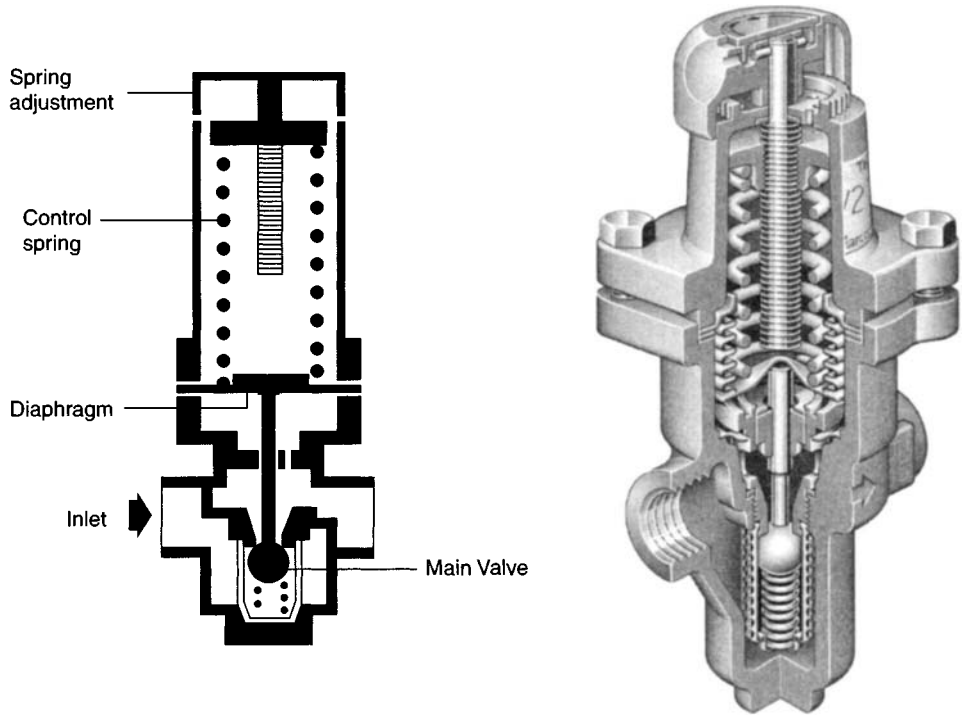


Figure 15.7 Direct-acting reducing valve

than the initial setting. Equally, at higher demand rates the downstream pressure falls by a small amount. A new balance point is reached when the lower pressure balances the spring force at a lower compression, with the valve disc now further away from the seat.

The pressure downstream of a simple reducing valve must vary, then, from a maximum at no-load with the valve closed to a lower value on-load with the valve open. The change in reduced pressure may be called 'droop' or sometimes 'accuracy of regulation'. Simple valves are used to supply fairly small loads, or loads which are fairly steady at all times, to minimize the droop effect or where the reducing valve is followed by a temperature control valve which can compensate for the droop.

In other cases of larger and varying loads the droop of a large valve of simple pattern may be unacceptable. A very small valve of simple pattern can then be used as a pilot or relay valve to operate a much larger valve. The combination then has the droop characteristic of the very small pilot valve. Typically, a 1/2 in (15 mm) simple reducing valve might pass full flow with a droop of 20% of the reduced pressure, while a 3 in (80 mm) pilot-operated valve can have a droop of only 0.2 bar (3 lb/in^2).

It is a mistake to install even the best of pressure-reducing valves in a pipeline without giving some thought to how best it can be helped to give optimal performance. First, the valve chosen must have a large enough capacity that it can pass the required steam flow, but oversizing should be avoided. The weight of steam to be passed in a given time must be calculated or estimated, and a valve selected which can cope with this flow from the given upstream pressure to the required downstream pressure. The size of the valve is usually smaller than either the upstream or downstream pipe size because of the very high velocities which accompany the pressure drop within the valve.

Second, any valve which has been designed to operate on steam should not be expected to work at its best when supplied with a mixture of steam, water and dirt. A separator, drained through a steam trap, will remove virtually all the water from the steam entering the pressure-reducing set. The baffle type separators are found to be effective over a wide range of flow rates.

A stop valve is needed so that the steam supply can be shut off when necessary, and if this valve follows the separator, the steam supply will be drained even when the valve is closed. After the valve a line size strainer is needed. It should have a 100-mesh stainless steel screen to catch the fine dirt particles which pass freely through standard strainers. The strainer is installed in the pipe on its side, rather than in the conventional way with the screen hanging below the pipe. This is to avoid the screen filling with condensate, which is often pumped between the valve plug and seat of a just-opening control valve as the flow (and pressure drop) through a strainer increases. This leads rapidly to wiredrawing of the control valve seat faces, and it is avoided by fitting the strainer horizontally to be self-draining. Pressure gauges at each side of a pressure-reducing valve both allow the downstream pressure to be set initially and aid in checking the functioning of the valve in service.

At the low-pressure side of the reducing valve it is usually essential to fit a relief or safety valve. If any of

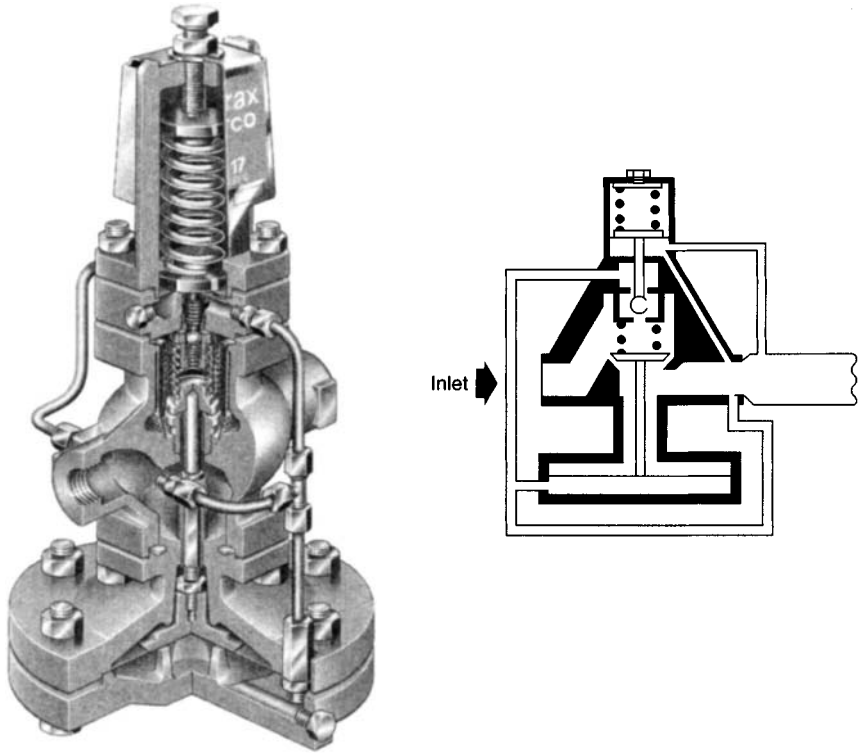


Figure 15.8 Pressure reducing valve

the steam-using equipment connected to the low-pressure range is designed to withstand a pressure below that of the upstream steam supply, then a safety valve is mandatory. Further, it may be called for when it is sought to protect material in process from over-high temperatures (Figure 15.9).

15.5.1 Safety relief valve sizing

When selecting a safety valve the pressure at which it is to be set must be decided. This may be sufficiently above the maximum normal operating pressure, under no-load conditions, to ensure the safety valve will reseat and not continue to blow steam, but it *must not* exceed the design pressure of the low-pressure equipment. The valve will give its rated capacity at an accumulated pressure of 10% above the set pressure. This capacity must equal or exceed the maximum possible capacity of the pressure-reducing valve if it should fail wide open, when passing steam from the upstream pressure to the accumulated pressure at the relief valve. For more information on this important subject, reference should be made to BS 6759: Part 1 and BS 5500.

15.5.2 Parallel and series operation of reducing valves

15.5.2.1 Parallel operation

In steam systems where load demands fluctuate over a wide range, parallel pressure control valves with combined

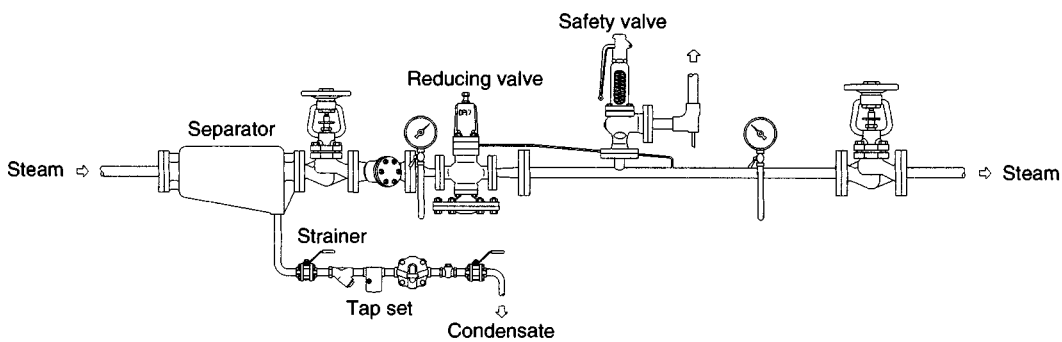


Figure 15.9 Pressure-control station

capacities meeting the maximum load perform better than a single large valve. Maintenance needs, downtime and lifetime total costs can all be minimized with such an arrangement.

Any reducing valve must be capable of both meeting its maximum load and modulating down towards minimum loads when required. The load turndown with which a given valve will satisfactorily cope is limited. There are no rules which apply without exception, but when the low load is less than about 10% of the maximum load, two valves should always be preferred.

Whether a reducing valve is wide open or nearly closed, movement of the valve head through a given distance in relation to the seat will be in response to a given change in the controlled pressure. This valve movement changes the flow rate by a given amount, the pressure-reducing valve having a nearly linear characteristic. However, the change in the controlled pressure follows from a given percentage change in the flow rate. A valve movement which changes the steam flow just enough to match the demand change at high loads will change the flow by too much at low loads. It follows that instability of 'hunting' becomes more likely when a single valve is asked to cope with a high turndown in load.

A single valve then tends to keep opening and closing, on light loads. This leads to wear of both the seating and guiding surfaces and reduces the life of the diaphragms which operate the valve. Where valves make use of pistons sliding within cylinders to position the valve head the situation is worsened. Friction and sticking between the sliding surfaces mean that the valve head can only be moved in a series of discrete steps. The flow changes resulting from these movements are likely to be grossly in excess of the load changes which initiate them.

Turndown ratios possible with piston-operated valves are inevitably smaller than those available with diaphragm-operated ones.

Stable control of reduced pressures is readily achieved by the use of two (or more) pressure-reducing valves is parallel (Figure 15.10). At full load and loads not too much below this level both valves are in use. As the load diminishes, the controlled pressure begins to increase and the valve which is set at the lower pressure begins to close. When the load can be supplied completely by the valve set at the higher pressure, the other valve closes. Any further load reduction causes the remaining valve to modulate through its proportional band.

Automatic changeover is achieved by the small difference between the pressure settings of the valves. For example, a maximum load of 5000 kg/h at 2 bar g might be supplied through one valve capable of passing 1200 kg/h and set at 2.1 bar g, and a parallel valve capable of passing 4000 kg/h set at 1.9 bar g. When the steam demand is at any value up to 1200 kg/h the smaller valve will supply the load at a controlled pressure just below 2.1 bar g. An increase in demand above 1200 kg/h will then lead to the controlled pressure falling to 1.9 bar or lower, and the second valve then opens to supplement the supply.

Equally, if the demand only rarely exceeded 4000 kg, or fell below about 1000 kg, it would be possible to set the larger valve at the higher pressure and supplement the supply through the smaller valve on those few occasions when this was necessary.

Sometimes the demand pattern is not known, except for the minimum and maximum values. Usually valves are then chosen with capacities of one third and two thirds of the maximum. The smaller valve is set at the slightly higher pressure.

15.5.2.2 Series operation

When the pressure reduction is through a ratio of more than about 10:1 the use of two valves in series should be considered. Much will depend on the valve being used, the pressures involved and the variations in the steam demand. Diaphragm-operated reducing valves have been used successfully with a pressure ratio as high as 20:1. They could perhaps be employed on a fairly steady load to reduce from 6.8 bar g (100 lb/in^2) to 0.3 bar g (5 lb/in^2). However, the same valve would probably be unstable on a variable load reducing from 2.75 bar (40 lb/in^2) to 0.15 bar g (2 lb/in^2).

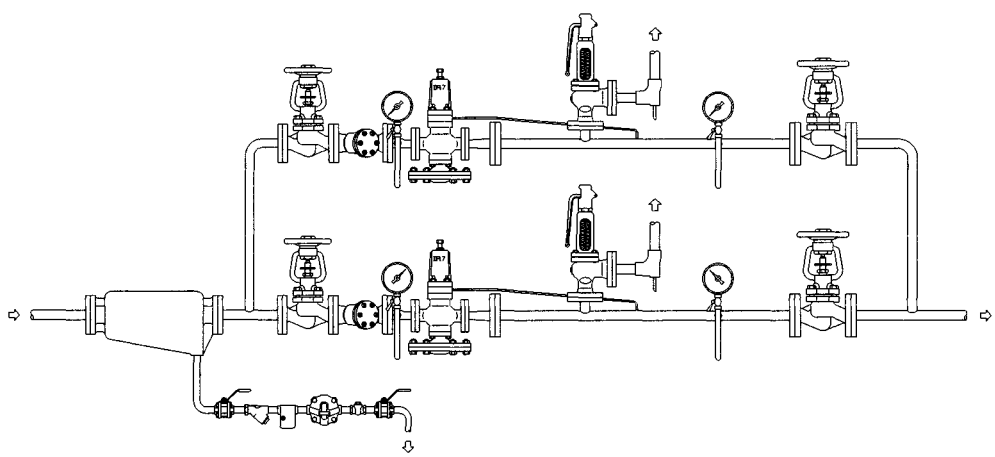


Figure 15.10 Typical installation of two reducing valves in parallel

There is no hard-and-fast rule, but two valves in series can be expected to provide more accurate control. The second, low-pressure, valve should give the 'fine control' with a modest turndown, due consideration being given to valve sizes and capacities.

15.5.3 Series installations

For stable operation of the valves some appreciable volume between them is necessary. A length equal to 50 diameters of the appropriately sized pipe is often recommended or the same volume of larger pipe.

The downstream pressure-sensing pipe of each valve is connected to a straight section of pipe 10 diameters or 1 m downstream of the nearest tee, elbow or valve. This sensing line should be pitched down, to drain into the low-pressure line. If it cannot drain when connected to the top of this line it can often be connected instead to the side of the pipe.

The pipe between the two control valves must be drained through a steam trap, just as would the foot of any riser downstream of the pressure-reducing station.

15.5.4 Bypasses

The use of bypass lines and valves is best avoided. Bypass valves are often found to be leaking steam because of wire drawing of the seating faces of valves which have not been tightly closed. If they are used, the capacity of the bypass valve should be added to that of the pressure-reducing valve when sizing relief valves.

If it is thought essential to maintain a steam supply even if a pressure-reducing valve should be faulty, or undergoing maintenance, consideration should be given to fitting a reducing valve in the bypass line. Sometimes the use of a parallel reducing station avoids the need for bypasses.

15.5.5 Selecting control valves for steam

The choice of a suitable temperature or pressure control valve for steam application will depend on the supply side pressure, the downstream pressure, and the flow rate of steam to be passed. In the case of temperature control valves the first of these is usually known and the third can be calculated, but the appropriate pressure drop through the valve is often to be decided. Sometimes the maker's rating of a heater will specify that it transfers heat at a certain rate when supplied with steam at a certain pressure. This pressure is then the pressure downstream of the control valve, and the valve may be selected on this basis.

If the pressure drop across the valve is to be more than 42% of the inlet absolute pressure the valve selection is the same as if the pressure drop were only 42%. With this pressure ratio the steam flow through the valve reaches a critical limit, with the steam flowing at sonic velocity, and lowering the downstream pressure below 58% of the inlet absolute pressure gives no increase in flow rate. When the heater needs a higher pressure, or when the pressure required in the heater is not known, it is safer to allow a smaller pressure drop across the control valve. If the necessary heater pressure is not known, a pressure drop across the control valve of 10–25% of the absolute inlet pressure usually ensures sufficient pressure within the heater. Of course, in the case of pressure-reducing valves the downstream pressure will be specified.

Valve capacities can be compared by use of the Kv (or Cv when Imperial units are used) values. These factors are determined experimentally, and the Kv value is the number of cubic metres per hour of water that will flow through a valve with a pressure drop of one bar. The Cv value is the number of gallons per minute of water that will flow through the valve with a pressure drop of one pound f. per square inch. As the gallon is a smaller unit in the USA, the number of gallons passed is greater, and the US Cv is 1.2 times the UK Cv. The Kv is about 0.97 of the UK Cv value.

The steam flow through a valve at critical pressure drop when $P2$, the downstream pressure, is 0.58 times $P1$, the supply pressure, or $P2/P1 = 0.58$, is given very closely by $W = 12KvP1$, where W = steam flow (kg/h), Kv = flow coefficient and $P1$ = supply pressure (bar). In the USA, $W = 1.5CvP1$, where W = steam flow (pph), Cv = flow coefficient and $P1$ = supply pressure (psia).

The factors 1.5 (US) and 12 (English metric) are not exactly equivalent but are sufficiently close for practical valve sizing purposes.

When the pressure drop ratio $(P1-P2)/P1$ is less than 0.42, the steam flow is less than the critical flow. While BS 5793: Part 2: Section 2.2: 1981 provides an approximate and a rigorous method of calculating flows, it is found in practice that the best results are not distinguishable from the empirical formula

$$W_x = (\text{Critical flow rate})\sqrt{[1 - 5.67(0.42 - x)^2]}$$

where x is the pressure drop ratio and W_x is the corresponding flow rate.

15.5.6 Draining condensate from heat exchangers

If heat exchangers are not to steadily fill with condensate and the flow of heat to cease, then the condensate must be drained from them, and steam traps are normally used for this purpose. However, it is clear that a positive pressure difference must always exist between the condensate within the heat exchanger and the outlet side of the steam trap. Where the steam is supplied through a pressure-reducing valve, to meet a steady load, and the condensate is drained to a return line at lower level than the outlet and running to a vented receiver, this positive differential pressure will exist. In a great number of applications the steam flow into the exchanger must be controlled in response to the temperature of the heated fluid, and if the heat load on the exchanger is less than the maximum, then the steam flow must be proportionately reduced.

With such a reduction in steam flow the steam pressure within the exchanger will fall. A balance is reached when the steam pressure is such that the steam temperature gives an appropriately lowered temperature difference between

the steam and the mean temperature of the heated fluid. Under no-load conditions, if the flow of the fluid being heated were to cease or if the fluid were already at the required temperature as it entered the exchanger then this temperature difference would have to be zero and the steam at the same temperature as the fluid leaving the exchanger.

As a first approximation, the expression

$$q_l = UA\Delta t$$

is used, and since A is a constant and U does not vary very much, the temperature of the steam must fall along a straight line from full-load steam temperature to the control temperature, as the load on the exchanger varies from maximum to zero. Clearly, as the steam temperature falls, the corresponding pressure in the steam space drops, and when it equals the pressure at the outlet side of the steam trap, condensate flow will cease.

15.5.7 Stall and the stall point

Steam has many benefits when used as a heat medium, some of which are its high heat content, its versatility for use in many different applications, and its ease of control. In temperature controlled plant, a condition commonly called *stall* can result in poor system performance. With proper arrangements, problems do not occur, but if they do, it is quite a simple matter to put things right. A basic understanding of these problems may benefit the practitioner.

The stall condition occurs when the steam space pressure approaches, equals, or is less than the condensate back pressure. This hinders the positive flow of condensate through a steam trap as its capacity reduces relative to the pressure drop across it. It can be identified on a graph known as a stall chart, where it is referred to as the stall point. *When stall is inevitable, an active method of condensate removal, such as a pumping trap, will ensure proper drainage of condensate under all load conditions.*

It is often thought that the steam pressure in a steam/liquid heat exchanger is always enough to force the condensate out. However, the relationship between two process conditions can prevent condensate draining out of a heat exchanger, they are:

- ☐ High condensate back pressure.
- ☐ Low steam pressure in the heat exchanger steam space.

When either occurs relative to the other, there can be insufficient pressure difference to move the condensate from the heat exchanger through the trap and into the condensate return line. Condensate will not drain, and the exchanger will begin to fill with water. Symptoms are poor temperature control, waterhammer and noise in the short term, and erosion and corrosion of the heat exchanger in the long term.

To maintain good process temperature control and prevent premature mechanical or corrosive failure of heat exchangers, it is essential that condensate is removed from the exchanger as quickly as it forms.

15.5.7.1 The stall cycle

The following is an example which shows how the stall situation develops (refer to Figure 15.11):

- ☐ When heat exchange occurs, the secondary fluid temperature will rise. This increase in temperature is detected by the control system and the steam valve closes down.
- ☐ The steam pressure falls, and the heat exchanger begins to flood because the back pressure in the condensate return pipe (P_2) is greater than the steam pressure after the control valve (P_1).
- ☐ When the heat exchanger floods, the secondary fluid temperature falls and the flow of steam through the control valve increases.
- ☐ The steam pressure rises ($P_1 > P_2$) and discharges the condensate, but leaves the heater filled with steam at a higher pressure than is needed to maintain a stable secondary temperature, as depicted in Figure 15.12. The cycle then repeats.

15.5.7.2 Temperature controlled plant

Condensate drainage to atmosphere Stall can also occur in temperature controlled heaters even when the condensate falls down to a steam trap and down again to a vented receiver or open ended pipe. The back pressure would be atmospheric, but it would be wrong to assume that there would always be enough steam pressure to push the condensate through the steam trap.

In this instance, where the secondary control temperature is less than 100°C, the steam temperature for some part load conditions will also be lower than 100°C (the saturation temperature of steam at atmospheric pressure). Here, the steam space pressure would be in vacuum, making it difficult for condensate to drain from the steam space and pass through the steam trap. A stall condition will exist and special arrangements are needed to drain the condensate.

On smaller heat exchangers draining to atmosphere, a simple remedy is to install a vacuum breaker on the steam inlet to the heat exchanger. When vacuum is reached in the steam space, the vacuum breaker opens to allow the condensate to drain down to the steam trap. The trap itself must be placed a discrete distance below the exchanger outlet, and must be sized to pass the condensate stall load on the static head created by the height of the outlet above the trap inlet. The condensate pipe from the trap should slope down so that no further back pressure is exerted on the trap (Figure 15.13).

Often, especially on larger plant, it is usually preferred not to introduce air into the steam space, and the use of a vacuum breaker may not be tolerated. Also, if the condensate lifts after the steam trap up to a higher level, a vacuum breaker cannot assist drainage. In these situations, a pumping trap or pump/trap combination should be used.

15.5.7.3 Closed loop condensate drainage

If stall is inevitable and a vacuum breaker cannot be used, an active method of condensate removal must be used to

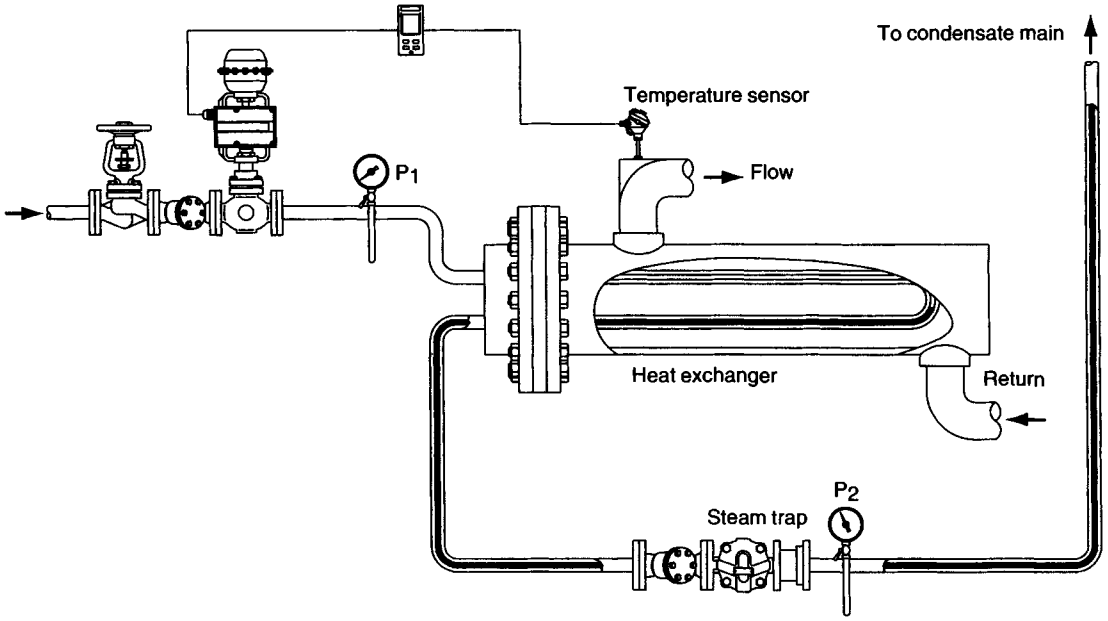


Figure 15.11 The onset of stall in a heat exchanger with temperature control

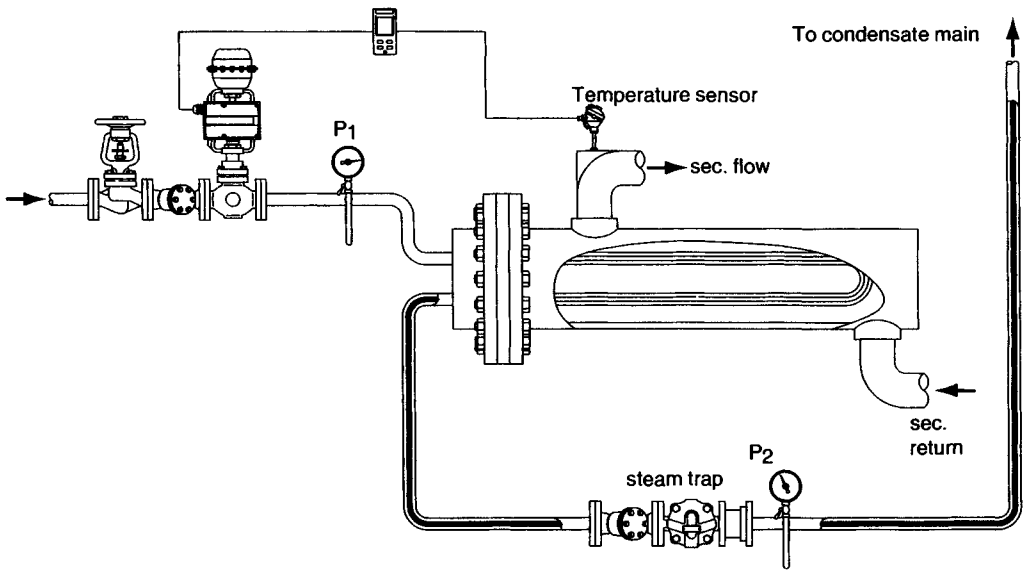


Figure 15.12 Continuation of the stall cycle

give good system performance, as shown in Figure 15.14. A pumping trap performs as a steam trap if there is sufficient steam pressure in the steam space to overcome the back pressure. If there is not, it acts as a pump. The device is fully self contained and automatic in its operation.

The pumping trap is also extremely valuable where there is restricted space below the heater, such as is often the case on air handling units which are often positioned close to the plant room floor. Figure 15.15 shows an example draining single- and multi-heater batteries to avoid both freezing and corrosion of the coils.

When a pumping trap arrangement is used, condensate will always be removed from the heater under all pressure conditions, ensuring maximum system efficiency at all times, with no escape of flash steam in the plant room.

Where plant capacity is too large for the pumping trap, it can be replaced by a separate pump and steam trap in combination, such as that shown in Figure 15.16. A mechanical fluid pump is dedicated to a single heater, connected so that the pump chamber, piping, and the steam

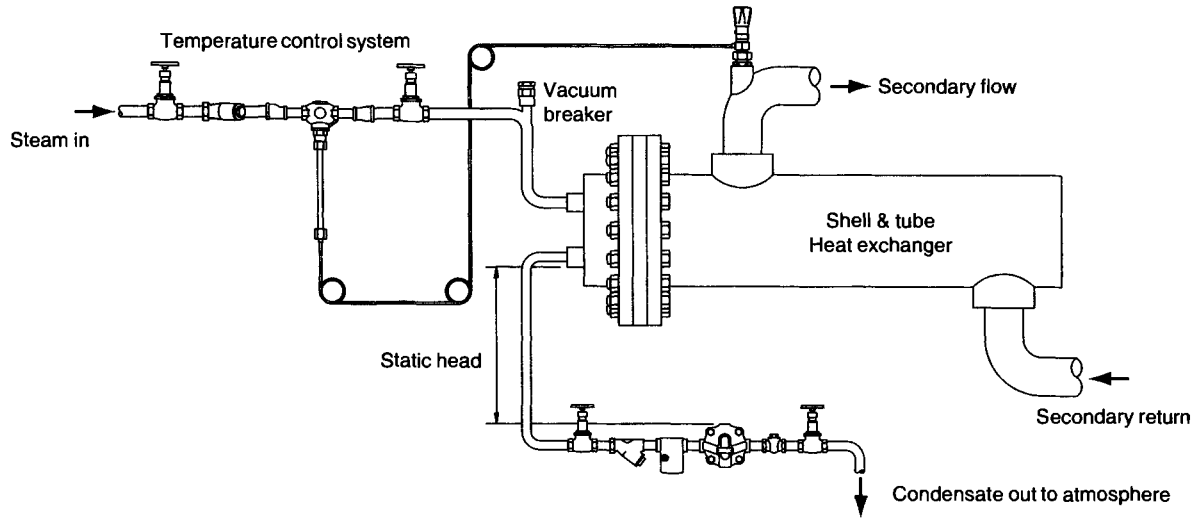


Figure 15.13 Shell and tube heat exchanger draining to atmosphere

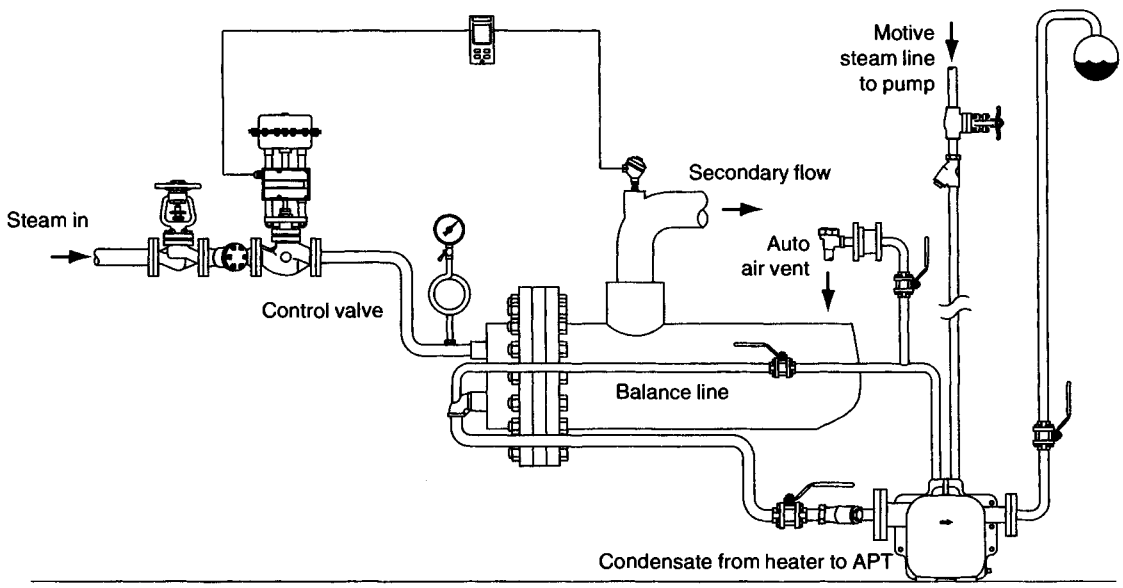


Figure 15.14 Shell and tube heat exchanger with pumping trap arrangement

side of the heater tubes form a common steam space. When the steam pressure is sufficiently high, condensate flows from the steam space and through the pump body and steam trap and away. When the pressure is lowered as the control valve closes down, condensate fills the pump chamber. Admittance of motive steam at high pressure is triggered, pushing condensate out of the chamber and away through the trap.

The pump exhaust line is connected to a reservoir and acts as a balance pipe when the pump is filling. The small amount of exhaust steam is then contained within the system, and pumping occurs with no waste of steam to atmosphere, making the system energy efficient, and the plant room free from flash steam.

15.5.7.4 Determining the stall point on temperature controlled plant

In any heat exchanger, the heat flow $\dot{Q}$, at any time, may be expressed by $\dot{Q} = U.\ A.\Delta\ Tm$.

where,

$\dot{Q}$	is heat transfer in watts
U	is the overall heat transfer coefficient ($W/m^2°C$)
A	is the area of the heat transfer surfaces(m^2)
Δ Tm	is the mean temperature difference between steam and water($°C$)

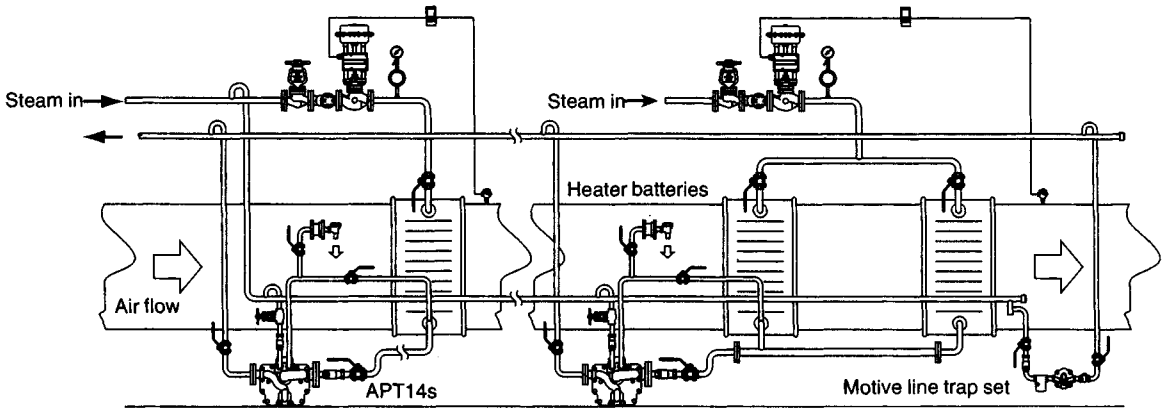


Figure 15.15 Pumping traps on heater batteries with low suction heads

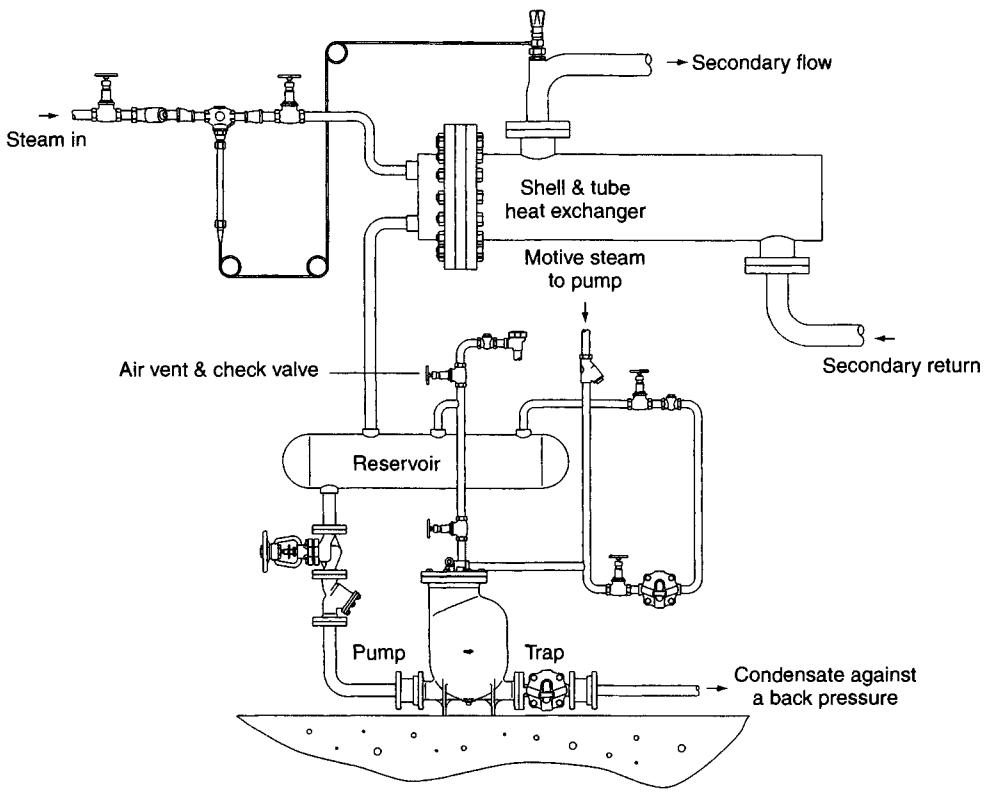


Figure 15.16 Shell and tube heat exchanger with pump and trap arrangement

If the heat flow in a steam/water or steam/gas heat exchanger is to be varied, a thermostatic control valve changes the steam flow. This leads to a change of pressure in the steam space, and so too a change in temperature. This immediately changes the value of Δ Tm in the heat flow equation. Since A and U virtually remain constant, the heat flow $\dot{Q}$ varies directly with Δ Tm.

For maximum heat load, Δ Tm must be at its greatest value, ie maximum steam temperature (and pressure) and minimum secondary temperature with secondary fluid flow at its greatest.

For no load, Δ Tm must be zero, ie the steam temperature must be the same as the fluid leaving the heat exchanger.

For 50% load, Δ Tm must be 50% of maximum Δ Tm and so on. This allows two straight lines to be drawn on a chart (see Figure 15.17), A–B and C–B which are furthest apart at full load, and meet at no load.

The upper line A–B represents the changing steam temperature (and pressure), and the lower line C–B represents the secondary inlet fluid temperature. The chart can relate any secondary inlet temperature and corresponding steam

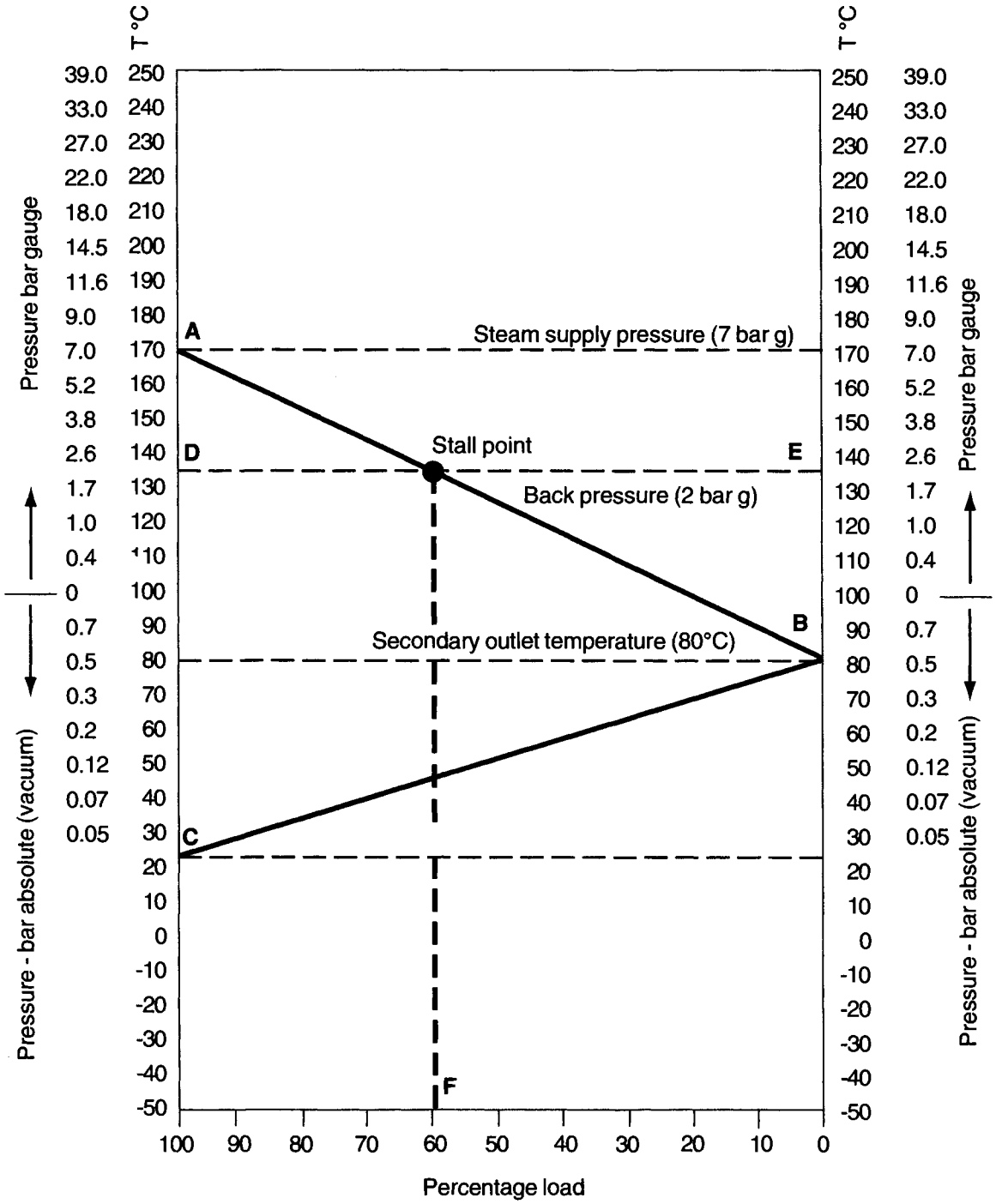


Figure 15.17 A typical stall chart

temperature to the heat load. If a horizontal line is drawn, D–E, representing the pressure downstream of the trap, it is possible to see when the steam pressure approaches the back pressure and the system starts to stall. Further reduction in load increases the waterlogging.

15.5.7.5 Using the stall chart

Q. Why use a stall chart?

A. It is a simple way of telling whether a steam trap or pumping trap is needed for the application!

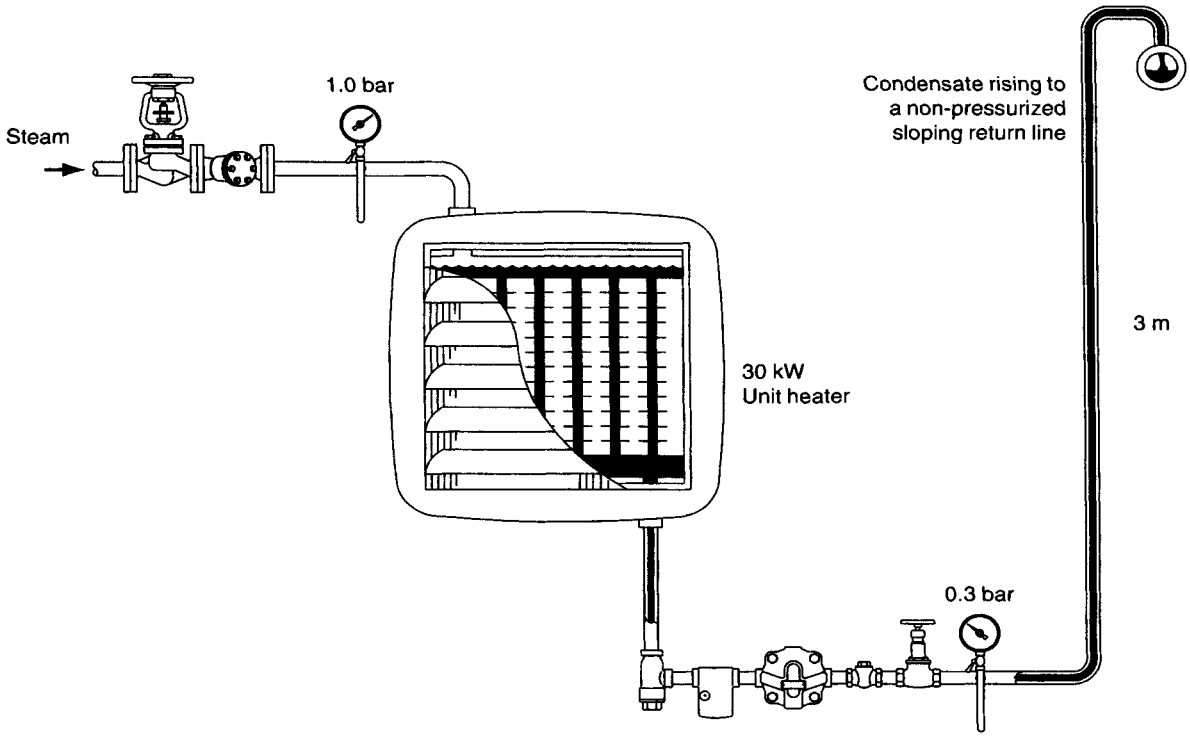


Figure 15.18 Trap capacity reduced due to an elevated return line

In order to select and size the trapping device correctly, the following information needs to be known:

- ☐ Steam flowrate at full load.
- ☐ Steam pressure in the steam space at full load.
- ☐ System back pressure.
- ☐ Secondary inlet temperature at full load.
- ☐ Secondary outlet temperature at full load.
- ☐ Minimum load condition

15.5.7.6 Example 1

- ☐ Steam flowrate at full load = 600 kg/h
- ☐ Steam pressure in heater at full load (A) = 7bar g
- ☐ Condensate system back pressure (E) = 2 bar g
- ☐ Inlet secondary medium temperature (C) = 25°C
- ☐ Outlet secondary medium temperature (B) = 80°C
- ☐ Minimum load condition (% of full load) = 40% = 240 kg/h

Plot the above information on the stall chart (Figure 15.17) in the following sequence.

1. Plot the incoming secondary inlet temperature (C) and outlet secondary temperature (B) to give the secondary temperature line C–B.
2. Plot the full load steam pressure (A) on the left side of the chart, and connect the line A–B.
3. Plot the condensate back pressure (point E).
4. Plot the point where the line A–B intersects with the system back pressure line (D–E), and drop straight down to the bottom of the chart to determine the percentage load (F) at which the stall condition will occur. Any loads lower than 60% will require the use of a pump or pumping trap.

From the chart, the stall condition is at 60%. From the maximum steam load of 600 kg/h, this will be approximately 360 kg/h. As the expected minimum load condition of 40% is lower than the stall load, a pumping trap will be required to provide proper and complete drainage.

NOTE: if the minimum load were higher than the stall load, (at say 70%, ie 30% reduction) then the system will never stall. Here, a steam trap only is needed, and is sized on the minimum load condition, ie 70% of 600 kg/h = 420 kg/h, at the pressure differential across the trap at this point/endash see below to establish this:

Steam temp. at full load	= 170°C	(a)
Steam temp. at no load	= 80°C	(b)
ie, steam temperature range	= 90°C	(a-b)
30% of range	= 30°C	(c) = ([a-b] ×0.3)
steam temp. at 30% reduction	= 140°C	(a-c)
steam pressure at 140°C	= 2.6 bar g	(from steam tables)
condensate back pressure	= 2.0 bar g	
Minimum load diff. pressure	= 0.6 bar	

Float trap sized to pass 420 kg/h with 0.6 bar diff. pressure.

15.5.7.7 Example 2

The stall load can also be calculated mathematically. This may be best explained using the information from the previous example:

$$\frac{\text{(Equivalent back pressure temp) } -\text{(Outlet secondary temp)}}{\text{(Full load steam space temp) } -\text{(Outlet secondary temp)}} = \frac{134-80}{170-80}$$

Percentage stall load = 60%

Actual stall load = 60% × 600 kg/h

= 360 kg//h

As the 40% minimum load (240 kg/h) is going to be lower than the 60% stall load (360 kg/h), the system will require a pumping trap or pump for correct condensate drainage.

Correct selection and sizing procedure of condensate removal devices is further explained in the Spirax Sarco Technical Reference Guide TR-GCM-23 'Draining condensate from heat exchangers'.

15.5.7.8 Example 3

An easier way of determining whether a system will stall and whether a steam trap or pumping trap is needed is achieved by the APT14 pumping trap computer sizing program, which accurately plots a bespoke stall chart for any installation.

For further details please contact any local Spirax Sarco office, or sales engineer.

15.5.7.9 Constant pressure plant

Although stall is unlikely to occur on items of plant supplied with a constant steam pressure above the condensate back pressure, any pressure in the condensate line will reduce the steam trap capacity. It is important that the steam trap is sized on the difference in the steam and condensate pressures, and not just the steam pressure, as depicted in Figure 15.18.

With constant pressure plant, a general rule is to size the steam trap on twice the full load rating of the plant to allow for the combination of low steam pressures and high condensation rates at start-up.

In this example, the differential pressure across the trap is 70% of the steam pressure. The trap is sized to pass twice the full load condition with a differential pressure of 1.0–0.3 bar g = 0.7 bar.

Full load = 30 kW

2 × 30 kW = 60 kW

$$\text{Steam load} = \frac{60\,\text{kW}}{2201\,\text{kJ/kg}} \times 3600 = 98\,\text{kg/h}$$

Size trap to pass 98 kg/h on a Δp of 0.7 bar.

15.5.8 Air venting

The existence of air (using this word to cover atmospheric air and also any other non-condensing gases) in steam systems was mentioned in Section 15.4.7. It is even more important that the presence of air in the heat exchangers themselves is recognized and arrangements made for its discharge. Air will exert its own partial pressure within the steam space, and this pressure will be added to the partial pressure of the steam in producing the total pressure present. The actual steam pressure is lower than the total pressure shown on a gauge by virtue of the presence of any air. Since the temperature of saturated steam must always be the condensing temperature corresponding with its partial pressure, the effect of air in a steam space is always to lower the temperature below the level which would be expected for pure steam at the total pressure present.

This means that thermostatic balanced pressure steam traps which open when their element senses a temperature somewhat below that of saturated steam at the pressure existing within the steam space are very effective when used as automatic air vents. They are connected to a steam space at any location where air will collect. Usually this means at any 'remote point' from the steam entry, along the path the steam takes as it fills the steam space.

Air vents are most effective when they are fitted at the end of a length of 300 mm or 450 mm of uninsulated pipe which can act as a collecting/cooling leg. Air is an excellent insulating material, having a thermal conductivity about 1300 times less than that of iron. The last place where it can be allowed to collect is in the steam space of heat exchangers. Further, as it contains oxygen or carbon dioxide, which dissolve readily in any subcooled condensate that may be present, the presence of air initiates corrosion of the plant and the condensate return system.

15.6 Flash steam

15.6.1 The release of flash steam

High-pressure condensate forms at the same temperature as the high-pressure steam from which it condenses, as the enthalpy of evaporation (latent heat) is transferred from it. When this condensate is discharged through a steam trap to a lower pressure the energy it contains is greater than it can hold while remaining as liquid water. The excess energy re-evaporates some of the water as steam at the lower pressure. Conventionally, this steam is referred to as 'flash steam', although in fact it is perfectly good steam, even if at low pressure.

15.6.2 Flash steam utilization

In an efficient and economical steam system this so-called flash steam will be utilized on any load which can make use of low-pressure steam. Sometimes it can be simply piped into a low-pressure distribution main for general use. The ideal is to have a greater demand for low-pressure steam at all times than the available supply of

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flash steam. Only as a last resort should flash steam be vented to atmosphere and lost.

This means that condensate from high-pressure sources should usually be collected and led to a flash vessel which operates at a lower pressure (but high enough to be useful). Remember, the flashing off does not normally take place within the flash vessel. It begins within the seat of the steam trap and continues in the condensate line. Only when the high-pressure steam traps are very close to the flash vessel does any flashing take place within it.

Instead, the flash vessel is primarily a flash steam separator. Its shape and dimensions are chosen to encourage separation of the considerable volume of low-pressure steam from the small volume of liquid.

15.6.3 Proportion of flash steam released

The amount of flash steam which a given weight of condensate will release may be readily calculated. Subtracting the sensible heat of the condensate at the lower pressure from that of the condensate passing through the traps will give the amount of heat available for use as the enthalpy of evaporation (latent heat). Dividing this amount by the actual enthalpy of evaporation at the lower pressure will give the proportion of the condensate which will flash off. Multiplying by the total quantity of condensate being considered gives the weight of low-pressure steam available.

Thus if, for example, 1000 kg of condensate from a source at 10 bar is flashed to 1 bar we can say:

Specific enthalpy of water (10 bar) = 781.6
Specific enthalpy of water (1 bar) = 505.6

Energy available for flashing = 276
Enthalpy of evaporation at 1 bar = 2201.1

$$\text{Proportion evaporated} = \frac{276}{2201.1} = 0.125$$

Flash steam available = 0.125 × 1000 kg = 125 kg

Alternatively, tables such as Table 15.7 or charts such as that shown in Figure 15.19 will allow the proportion of flash steam available between two pressures to be read off directly, within the more usual pressure ranges.

15.6.4 Sub-cooled condensate

Note that the method described assumes that the high-pressure condensate has not been sub-cooled. If any sub-cooling has taken place, then the figure taken for the enthalpy of water at the higher pressure is reduced by the amount of sub-cooling. The chart or table can still be used if the upstream pressure is taken as that corresponding to saturated steam at the same temperature as the sub-cooled condensate.

In the previous example condensate sub-cooled by 20°C would be at 164.13°C instead of 184.13°C. Steam at this temperature would be at a pressure of some 5.83 bar, so that the chart in Figure 15.19 would be used for a drop from 5.83 bar to 1 bar instead of from 10 bar to 1 bar, to allow for the sub-cooling.

15.6.5 Making use of flash steam

The steam/process air heater with multiple coils typifies the kind of application on which recovery of flash steam from the condensate is most readily effected. Condensate from the high-pressure coils is taken to a flash steam recovery vessel. Low-pressure steam leaving the vessel is supplied to the first coil at the air-inlet side of the heater or to an extra coil acting as a pre-heater unit.

Condensate from the low-pressure coil together with that from the flash vessel will then drain to a collecting tank, or direct to a condensate pump, for return to the boiler plant. If the pressure of the flash steam is left to find its own level it will often be sub-atmospheric. As the condensate must then drain by gravity through the steam traps these also must be sufficiently below the condensate drain points to provide an appropriate hydraulic head, and a vacuum breaker fitted above the coil. The alternatives are to allow the condensate to drain

Table 15.7 Condensate proportion released as flash steam

Pressure at traps (bar G)	*Pressure in flash vessel (bar G)*												
	0	*0.2*	*0.5*	*0.75*	*1.0*	*2*	*3*	*4*	*5*	*6*	*7*	*10*	*15*
1	0.038	0.029	0.017	0.008	0								
2	0.063	0.054	0.042	0.033	0.025	0							
3	0.082	0.073	0.061	0.053	0.045	0.02	0						
4	0.098	0.089	0.077	0.069	0.061	0.036	0.017	0					
5	0.111	0.102	0.091	0.083	0.078	0.05	0.03	0.014	0				
6	0.123	0.119	0.108	0.1	0.093	0.068	0.049	0.032	0.019	0			
7	0.133	0.125	0.113	0.106	0.098	0.074	0.054	0.038	0.024	0.012	0		
10	0.16	0.152	0.141	0.133	0.125	0.101	0.083	0.067	0.053	0.04	0.029	0	
15	0.192	0.183	0.172	0.165	0.157	0.134	0.116	0.1	0.087	0.075	0.014	0.035	0
20	0.222	0.214	0.203	0.195	0.188	0.165	0.148	0.133	0.12	0.108	0.097	0.069	0.032
25	0.245	0.237	0.226	0.219	0.212	0.189	0.172	0.157	0.144	0.133	0.122	0.095	0.058
30	0.261	0.253	0.243	0.235	0.228	0.206	0.189	0.174	0.162	0.15	0.14	0.113	0.077
40	0.296	0.288	0.278	0.271	0.264	0.242	0.226	0.212	0.2	0.189	0.179	0.153	0.118

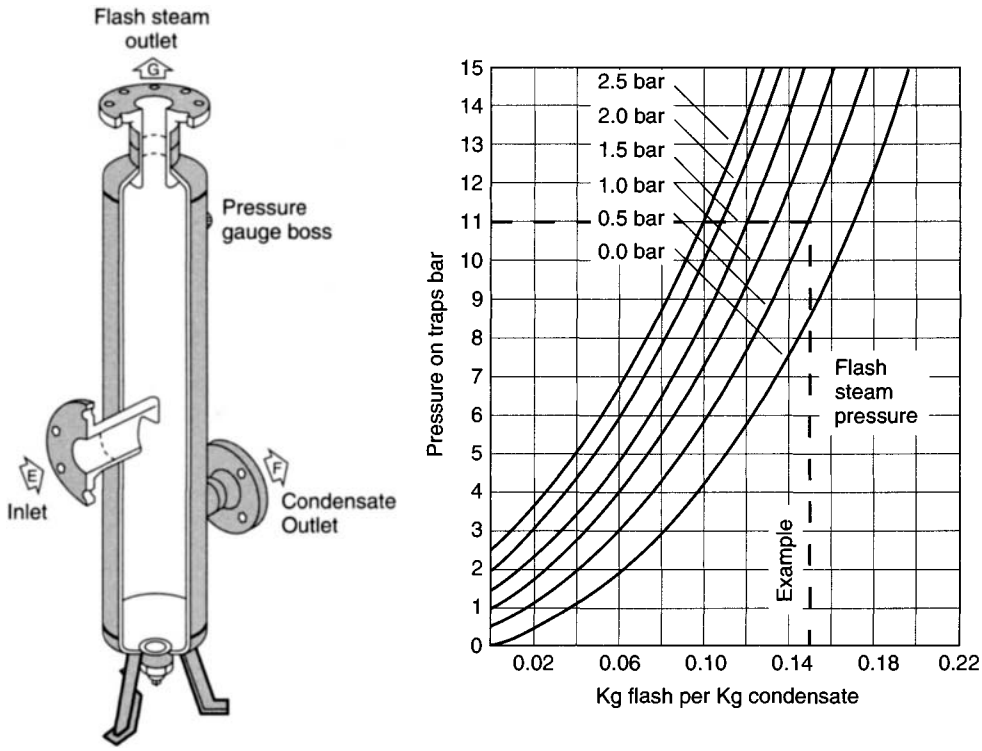


Figure 15.19 Flash vessel

directly to a condensate pump, or to supply additional low-pressure steam through a pressure-reducing valve, to maintain a positive pressure in the coil and flash vessel.

15.6.6 Space heating

Somewhat similar arrangements can be used when large areas are heated by radiant panels or unit heaters. Some 10–15% of the heaters are separated from the high-pressure steam supply and supplied instead with low-pressure steam flashed off the high-pressure condensate. The heating demands of the whole area remain in step, so supply and demand for the flash steam are balanced.

15.6.7 The general case

In other cases flash steam is utilized on equipment which is completely separated from the high-pressure source. Often the low-pressure demand does not at all times match the availability of the flash steam. A pressure-reducing station is often needed to make up any deficit and a surplussing valve is required to vent any flash steam in excess of the amount being condensed.

15.6.8 Steam traps

The wide choice of steam trap types which are available must at first seem confusing, and it is useful to first define the term 'steam trap'. In practice, a steam trap has two separate elements. The first of these is a valve and seat assembly, which can provide a variable orifice through which the condensate can be discharged at such a rate as to match the rate of condensation in the equipment being drained. The opening may be modulated continually to provide a continuous flow of condensate, or may operate in an on/off fashion so that the average rate over a period of time matches the condensation rate.

The second element is a device which will open or close the valve by measuring some parameter of the fluid reaching it and 'deciding' whether this may or may not be discharged. It would be found that the controlling elements mainly fall into one of three categories. The steam trap can decide automatically whether to open or to close to the fluid reaching it on the basis of:

1. The density of the fluid, by using a float which will float in water or sink in steam;
2. By measuring the temperature of the fluid, closing the valve at or near to steam temperature, and opening it when the fluid has cooled to a temperature sufficiently far below that of steam;
3. By measuring the kinetic effects of the fluid in motion, since at a given pressure drop, low-density steam will move at a much greater velocity than will high-density condensate, and the conversion of pressure energy into kinetic energy can be used to position a valve.

The groupings then may be described as *mechanical*, which will include both ball float and inverted bucket

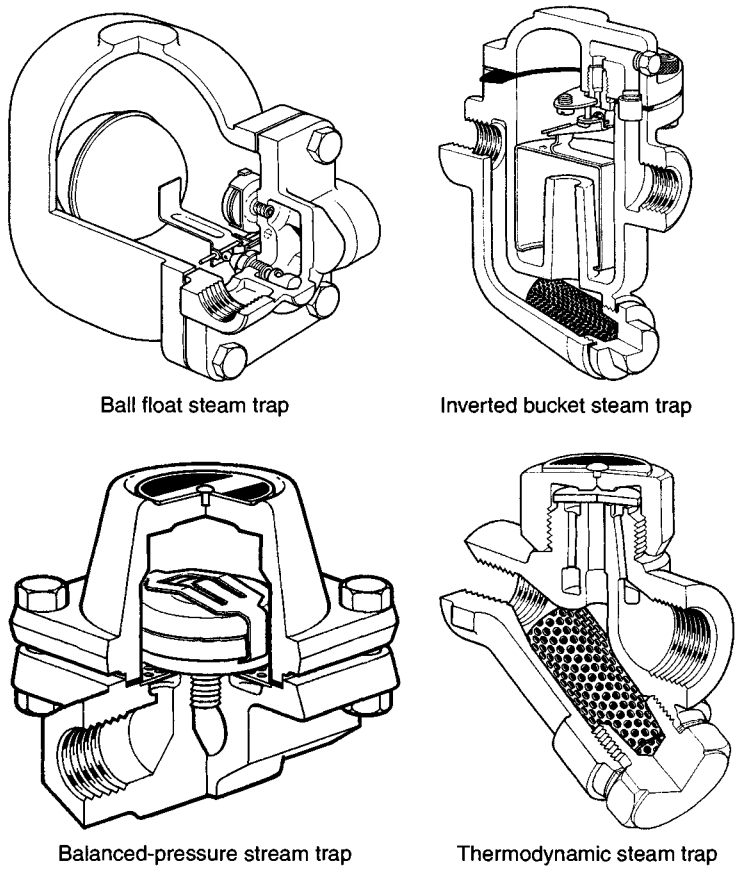


Figure 15.20 Steam traps

steam traps; *thermostatic*, which will include both balanced pressure and bimetallic elements; and *thermodynamic* or *disc* pattern traps (Figure 15.20). Each type of trap has its own characteristics, and these will make one pattern of trap more suitable for use on a given application than another. In practice, it is usual to find that the applications in any given plant fall into a small number of categories, and it often is possible to standardize on a quite small number of trap types.

Thus the requirements for draining condensate from the steam mains are that the trap should discharge condensate at a temperature very close to that of steam to ensure that it is in fact drained from the collecting pockets and not held back because it is not cooled to a sufficiently low temperature; that the trap is not physically large yet has adequate capacity; that the trap is robust enough to withstand severe operating conditions, such as waterhammer in inadequately drained lines or freezing conditions when installed outdoors. The thermodynamic trap is very widely used for this application and is capable of giving excellent results.

In a similar way, many small jacketed pans, steam radiators and convectors, and some steam tracer lines can operate most economically if the condensate is retained within the steam space until it has sub-cooled a little, making thermostatic pattern traps the most suitable for these applications. On the other hand, many heat exchangers are required to give their maximum output. This requires that the condensate be removed immediately it forms, or perhaps, as in air heater batteries, any holding back of condensate will lead to corrosion. In these cases the use of a mechanical trap such as the ball float pattern or perhaps the inverted bucket trap becomes essential. Care is needed when inverted bucket traps are chosen for jobs where the steam control valve may at times close down, lowering the pressure in the steam space. This can lead to re-evaporation of the water seal in an inverted bucket trap, which would then blow steam. Further, on many heater exchangers it is important to provide air-venting capacity at the trap. Float thermostatic traps incorporate a suitable air vent at the ideal location, just above the water level, while if inverted bucket traps are used, then separate air vents must be fitted in bypasses around the trap. Many steam users prefer to draw up a selection guide list such as the one shown in Table 15.8.

15.7 Condensate return systems

No single set of recommendations can cover condensate return systems. These divide naturally into at least three sections, each with its own requirements.

Table 15.8 Selecting steam traps

Application	*FT range (float-thermo-static)*	*FT-C float-thermo-static with steam release*	*TD range (Thermo-dynamic)*	*BPT (Balanced pressure thermo-static)*	*SM Bimetallic*	*No. 8 (Liquid expansion)*	*IB range (Inverted bucket)*
Canteen equipment							
Boiling pans-fixed	A	B	B1	B			
Boiling pans-tilting		B		A2			
Boiling pans-pedestal	B			A2			
Steaming ovens				A2			
Hot plates	B			A2			
Oil transfer/storage							
Bulk oil storage tanks	A						B1
Line heaters	A						B1
Outflow heaters	A						B1
Tracer lines			B	A	B2		B
Jacketed pipes			B1	A	(non-critical only)		B1
Hospital equipment							
Autoclaves and sterilizers	B	B		A			
Industrial dryers							
Drying coils (continuous)	A		B1	B			
Drying coils (grid)			B1	A			B1
Drying cylinders	B	A					B1
Multi-bank pipe dryers	A		B1	B			B1
Multi-cylinder sizing machines	B	A					B1
Laundry equipment							
Garment presses	B	B	A				
Ironers and calenders	B	A	B1	B5			
Dry cleaning machines	A		B1				
Tumbler dryers	A	B					
Presses							
Multi-platen presses (parallel connections)	B		A6				
Multi-platen presses (series connections)			A1				
Tyre presses	B		B1	A			B1
Process equipment							
Boiling pans - fixed	A	B	B1	B			
Boiling pans - tilting	B	A					
Brewing coppers	A1	B					
Digesters	A1		B1				
Evaporators	A1	B					B1
Hot tables	B		B	A2			
Retorts	A						
Bulk storage tanks	A						B1
Vulcanizers	A		B1 (jacket only)				B1
Space heating equipment							
Calorifiers	A						
Heater batteries	A						
Radiant panels and strips	A	B1	B1				B1
Radiators and convection cabinets	B			A	B		
Overhead pipe coils	B			A			B1
Steam mains							
Horizontal runs	B		A				B
Separators	A		B				B
Terminal ends	B		A1				B1

(*continued overleaf*)

Table 15.8 *(continued)*

Application	*FT range (float-thermo-static)*	*FT-C float-thermo-static) with steam release*	*TD range (Thermo-dynamic)*	*BPT (Balanced pressure thermo-static)*	*SM Bimetallic*	*No. 8 (Liquid expansion)*	*IB range (Inverted bucket)*
Shut down drain (frost protection)				B3	B	A	
Header drainage	A		B6				B
Tanks and vats							
Process vats (rising discharge pipe)	B	B	A	B5			B
Process vats (discharge pipe at base)	A		B6	B5			
Small coil heated tanks (quick boiling)	A			B5			
Small coil heated tanks (slow boiling)					B	A	

A = Best choice
B = Acceptable alternative
1 = With air vent in parallel
2 = At end of cooling leg min. length 1 m (3 ft)

15.7.1 Drain lines to traps

In the first section the condensate flows from the condensing surface to the steam trap. Since the heat exchanger steam space and the traps are at the same pressure, gravity is relied on to induce flow. When the traps are vertically below the drainage points, or are close to them, it may be satisfactory to use a line of the same size as the inlet connection of the trap. However, if the trap must be located a little further away from the drainage point, then the line between the trap point and the trap can be laid with a slight fall (say, 1 in 250), and Table 15.9 shows the water-carrying capacities of the pipes with such a gradient. It is important to allow for the passage of incondensables to the trap and for the extra water which is carried during cold-start conditions.

In most cases it is sufficient to size these pipes on twice the full running load.

15.7.2 Trap discharge lines

At the outlet side of the traps the 'condensate' lines have to carry both the condensate and any incondensable gases, together with the flash steam released from the condensate. Wherever possible, these pipes should drain by gravity from the traps to the condensate receiver, whether this be a flash recovery vessel or the vented receiver of a pump. With atmospheric pressure in the return line, and pressures upstream of the traps of up to about 4 bar (60 lb/in^2), the sizing method described above is more than adequate. At higher upstream pressures the volume of the flash steam released from the condensate becomes significant and must be given due consideration. If the pressure at the discharge side of the traps is above atmospheric pressure, then sizing these lines on twice the full running load may still be adequate even with pressures well above 4 bar (60 lb/in^2) at the inlet side. The chart shown in Figure 15.21 allows the lines to be sized as flash steam lines, since the volume of the condensate is so much less than that of the steam released.

Draining condensate from traps which serve loads at differing pressures to a common condensate return line is a concept which is often found difficult. Many users assume that the high-pressure condensate will prevent

Table 15.9 Water-carrying capacity of pipes (SI units) (approximate frictional resistance in mbar per m of travel)

Steel tube (mm)	*0.3 (30 Pa)*	*0.5 (50 Pa)*	*0.6 (60 Pa)*	*0.8 (80 Pa)*	*1.0 (100 Pa)*	*1.4 (140 Pa)*
15	95	130	140	160	180	220
20	220	290	320	370	420	500
25	410	540	600	690	790	940
32	980	1180	1300	1500	1700	2040
40	1360	1790	2000	2290	2590	3100
50	2630	3450	3810	4390	4990	6000
65	5350	6950	7730	8900	10 150	12 100
80	8 320	10 900	12 000	13 800	15 650	18 700
100	17 000	22 200	24 500	28 200	31 900	38 000

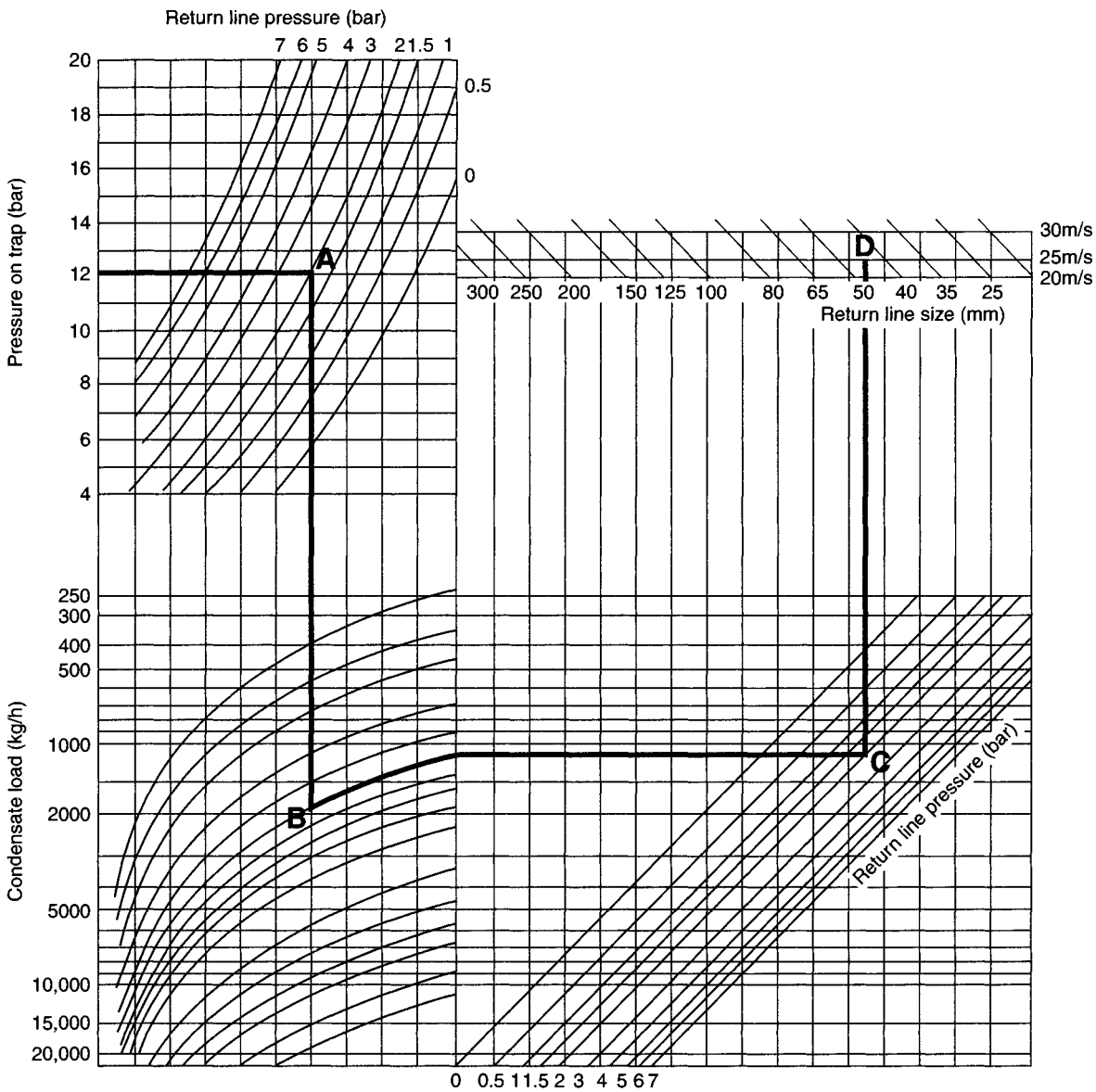


Figure 15.21 Condensate line sizing chart where pressure at traps is above 4 bar (SI units). 1: From pressure upstream of trap move horizontally to pressure in return line (A). 2: Drop vertically to condensate load in kg/h (B). 3: Follow curve to RH scale and across to same return line pressure (C). 4: Move upward to return line flash velocity – say, 25 m/s maximum (D). 5: Read return line size

the low-pressure condensate from passing through the low-pressure traps and give rise to waterlogging of the low-pressure systems.

However, the terms 'high pressure' and 'low pressure' can only apply to the conditions on the upstream side of the seats in the steam traps. At the downstream or outlet side of the traps the pressure must be the common pressure in the return line. This return line pressure will be the sum of at least three components:

1. The pressure at the end of the return line, either atmospheric or of the vessel into which the line discharges;
2. The hydrostatic head needed to lift the condensate up any risers in the line;
3. The pressure drop needed to carry the condensate and any flash steam along the line.

Item 3 is the only one likely to give rise to any problems if condensate from sources at different pressures enters a common line. The return should be sufficiently large to carry all the liquid condensate and the varying amounts of flash steam associated with it, without requiring excessive line velocities and excessive pressure drop. If this is accepted, then the total return line cross-sectional area

will be the same, whether a single line is used or if two or more lines are fitted with each taking the condensate from a single pressure source.

Return lines may become undersized, requiring a high pressure at the trap discharges and restricting or even preventing discharge from the low-pressure traps, if it is forgotten that the pipe must carry flash steam as well as water and that flash steam is released in appreciable quantity from high-pressure condensate.

15.7.3 Pumped return line

Finally, the condensate is often pumped from the receiver to the boiler house. Pumped condensate lines carry only water, and rather higher water velocities can often be used to minimize pipe sizes. The extra friction losses entailed must not increase back pressures to the point where pump capacity is affected. Table 15.10 can be used to help estimate the frictional resistance presented by the pipe.

Condensate pumps usually operate with an on/off action, so that the instantaneous flow rate during the 'on' period is greater than the average rate of flow of condensate to the pump receiver. This increased instantaneous flow rate must be kept in mind when sizing the delivery lines.

Where long delivery lines are used, the water flowing along the pipe as the pump discharges attains a considerable momentum. At the end of the discharge period when the pump stops, the water tends to keep moving along the pipe and may pull air or steam into the delivery pipe through the pump outlet check valve. When this bubble of steam reaches a cooler zone and condenses, the water in the pipe is pulled back towards the pump. When the reverse flow reaches and closes the check valve, waterhammer often results. This problem is greatly reduced by adding a second check valve in the delivery line some 5 or 6 m from the pump. If the line lifts to a high level as soon as it leaves the pump then adding a generously sized vacuum breaker at the top of the riser is often an extra help. However, it may be necessary to provide means of venting from the pipe at appropriate points the air which enters through the vacuum breaker.

The practice of connecting additional trap discharge lines into the pumped main is usually to be avoided. The flash steam which is released from this extra condensate can lead to waterhammer. Preferably, the trap should discharge into a separate gravity line which carries the condensate to the receiver of the pump. If this is impossible one may arrange for the condensate and associated flash steam to enter the pumped main through a small 'sparge' or diffuser fitting so that the flash steam can be condensed immediately in the pumped water.

15.7.4 Condensate pumping

In nearly all steam-using plants condensate must be pumped back to the boilerhouse from the location where it is formed, and even in those cases where gravity drainage to the boilerhouse is practical, often the condensate must be lifted into a boiler feed tank. Where de-aerators are used they usually operate at a pressure of about 0.3 bar above atmospheric, and again a pump is needed to lift condensate from atmospheric pressure to de-aerator pressure.

Most pump units comprise a receiver tank which conventionally is vented to atmosphere and one or more motorized pumps. It is important with these units to make sure that the maximum condensate temperature as specified by the manufacturer is not exceeded, as well as that the pump has sufficient capacity to handle the load. Condensate temperature usually presents no problem with returns from low-pressure heating systems. There, the condensate is often below 100°C even as it leaves the traps, and a little further sub-cooling in the gravity return lines and in the pump receiver itself means that there is little difficulty in meeting the maximum temperature limitations.

On higher-pressure systems the gravity return lines often contain condensate at a little above 100°C, together with some flash steam. The cooling effect of the piping is limited to condensing a little of the flash steam, and the remainder passes through the vent at the pump receiver. The water must remain in the receiver for an appreciable time if it is to cool sufficiently, or sometimes the pump discharge may be throttled down to reduce the pump's capacity if cavitation is to be avoided.

The absolute pressure at the inlet to the pump is usually the atmospheric pressure in the receiver, plus the static head from the water surface to the pump inlet and minus the friction loss through the pipes, valves and fittings joining the pump to the receiver. If this absolute pressure exceeds the vapour pressure of water at the temperature at which it enters the pump, then a nett positive suction hand (NPSH) exists. If this NPSH is above the value specified by the pump manufacturer, the water does not begin to boil as it enters the pump suction and cavitation is avoided. If the water entering the pump is at a higher temperature, its vapour pressure is increased and a greater hydrostatic head over the pump suction is needed to ensure that the necessary NPSH is obtained.

However, since in most cases pumps are supplied coupled to receivers and the static head above the pump inlet is already fixed by the manufacturer, it is only necessary to ensure that the pump set has sufficient capacity at the water temperature expected at the pump. Pump manufacturers usually have a set of capacity curves for the pump when handling water at different temperatures, and these should be consulted.

Where steam systems operate at higher pressures than those used in low-pressure space heating systems, as in process work, condensate temperatures can be 100°C, or more when positive pressures exist in the return lines. Electric pumps are then used only if their capacity is downrated by partial closure of a valve at the pump outlet; by using a receiver mounted well above the pump to ensure sufficient NPSH; or by sub-cooling the condensate through a heat exchanger of some type.

All these difficulties are avoided by the use of steam-powered alternating receiver pumps of the type illustrated in Figure 15.23. These pumps are essentially alternating receivers which can be pressurized using steam (or air

Table 15.10 Flow of water at 75°C in black steel pipes

M = mass flow rate kg/s
l_e = equivalent length of pipe ($\zeta = 1$) m
Δp_l = pressure loss per unit length Pa/m
v = velocity m/s

*$(Re) = 2000$
†$(Re) = 3000$

Δp_l	v	10 mm		15 mm		20 mm		25 mm		32 mm		40 mm		50 mm		v	Δp_l
		M	l_e	M	l_e	M	l_e	M	l_e	M	l_e	M	l_e	M	l_e		
0·1								0.003	0.1	0.009	0.5	0.017*	0.9	0.031	1.2		0·1
0·2								0.006	0.3	0.018*	0.9	0.024	0.9	0.044†	1.2		0·2
0·3						0.003	0.2	0.008	0.4	0.020	0.8	0.029	0.9	0.055	1.2		0·3
0·4						0.004	0.2	0.011	0.6	0.023	0.8	0.034†	0.9	0·065	1·3		0·4
0·5						0.005	0.3	0.014*	0.7	0.025	0.8	0.038	0.9	0·074	1·3		0·5
0·6						0.007	0.3	0.013	0.6	0.028	0.8	0·042	1·0	0·082	1·4		0·6
0·7						0.008	0.4	0.014	0.6	0.030†	0.8	0·046	1·0	0·090	1·4		0·7
0·8						0.009	0.5	0.015	0.6	0·032	0·8	0·050	1·0	0·097	1·4	0·05	0·8
0·9						0.010	0.5	0.016	0.6	0·035	0·8	0·054	1·0	0·104	1·5		0·9
1·0				0.003	0.2	0.011*	0.6	0.017	0.6	0·037	0·8	0·057	1·0	0·110	1·5		1·0
1·5				0.005	0.2	0.012	0.4	0.021†	0.6	0·047	0·9	0·072	1·1	0·139	1·6		1·5
2·0				0.006	0.3	0.014	0.4	0·025	0·6	0·055	0·9	0·085	1·1	0·164	1·6		2·0
2·5				0·008	0·4	0·015	0·4	0·028	0·6	0·062	0·9	0·096	1·2	0·186	1·7		2·5
3·0				0.009*	0.5	0.017	0.4	0·031	0·6	0·069	1·0	0·107	1·2	0·206	1·7		3·0
3·5				0.008	0.3	0.018†	0.4	0·034	0·6	0·076	1·0	0·116	1·2	0·224	1·7		3·5
4·0		0.004	0.2	0.009	0.3	0.020	0.4	0·037	0·7	0·082	1·0	0·126	1·3	0·242	1·8		4·0
4·5	0.05	0.005	0.2	0.009	0.3	0·021	0·5	0·039	0·7	0·087	1·0	0·134	1·3	0·258	1·8		4·5
5·0		0·005	0·3	0.010	0.3	0·022	0·5	0·042	0·7	0·093	1·0	0·142	1·3	0·274	1·8		5·0
5·5		0.006	0.3	0.010	0.3	0·023	0·5	0·044	0·7	0·098	1·0	0·150	1·3	0·289	1·8	0·15	5·5
6·0		0.006	0.3	0.011	0.3	0·025	0·5	0·046	0·7	0·103	1·1	0·158	1·3	0·303	1·9		6·0
6·5		0.007*	0.4	0.011	0.3	0·026	0·5	0·048	0·7	0·107	1·1	0·165	1·3	0·317	1·9		6·5
7·0		0.006	0.2	0.012	0.3	0·027	0·6	0·050	0·7	0·112	1·1	0·172	1·3	0·330	1·9		7·0
7·5		0.006	0.2	0.012	0.3	0·028	0·5	0·052	0·7	0·116	1·1	0·179	1·4	0·343	1·9		7·5
8·0		0.006	0.2	0.012	0.3	0·029	0·5	0·054	0·7	0·120	1·1	0·185	1·4	0·355	1·9		8·0
8·5		0.006	0.2	0.013	0.3	0·030	0·5	0·056	0·7	0·125	1·1	0·191	1·4	0·368	1·9		8·5
9·0		0.007	0.2	0.013†	0.3	0·031	0·5	0·058	0·7	0·129	1·1	0·198	1·4	0·379	1·9		9·0
9·5		0.007	0.2	0·014	0·3	0·032	0·5	0·060	0·7	0·133	1·1	0·204	1·4	0·391	1·9		9·5
10·0		0.007	0.2	0·014	0·3	0·033	0·5	0·062	0·7	0·136	1·1	0·210	1·4	0·402	2·0		10·0
12·5		0.008	0.2	0·016	0·3	0·037	0·5	0·070	0·8	0·154	1·1	0·237	1·4	0·454	2·0		12·5
15·0		0.008	0.2	0·018	0·4	0·042	0·6	0·077	0·8	0·171	1·2	0·262	1·5	0·502	2·0		15·0
17·5		0.009	0.2	0·019	0·4	0·045	0·6	0·084	0·8	0·186	1·2	0·285	1·5	0·546	2·0		17·5
20·0		0.010	0.2	0·021	0·4	0·049	0·6	0·091	0·8	0·200	1·2	0·307	1·5	0·587	2·1	0·30	20·0
22·5		0.010†	0.2	0·022	0·4	0·052	0·6	0·097	0·8	0·214	1·2	0·327	1·5	0·626	2·1		22·5
25·0		0.011	0.3	0·023	0·4	0·055	0·6	0·103	0·8	0·226	1·2	0·347	1·5	0·663	2·1		25·0
27·5		0.012	0.3	0·025	0·4	0·058	0·6	0·108	0·8	0·238	1·2	0·365	1·5	0·698	2·1		27·5
30·0		0.012	0.3	0·026	0·4	0·061	0·6	0·114	0·8	0·250	1·2	0·383	1·6	0·731	2·2		30·0
32·5		0·013	0·3	0·027	0·4	0·064	0·6	0·119	0·8	0·261	1·3	0·400	1·6	0·763	2·2		32·5
35·0		0·013	0·3	0·028	0·4	0·067	0·6	0·124	0·8	0·272	1·3	0·416	1·6	0·794	2·2		35·0
37·5		0·014	0·3	0·029	0·4	0·069	0·6	0·129	0·9	0·282	1·3	0·432	1·6	0·824	2·2		37·5
40·0		0·014	0·3	0·031	0·4	0·072	0·6	0·133	0·9	0·292	1·3	0·447	1·6	0·853	2·2		40·0
42·5	0·15	0·015	0·3	0·032	0·4	0·074	0·6	0·138	0·9	0·302	1·3	0·462	1·6	0·882	2·2		42·5
45·0		0·015	0·3	0·033	0·4	0·077	0·6	0·142	0·9	0·312	1·3	0·477	1·6	0·909	2·2		45·0
47·5		0·016	0·3	0·034	0·4	0·079	0·6	0·146	0·9	0·321	1·3	0·491	1·6	0·936	2·2		47·5
50·0		0·016	0·3	0·035	0·4	0·081	0·6	0·150	0·9	0·330	1·3	0·504	1·6	0·962	2·2		50·0
52·5		0·017	0·3	0·036	0·4	0·083	0·6	0·155	0·9	0·339	1·3	0·518	1·6	0·987	2·2	0·50	52·5
55·0		0·017	0·3	0·036	0·4	0·085	0·6	0·159	0·9	0·347	1·3	0·531	1·6	1·01	2·2		55·0
57·5		0·018	0·3	0·037	0·4	0·088	0·6	0·162	0·9	0·356	1·3	0·544	1·6	1·04	2·3		57·5
60·0		0·018	0·3	0·038	0·4	0·090	0·6	0·166	0·9	0·364	1·3	0·556	1·6	1·06	2·3		60·0
62·5		0·018	0·3	0·039	0·4	0·092	0·7	0·170	0·9	0·372	1·3	0·569	1·6	1·08	2·3		62·5
65·0		0·019	0·3	0·040	0·4	0·094	0·7	0·174	0·9	0·380	1·3	0·581	1·6	1·11	2·3		65·0
67·5		0·019	0·3	0·041	0·4	0·096	0·7	0·177	0·9	0·388	1·3	0·592	1·7	1·13	2·3		67·5
70·0		0·020	0·3	0·042	0·4	0·098	0·7	0·181	0·9	0·395	1·3	0·604	1·7	1·15	2·3		70·0
72·5		0·020	0·3	0·042	0·4	0·099	0·7	0·184	0·9	0·403	1·3	0·616	1·7	1·17	2·3		72·5
75·0		0·020	0·3	0·043	0·4	0·101	0·7	0·188	0·9	0·410	1·3	0·627	1·7	1·19	2·3		75·0
77·5		0·021	0·3	0·044	0·4	0·103	0·7	0·191	0·9	0·418	1·3	0·638	1·7	1·21	2·3		77·5

(continued overleaf)

Table 15.10 (*continued*)

Δp_l	ν	10 mm		15 mm		20 mm		25 mm		32 mm		40 mm		50 mm		ν	Δp_l
		M	l_e	M	l_e	M	l_e	M	l_e	M	l_e	M	l_e	M	l_e		
80·0		0·021	0·3	0·045	0·4	0·105	0·7	0·194	0·9	0·425	1·4	0·649	1·7	1·24	2·3		80·0
82·5		0·021	0·3	0·046	0·4	0·107	0·7	0·197	0·9	0·432	1·4	0·659	1·7	1·26	2·3		82·5
85·0		0·022	0·3	0·046	0·4	0·108	0·7	0·201	0·9	0·439	1·4	0·670	1·7	1·28	2·3		85·0
87·5		0·022	0·3	0·047	0·4	0·110	0·7	0·204	0·9	0·446	1·4	0·680	1·7	1·30	2·3		87·5
90·0		0·023	0·3	0·048	0·4	0·112	0·7	0·207	0·9	0·452	1·4	0·691	1·7	1·31	2·3		90·0
92·5		0·023	0·3	0·049	0·4	0·113	0·7	0·210	0·9	0·459	1·4	0·701	1·7	1·33	2·3		92·5
95·0		0·023	0·3	0·049	0·4	0·115	0·7	0·213	0·9	0·466	1·4	0·711	1·7	1·35	2·3		95·0
97·5		0·024	0·3	0·050	0·4	0·117	0·7	0·216	0·9	0·472	1·4	0·721	1·7	1·37	2·3		97·5
100		0·024	0·3	0·051	0·4	0·118	0·7	0·219	0·9	0·479	1·4	0·731	1·7	1·39	2·3		100
120		0·026	0·3	0·056	0·4	0·131	0·7	0·242	0·9	0·527	1·4	0·805	1·7	1·53	2·4		120
140	0·3	0·029	0·3	0·061	0·5	0·142	0·7	0·262	0·9	0·572	1·4	0·873	1·7	1·66	2·4		140
160		0·031	0·3	0·065	0·5	0·152	0·7	0·282	1·0	0·614	1·4	0·937	1·7	1·78	2·4		160
180		0·033	0·3	0·070	0·5	0·162	0·7	0·300	1·0	0·654	1·4	0·997	1·8	1·89	2·4		180
200		0·035	0·3	0·074	0·5	0·172	0·7	0·317	1·0	0·691	1·4	1·05	1·8	2·00	2·4	1·0	200
220		0·037	0·3	0·078	0·5	0·181	0·7	0·334	1·0	0·727	1·4	1·11	1·8	2·10	2·4		220
240		0·039	0·3	0·081	0·5	0·189	0·7	0·349	1·0	0·761	1·4	1·16	1·8	2·20	2·4		240
260		0·040	0·3	0·085	0·5	0·198	0·7	0·364	1·0	0·793	1·5	1·21	1·8	2·29	2·4		260
280		0·042	0·3	0·088	0·5	0·206	0·7	0·379	1·0	0·825	1·5	1·26	1·8	2·38	2·4		280
300		0·044	0·3	0·092	0·5	0·213	0·7	0·393	1·0	0·855	1·5	1·30	1·8	2·47	2·5		300
320		0·045	0·3	0·095	0·5	0·221	0·7	0·407	1·0	0·884	1·5	1·35	1·8	2·55	2·5		320
340		0·047	0·3	0·098	0·5	0·228	0·7	0·420	1·0	0·913	1·5	1·39	1·8	2·64	2·5		340
360		0·048	0·3	0·101	0·5	0·235	0·7	0·433	1·0	0·941	1·5	1·43	1·8	2·71	2·5		360
380	0·5	0·049	0·3	0·104	0·5	0·242	0·7	0·445	1·0	0·970	1·5	1·47	1·8	2·79	2·5		380
400		0·051	0·3	0·107	0·5	0·248	0·7	0·457	1·0	0·994	1·5	1·51	1·8	2·87	2·5		400
420		0·052	0·3	0·110	0·5	0·255	0·7	0·469	1·0	1·02	1·5	1·55	1·8	2·94	2·5		420
440		0·054	0·3	0·113	0·5	0·261	0·7	0·481	1·0	1·04	1·5	1·59	1·8	3·01	2·5	1·5	440
460		0·055	0·3	0·115	0·5	0·267	0·7	0·492	1·0	1·07	1·5	1·63	1·8	3·08	2·5		460
480		0·056	0·3	0·118	0·5	0·273	0·8	0·503	1·0	1·09	1·5	1·66	1·8	3·15	2·5		480
500		0·057	0·3	0·120	0·5	0·279	0·8	0·514	1·0	1·12	1·5	1·69	1·8	3·22	2·5		500
520		0·059	0·3	0·123	0·5	0·285	0·8	0·524	1·0	1·14	1·5	1·73	1·8	3·28	2·5		520
540		0·060	0·3	0·125	0·5	0·291	0·8	0·535	1·0	1·16	1·5	1·77	1·8	3·35	2·5		540
560		0·061	0·3	0·128	0·5	0·296	0·8	0·545	1·0	1·17	1·5	1·80	1·8	3·41	2·5		560
580		0·062	0·3	0·130	0·5	0·302	0·8	0·555	1·0	1·21	1·5	1·83	1·8	3·47	2·5		580
600		0·063	0·3	0·133	0·5	0·307	0·8	0·565	1·0	1·23	1·5	1·87	1·8	3·53	2·5		600
620		0·064	0·3	0·135	0·5	0·312	0·8	0·575	1·0	1·25	1·5	1·90	1·8	3·59	2·5		620
640		0·065	0·3	0·137	0·5	0·318	0·8	0·584	1·0	1·27	1·5	1·93	1·8	3·65	2·5		640
660		0·066	0·3	0·139	0·5	0·323	0·8	0·594	1·0	1·29	1·5	1·96	1·8	3·71	2·5		660
680		0·067	0·3	0·142	0·5	0·328	0·8	0·603	1·0	1·31	1·5	1·99	1·9	3·77	2·5		680
700		0·069	0·3	0·144	0·5	0·333	0·8	0·612	1·0	1·33	1·5	2·02	1·9	3·83	2·5		700
720		0·070	0·3	0·146	0·5	0·338	0·8	0·621	1·0	1·35	1·5	2·05	1·9	3·88	2·5		720
740		0·071	0·3	0·148	0·5	0·343	0·8	0·630	1·0	1·37	1·5	2·08	1·9	3·94	2·5		740
760		0·072	0·3	0·150	0·5	0·347	0·8	0·639	1·0	1·39	1·5	2·10	1·9	3·99	2·5	2·0	760
780		0·073	0·3	0·152	0·5	0·352	0·8	0·648	1·0	1·41	1·5	2·14	1·9	4·04	2·5		780
800		0·074	0·3	0·154	0·5	0·357	0·8	0·656	1·0	1·42	1·5	2·17	1·9	4·10	2·5		800
820		0·075	0·4	0·156	0·5	0·362	0·8	0·665	1·0	1·44	1·5	2·19	1·9	4·15	2·5		820
840		0·075	0·4	0·158	0·5	0·366	0·8	0·673	1·0	1·46	1·5	2·22	1·9	4·20	2·5		840
860		0·076	0·4	0·160	0·5	0·371	0·8	0·681	1·0	1·48	1·5	2·25	1·9	4·25	2·5		860
880		0·077	0·4	0·162	0·5	0·375	0·8	0·689	1·0	1·50	1·5	2·27	1·9	4·30	2·5		880
900		0·078	0·4	0·164	0·5	0·379	0·8	0·698	1·0	1·51	1·5	2·30	1·9	4·35	2·5		900
920		0·079	0·4	0·166	0·5	0·384	0·8	0·706	1·0	1·53	1·5	2·33	1·9	4·40	2·5		920
940		0·080	0·4	0·168	0·5	0·388	0·8	0·713	1·0	1·55	1·5	2·35	1·9	4·45	2·5		940
960		0·081	0·4	0·170	0·5	0·392	0·8	0·721	1·0	1·56	1·5	2·38	1·9	4·50	2·5		960
980		0·082	0·4	0·172	0·5	0·397	0·8	0·729	1·0	1·58	1·5	2·40	1·9	4·55	2·5		980
1 000		0·083	0·4	0·173	0·5	0·401	0·8	0·737	1·0	1·60	1·5	2·43	1·9	4·59	2·5		1 000
1 100		0·087	0·4	0·182	0·5	0·421	0·8	0·774	1·1	1·68	1·5	2·55	1·9	4·82	2·6		1 100
1 200		0·091	0·4	0·191	0·5	0·441	0·8	0·809	1·1	1·75	1·5	2·67	1·9	5·04	2·6		1 200
1 300	1·0	0·095	0·4	0·199	0·5	0·459	0·8	0·844	1·1	1·83	1·5	2·78	1·9	5·25	2·6		1 300
1 400		0·099	0·4	0·207	0·5	0·477	0·8	0·876	1·1	1·90	1·5	2·89	1·9	5·46	2·6		1 400
1 500		0·102	0·4	0·214	0·5	0·495	0·8	0·908	1·1	1·98	1·5	2·99	1·9	5·65	2·6		1 500
1 600		0·106	0·4	0·222	0·5	0·511	0·8	0·939	1·1	2·03	1·5	3·09	1·9	5·84	2·6		1 600
1 700		0·109	0·4	0·229	0·5	0·528	0·8	0·968	1·1	2·10	1·5	3·19	1·9	6·02	2·6	3·0	1 700
1 800		0·113	0·4	0·236	0·5	0·543	0·8	0·997	1·1	2·16	1·6	3·28	1·9				1 800
1 900		0·116	0·4	0·242	0·5	0·559	0·8	1·03	1·1	2·22	1·6	3·37	1·9				1 900
2 000		0·119	0·4	0·249	0·5	0·574	0·8	1·05	1·1	2·28	1·6	3·46	1·9				2 000

Table 15.10 (*continued*)

Δp_1	v	65 mm		80 mm		90 mm		100 mm		125 mm		150 mm		v	Δp_1
		M	l_e	M	l_e	M	l_e	M	l_e	M	l_e	M	l_e		
0·1		0·061	1·5	0·096	2·0	0.144	2·5	0·200	2·9	0·362	4·1	0·600	5·3		0·1
0·2		0·091	1·7	0·144	2·2	0·215	2·7	0·298	3·3	0·544	4·5	0·889	5·8	0·05	0·2
0·3		0·115	1·8	0·181	2·3	0·271	2·9	0·375	3·4	0·685	4·7	1·12	6·1		0·3
0·4		0·136	1·9	0·214	2·4	0·319	3·0	0·442	3·6	0·805	4·9	1·31	6·4		0·4
0·5		0·154	2·0	0·243	2·5	0·362	3·1	0·501	3·7	0·913	5·0	1·49	6·5		0·5
0·6	0·05	0·171	2·0	0·269	2·6	0·401	3·2	0·556	3·8	1·01	5·1	1·65	6·6		0·6
0·7		0·187	2·1	0·294	2·6	0·438	3·2	0·606	3·8	1·10	5·2	1·79	6·7		0·7
0·8		0·202	2·1	0·317	2·7	0·472	3·3	0·653	3·9	1·19	5·3	1·93	6·8		0·8
0·9		0·216	2·1	0·339	2·7	0·504	3·3	0·698	4·0	1·27	5·4	2·06	6·9		0·9
1·0		0·229	2·2	0·359	2·8	0·535	3·4	0·740	4·0	1·34	5·5	2·18	7·0		1·0
1·5		0·288	2·3	0·451	2·9	0·671	3·6	0·928	4·2	1·68	5·7	2·73	7·3	0·15	1·5
2·0		0·338	2·4	0·530	3·0	0·787	3·7	1·09	4·3	1·97	5·9	3·20	7·5		2·0
2·5		0·383	2·4	0·600	3·1	0·891	3·8	1·23	4·4	2·23	6·0	3·61	7·6		2·5
3·0		0·424	2·5	0·664	3·1	0·985	3·8	1·36	4·5	2·46	6·1	3·99	7·7		3·0
3·5		0·462	2·5	0·723	3·2	1·07	3·9	1·48	4·6	2·68	6·2	4·34	7·9		3·5
4·0	0·15	0·498	2·6	0·778	3·2	1·15	3·9	1·59	4·6	2·88	6·3	4·66	8·0		4·0
4·5		0·531	2·6	0·830	3·3	1·23	4·0	1·70	4·7	3·07	6·3	4·97	8·0		4·5
5·0		0·563	2·6	0·880	3·3	1·30	4·0	1·80	4·7	3·25	6·4	5·26	8·1	0·30	5·0
5·5		0·594	2·7	0·927	3·3	1·37	4·1	1·90	4·8	3·42	6·4	5·54	8·2		5·5
6·0		0·623	2·7	0·973	3·4	1·44	4·1	1·99	4·8	3·59	6·5	5·81	8·2		6·0
6·5		0·651	2·7	1·02	3·4	1·51	4·1	2·08	4·9	3·75	6·5	6·06	8·3		6·5
7·0		0·678	2·7	1·06	3·4	1·57	4·2	2·16	4·9	3·90	6·6	6·31	8·3		7·0
7·5		0·704	2·7	1·10	3·4	1·63	4·2	2·24	4·9	4·05	6·6	6·55	8·4		7·5
8·0		0·729	2·7	1·14	3·5	1·69	4·2	2·32	4·9	4·19	6·6	6·78	8·4		8·0
8·5		0·754	2·8	1·18	3·5	1·74	4·2	2·40	5·0	4·33	6·7	7·00	8·4		8·5
9·0		0·778	2·8	1·21	3·5	1·80	4·2	2·48	5·0	4·46	6·7	7·22	8·5		9·0
9·5		0·801	2·8	1·25	3·5	1·85	4·3	2·55	5·0	4·60	6·7	7·43	8·5		9·5
10·0		0·824	2·8	1·29	3·5	1·90	4·3	2·62	5·0	4·72	6·7	7·63	8·5		10·0
12·5		0·930	2·9	1·45	3·6	2·14	4·4	2·96	5·1	5·32	6·8	8·60	8·7	0·50	12·5
15·0	0·30	1·03	2·9	1·60	3·6	2·37	4·4	3·26	5·2	5·87	6·9	9·47	8·8		15·0
17·5		1·12	3·0	1·74	3·7	2·57	4·5	3·54	5·2	6·37	7·0	10·3	8·8		17·5
20·0		1·20	3·0	1·87	3·7	2·76	4·5	3·80	5·3	6·84	7·1	11·0	8·9		20·0
22·5		1·28	3·0	1·99	3·8	2·94	4·6	4·05	5·3	7·28	7·1	11·7	9·0		22·5
25·0		1·35	3·0	2·11	3·8	3·11	4·6	4·28	5·4	7·69	7·1	12·4	9·0		25·0
27·5		1·42	3·1	2·22	3·8	3·27	4·6	4·50	5·4	8·09	7·2	13·0	9·1		27·5
30·0		1·49	3·1	2·32	3·8	3·43	4·6	4·71	5·4	8·47	7·2	13·6	9·1		30·0
32·5		1·56	3·1	2·42	3·8	3·58	4·7	4·92	5·4	8·84	7·3	14·2	9·1		32·5
35·0		1·62	3·1	2·52	3·9	3·72	4·7	5·12	5·5	9·19	7·3	14·8	9·2		35·0
37·5	0·50	1·68	3·1	2·61	3·9	3·86	4·7	5·31	5·5	9·53	7·3	15·3	9·2		37·5
40·0		1·74	3·1	2·70	3·9	3·99	4·7	5·49	5·5	9·86	7·3	15·9	9·2		40·0
42·5		1·80	3·1	2·79	3·9	4·12	4·7	5·67	5·5	10·2	7·4	16·4	9·3		42·5
45·0		1·85	3·2	2·88	3·9	4·25	4·7	5·84	5·5	10·5	7·4	16·9	9·3		45·0
47·5		1·91	3·2	2·96	3·9	4·37	4·8	6·01	5·6	10·8	7·4	17·4	9·3		47·5
50·0		1·96	3·2	3·04	3·9	4·49	4·8	6·17	5·6	11·1	7·4	17·8	9·3	1·0	50·0
52·5		2·01	3·2	3·12	4·0	4·61	4·8	6·33	5·6	11·4	7·4	18·3	9·3		52·5
55·0		2·06	3·2	3·20	4·0	4·72	4·8	6·49	5·6	11·6	7·4	18·8	9·4		55·0
57·5		2·11	3·2	3·28	4·0	4·83	4·8	6·64	5·6	11·9	7·5	19·2	9·4		57·5
60·0		2·16	3·2	3·35	4·0	4·94	4·8	6·79	5·6	12·2	7·5	19·6	9·4		60·0
62·5		2·20	3·2	3·42	4·0	5·05	4·8	6·94	5·6	12·5	7·5	20·0	9·4		62·5
65·0		2·25	3·2	3·50	4·0	5·16	4·8	7·08	5·7	12·7	7·5	20·5	9·4		65·0
67·5		2·30	3·2	3·57	4·0	5·26	4·9	7·22	5·7	13·0	7·5	20·9	9·4		67·5
70·0		2·34	3·2	3·63	4·0	5·36	4·9	7·36	5·7	13·2	7·5	21·3	9·4		70·0
72·5		2·38	3·2	3·70	4·0	5·46	4·9	7·50	5·7	13·5	7·5	21·7	9·5		72·5
75·0		2·43	3·3	3·77	4·0	5·56	4·9	7·63	5·7	13·7	7·5	22·0	9·5		75·0
77·5		2·47	3·3	3·83	4·0	5·65	4·9	7·77	5·7	13·9	7·5	22·4	9·5		77·5

(*continued overleaf*)

or other gas). The gas pressure displaces the condensate (which can be at any temperature up to and including boiling point) through a check valve at the outlet from the pump body. At the end of the discharge stroke, the internal mechanism changes over to close the pressurizing inlet valve and open the exhaust valve. The pressurizing gas is then vented to atmosphere, or to the space from which the condensate is being drained. When the pressures are equalized, condensate can flow by gravity into the pump body to refill it and complete the cycle. As the pump fills only by gravity, there can be no cavitation and pumps of this type readily handle boiling water or other liquids, compatible with the materials of construction.

Most often, the pump uses steam as the operating medium. This steam is exhausted at the end of the discharge stroke to the same pressure as the space from

Table 15.10 (*continued*)

Δp_l	v	65 mm		80 mm		90 mm		100 mm		125 mm		150 mm		v	Δp_l
		M	l_e	M	l_e	M	l_e	M	l_e	M	l_e	M	l_e		
80·0		2·51	3·3	3·90	4·0	5·75	4·9	7·90	5·7	14·2	7·6	22·8	9·5		80·0
82·5		2·55	3·3	3·96	4·1	5·84	4·9	8·02	5·7	14·4	7·6	23·2	9·5		82·5
85·0		2·59	3·3	4·02	4·1	5·93	4·9	8·15	5·7	14·6	7·6	23·5	9·5		85·0
87·5		2·63	3·3	4·09	4·1	6·02	4·9	8·27	5·7	14·8	7·6	23·9	9·5		87·5
90·0		2·67	3·3	4·15	4·1	6·11	4·9	8·40	5·7	15·0	7·6	24·2	9·5		90·0
92·5		2·71	3·3	4·21	4·1	6·20	4·9	8·52	5·7	15·3	7·6	24·6	9·5		92·5
95·0		2·75	3·3	4·27	4·1	6·29	4·9	8·64	5·7	15·5	7·6	24·9	9·6		95·0
97·5		2·79	3·3	4·32	4·1	6·37	4·9	8·75	5·8	15·7	7·6	25·2	9·6		97·5
100·0		2·82	3·3	4·38	4·1	6·46	4·9	8·87	5·8	15·9	7·6	25·6	9·6	1·5	100·0
120·0		3·11	3·3	4·82	4·1	7·10	5·0	9·75	5·8	17·5	7·7	28·1	9·6		120·0
140·0	1·0	3·37	3·4	5·22	4·2	7·69	5·0	10·6	5·8	18·9	7·7	30·4	9·7		140·0
160·0		3·61	3·4	5·60	4·2	8·25	5·0	11·3	5·9	20·3	7·7	32·6	9·7		160·0
180·0		3·84	3·4	5·95	4·2	8·76	5·0	12·0	5·9	21·6	7·8	34·6	9·7	2·0	180·0
200·0		4·05	3·4	6·29	4·2	9·25	5·0	12·7	5·9	22·7	7·8	36·5	9·8		200·0
220·0		4·26	3·4	6·60	4·2	9·72	5·1	13·3	5·9	23·9	7·8	38·4	9·8		220·0
240·0		4·46	3·4	6·91	4·2	10·2	5·1	14·0	5·9	25·0	7·8	40·1	9·8		240·0
260·0		4·65	3·4	7·20	4·2	10·6	5·1	14·5	6·0	26·0	7·9	41·8	9·8		260·0
280·0		4·83	3·4	7·48	4·3	11·0	5·1	15·1	6·0	27·0	7·9	43·4	9·9		280·0
300·0	1·5	5·00	3·5	7·75	4·3	11·4	5·1	15·6	6·0	28·0	7·9	45·0	9·9		300·0
320·0		5·17	3·5	8·01	4·3	11·8	5·1	16·2	6·0	29·0	7·9	46·5	9·9		320·0
340·0		5·34	3·5	8·27	4·3	12·2	5·2	16·7	6·0	29·8	7·9	47·9	9·9		340·0
360·0		5·50	3·5	8·51	4·3	12·5	5·2	17·2	6·0	30·7	7·9	49·4	9·9		360·0
380·0		5·65	3·5	8·75	4·3	12·8	5·2	17·7	6·0	31·6	7·9	50·7	9·9		380·0
400·0		5·80	3·5	8·99	4·3	13·2	5·2	18·1	6·0	32·4	7·9	52·1	9·9		400·0
420·0		5·95	3·5	9·22	4·3	13·6	5·2	18·6	6·0	33·2	7·9	53·4	9·9		420·0
440·0		6·09	3·5	9·44	4·3	13·9	5·2	19·0	6·0	34·0	7·9	54·7	9·9	3·0	440·0
460·0		6·24	3·5	9·66	4·3	14·2	5·2	19·5	6·0	34·8	8·0	55·9	9·9		460·0
480·0		6·37	3·5	9·87	4·3	14·5	5·2	19·9	6·0	35·6	8·0	57·2	10		480·0
500·0		6·51	3·5	10·1	4·3	14·8	5·2	20·3	6·0	36·3	8·0	58·4	10		500·0
520·0		6·64	3·5	10·3	4·3	15·1	5·2	20·7	6·1	37·1	8·0	59·5	10		520·0
540·0	2·0	6·77	3·5	10·5	4·3	15·4	5·2	21·1	6·1	37·8	8·0	60·7	10		540·0
560·0		6·90	3·5	10·7	4·3	15·7	5·2	21·5	6·1	38·5	8·0	61·8	10		560·0
580·0		7·02	3·5	10·9	4·3	16·0	5·2	21·9	6·1	39·2	8·0	62·9	10		580·0
600·0		7·15	3·5	11·1	4·3	16·3	5·2	22·3	6·1	39·9	8·0	64·0	10		600·0
620·0		7·27	3·5	11·3	4·4	16·6	5·2	22·7	6·1	40·5	8·0	65·1	10		620·0
640·0		7·39	3·5	11·4	4·4	16·8	5·2	23·1	6·1	41·2	8·0	66·2	10		640·0
660·0		7·50	3·5	11·6	4·4	17·1	5·2	23·4	6·1	41·9	8·0	67·2	10		660·0
680·0		7·62	3·5	11·8	4·4	17·3	5·2	23·8	6·1	42·5	8·0	68·2	10		680·0
700·0		7·73	3·5	12·0	4·4	17·6	5·2	24·1	6·1	43·1	8·0	69·2	10		700·0
720·0		7·85	3·5	12·2	4·4	17·8	5·2	24·5	6·1	43·7	8·0	70·2	10		720·0
740·0		7·96	3·5	12·3	4·4	18·1	5·2	24·8	6·1	44·4	8·0	71·2	10		740·0
760·0		8·07	3·5	12·4	4·4	18·4	5·3	25·1	6·1	45·0	8·0	72·2	10	4·0	760·0
780·0		8·17	3·5	12·6	4·4	18·6	5·3	25·5	6·1	45·6	8·0				780·0
800·0		8·28	3·6	12·8	4·4	18·8	5·3	25·8	6·1	46·2	8·0				800·0
820·0		8·39	3·6	12·9	4·4	19·1	5·3	26·2	6·1	46·7	8·0				820·0
840·0		8·49	3·6	13·1	4·4	19·3	5·3	26·5	6·1	47·3	8·0				840·0
860·0		8·59	3·6	13·3	4·4	19·6	5·3	26·8	6·1	47·9	8·0				860·0
880·0		8·69	3·6	13·5	4·4	19·8	5·3	27·1	6·1	48·4	8·0				880·0
900·0		8·80	3·6	13·6	4·4	20·0	5·3	27·4	6·1	49·0	8·0				900·0
920·0		8·89	3·6	13·8	4·4	20·2	5·3	27·7	6·1	49·6	8·1				920·0
940·0		8·99	3·6	13·9	4·4	20·5	5·3	28·0	6·1	50·1	8·1				940·0
960·0		9·09	3·6	14·1	4·4	20·7	5·3	28·3	6·1	50·6	8·1				960·0
980·0		9·19	3·6	14·2	4·4	20·9	5·3	28·6	6·1						980·0
1 000·0		9·28	3·6	14·4	4·4	21·1	5·3	28·9	6·1						1 000·0
1 100·0		9·74	3·6	15·1	4·4	22·2	5·3	30·4	6·1						1 100·0
1 200·0	3·0	10·2	3·6	15·8	4·4	23·2	5·3	31·7	6·1						1 200·0
1 300·0		10·6	3·6	16·4	4·4	24·1	5·3								1 300·0
1 400·0		11·0	3·6	17·0	4·4	25·0	5·3								1 400·0
1 500·0		11·4	3·6	17·6	4·4										1 500·0
1 600·0		11·8	3·6	18·2	4·4										1 600·0
1 700·0		12·2	3·6	18·8	4·4										1 700·0
1 800·0		12·5	3·6												1 800·0
1 900·0		12·9	3·6												1 900·0
2 000·0		13·2	3·6												2 000·0

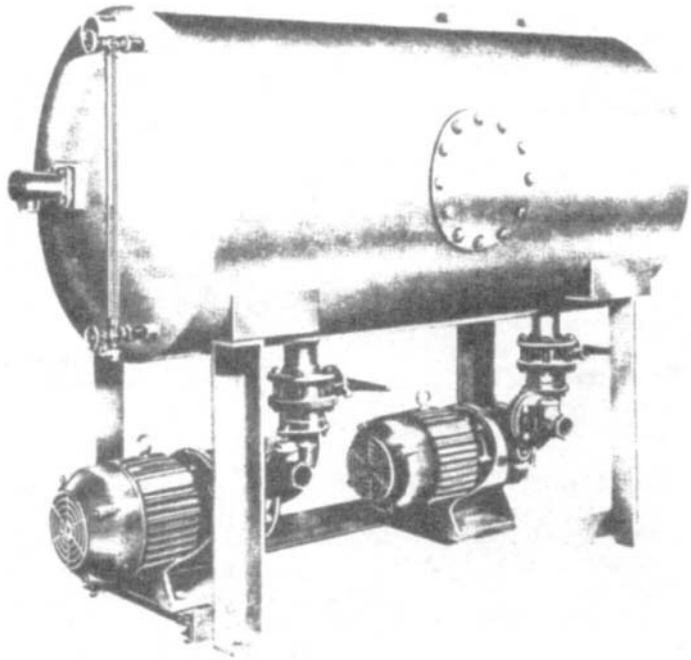


Figure 15.22 Condensate-recovery unit

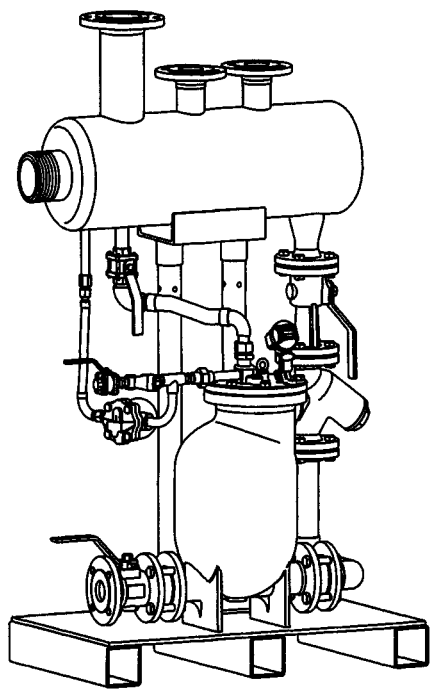


Figure 15.23 Spirax Ogden packaged unit

which the condensate is being drained. It is often possible where the larger condensate loads are being handled to dedicate a single pump to each load. The pump exhaust line can then be directly connected to the steam space of the heat exchanger, with condensate draining freely to the pump inlet and with any steam trap at the pump outlet.

During the discharge stroke the inlet check valve is closed. Condensate draining from the steam space then fills the inlet piping. Unless the piping is sufficiently

large or contains a receiver section (reservoir), condensate could back up into the steam space being drained.

A similar reservoir is desirable where multiple loads discharge through individual steam traps to a common pump. Provision should then be made for venting incondensables and flash steam which reach the reservoir. The exhaust line from the pump can then be connected to the same vent line.

15.7.5 Allowance for expansion

All pipes will be installed at ambient temperature. Pipes used to carry hot fluids, whether water, oil or steam, operate at higher temperatures. It follows that they expand (especially in length) with the increase from ambient to working temperatures. The amount of the expansion is readily calculated or read from charts, and Table 15.11 may be helpful.

The piping must be sufficiently flexible to accommodate the movements of the components as it heats up. In many cases the piping has enough natural flexibility, by virtue of having reasonable lengths and plenty of bends, that no undue stresses are set up. In other installations it is necessary to build in some means of achieving the required flexibility.

Where the condensate from a steam main drain trap is discharged into a return line running alongside the steam line the difference between the expansion of the two lines must be remembered. The steam line may be at a temperature very much above that of the return line, and the two connection points can move in relation to each other during system warm-up. Some flexibility should be incorporated into the steam trap piping so that branch connections do not become overstressed, as in Figure 15.24.

Table 15.11 Expansion of pipes

Final temperature		*Expansion per 30 m(mm)*	*(100 ft)(in)*
(°C)	*(°F)*		
66	150	19	0.75
93	200	29	1.14
121	250	41	1.61
149	300	50	1.97
177	350	61	2.4
204	400	74	2.91
232	450	84	3.3
260	500	97	3.8

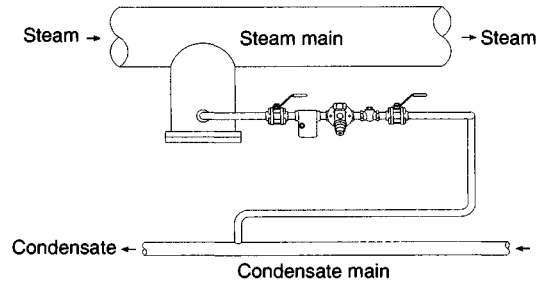


Figure 15.24 Flexible trapping arrangements

The amount of movement to be taken up by the piping and any device incorporated into it can be reduced by the use of 'cold draw'. The total amount of expansion is first calculated for each section between fixed anchor points. The pipes are left short by half this amount, and stretched cold, as by pulling up bolts at a flanged joint, so that at ambient temperature the system is stressed in one direction. When warmed through half the total temperature rise, and having expanded by half the total amount, the piping is unstressed. At working temperature and having fully expanded, the piping is stressed in the opposite direction. The effect is that instead of being stressed from zero to $+f$ units, the piping is stressed from $-1/2f$ to $+1/2f$.

In practical terms the piping is assembled with a spacer piece, of length equal to half the expansion, between two flanges. When the piping is fully installed and anchored the spacer is removed and the joint pulled up tight (Figure 15.25). The remaining part of the expansion, if not accepted by the natural flexibility of the piping, will call for the use of an expansion fitting. These can take several forms.

15.7.6 Full loop

This is simply one complete turn of the pipe and should preferably be fitted in a horizontal rather than a vertical position to prevent condensate building up. The downstream side passes below the upstream side and great care must be taken that it is not fitted the wrong way round. When full loops are to be fitted in a confined space, care must be taken in ordering, otherwise wrong-handed loops may be supplied.

The full loop does not produce a force in opposition to the expanding pipework as in some other types but with steam pressure inside the loop, there is a slight tendency to unwind, which puts an additional stress on the flanges.

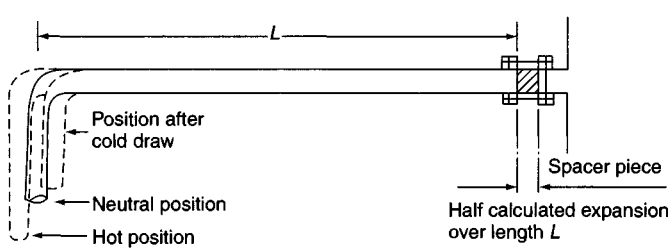


Figure 15.25 Cold draw

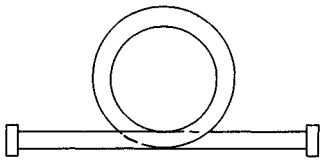


Figure 15.26 Full loop

15.7.7 The horse-shoe or lyre loop

Where space is available this type is sometimes used. It is best fitted horizontally so that the loop and main are all in the same plane. Pressure does not tend to blow the ends of the loop apart but there is a very slight straightening out effect. This is due to the design but causes no misalignment of the flanges.

In other cases the 'loop' is fabricated from straight lengths of pipe and 90° bends. This may not be as effective and requires more space but it meets the same need.

If any of these arrangements are fitted with the loop vertically above the pipe then a drain point must be provided on the upstream side.

15.7.8 Sliding joint

These are often used because they take up little room but it is essential that the pipeline is rigidly anchored and guided. This is because steam pressure acting on the cross-sectional area of the sleeve part of the joint tends to blow the joint apart in opposition to the forces produced by the expanding pipework. Misalignment will cause the sliding sleeve to bend, while regular maintenance of the gland packing is also needed.

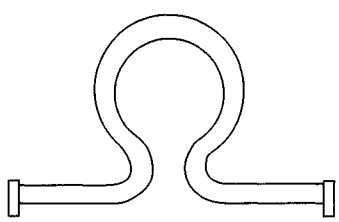


Figure 15.27 Horse-shoe loop

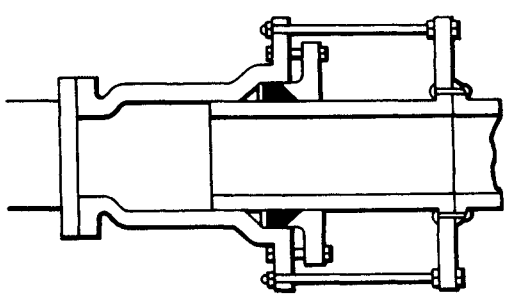


Figure 15.28 Sliding joint

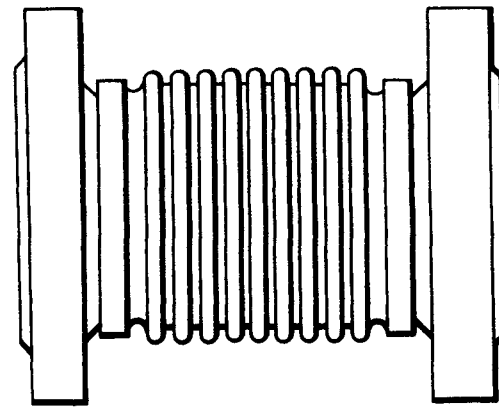


Figure 15.29 Bellows

15.7.9 Bellows

A simple bellows has the advantage that it is an in-line fitting and requires no packing as does the sliding joint type. But it does have the same disadvantage as the sliding joint in that pressure inside tends to extend the fitting so that anchors and guides must be able to withstand this force.

The bellows can, however, be incorporated into a properly designed expansion fitting as shown in Figure 15.30, which is capable of absorbing not only axial movement of the pipeline but some lateral and angular displacement as well.

If expansion fittings are to work as intended, it is essential that the steam line is properly anchored at some

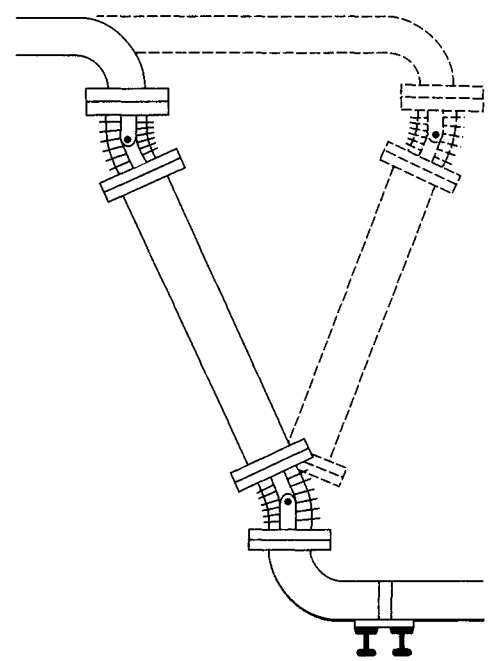


Figure 15.30 Expansion fitting

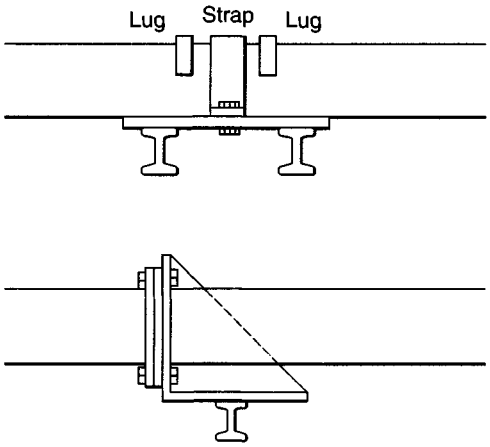


Figure 15.31 Anchor points

point between the expansion fittings. Guiding is also important to ensure that any movement does not interfere with the designed fall towards the drain points.

Detailed design is clearly outside the scope of this section but Figure 15.31 shows some typical anchor points utilizing pipe flanges or lugs welded onto the pipe.

15.8 Proposed pressure systems and transportable gas containers regulations

What are these proposed regulations?

A set of legally enforceable rules, to ensure the integrity of pressure systems and certain containers for gases under pressure, by a written scheme of examination.

Is there a Code of Practice?

Yes, and compliance with the Code of Practice will be acceptable providing that the requirements of the Health and Safety at Work Act 1974 and the Pressure Systems Regulations are fulfilled.

Why do we need more regulations?

The existing Factories Act has many grey areas, which can allow certain potentially dangerous systems to escape examination. This was highlighted, for example, by the enquiry which followed the Flixborough incident. It was then established that many pressure systems containing or carrying corrosive, flammable, explosive or toxic gases are not covered by the Factories Act.

Typically, the Factories Act applies to the boiler or other pressure-containing vessels. However, there may well be other parts of the pressure system which are equally dangerous.

What types of pressure systems are included?

All steam systems (regardless of pressure). All medium- and high-temperature hot water systems where an escape of liquid could lead to 'flashing'. Gas systems operating above 0.5 bar g pressure containing any substance included within the definition of a 'relevant fluid'.

Are there any total exemptions?

Yes, there are many. They are mainly confined to MoD, merchant shipping, aircraft and industries already covered by more stringent requirements. Exemptions also apply to some systems which are small and already have an excellent safety record, such as domestic refrigerators, pneumatic tyres and vehicle braking systems. However, it is believed that an 'Espresso' coffee percolator in a restaurant would be included.

How often will examination of a system be required?

Existing boiler examinations are at not more than 13-month intervals, while examination of air/oil separators is required at not more than 72 months, currently. Depending on the actual condition of the system as found at the time of the first examination, the required period could be anywhere between 13 and 72 months. Provision is made in the proposed regulations for the period to be extended even further.

What parts of the system must be examined?

In theory, all parts of it – but much will depend on the actual condition, and the quality of the maintenance. All pressure vessels, and all protective devices, will be examined. Whether pipework, pipe supports, and flexible hoses will be included will depend on the type of industry.

Whose responsibility is it to have a written system of examination?

The person who has overall control of the factory. Generally, this would be the owner, or user or the appointed agent.

Who draws up, and implements, the written scheme of examination?

A 'Competent Person'. That is, a person or a corporate body with certain qualifications and relevant industrial experience. The competency may be found in-house or be an outside consultant. A Competent Person could actually be two persons, perhaps one to draw up a scheme and one to implement it.

Table 1 Steam Tables (metric SI units)

Pressure		*Temperature* °C	*Specific enthalpy*			*Specific volume steam*
bar	*kPa*		*Water* (h_f) *kJ/kg*	*Evaporation* (h_{fg}) *kJ/kg*	*Steam* (h_g) *kJ/kg*	m^3/kg
0.30	30.0	69.10	289.23	2336.1	2625.3	5.229
0.50	50.0	81.33	340.49	2305.4	2645.9	3.240
absolute						
0.75	75.0	91.78	384.39	2278.6	2663.0	2.217
0.95	95.0	98.20	411.43	2261.8	2673.2	1.777
0	0	100.00	419.04	2257.0	2676.0	1.673
gauge						
0.10	10.0	102.66	430.2	2250.2	2680.4	1.533
0.20	20.0	105.10	440.8	2243.4	2684.2	1.414
0.30	30.0	107.39	450.4	2237.2	2687.6	1.312
0.40	40.0	109.55	459.7	2231.3	2691.0	1.225
0.50	50.0	111.61	468.3	2225.6	2693.9	1.149
0.60	60.0	113.56	476.4	2220.4	2696.8	1.083
0.70	70.0	115.40	484.1	2215.4	2699.5	1.024
0.80	80.0	117.14	491.6	2210.5	2702.1	0.971
0.90	90.0	118.80	498.9	2205.6	2704.5	0.923
1.00	100.0	120.42	505.6	2201.1	2706.7	0.881
1.10	110.0	121.96	512.2	2197.0	2709.2	0.841
1.20	120.0	123.46	518.7	2192.8	2711.5	0.806
1.30	130.0	124.90	524.6	2188.7	2713.3	0.773
1.40	140.0	126.28	530.5	2184.8	2715.3	0.743
1.50	150.0	127.62	536.1	2181.0	2717.1	0.714
1.60	160.0	128.89	541.6	2177.3	2718.9	0.689
1.70	170.0	130.13	547.1	2173.7	2720.8	0.665
1.80	180.0	131.37	552.3	2170.1	2722.4	0.643
1.90	190.0	132.54	557.3	2166.7	2724.0	0.622
2.00	200.0	133.69	562.2	2163.3	2725.5	0.603
2.20	220.0	135.88	571.7	2156.9	2728.6	0.568
2.40	240.0	138.01	580.7	2150.7	2731.4	0.536
2.60	260.0	140.00	589.2	2144.7	2733.9	0.509
2.80	280.0	141.92	597.4	2139.0	2736.4	0.483
3.00	300.0	143.75	605.3	2133.4	2738.7	0.461
3.20	320.0	145.46	612.9	2128.1	2741.0	0.440
3.40	340.0	147.20	620.0	2122.9	2742.9	0.422
3.60	360.0	148.84	627.1	2117.8	2744.9	0.406
3.80	380.0	150.44	634.0	2112.9	2746.9	0.389
4.00	400.0	151.96	640.7	2108.1	2748.8	0.374
4.50	450.0	155.55	656.3	2096.7	2753.0	0.342
5.00	500.0	158.92	670.9	2086.0	2756.9	0.315
5.50	550.0	162.08	684.6	2075.7	2760.3	0.292
6.00	600.0	165.04	697.5	2066.0	2763.5	0.272
6.50	650.0	167.83	709.7	2056.8	2766.5	0.255
7.00	700.0	170.50	721.4	2047.7	2769.1	0.240
7.50	750.0	173.02	732.5	2039.2	2771.7	0.227
8.00	800.0	175.43	743.1	2030.9	2774.0	0.215
8.50	850.0	177.75	753.3	2022.9	2776.2	0.204
9.00	900.0	179.97	763.0	2015.1	2778.1	0.194
9.50	950.0	182.10	772.5	2007.5	2780.0	0.185
10.00	1000.0	184.13	781.6	2000.1	2781.7	0.177
10.50	1050.0	186.05	790.1	1993.0	2783.3	0.171
11.00	1100.0	188.02	798.8	1986.0	2784.8	0.163
11.50	1150.0	189.82	807.1	1979.1	2786.3	0.157
12.00	1200.0	191.68	815.1	1972.5	2787.6	0.151
12.50	1250.0	193.43	822.9	1965.4	2788.8	0.148
13.00	1300.0	195.10	830.4	1959.6	2790.0	0.141
13.50	1350.0	196.62	837.9	1953.2	2791.1	0.136

(*continued overleaf*)

Pressure		Temperature °C	Specific enthalpy			Specific volume steam m^3/kg
bar	kPa		Water (h_f) kJ/kg	Evaporation (h_{fg}) kJ/kg	Steam (h_g) kJ/kg	
14.00	1400.0	198.35	845.1	1947.1	2792.2	0.132
14.50	1450.0	199.92	852.1	1941.0	2793.1	0.128
15.00	1500.0	201.45	859.0	1935.0	2794.0	0.124
15.50	1550.0	202.92	865.7	1928.8	2794.9	0.119
16.00	1600.0	204.38	872.3	1923.4	2795.7	0.117
17.00	1700.0	207.17	885.0	1912.1	2797.1	0.110
18.00	1800.0	209.90	897.2	1901.3	2798.5	0.105
19.00	1900.0	212.47	909.0	1890.5	2799.5	0.100
20.00	2000.0	214.96	920.3	1880.2	2800.5	0.0949
21.00	2100.0	217.35	931.3	1870.1	2801.4	0.0906
22.00	2200.0	219.65	941.9	1860.1	2802.0	0.0868
23.00	2300.0	221.85	952.2	1850.4	2802.6	0.0832
24.00	2400.0	224.02	962.2	1840.9	2803.1	0.0797
25.00	2500.0	226.12	972.1	1831.4	2803.5	0.0768
26.00	2600.0	228.15	981.6	1822.2	2803.8	0.0740
27.00	2700.0	230.14	990.7	1813.3	2804.0	0.0714

What are the minimum qualifications of a competent person?

For minor systems, a Tech. Eng.

For intermediate and major systems, a Chartered Engineer.

What is involved in implementation of a written scheme?

A critical scrutiny of a pressure system, or of part of it, whether or not in service, and including testing as necessary, to determine the actual condition and fitness for use during the period until the next examination. A written report must be made and copies of this kept by both the examiner and the user. In any case where the report indicates that the system is unsafe it will then be an offence to operate the system until the necessary repairs are carried out.

What changes in working practices will be needed in a steam-using plant?

Where preventive maintenance and good housekeeping are already the normal practice, the new regulations will have little effect on most steam users. On the other hand, where this is not the case, then upgrading of practices and maintenance of proper records will, quite rightly, become enforceable requirements.

16 Heating

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Chartered Engineer

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16.1 Introduction

The past 50 years have seen significant advances in every aspect of space heating, resulting from increased demands for the provision within buildings of more closely controlled environments and services of progressively increasing complexity. Although it remains impossible in a chapter of this size to cover adequately the extent of the subjects associated with these services, hopefully it will provide a useful reference.

16.2 Statutory regulations

The Fuel and Electricity (Heating) (Control) Order 1974 and Fuel and Electricity (Heating) (Control) (Amendment) Order 1980 prohibit the use of fuels or electricity to heat premises above 19°C. This does not mean that the temperature in buildings must be kept below 19°C but only that fuel or electricity must not be used to raise the temperature above this level. For some applications, the recommended minimum winter design temperatures exceed 19°C. In these cases, it is assumed that the recommended temperatures can be maintained by contributions from heat sources other than the heating system. These may include solar radiation, heat gains from lighting, equipment and machinery and heat gains from the occupants themselves.

16.3 Building regulations

It is essential for designers to be fully conversant with current statutory requirements, the various means of compliance, and beware of any proposed amendments which may be relevant to design work already in hand. This is very important since the designer may be called upon to certify compliance with Building Regulations.

Unfortunately, the optimum results in cutting down space heating energy usage can often be obtained only when a building is at the design stage. Insulation, draught exclusion and the best possible heating system can then be built-in at minimum cost. It is usually more expensive to add to (or modify) an existing building. Space heating is probably the largest usage of energy in buildings, so this section considers what can be done to improve insulation and other thermal properties. When energy was relatively cheap, little thought was given to conservation, and these omissions now have to be rectified.

In 1957 the Thermal Insulation (Industrial Buildings) Act laid down standards of insulation for roofs of new buildings. This first attempt to minimize heat losses did not cover walls, floors or windows. However, in 1978, Amendments to the Building Regulations rectified this by specifying standards for walls and windows. At this point it is necessary to define the terms '*U* value', or the insulation characteristic of the building material. This measures the rate at which energy flows through the material when there is a temperature difference of 1°C between the inside and outside faces, and this value is measured in watts (the unit of energy) per square metre of surface area, i.e. W/m^2K.

Table 16.1

Industrial and commercial buildings
External walls of building enclosing heated spaces, internal walls exposed to unheated ventilated spaces, floors where the under-surface is exposed to outside air or an unheated ventilated space, and roofs over heated spaces (including the cases of ceilings with an unheated ventilated space above them).

Maximum average U value
For factories and storage buildings, such as warehouses, the *U* value is laid down to be 0.7. For shops, offices, institutional buildings and places of assembly, such as meeting halls, theatres, etc., the maximum average *U* value is to be 0.6.

The amendments can briefly be summarized in Table 16.1.

The *U* values for walls, roofs and floor are intended as average figures, so it is permissible to have some areas of the structure underinsulated (i.e. with higher *U* values) providing other areas have sufficient extra insulation to bring the average of all areas down to (or below) the Regulation values.

Limits are also imposed on window areas and apply to all buildings above $30\,m^2$ floor area. For the first group, industrial and commercial buildings, these limits apply both to rooflights and to windows in the walls. These percentages for windows or rooflights assume single glazing, and somewhat larger values can be used if double or triple glazing is to be fitted. However, calculations must be produced to show that the total heat loss from such units would be no greater than the single-glazed unit complying with the set limits (Table 16.2).

In most single- and two-storey buildings the largest proportion of heat loss from the building structure is usually through the roof. (In buildings of three storeys or more the losses through walls and windows may overtake the roof loss.)

If we first consider typical roofs, the methods of insulation break down into four groups:

Table 16.2

Type of building	*Maximum permitted glazed area*	
	In walls as percentage of wall area	*As rooflights as percentage of roof area*
Factories and storage	15	20
Offices, shops and places of assembly	35	20
Institutional, including residential	25	20

Note: Where figures for both rooflights and windows in walls are given, these really apply as a combined total. If the full wall window allowance is not used the balance can be reallocated to rooflight areas and vice versa. For example, a factory with only 10% of wall area as windows could add the other 5% of wall area as an increase to the permitted 20% of roof area that could be rooflights.

1. Under-drawing, involving the fitting of insulation below the existing roof, as rigid self-supporting slabs, semi-rigid sheets supported by framing or a combination of an insulating blanket on top of sheets. This insulating blanket could be of mineral or glass fibre or a flexible 'foamed' plastic.
2. External, where insulation is added on top of the existing roof. This can be done with sheets or slabs of insulating material finished with some waterproofing layer or very conveniently for corrugated or shaped roofing sheets by using a spray system to apply both the insulation and final waterproofing layer.
3. Where there is a ceiling below the actual roof, to place insulation above this ceiling. Where there are wooden ceiling joists, the insulation can be a flexible blanket laid between joists or loose granular fill spread between them. Alternatively, an overall quilt or blanket can be laid over the ceiling, taking care to check that the ceiling and its supports can safely carry the extra weight.
4. Possibly in a small minority of cases, it could be advantageous to install a false ceiling which could be of insulating sheets or panels. This can reduce the volume to be heated, particularly with steeply pitched roofs. Obviously, this idea could not be recommended where valuable daylight was available from rooflights and where this daylight significantly reduced the artificial illumination necessary. Often such a false ceiling unfortunately conflicts with the existing architecture.
5. New Building Regulations for the Conservation of Fuel and Power for England and Wales came into operation on 1 April 1990. The new maximum U values of the elements ($W/m^2 K$) are shown in Table 16.4.

Table 16.3 gives some of the insulation properties for various building materials. The property given is for the rate at which energy would pass through a unit area of the material. In the standard units it becomes the number of watts that would be transferred through a square metre of the material of normal thickness in the form it would be used, if the air at either side of the material shows a temperature difference of 1°C. In SI units this becomes $W/m^2 K$, which, in this case, is commonly known as the U value. The larger the U value, the more energy it will transfer, so the worse are its insulation properties.

A very poor insulating material can be detected very simply. If the material is at normal room conditions and a hand placed upon its surface feels cold, heat is being conducted away from it as the U value is very high. A low U value is shown by no cooling effect. To try this, if one places a hand on a window and a wooden table there should be a notable difference between the two showing a difference in the U value. Wood's U value is about $1 W/m^2 K$ and glass has a value of over $5.5 W/m^2 K$.

The U values are given in $W/m^2 K$ for various building materials under normal weather conditions. There will always be slight variations around these values, dependent on particular manufacturers of the materials. With any insulation which is being fitted, advice should be sought regarding the fire risk and condensation problems.

Table 16.3 U values

Roofs		
Pitch covered with slates or tiles, roofing felt underlay, foil-backed plasterboard ceiling		1.5
Pitched covered with slates or tiles and roofing felt underlay, foil-backed plasterboard ceiling with 100 mm glass-fibre insulation between joists		0.35
Corrugated steel		6.1–6.7
Corrugated steel 75 mm fibreglass lightweight liner		0.38
Corrugated steel roofing sheets with cavity and aluminium foil-backed 10 mm plasterboard lining		1.9–2.0
Steel or roofing sheets, no lining with rigid insulating lining board 75 mm		0.4
Asphalt 19 thick or felt/bitumen layer on solid concrete 150 mm thick		3.5
Asphalt 19 mm thick or felt/bitumen layer on 150 mm autoclaved aerated concrete roof slabs		0.9
Flat roof, three layers of felt on chipboard or plasterboard		1.54
Flat roof, three layers of felt on rigid insulating board 100 mm thick		0.29
Timber roof with zinc or lead covering and 25 mm plaster ceiling		0.96
Walls		
Steel cladding		5.3–5.7
Steel cladding 75 mm fibre glass lightweight liner		0.37
Steel cladding with plaster-board lining and 100 mm fibre insulating roll		0.4
Solid brick wall unplastered 105 mm		3.3
Solid brick wall unplastered 335 mm		1.7
Solid brick wall 220 mm thick with 16 mm lightweight plaster on inside face		1.9
Brick/cavity/brick (260 mm total thickness)		1.4
260 mm brick/mineral fibre-filled cavity/brick		0.5
260 mm brick/cavity/load-density block		1.0–1.1
Brick/expanded polystyrene board in cavity/low-density block/inside face plastered		0.5
Weather boarding on timber framing with 10 mm plasterboard lining, 50 mm glass-fibre insulation in the cavity and building paper behind the boarding		0.62
Glazing		
Single glazing	Wood frame	4.3
	Metal frame	5.6
Double glazing	Wood frame	2.5
	Metal frame	3.2
Triple glazing		2.0
Roof skylights		6.6
Floors		
20 mm intermediate wood floor on 100 mm × 50 mm joists 10 mm plasterboard ceiling allowed for 10% bridging by joists		1.5
150 mm concrete intermediate floor with 150 mm screed and 20 mm wood flooring		1.8
The heat loss through floors in contact with the earth is dependent upon the size of the floor and the amount of edge insulation. Insulating the edge of a floor to a depth of 1 m can reduce the U value by 35%. Following are some typical U values for ground		

Table 16.3 *(continued)*

floors. Effectively, most of the heat loss is around the perimeter of the floor.	
Solid floor in contact with the earth with four exposed edges:	
150 m × 50 m	0.11
60 m × 60 m	0.15
15 m × 60 m	0.32
15 m × 15 m	0.45
7.5 m × 15 m	0.62
3 m × 3 m	1.47
Suspended timber floors directly above ground. Bare or with linoleum, plastic or rubber tiles:	
150 m × 60 m	0.14
60 m × 60 m	0.16
15 m × 60 m	0.37
15 m × 15 m	0.45
7.5 m × 15 m	0.61
3 m × 3 m	1.05
Suspended timber floors directly above ground with carpet or cork tiles:	
150 m × 60 m	0.14
60 m × 60 m	0.16
15 m × 60 m	0.34
15 m × 15 m	0.44
7.5 m × 15 m	0.59
3 m × 3 m	0.99

Table 16.4

Building type	*Ground floors*	*Exposed walls and floors*	*Semi-exposed walls and floors*	*Roofs*
Industrial storage and other buildings, excluding dwellings	0.45	0.45	0.60	0.45

Note: An exposed element is exposed to the outside air; a semi-exposed element separates a heated space from a space having one or more elements which are not insulated to the levels in the table.
Maximum window areas for single glazing in buildings other than dwellings will be unchanged.

16.4 Estimation of heat losses from buildings

The normal procedure in estimating the heat loss from any building is as follows:

1. Decide upon the internal air temperature to be maintained at the given external air temperature.
2. Decide the heat transmission coefficient (U values) for the outside walls and glass, roof and bottom floor, and the inside walls, ceilings, or of heated spaces adjacent to non-heated spaces.
3. Measure up the area of each type of surface and compute the loss through each surface by multiplying the transmission coefficient by the measured area by the difference between the inside and the outside temperatures.
4. Calculate the cubic contents of each room and, using the appropriate air change rate, the amount of heat required to warm the air to the desired temperature by multiplying the volume of air by the difference between the inside and outside temperatures and the specific heat of air.

The above calculations will give the heat losses after the building has been heated. Under conditions in which the heating system will operate continuously, satisfactory results will be obtained if the heating system is designed to provide heat equivalent to the amount calculated above. Suitable allowance must be made for losses from mains.

When, however, operation is intermittent, safety margins are necessary. These are, of course, speculative, but the following suggestion has frequently proved satisfactory. When it is necessary to operate after a long period of vacancy, as may happen in certain types of substantially built buildings; it is necessary to add up to 30% to the 'steady state' heat transmissions. In buildings of light construction this margin may be reduced.

In selecting the appropriate U values we must pay due regard to the exposure and aspect of the room. It appears reasonable to make allowance for the height of a room, bearing in mind that warm air rises towards the ceiling. Thus in a room designed to keep a comfortable temperature in the lower $1\frac{1}{2}$ or 2 m, a higher temperature must exist nearer the ceiling, which will inevitably cause greater losses through the upper parts of windows, walls and roof. This effect is greatest with a convective system, i.e. one which relies on the warming of the air in the room for the conveyance of heat. This would occur in the case of conventional radiators, convectors and warm air systems. In the case of radiant heated rooms, this does not occur, and a much more uniform temperature exists from floor to ceiling.

16.5 Allowance for height of space

In heat loss calculations a uniform temperature throughout the height of the heated space is assumed, although certain modes of heating cause vertical temperature gradients which lead to increased heat losses, particularly through the roof. These gradients need to be taken into account when sizing appliances. Additions to the calculated heat loss to allow for this are proposed in Table 16.5. However, these percentages should not be added to replacement heat to balance that in air mechanically exhausted from process plant. Attention is also drawn to the means of reducing the effect of temperature stratification, discussed in Section 16.10.13.

16.6 Characteristics of heat emitters

Designers will need to decide whether it is necessary to add a margin to the output of heat emitters. During the warm-up cycle with intermittently operated heating systems, emitter output will be higher than design because space temperatures are lower. Also, boost system temperatures may be used to provide an emission margin during warm-up. The need for heat emitter margins to meet

Table 16.5 Allowances for height of heated space

Method of heating and type or disposition of heaters	*Percentage addition for following heights of heated space (m)*		
	5	*5–10*	*>10*
Mainly radiant			
Warm floor	Nil	Nil	Nil
Warm ceiling	Nil	0–5	[a]
Medium- and high-temperature downward radiation from high level	Nil	Nil	0–5
Mainly convective			
Natural warm air convection	Nil	0–5	[a]
Forced warm air			
Cross flow at low level	0–5	5–15	15–30
Downward from high level	0–5	5–10	10–20
Medium and high-temperature cross radiation from intermediate level	Nil	0–5	5–10

[a] Not appropriate to this application.

extreme weather conditions will depend on the design parameters used in determining heat losses.

In summary, although the addition of a modest margin to heat emitter output would add little to the overall system cost and a margin on the heat generator or boiler output can only be utilized if the appropriate emitter capacity is available, the decision should be based on careful discrimination rather than using an arbitrary percentage allowance. In general, for buildings of traditional construction and for the incidence of design weather in normal winters in the UK an emitter margin in excess of, say, 5% or 10% is unlikely to be justified. However, for well-insulated buildings the heat loss reduces in significance relative to the heat stored in or needed to warm up the structure. For such applications a larger heating system margin is required, and the emitter margin provided would need to be considered accordingly.

16.7 Central plant size

In estimating the required duty of a central plant for a building it should be remembered that the total net infiltration of outdoor air is about half the sum of the rates for the separate rooms. This is because, at any one time, infiltration of outdoor air takes place only on the windward part of the building, the flow in the remainder being *outwards*.

When intermittent heating is to be practised the preheating periods for all rooms in a building will generally be coincident. The central plant rating is then the sum of the individual room heat demands, modified to take account of the *net* infiltration.

If heating is to be continuous some diversity between the several room heating loads can be expected. The values listed in Table 16.6 are suggested. When mechanical ventilation is combined with heating, the heating and the ventilation plant may have different hours of use, and the peak loads on the two sections of the plant will often occur at different times.

Table 16.6 Diversity factors for central plant (continuous heating)

Space or building served by plant	*Diversity factor*
Single	1.0
Single building or zone, central control	0.9
Single building, individual room control	0.8
Group of buildings, similar type and use	0.8
Group of buildings, dissimilar uses[a]	0.7

[a] This applies to group and district heating schemes where there is substantial storage of heat in the distribution mains, whether heating is continuous or intermittent.

The central plant may also be required to provide a domestic hot water supply and/or heat for process purposes. These loads may have to be added to the net heating load to arrive at the necessary plant duty, but careful design may avoid the occurrence of simultaneous peaks. In large installations the construction of boiler curves may indicate whether savings in boiler rating can be made. In many cases little or no extra capacity may be needed for the hot water supply, its demands being met by 'robbing' the heating circuits for short periods.

16.8 Selective systems

In some cases the various rooms of a building do not all require heating at the same time of day and here a so-called 'selective system' may be used. The supply of heat is restricted to different parts of the building at different times of the day; the whole building cannot be heated at one time. A typical application is in dwellings where the demands for heat in living spaces and bedrooms do not normally coincide.

In a selective system the individual room appliances must be sized as indicated above, to provide the appropriate output according to heat loss, gains and intermittency. The central plant need only be capable of meeting the greatest simultaneous demands of those room units which are in use at the same time. This will generally lead to a large power being required to meet the demands of those units which form the lesser part of the load. These units may then be operated with a high degree of intermittency.

16.9 Multiple-boiler installations

Load variation throughout the season is clearly large, and consideration should be given to the number of boilers required in the system. Operation at low loads leads to corrosion and loss in efficiency and should be avoided. On the other hand, a number of smaller boilers gives an increase in capital costs.

It has been shown that when boilers are chosen which have a fairly constant and good efficiency over a working range of 30–100%, then the effects on overall costs (running + capital) of varying the number and relative sizes of boilers in the system is less than 5%. The

optimum number depends on the frequency of occurrence of low loads.

Under these circumstances the engineer is free to choose the number of boilers in the system based on practical rather than economic considerations. The following procedure is recommended:

1. Choose a type of boiler with a fairly constant and high efficiency over its full turndown range. Obtain its efficiency curve.
2. On the basis of avoiding acid corrosion and obtaining required standby, choose the number of boilers required and their relative sizes. Equally sized boilers should be used except where the provision of domestic hot water in summer requires one smaller boiler. Table 16.7 gives suggested relative sizes based on turndown to 30%.
3. The boilers should be controlled in sequence, the switching points for bringing boilers on line occurring whenever an additional boiler makes the system more efficient (for an evaluation of this see Figure 16.1). Full boiler load is not usually the most economic switching point, but switching points too close to full turndown should also be avoided. At any given system load the boilers on-line should share the load between them in proportion.

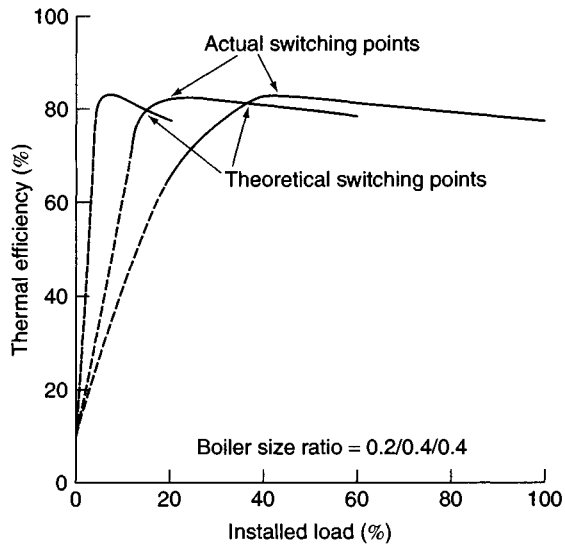


Figure 16.1 Evaluation of optimum boiler control

16.10 Heating systems

16.10.1 Warm and hot water heating systems

Warm water or low-, medium- or high-temperature hot water systems are categorized in Table 16.8. Warm water systems may use heat pumps, fully condensing boilers or similar generators, or reclaimed heat. In many cases the system design may incorporate an alternative heat generator for standby purposes or for extreme whether operation. Under such circumstances the system may continue to function at warm water temperatures or could operate at more conventional LTHW ones.

LTHW systems are usually under a pressure of static head only, with an open expansion tank, in which case

Table 16.7 Appropriate boiler size ratios assuming turndown to 30% of full load

Number of boilers	*Installed plant ratio*[a]	*Heating only*			*Heating plus domestic hot water*			*Remarks*
		Installed boiler size ratios	*Lowest load (%)*	*Load if largest fails (%)*	*Installed boiler size ratios*	*Lowest load (%)*	*Load if largest fails (%)*	
1	1.0	1.0	30	0	–	–	–	Use only if load is seldom <30%. No standby
2	1.0	0.5/0.5	15	50	–	–	–	Impossible to gain reasonable standby and meet low loads
	1.0	0.33/0.67	10	33	0.30/0.70	9	30	
	1.25	0.3/0.7	11.3	37	0.25/0.75	9.4	31	
	1.5	0.25/0.75	11.3	37	–	–	–	
3	1.0	0.33/0.33/0.33	10	67	0.2/0.4/0.4	6	60	
	1.25	0.2/0.4/0.4	7.5	75	0.2/0.4/0.4	7.5	75	
	1.50	0.2/0.4/0.4	9	90	0.2/0.4/0.4	9	90	
	1.67	0.2/0.4/0.4	10	100	0.2/0.4/0.4	10	100	
4	1.0	0.25/0.25/0.25/0.25	7.5	75	0.25/0.25/0.25/0.25	7.5	75	
	1.25	0.25/0.25/0.25/0.25	9.4	94	0.1/0.3/0.3/0.3	3.7	87	
	1.50	0.1/0.3/0.3/0.3	4.3	105	0.1/0.3/0.3/0.3	4.5	105	
	1.33	0.25/0.25/0.25/0.25	10	100	0.1/0.3/0.3/0.3	4	93	
5	1.0	0.2/0.2/0.2/0.2/0.2	6	80	0.2/0.2/0.2/0.2/0.2	6	80	
	1.25	0.2/0.2/0.2/0.2/0.2	7.5	100	0.2/0.2/0.2/0.2/0.2	7.5	100	
	1.50	0.2/0.2/0.2/0.2/0.2	9.0	120	0.2/0.2/0.2/0.2/0.2	9.0	120	

[a] Installed plant ratio = $\frac{\text{Total installed boiler capacity}}{\text{Design maximum heat requirement}}$

Table 16.8 Design water temperatures for warm and hot water heating systems

Category	*System design water temperatures (°C)*
Warm	40–70
LTHW	70–100
MTHW	100–120
HTHW	Over 120

Note: Account must be taken of the margin necessary between the maximum system operating temperature and saturation temperature at the system operating pressure.

the design operating temperature should not exceed 83°C. Where MTHW systems operating above 110°C are pressurized by means of a head tank, an expansion vessel should be incorporated into the feed and expansion pipe. This vessel should be adequately sized to take the volume of expansion of the whole system so that boiling will not occur in the upper part of the feed pipe. On no account should an open vent be provided for this type of system.

MTHW and HTHW systems require pressurization such that the saturation temperature at operating pressure at all points in the circuit exceeds the maximum system flow temperature required. A margin of 17 K (minimum) is recommended and is based on the use of conventional automatic boiler plant and includes an allowance for tolerances on temperature set points for the automatic control of heat-generation output. A check must be made on actual tolerance used in the design of a control system to ensure that this allowance is adequate.

When selecting the operating pressure, allowance must be made for the effect of static head reduction at the highest point of the system and velocity head reduction at the circulating pump section, to ensure that all parts of the system are above saturation pressure within an adequate anti-flash temperature margin. Additionally, the margin on the set point of the high-temperature cut-out control should be 6 K, except for boilers fired with solid fuel automatic stokers, where it should be at least 10 K.

Medium- and high-temperature systems should be fully pressurized before the operating temperature is achieved and remain fully pressurized until the temperature has dropped to a safe level. In all systems the heat generator or boiler must be mechanically suitable to withstand the temperature differentials, and the return temperature to the boiler must be kept high enough to minimize corrosion. Automatic controls may be used to achieve this.

16.10.2 Design water flow temperature

For low-temperature heating systems using natural convective or radiant appliances the normal design water flow temperature to the system is 83°C (see also Table 16.8). Boost temperatures may be used on modulated-temperature systems because of the changes in heat output characteristics with varying temperatures. Additionally, comfort aspects must be borne in mind, as forced convective emitters operating on modulated temperature systems can deliver airstreams at unacceptably low temperatures.

For MTHW and HTHW systems heat emitters may be as for LTHW systems, except that, for safety reasons, units with accessible surfaces at water temperature would not normally be employed. Embedded panel coils may be used in conjunction with a MTHW or HTHW distribution system, with insulating sleeves around the coil piping to reduce the heat flow. Alternatively, the coils can be operated as reduced temperature secondary systems by allowing only a small, carefully controlled proportion of flow temperature water to be mixed with the water circulating in the coils. Design arrangements for reduced-temperature secondary systems (sometimes referred to as injection circuits) include fixed provisions for minimum dilution rates. Conventional system-balancing devices with three-port automatic modulating valves to regulate mixed water temperatures and, hence, heat output are used. Automatic safety controls must prevent excessive temperatures occurring in the coil circuits, as floor fabrics or finishes could be damaged very rapidly.

16.10.3 Maximum water velocity

The maximum water velocity in pipework systems is limited by noise generation and erosion/corrosion considerations. Noise is caused by the free air present in the water, sudden pressure drops (which, in turn, cause cavitation or the flashing of water into steam), turbulence or a combination of these. Noise will therefore be generated at valves and fittings where turbulence and local velocities are high, rather than in straight pipe lengths.

A particular noise problem can arise where branch circuits are close to a pump and where the regulating valve used for flow-rate balancing may give rize to considerable pressure differences. Oversizing regulating valves should be avoided, as this will result in poor regulation characteristics; the valve operating in an almost shut position and creating a very high local velocity.

High water velocities can result in erosion or corrosion due to the abrasive action of particles in the water and the breakdown of the protective film which normally forms on the inside surface of the pipe. Erosion can also result from the formation of flash steam and from cavitation caused by turbulence.

Publishing data on limiting water velocities are inconclusive. Table 16.9 summarizes the available information.

16.10.4 Minimum water velocity

Minimum water velocities should be maintained in the upper floors of high-rise buildings where air may tend to come out of solution because of reduced pressures. High velocities should be used in down-return mains feeding into air-separation units located at a low level in the system. Table 16.10 can be taken as a guide.

Water velocities shown in Tables 16.9 and 16.10 are indicative parameters only; on the one hand, to limit noise problems and erosion and, on the other, to try to ensure air entrainment. Within these parameters the design engineer will need to discriminate on the selection of water velocities in a distribution system based on

Table 16.9 Limiting water velocities in pipework

Pipe diameter (mm)	*Steel pipework*		*Copper pipework (m/s)*
	Non-corrosive water (m/s)	*Corrosive water (m/s)*	
50 and below	1.5	1	1
Above 50	3	1.5	1.5
Large distribution mains with long lengths of straight pipe	4	2	–

Table 16.10 Minimum water velocities

Pipe diameter (mm)	*Minimum water velocity (m/s)*
50 and below	0.75
Above 50	1.25

other considerations. It is particularly necessary to bear in mind the effect of low water velocities on flow-measuring components used in balancing flow rates in systems.

16.10.5 System temperature drop

British practice on LTHW systems uses a typical system temperature drop of 11 K and a maximum system temperature of 17 K. Continental practice has tended to use higher drops (up to 40 K). An advantage of a higher system temperature drop is the reduction in water flow rates. This will result in reduced pipe sizes with savings in capital cost and distribution heat losses and a reduced pump duty, with savings in running costs. A disadvantage of higher system temperature drops is the need for larger and consequently more expensive heat emitters. However, if it is possible to raise the system flow temperature so that the mean water temperature remains the same, then with certain types of emitter only a small increase in size is required. With large system temperature drops the average water temperature in a radiator tends to fall below the mean of flow and return temperature and, thus, a larger surface is needed. Furthermore, on one-pipe circuits the progressive reduction in temperature around the circuit may lead to excessively large heat emitters.

Higher system temperature drops can be used with MHTW and HTHW systems since the mean temperature of the heat emitters will be correspondingly higher. Additionally, these media are well suited to use for primary distribution systems, conveying heat over long distances.

Precautions should be taken to prevent the danger of injury from contact with hot surfaces. The safe temperature for prolonged contact is relatively low and reference should be made to BS 4086 and other sources.

16.10.6 Use of temperature-limiting valves on emitters

On some group and district heating schemes, outlet limiting valves which permit flow only when the water temperature has dropped to a specified low level are used. This procedure minimizes the water quantity to be pumped and permits indicative heat metering by water quantity alone. In such cases care must be taken to size emitters to suit the available water temperatures. The effect of low water velocities through the emitter must also be taken into consideration, since the heat output of some convective appliances is greatly reduced under such conditions.

16.10.7 Miscellaneous components

Data regarding relief valves, feed and expansion cisterns, etc. are given in Tables 16.11 and 16.12. Cistern sizes shown in Table 16.12 are based on typical system designs and are approximate only. An estimate of the water content of the particular system should always be made where there is any doubt regarding these typical data, to ensure that the cistern capacity is adequate to contain the expansion volume.

16.10.8 Distribution system design

The design of pipework distribution systems must allow for the following:

1. Future extensions, where required, by the provision of valved, plugged or capped tee connections.
2. Provision for isolation for maintenance. Where it is necessary to carry out maintenance on a 'live' system, valves must be lockable and may need to be installed in tandem.
3. Thermal expansion.
4. Provision for distribution flow rate balancing for initial commissioning or rebalancing to meet changed operational requirements. Typical provisions for balancing comprise the following:
   (a) A measuring station – which may be an orifice plate, a venturi, an orifice valve or other proprietary device – provided with a pair of tappings to

Table 16.11 Hot water heating boilers – recommended sizes of relief valves

Rated output of boiler (kW)	*Minimum clear bore of relief valve (mm)*	*Equivalent area (mm^2)*
Up to 250	20	310
250–350	25	490
350–450	32	800
450–500	40	1250
500–750	50	1960
750–1000	65	3320

Note: The above sizes apply to boilers fired with solid fuel. For oil- and gas-fired boilers the relief valve should be one size larger.

Table 16.12 Approximate sizes of feed and expansion cisterns for low-pressure hot water heating systems

Boiler or water-heating (kW)	*Cistern size (l)*	*Ball-valve size (mm)*	*Cold-feed size (mm)*	*Open-vent size (mm)*	*Overflow size (mm)*
15	18	15	20	25	25
22	18	15	20	25	32
30	36	15	20	25	32
45	36	15	20	25	32
60	55	15	20	25	32
75	68	15	25	32	32
150	114	15	25	32	32
225	159	20	32	40	40
300	191	20	32	40	40
400	227	20	40	50	40
450	264	20	40	50	50
600	318	25	40	50	50
750	455	25	50	65	50
900	636	25	50	65	50
1200	636	25	50	65	80
1500	910	25	50	65	80

Notes: (1) Cistern sizes are actual.
(2) Cistern sizes are based on radiator-heating systems and are approximate only.
(3) The ball-valve sizes apply to installations where an adequate mains water pressure is available at the ball-valve.

permit the measurement of upstream and downstream system dynamic pressures.

(b) An associated regulating valve – preferably a double-regulating valve or other arrangement which permits the required setting to remain undisturbed by closure.

5. Provision for drainage, including drainage after pre-commission flushing; water circulation during flushing must be in excess of design flow rates and, in order to discharge the flushing effluent effectively, drainage connections must be full diameter.
6. Removal of air from the system by provision of:
   (a) Air separators, one form of which uses the principle of centrifugal force to separate the heavier constituent (water) from the lighter one (non-condensable gases). Best results are achieved by locating the separator at the highest temperature point of the system where air has a greater tendency to come out of solution. The velocity of the medium requires to be above the minimum stated by the manufacturer (usually about 0.25 m/s).
   (b) Automatic air vents for systems operating at temperatures below atmospheric boiling point.
   (c) Air bottles with manually operated needle valves to release accumulated air, for systems operating at temperatures in excess of atmospheric boiling point.
7. Provision of test points for sensing temperature and pressure at selected locations.

16.10.9 Sealed heating systems

Pressurization of medium- and high-temperature hot water sealed heating systems referred to above may take the following forms.

16.10.9.1 Pressurization by expansion of water

The simplest form of pressurization uses the expansion of the water content of the system to create a sufficient pressure in an expansion vessel to provide an anti-flash margin of, say, 17°C at the lowest pressure (highest point) of the system. The main disadvantage of a naturally pressurized expansion vessel is the ability of water to absorb air and the consequent risk of oxygen corrosion.

A diaphragm expansion vessel is divided into two compartments by a special membrane or diaphragm of rubber or rubber composition which prevents the water coming into contact with the air. On one side of the diaphragm the vessel is filled with air or nitrogen at the required pressure. The other section of the vessel is connected directly to the water system. A correctly positioned air separator will assist in de-aerating the water in the system.

16.10.9.2 Pressurization of elevated header tanks

Given very careful attention to design, installation and commissioning, MTHW systems may be operated with the necessary system pressure provided by an elevated feed and expansion tank. Where the system operating temperature exceeds 110°C an expansion vessel should be sized to absorb the volume of expansion for the complete system, thus preventing water at operating temperatures entering the feed and expansion tank and causing boiling. On no account should an open vent be provided for this type of system.

16.10.9.3 Gas pressurization with spill tank

This form consists of a pressure cylinder maintained partly filled with water and partly with gas (usually nitrogen) which is topped up from pressure bottles. Water expansion

is usually arranged to discharge from the system through a pressure-control valve into a spill tank open to atmosphere or to a closed cylinder lightly pressurized with nitrogen. A pump is provided to take water from the spill tank and return it under pressure to the system as cooling-down results in a pressure drop. The pump operation is regulated by a system pressure sensor.

16.10.9.4 Hydraulic pressurization with spill tank

In this form the pressure is maintained by a continuously running centrifugal pump. A second pump under the control of a pressure switch is provided to come into operation at a predetermined pressure differential and as an automatic standby to the duty pump. Surplus water is delivered to or taken from a spill tank or cylinder as described previously.

16.10.9.5 Example of pressure differential

Assume system flow temperature of 120°C	
Allow 17 K anti-flash margin – 137°C	
Corresponding absolute pressure	3.4 bar
Assume static absolute pressure on system	2.0 bar
Minimum absolute pressure at cylinder	5.4 bar
Allow operating differential on pressure cylinder, say –	0.5 bar
Minimum operating absolute pressure of system	5.9 bar

16.10.9.6 Example of water expansion

Assume water capacity of system 200 000 l
Assume ambient temperature of 10°C
Assume system maximum flow temperature of 120°C
Assume system minimum return temperature of 65°C
Increase in volume from 10°C to 65°C

$$200\,000\frac{(999.7-980.5)}{980.5}=39161$$

Increase in volume from 65°C to 120°C

$$200\,000\frac{(980.5-943.1)}{943.1}=79311$$

Total increase in volume = 11 8471

16.10.10 Maintenance of water heating systems

A common practice in many hot water heating installations is to drain the complete system during summer months. This practice, involving a complete change of raw water every year, is to be deprecated. It introduces additional hardness salts and oxygen to the system, resulting in very significant increases in scaling and corrosion. Where it is necessary to drain the boiler or heat generator or other parts of the system for inspection or maintenance purposes, isolating valves or other arrangements should be used to ensure that the section drained is kept to a minimum.

16.10.11 Steam heating systems

These are designed to use the latent heat of steam at the heat emitter. Control of heat output is generally by variation of the steam saturation pressure within the emitter. For heating applications with emitters in occupied areas low absolute pressures may be necessary in order to reduce the saturation temperature to safe levels.

The presence of non-condensable gases in steam systems (e.g. air and CO_2) will reduce the partial pressure of the steam, and hence its temperature, thus affecting the output of the appliance. A further adverse effect is the presence of a non-condensable gas at the inside surface of a heat emitter. This impedes condensation and, hence, heat output. It is therefore imperative that suitable means are provided to prevent formation of CO_2 and to evacuate all gases from the system.

Superheat, which must be dissipated before condensation occurs, can be used to reduce condensation in the distribution mains.

On–off control of steam systems can result in the formation of a partial vacuum, leading to condensate locking or back feeding, and infiltration of air which subsequently reduces the heat transfer.

When using modulating valves for steam, heat emitter output must be based on the steam pressure downstream of the valve, which often has a high-pressure drop across it, even when fully open.

Steam traps must be sized to cope with the maximum rate of condensation (which may be on start-up) but must perform effectively over the whole operational range, minimizing the escape of live steam.

Partial waterlogging of heater batteries can lead to early failure due to differential thermal expansion. Steam trap selection should take account of this.

Where high temperatures are required (e.g. for process work) and lower temperatures for space heating, it is desirable to use flash steam recovery from the high-temperature condensate to feed into the low-temperature system, augmented as required by reduced pressure live steam.

Steam as a medium for heating is now seldom used. Hot water, with its flexibility to meet variable weather conditions and its simplicity, has supplanted it in new commercial buildings. Steam is, however, often used for the heating of industrial buildings where steam-raising plant occurs for process or other purposes. It is also employed as a primary conveyor of heat to calorifiers such as in hospitals, where again steam boiler plant may be required for sundry duties such as in kitchens, laundry and for sterilizing. Heating is then by hot water served from calorifiers.

16.10.12 High-temperature thermal fluid systems

Where high operating temperatures are required, high-temperature thermal fluid systems may be used instead of pressurized water or steam systems. These systems operate at atmospheric pressure using non-toxic media such as petroleum oil for temperatures up to 300°C or synthetic chemical mixtures where temperatures in excess

of this are required (up to 400°C). Some advantages and disadvantages of thermal fluid or heat transfer oil systems are listed below.

16.10.12.1 Advantages

No corrosion problems.
Statutory inspections of boilers/pressure vessels not required.
No scale deposits.
No need for frost protection of system.
Cost of heat exchangers/heat emitters less, as only atmospheric pressures are involved.
Better energy efficiency than steam systems.
Operating temperature can be increased subsequent to design without increasing operating pressure.

16.10.12.2 Disadvantages

Medium more expensive than water (but no treatment costs).
Medium is flammable under certain conditions.
Heat transfer coefficient is inferior to that of water.
Care necessary in commissioning and in heat-up rates due to viscosity changes in medium.
Circulating pump necessary (not required for steam systems).
Air must be excluded from the system.
In the event of leakage the medium presents more problems than water.

16.10.13 Warm air heating systems

These may be provided with electric or indirect oil- or gas-fired heaters or with a hot water heater or steam battery supplied from a central source. Because the radiant heat output of warm-air systems is negligible, the space air temperature will generally need to be higher for equivalent comfort standards than for a system with some radiant output. This will increase energy use, and legislative standards for limiting space temperatures should be considered. Attention is drawn to the vertical temperature gradient with convective systems and, when used for cellular accommodation, the likelihood of some spaces being overheated due to the difficulty of controlling such systems on a room-by-room basis.

With the advent of natural gas, direct-fired warm air systems are used where the heat and products of combustion, diluted by fresh air introduced into the system, are distributed to the heated spaces. In designing such installations account must be taken of the requirements of the Building Regulations, and of the Regional Gas Authority. Care must also be taken in design and application to ensure that the moisture in the products of combustion will not create condensation problems. Direct-fired systems are more suited to large, single-space low-occupancy applications such as warehouses and hangers and should not be used to serve sleeping accommodation.

16.10.14 Reducing the effect of temperature stratification

As with all convective systems, warm air heating installations produce large temperature gradients in the spaces they serve. This results in the inefficient use of heat and high heat losses from roofs and upper wall areas. To improve the energy efficiency of warm air systems, pendant-type punkah fans or similar devices may be installed at roof level in the heated space. During the operational hours of the heating system these fans work either continuously or under the control of a roof-level thermostat and return the stratified warm air down to occupied levels.

The energy effectiveness of these fans should be assessed, taking into account the cost of the electricity used to operate them. The following factors should also be borne in mind:

1. The necessary mounting height of fans to minimize draughts;
2. The effect of the spacing of fans and the distance of the impeller from the roof soffit;
3. Any risk to occupants from stroboscopic effects of blade movements;
4. The availability of multi- or variable-speed units.

Punkah fans may also be operated during summer months to provide air movement and offer a measure of convective cooling for occupants.

16.10.15 High-temperature high-velocity warm air heating systems

These systems, best suited to heating large, single spaces, may use indirect heating by gas or oil or direct gas heating. Relatively small volumes of air are distributed at high temperature (up to 235°C) and high velocity (30–42.5 m/s from heater unit) through a system of well-insulated conventional ductwork. Air outlets are in the form of truncated conical nozzles discharging from the primary ductwork system into purpose-designed diffuser ducts. The high-velocity discharge induces large volumes of secondary air to boost the outlet volume and reduces the outlet temperature delivered to the space, thereby reducing stratification. Most of the ductwork thermal expansion is absorbed by allowing free movement and long, drop-rod hangers are used for this purpose. Light, flexible, axial-bellows with very low thrust loads can also be employed where free expansion movement is not possible. System design and installation is generally handled as a package deal by specialist manufacturers.

16.11 Heating equipment – attributes and applications

16.11.1 Water system heating equipment

The range of heat emitters may be divided into three generic groups:

Table 16.13 Characteristics of water system heating equipment

Type	*Description*	*Advantages*	*Disadvantages*	*Emission range*
Radiant				
Radiant panel	Consists of steel tube or cast-iron waterways attached to a radiating surface. Back may be insulated to reduce rear admission or may be left open to give added convective emission. Particularly useful for spot heating and for areas having high ventilation rates (e.g. loading bays), the radiant component giving a degree of comfort in relatively low ambient air temperatures.	No moving parts, hence little maintenance required; may be mounted at considerable height or, in low-temperature applications, set flush into building structure.	Slow response to control; must be mounted high enough to avoid local high intensities of radiation (e.g. onto head).	350 W/m^2 to 15 k W/m^2 of which up to 60% may be radiant.
Radiant strip	Consists of one or more pipes attached to an emissive radiant surface. Is normally assembled in long runs to maintain high water flow rates. The back may be insulated to reduce rear emission. When using steam, adequate trapping is essential together with good grading to ensure that tubes are not flooded. Multiple-tube types should be fed in parallel to avoid problems due to differential expansion. Hanger lengths should be sufficient to allow for expansion without lifting the ends of the strip. Heating media may be steam, hot water or hot oil.	No moving parts, hence little maintenance required; may be mounted at considerable height or, in low-temperature applications, set flush into building structure.	Slow response to control; must be mounted high enough to avoid local high intensities of radiation (e.g. onto head).	150 W/m to 5 kW/m of which radiant emission may be up to 65% of total.
Natural convective				
Radiators	Despite their name, 70% of the emission from these devices is convective. Three basic types are available; column, panel, and high output, the last incorporating convective attachments to increase emission. Panel radiators offer the least projection from the wall but emission is higher from column and high-output units. In application they should be set below windows to offset the major source of heat loss and minimize cold downdraughts.	Cheap to install; little maintenance required.	Fairly slow response to control. With steel panel radiators there is a risk of corrosive attack in areas having aggressive water, which may be accentuated by copper swarf left in the radiator. This leads to rapid failure unless a suitable inhibitor is used. Not suitable for high-temperature water or steam.	450–750 W/m^2.
Natural convectors	Compact units with high emissions. Often fitted with damper to reduce output when full emission not required, usually to about 30% of full output. Heat exchangers normally finned tube. Units may be built into wall of building.	May be used on high-temperature hot water or low-pressure steam without casing temperature becoming dangerously high: fairly rapid response to control.	Take up more floor space than radiators. Likelihood of fairly high-temperature gradients when using high-temperature heating media.	200 W to 20 kW.
Continuous convectors	Comprise single-or double-finned tube high-output emitters in factory-made sill-height sheet metal casings or builders' work enclosures which may be designed to fit wall to wall. Can be fitted with local output damper control, which reduces the emission to approximately 30% of the full output. They	Take up relatively little space; give even distribution of heat in room. May be used with medium-temperature hot water or low-pressure steam	May produce large temperature gradients on high-temperature heating media if poorly sited.	500 W/m to 4 kW/m.

(*continued overleaf*)

Table 16.13 (*continued*)

Type	*Description*	*Advantages*	*Disadvantages*	*Emission range*
	should be placed at the point of maximum heat loss, usually under windows. The wall behind the unit should be well insulated. For long-run applications distribution of flow water must be provided to modular sections of the unit to ensure that input remains reasonably consistent over full length of unit. For builders' work casings inlet and outlet apertures must have the free-area requirements stipulated by the manufacturer.	without casing temperatures becoming dangerously high. Return pipework may be concealed within casing.		
Skirting heating	Finned-tube emitters in a single or double skirting height sheet metal casing, usually with provision for a return pipe within the casing. Applications and distribution of flow water similar to continuous convectors.	May be used on water or low-pressure steam. Give low-temperature gradients in the room. All pipework concealed.	Relatively low output per metre of wall. More work involved when installing in existing building as existing skirting has to be removed.	300 W/m to 1.3 kW/m.
Forced convective				
Fan convectors	These units give a high heat output for volume of space occupied by the unit, together with the ability to distribute the heat over a considerable area using directional grilles. May be used to bring in heated fresh air for room ventilation. Leaving air temperatures should be above 35°C to avoid cold draughts. Where mixed systems of radiators and fan convectors are installed it is advisable to supply fan-assisted units on a separate constant-temperature circuit to avoid the above problems. To minimize stratification, leaving air temperatures above 50°C should be avoided. Must not be used on single-pipe systems. Care must be taken at design stage to avoid unacceptable noise levels. Control by speed variation or on/off regulation of fan.	Rapid response to control by individual thermostat. By use of variable speed motors rapid warmup available in intermittent systems; filtered fresh air inlet facility.	Electric supply required to each individual unit.	2 to 25 kW.
Unit heaters	A unit with a large propeller or centrifugal fan to give high air volume and wide throws. Louvres direct the air flow in the direction required. May be ceiling mounted, discharging vertically or horizontally or floor mounted. Can be used with fresh air supply to ventilate buildings. Large units may be mounted at a considerable height above the floor to clear travelling cranes, etc. May be used with steam or hot water but care should be taken to restrict leaving air temperature, usually 40–55°C to avoid reduction of downward throw and large temperature gradients in the building. The air flow from the units should be directed towards the points of maximum heat loss. Control as for fan convectors.	Rapid response to control by individual thermostat; by use of multi-speed motors rapid warm-up available on intermittent systems; filtered fresh air inlet facility.	Electric supply required for each individual unit.	3 to 300 kW.

Table 16.14 Electric heating equipment

Type	*Description*	*Advantages*	*Disadvantages*	*Emission range*
Radiant				
High-intensity radiant heaters	Consist of high-temperature elements mounted in front of polished reflector. Element can be silica or metal sheathed wire (up to 900°C) or quartz lamp (up to 2200°C)	Fast response time. Little regular maintenance required. May be mounted at considerable height. Quartz lamp heaters have improved beam accuracy allowing higher mounting heights. Especially suitable for spaces with high air movement.	Must be mounted sufficiently high to avoid local high intensities of radiation (e.g. onto head).	0.5 to 6 kW per heater.
Low-temperature radiant panels	Consist of low-temperature elements (300°C and below) mounted behind a radiating surface. Thermal insulation behind the elements minimizes heat loss. Very low-temperature elements (40°C) used in ceiling heating applications.	No regular maintenance required. Set flush into building structure and unobtrusive.	Slow response time.	Up to 200 W/m^2.
Natural convective				
Storage heater	Consists of a thermal storage medium which is heated during off-peak electricity periods. A casing and insulation around the medium enables the heat to be gradually released throughout the day. Manual or automatic damper control allows 20% of heat output to be controlled.	No regular maintenance required.	Not intermittent. Limited control of heat charging and output.	Storage element sizes 1.4 to 3.4 kW.
Panel heaters, convectors or skirting heaters	Consist of a heating element within a steel casing with air grilles allowing the natural convection of air across the element. Generally controlled by an integral room thermostat.	No regular maintenance required. Cheap to install. Suitable for low heat loss applications. Fast response time for intermittent operation.	High surface temperatures. High-temperature gradients if poorly sited.	0.5 to 3 kW output.
Forced convective				
Storage fan heaters/ electrical	These storage heaters have increased core thermal insulation and contain a fan which distributes warm air to the space to be heated. The fan is usually controlled by a room thermostat. Storage fan heaters are single room units but can heat an adjacent room with a stub duct. Electrical units are larger and can be ducted to service several areas. Up to 80% controllable heat.	Use off-peak electricity. Suitable for intermittent operation.	Heavyweight.	Fan storage heaters: 3 to 6 kW. Electrical 6 to 15 kW. Industrial models up to 100 kW.
Fan convectors	These wall-mounted or free-standing units incorporate a fan which forces air over the heating elements into the space. High output rate relative to size. Can incorporate integral room thermostat control	Low maintenance. Fast response. Accurate temperature control. Suitable for highly intermittent heating applications. Low surface temperatures. Fan-only operation for summer use.		2 to 3 kW.
Downflow fan convectors	These units are forced air convectors mounted to direct the heated air downwards. High air flow and heat output. Often used to provide a hot air curtain over entrance doorways.	Suitable for localized heating.	Can be noisy.	3 to 18 kW.

Table 16.15 Direct gas-fired heating equipment

Type of heater	*Usual rating (kW)*	*Surface temperature (°C)*	*Flue system*	*Notes*
Radiant convector gas	4.4–7.3	1100 at radiant tips	Conventional	Wall mounted or at low level
Overhead radiant heaters	3.1–41	850–900	Flueless[a]	High level or ceiling mounted
Overhead tubular radiant	10–15	315 mean	Conventional or fan-assisted flue or flue-less[a]	High level or ceiling mounted
Convector heaters	2.5–16.7	–	Conventional or balanced flue or flueless	Wall mounted or at low level
Fan convectors	1.4–3.7	–	Balanced flue or fan-assisted flue	Wall mounted or at low level
Make-up air heaters[b]	49–250	–	Flueless[a]	Mounted at high level and fan assisted
Unit air heaters[b]	17–350	–	Flued or flueless[a]	Mounted at high level and fan assisted

[a] The use of flueless appliances should be discouraged, since they discharge much moisture into the heated space.
[b] The installation of flueless appliances in excess of 44 kW is not permitted by the Building Regulations (1985) and application should be made to the local authority for the necessary waiver where installations of this size are contemplated.

Table 16.16 Direct oil-fired heating equipment

Type of heater	*Usual rating (kW)*	*Surface temperature (°C)*	*Flue system*	*Notes*
Radiant paraffin heaters	1.5	Less than 121[b]	Flueless[a]	Mounted at low or floor level
Flued radiant convector heaters	8.5–10.9	Less than 121[b]	Conventional	Mounted at low or floor level
Convective paraffin heaters	1–4	Less than 121[b]	Flueless[a]	Mounted at low or floor level
Air heaters	8.5–13.5	Less than 121[b]	Conventional	Mounted at low or floor level
Blown air heaters	10.7–16.7	Less than 121[b]	Conventional	Mounted at low or floor level
Warm air heaters	50–450	Maximum 60[c]	Flued	Floor mounted or overhead
Make-up air heaters	90–450	Maximum 60[c]	Flued	Can be flueless Floor or overhead mounted

[a] The use of flueless appliances should be discouraged since they discharge much moisture into the heated space.
[b] See BS 799.
[c] See BS 4256.

1. Radiant
2. Natural convective
3. Forced convective

Table 16.13 lists the principal types of appliance in each group, together with descriptive notes. Typical emission ranges are quoted for each type over its normal span of working temperatures. These are intended as a guide only and manufacturers' catalogues should be consulted for detailed performance values.

16.11.2 Electric heating equipment

Where electric heating equipment is installed within the space to be heated the total electrical input is converted into useful heat. There are two categories of electric heating equipment, direct acting and storage heating. The two types of electric heating can be used independently or to complement one another to meet particular heating requirements. Table 16.14 gives a brief description of the different types of electric heating.

16.11.3 Gas- and oil-fired heating equipment

Where gas or oil appliances are used for heating and installed within the heated space, between 70% and 90% of the total energy content of the fuel input will be converted into useful heat. Table 16.15 gives particulars of some gas-fired equipment types and Table 16.16 gives similar details for some oil-fired heaters. The first three types of equipment detailed in Table 16.15 and the first two in Table 16.16 are usually used for local warming of individuals rather than to provide a particular temperature throughout the space.

Acknowledgement

The Author wishes to thank the Chartered Institute of Building Services for permission to provide information from Guides 'A' & 'B'.

17 Ventilation

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17.1 Introduction

Any building, even with all windows and doors shut, will have a degree of ventilation (referred to as natural infiltration) by virtue of pressure differences across cracks or permeable materials in the structure causing air to flow through the structure. The degree of infiltration is governed by the quality of design and build of the structure and by the pressures generated by wind and thermal buoyancy.

This fortuitous infiltration is essential in otherwise unventilated buildings, since it allows ingress of air providing oxygen for us to breathe and for combustion equipment to burn. The infiltration is, however, effectively uncontrolled, and is often insufficient in quantity, at the wrong temperature or too contaminated to maintain satisfactory internal environmental conditions.

We must therefore be able to define the conditions we need and to design, install and operate systems to provide them. These systems cover three main areas: heating, ventilation and air conditioning. Heating and air conditioning are dealt with in Chapters 16 and 18. This chapter covers ventilation systems, defined as systems providing air movement through a space without artificially heating or cooling the air. It must be said, however, that, in practice, there is often a large degree of overlap, since office ventilation systems often provide heating in winter and complex ducted ventilation systems share much equipment and design procedures with air-conditioning systems.

This chapter is intended to provide guidance towards defining needs, assessing whether ventilation is the correct solution and selecting equipment and systems to match these requirements in as economic a manner as possible.

17.1.1 Reasons for ventilation

Ventilation is used to maintain a satisfactory environment within enclosed spaces. The environmental criteria controlled may be:

Temperature – relief from overheating
Humidity – prevention of condensation or fogging
Odour – dilution of odour from smoking, body odour, processes, etc.
Contamination – dilution or removal of dangerous or unpleasant fumes and dust

The required values for these criteria will depend upon the reason the space is being ventilated. It may be for the benefit of people, processes, equipment, materials, livestock, horticulture, building preservation or any combination of these. Guidance on selection of these values is provided by CIBSE[1] and ASHRAE.[4]

17.1.2 Definitions

Aerodynamic area – The effective theoretical open area of an opening. It is related to the measured area by the coefficient of entry or discharge (C_d).
Air-handling unit – A self-contained package incorporating all equipment needed to move and treat air, requiring only connection to ductwork and services to provide a complete ventilation system.
Coefficient (entry or discharge) – The ratio of aerodynamic (effective) area to the measured area of an opening. The value for a square-edged hole of 0.61 is used for most building openings.
Capture velocity – The air velocity needed to capture a contaminant at source, overcoming any opposing air currents.
Dilution ventilation – A ventilation strategy whereby contaminants are allowed to escape into the ventilated space and are then diluted to an acceptable level by means of the ventilation system.
Industrial ventilation – A term used to cover any ventilation system designed to remove contaminants. Its use is sometimes restricted to local extract systems.
Maximum Exposure Limit (MEL) – Maximum limits of concentration of airborne toxic contaminants, listed by the Health and Safety Executive[18] which must not be exceeded.
Occupational Exposure Standards (OES) – Limits of concentration of airborne toxic contaminants, listed by the Health and Safety Executive[18] which are regarded as safe for prolonged exposure for 8 hours per day.
Infiltration – Movement of air through a space with no specific ventilation openings by natural forces.
Local extract – A ventilation strategy whereby heat, steam or contaminants are captured at source and ducted to discharge outside the space.
Mechanical ventilation – See *Powered ventilation.*
Natural ventilation – A ventilation system in which air movement is produced through purpose-designed openings by natural forces (wind and thermal buoyancy).
Powered ventilation – A ventilation system in which air movement is induced by mechanical means – almost invariably a fan.
Smoke logging – The filling of a space with smoke in the event of fire.
Smoke and Heat Exhaust Ventilation System (SHEVS) – A ventilation system designed to remove smoke and heat in the event of fire to prevent or delay smoke logging allowing personnel to escape and firefighters to attack the fire.
Spot cooling – A ventilation strategy whereby the space temperature is allowed to rise and air movement is induced locally to provide comfort conditions within a limited area.
Threshold Limit Value (TLV) – Maximum values of concentrations of airborne toxic contaminants, listed by the American Conference of Governmental Industrial Hygienists[5] (ACGIH), regarded to be safe for 8 hours per day exposure.
Transport velocity – The air velocity required in a duct to transport a contaminant without it falling out of suspension.

17.2 Ventilation systems and controls

17.2.1 Natural ventilation

17.2.1.1 How natural ventilation works

Natural ventilation operates by means of airflows generated by pressure differences across the fabric of the

building. An airflow will occur wherever there is a crack, hole or porous surface and a pressure difference.

For the relatively large openings in which we are interested the flow rate can be found from the velocity of airflow generated through the aerodynamic area of the opening from the formulae:

$$V = \sqrt{\frac{2\Delta P}{\rho}} \tag{17.1}$$

where V = velocity (m/s),
ΔP = pressure difference (Pa),
ρ = density (kg/m^3).

Then flow rate:

$$\dot{V} = AC_dV \tag{17.2}$$

where $\dot{V}$ = volumetric flow rate (m^3/s),
A = measured area of opening (m^2),
C_d = coefficient of opening.

For purpose-built ventilators the manufacturer will be able to provide values of C_d. For other openings it is conventional to use the value for a sharp-edged square orifice of 0.61.

The pressure can be generated by three mechanisms:

1. Powered ventilation equipment (see Section 17.3);
2. Buoyancy (temperature difference);
3. Wind.

In still air conditions the source of pressure difference to drive ventilation is buoyancy due to the decrease in density of heated air. In any occupied building there will be a higher temperature inside than outside due to heat gains from people, plant and solar radiation. The lighter heated air will try to rise, causing an increase in internal pressure at high level and a reduction at low level with a neutral plane between the two conditions. Any opening above the neutral plane will therefore exhaust air and any opening below the neutral plane will provide inlet air. Under steady heat load conditions a balance will be achieved with a throughput of air dependent upon the heat load and the size and location of the openings. Conditions at this balance point can be readily calculated using one of the following formulae:

For more than one opening (inlets all at one height, exhausts all at one height)

$$\dot{V} = A_eC_e\sqrt{\frac{2gH\Delta t}{\overline{T}}} \tag{17.3}$$

For a single opening

$$\dot{V} = \frac{AC_d}{3}\sqrt{\frac{gh\Delta t}{\overline{T}}} \tag{17.4}$$

where g = acceleration due to gravity (m/s^2),
H = height between centre lines of inlet and outlet openings (m),
Δt = temperature difference between inside and outside (°C),
$\overline{T}$ = average of inside and outside temperatures (absolute) (K),
h = height of single opening (m),
C_eA_e = overall effective opening size calculated from

$$\frac{1}{(C_eA_e)^2} = \frac{1}{\left(\sum C_iA_i\right)^2} + \frac{1}{\left(\sum C_vA_v\right)^2}$$

(subscript i denotes inlet opening, subscript v exhaust opening).

Where openings are at various heights throughout the building, as is common in office and commercial developments, the same principles apply but the mathematics becomes more complex to take account of the variations in buoyancy pressure at each height.[21]

Under wind conditions a complex system of pressures is set up on the external surfaces of the building which will vary with wind speed and direction. Pressure coefficients Cp[6,7] define the relationship according to the formula:

$$\dot{V} = A_eC_eU_r\sqrt{(\Delta Cp)} \tag{17.5}$$

where U_r = reference wind speed,
ΔCp = difference between coefficients at ventilation openings.

The coefficients Cp will vary across each surface of the building and, except for very simple shapes, can only be found by model or full-scale test. Since the coefficients will change with wind direction, complete calculation of wind-induced ventilation is very tedious, needing computer analysis.

When both wind and temperature difference act on ventilation openings the result is very complex and computer analysis is needed. A reasonable, but conservative, approximation of flow rate can be made by taking the higher of the two individual flow rates. This means that for ventilation design purposes we can often ignore wind effects and design on temperature difference only, since wind effects can be assumed to only increase the ventilation rate. This approximation generally applies only to industrial/warehouse/retail warehouse type buildings. A full analysis is usually required for applications such as offices where fine control of environmental conditions is expected.

17.2.1.2 Advantages and disadvantages

Advantages	*Disadvantages*
Quiet	Variable flow rate and
Virtually no running cost	direction dependent upon
Self-regulation (flow rate	wind conditions
increases with heat load)	Filtration is generally
Low maintenance cost	impractical
Provides daylight when	Limited ducting can be
open (roof vent)	tolerated
Psychological appeal of	Effectiveness depends on
clear sky (roof vent)	height and temperature
Easy installation	difference

17.2.1.3 When to use natural ventilation

Natural ventilation is used in a number of situations:

1. Shallow-plan offices – by opening windows to remove heat and odour;

2. Large single-storey spaces (factories, warehouses, sports halls, etc.) – by roof and wall ventilators – to remove heat, contaminants, smoke, steam;
3. Plant rooms.

It is not suitable in situations where:

1. Dust, toxic or noxious contaminants must be removed at source;
2. Unfavourable external conditions exist requiring treatment to incoming air – e.g. noise, dust, pollution;
3. A steady controlled flow rate is required – e.g. hospitals, commercial kitchens;
4. Existing mechanical ventilation will affect the flow adversely;
5. Abnormal wind effects can be anticipated due to surrounding higher buildings;
6. The space is enclosed so as to have no suitable source of inlet air.

In many of these situations a system of natural inlet/powered exhaust or powered inlet/natural exhaust will be the best option.

17.2.1.4 Control

Low-level ventilation openings, whether windows, doors or ventilators, are generally manually operated for simplicity and economy, allowing personnel to control their own environment. High-level openings can also be manually controlled by means of rod or cable operation, although this has generally lost favour (except in the case of simple windows) and automatic operation is preferred.

Automatic operation may be by means of compressed air, operating a pneumatic cylinder, or electricity. Pneumatics are generally favoured for industrial applications and electricity for commercial premises. Economy of installation is normally the deciding factor, since running costs are low for either system.

Automatic control allows a number of options to be considered to provide the best form of control for the circumstances. Generally available controls offer the following features:

1. Local control by personnel;
2. Automatic thermostatic control (single or multiple stage);
3. Fire override to open ventilators automatically by means of a connection to the fire-detection system or fireman's switch. This normally overrides all other control settings;
4. Timeswitch control to shut ventilators during unoccupied periods;
5. Weather override to close ventilators during rain or snow;
6. Wind override to shut high-level exhaust ventilators on windward walls (mainly used for smoke ventilation).

17.2.2 Powered (mechanical) ventilation

17.2.2.1 How powered ventilation works[9]

By definition, a powered ventilation system includes a mechanical means of inducing an airflow using an external power source. This is invariably an electrically driven fan. When a fan blade rotates it does work on the air around it, creating both a static pressure increase (P_s) and an airflow across the fan. The airflow has a velocity pressure associated with it, defined as $P_V = \frac{1}{2}\rho V^2$, and the fan can be described as producing a total pressure $P_T = P_s + P_V$. The pressure generated is used to overcome pressure losses (resistances) within the ventilation system.

Each fan has a unique set of characteristics which are normally defined by means of a fan curve produced by the manufacturer which specifies the relationship between airflow, pressure generation, power input, efficiency and noise level (see Figure 17.1). For geometrically similar fans the performance can be predicted for other sizes, speeds, gas densities, etc. from one fan curve using the 'fan laws' set out below.

For a given size of fan and fluid density:

1. $\frac{\dot{V}_1}{\dot{V}_2} = \frac{N_1}{N_2}$ — Volume flow is directly proportional to fan speed
2. $\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^2$ — Total pressure and static pressure are directly proportional to the square of the fan speed
3. $\frac{W_1}{W_2} = \left(\frac{N_1}{N_2}\right)^3$ — Air power and impeller power are directly proportional to the cube of the fan speed

For changes in density:

4. $\frac{P_1}{P_2} = \frac{W_1}{W_2} = \frac{\rho_1}{\rho_2}$ — Pressure and power are directly proportional to density and therefore for a given gas are inversely proportional to absolute temperature

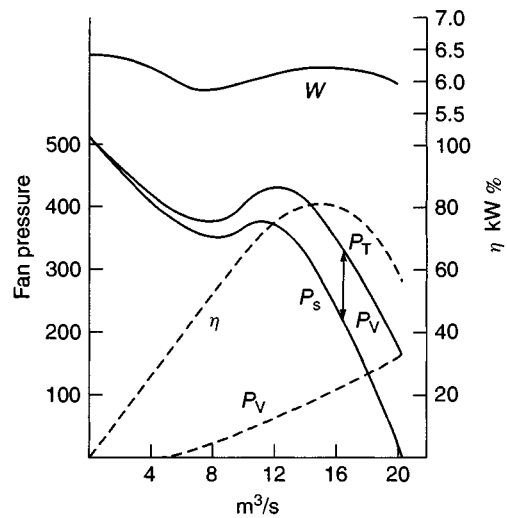


Figure 17.1 Typical fan curve for an axial fan

For geometrically similar fans operating at constant speed and efficiency with constant fluid density:

5. $\frac{\dot{V}_1}{\dot{V}_2} = \left(\frac{D_1}{D_2}\right)^3$ Volume flow is directly proportional to the cube of fan size

6. $\frac{P_1}{P_2} = \left(\frac{D_1}{D_2}\right)^2$ Total pressure and static pressure are directly proportional to the square of fan size

7. $\frac{W_1}{W_2} = \left(\frac{D_1}{D_2}\right)^5$ Air power and impeller power are directly proportional to the fifth power of fan size

where $\dot{V}$ = volumetric flow (m^3/s),
P = pressure (kN/m^2),
W = power (W),
D = size parameter (diameter) (mm).

In passing through the fans gases are compressed slightly due to the increase in pressure. For absolute accuracy note should be taken of this effect using the gas compressibility factor which will affect flow rate, static and total pressure and power. However, in most fan systems the effect is very small, since the pressure increase through the fan is insignificant compared to atmospheric pressure. By convention, compressibility effects are therefore normally ignored.

Since the pressure generated by most fans is far in excess of pressure differences due to buoyancy, the performance of a powered ventilation system is effectively constant, and flow rates and directions can be confidently predicted. Wind can affect the system performance, although the effects are normally not important provided some care is taken in locating atmospheric inlet and discharge points. The high-pressure generation also allows resistive components such as heater batteries, filters and attenuators to be used within the system.

17.2.2.2 Advantages and disadvantages

Advantages	*Disadvantages*
Weatherproof	Fixed air flow – not self-regulating
Predictable constant performance	Running costs (electrical and maintenance)
Air treatment can be incorporated	Noise
Fresh air can be delivered at optimum volume, velocity and temperature	

17.2.2.3 When to use powered ventilation

Powered ventilation is essential in some instances:

1. Local extract;
2. When pre-treatment of incoming air is required;
3. When a steady controlled airflow is required;
4. When there are no suitable external walls or roof for natural ventilation;
5. In deep-plan offices or large industrial spaces to provide positive air movement in central zones.

It can also be used in any situation where natural ventilation is suitable, generally becoming more economic as the roof height lowers, subject to noise levels being acceptable.

17.2.2.4 Control

Simple systems are normally controlled by a starter or contactor with manual push-button or thermostatic operation to start and stop the fan. More complex systems incorporating other components needing control or monitoring are normally operated from purpose-built central control panels. The most common functions provided are fan motor stop, start and speed control, damper control, filter-condition indication and heater battery control. For optimum control the system should be automatically controlled from thermostats or other sensors and a timeswitch.

17.3 Powered ventilation equipment

This falls into two basic groupings: supply air systems and extract systems. The equipment used for both is similar, comprising, as a minimum, a fan and weatherproof cowl, plus ducting, air-treatment equipment and grilles as required.

17.3.1 Fans

Five main types of fan are used in ventilation systems as described below.

17.3.1.1 Centrifugal

In this type air enters the impeller axially and is discharged radially into a volute casing. The airflow therefore changes direction through 90°, which can make this type of fan difficult to use within a ducted system. Two blade types are used, backward curved providing high-pressure at low volume flow and forward curved providing medium-pressure and volume flow. Typical static efficiencies are 70–75% and 80–85%, respectively.

17.3.1.2 Axial

Air enters and leaves the fan axially giving a straight-through configuration. Duties are usually high- to medium-volume flow rates at medium to low pressures. In its simplest form there is an impeller and its drive motor only mounted within the cylindrical casing, and the discharge flow usually contains a fairly pronounced element of rotational swirl which may, if not corrected, materially increase the resistance of the downstream part of the system. More sophisticated versions include either downstream or upstream guide vanes to correct the swirl. Typical static efficiencies are 60–65% or 70–75% with guide vanes.

17.3.1.3 Propeller

This is really a simple form of axial fan but with its impeller mounted in a ring or diaphragm which permits it to discharge air with both axial and radial components. Duties covered are high volume and low pressure. Static efficiency is normally under 40%.

17.3.1.4 Mixed flow

This is a fan in which the air path through the impeller is intermediate between the axial and centrifugal types giving the benefit of increased pressures but capable of being constructed to provide either axial or radial discharge. Static efficiency is typically 70–75%.

17.3.1.5 Cross flow

This type normally has a long cylindrical impeller having a relatively large number of shallow forward-curved blades. Due to the shape of the casing surrounding this impeller, air enters all along one side of the cylindrical surface of the impeller and leaves on another side. Static efficiency is typically 40–50%.

In general, axial fans are used for roof extract units and small ducted systems and centrifugal fans for large-ducted systems.

17.3.2 Roof extract units

These are the most commonly used powered ventilators in large open buildings such as factories, warehouses and sports halls. Mounted directly onto the roof or wall, they comprise an axial fan, a safety grille and a weatherproof casing. Two forms are normally available, the vertical-discharge type which tends to have a complex casing arrangement but which throws the exhaust clear of the building, and the low-discharge type which has a simple casing but directs the exhaust onto the roof of the building. Vertical discharge is essential when smoke or fumes are being exhausted (Figures 17.2 and 17.3).

These ventilators can normally be used with limited ducting or accessories. A variation, fitted with a centrifugal fan, is available for more extensive ducting and is often used for duties such as toilet extract in commercial buildings.

17.3.3 Roof inlet units

This specialized form of supply air system is often used in large open industrial spaces. It comprises a modular system of components which can be built up into simple systems. A typical system might have a roof inlet cowl, a recirculation damper, a heater battery, a fan, one or two outlet grilles and short sections of connecting ductwork, and would handle airflows up to 3–4 m^3/s, depending on size. A number of individual systems would be used to provide the total airflow required in the space (Figure 17.4). Systems are normally manufactured with aluminium casings to reduce the roof load.

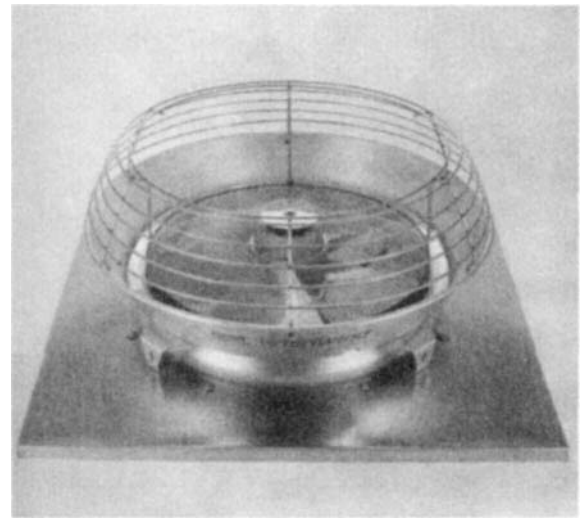


Figure 17.2 Vertical discharge powered roof ventilator

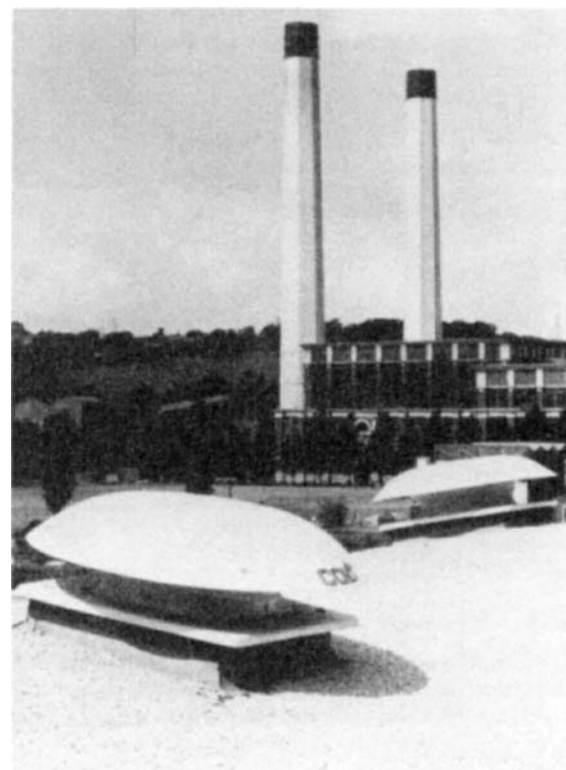


Figure 17.3 Low discharge powered roof ventilator

17.3.4 Ducted systems[10,11]

Larger ducted ventilation systems, as used in offices and commercial premises using a central air-handling unit and fabricated distribution ductwork, are akin to air-conditioning systems but with less treatment to the air at the Air Handling Unit (AHU) (see Chapter 18).



Figure 17.4 Roof inlet system

Volume flow rate requirements are normally higher for a ventilation system than for an air conditioning system due to the restricted temperature differential available.

17.3.5 Local extract systems[12]

Local extract systems are designed specifically to remove fumes, dust, mists, heat, etc. at source from machinery and fume cupboards. The main design considerations are capture of the contaminant, which will normally involve special hoods or cabins, and extract at sufficient velocity to satisfactorily transport the contaminant. Ductwork must be manufactured to resist abrasion or corrosion and sufficiently well sealed to prevent leakage. Welded ductwork is often needed. The fan may also need protection and the motor may need to be flameproof or out of airstream if the contaminant is flammable or corrosive. Treatment of the exhaust may be required to reduce pollution and nuisance and to comply with legislation. See Chapter 27 for a fuller treatment of this subject.

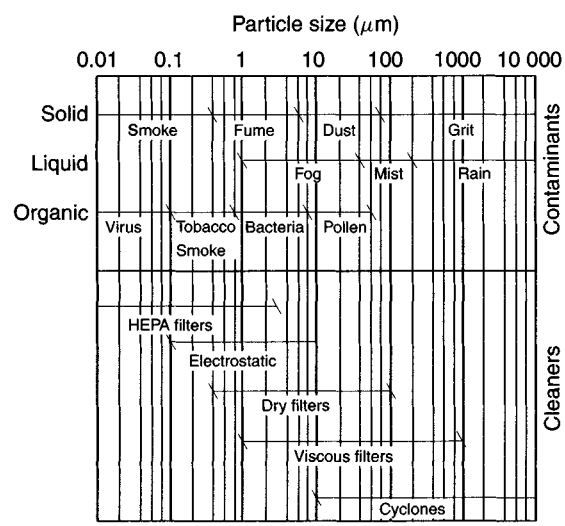


Figure 17.5 Typical particle sizes

17.3.6 Air cleaners

A wide range of types of air cleaners are available to match the number of contaminants needing removal from air. Figure 17.5 shows typical particle size ranges and the range of operation of each type of air cleaner.

17.3.6.1 Filters

Filters are a type of air cleaner in which a membrane of some kind is placed across the duct so that all airflow has to pass through it. In passing through, the particles can be separated.

There are three main types of filter: viscous, dry and HEPA. Viscous filters are normally a coarse weave of glass, plastic or metal strands coated with oil. As the air passes through the filter, particles impact against the material and are held in the oil. The panels are normally washable and can be re-used after re-oiling. Viscous filters provide good general filtration for air inlet to buildings.

Dry filters are normally a finer-weave fabric or fibrous material and will separate smaller particles than viscous filters, typically down to 0.5 μm. They may be thrown away or washed when dirty, depending upon type.

HEPA (or absolute) filters provide the greatest degree of air cleaning. These filters, which are akin to paper or felt, will capture particles down to 0.01 μm with efficiencies of up to 99.995%. They are generally used for clean room applications and are expensive.

If a high degree of filtration is required it is normal practice to have several grades of filter in series so that the coarser, cheaper filters can take most of the dust load,

extending the life of the more expensive filters. Filters add a fairly high resistance to the ducting system, increasing the energy use and running cost of the system, and they require regular maintenance.

17.3.6.2 Electrostatic precipitators

In these devices the incoming air is passed through an ionizer which gives each particle a positive charge (+6000 V) and then through a collector which has a negative charge (−6000 V). The positively charged particles are attracted to the collector walls. Regular washing is required to remove the collected particles.

Very small particles can be collected but large ones (above 5 μm) can cause arcing across the narrow gap between collector plates. These large particles should first be removed by a coarse filter. Precipitators are not normally suitable for wet environments since excessive moisture can cause electrical tracking and failure. Resistance to airflow is negligible.

Electrostatic precipitators are usually used in industrial extract systems. They may also be used as stand alone units, recirculating and cleaning air within a space. A common use is cleaning tobacco smoke particles from the air in pubs and clubs.

17.3.6.3 Activated carbon filters

These are used to provide adsorption of gases and vapours, most commonly to remove odours from extracts from kitchens or industrial processes. An efficiency of 95% is obtainable and the carbon has a long life since it can be reactivated by heating.

Replaceable carbon impregnated fabric filters may be used in supply air systems to improve air quality or reduce odours.

17.3.6.4 Cyclones

These are dynamic setting chambers in which a vortex is generated by the high-velocity tangential inlet airflow. Centrifugal force holds particles close to the wall where they collect and drain down if wet or spiral down if dry. The contaminant is collected at the bottom and the cleaned air is exhausted through the top. They range in size from small 200 mm diameter units used to collect oil mist from machinery to the large units seen outside paper and woodworking factories.

17.4 Natural ventilation equipment

The natural ventilation equipment commercially available can be split into two basic groups, fixed and controllable. Fixed ventilation, normally a weathered louvre system, is used in applications where ventilation is constantly needed, winter and summer, with no need for control to maintain human comfort conditions. Typical examples are plant rooms and building block drying rooms. Louvre systems are also often used for inlet or exhaust to powered ventilation or air-conditioning systems and for architectural cladding. A number of years ago, before energy efficiency became important, many factories had uncontrollable ridge vents of various types, but most have now been replaced. Controllable ventilation, which may be weatherproof if required, is used in buildings which are normally occupied and where waste process heat is not sufficient to heat a ventilated building in winter (i.e. most buildings).

17.4.1 Fixed ventilation

Fixed ventilation has to be weatherproof to some degree. If it were not, then a simple hole in the wall or roof would be sufficient. The normal form of fixed ventilator is the louvre panel. At its simplest, this may be a number of slats of wood mounted at 45–60° in a door or wall opening, and at its most sophisticated an aerodynamically designed two- or three-bank 'chevron' of roll-formed or extruded aluminium (Figure 17.6).

With all louvres there is a balance between their weatherproofing qualities and their airflow, and it is important to select a louvre with the correct balance for each application. No louvre can be guaranteed to be 100% waterproof under all conditions, but the best ones approach this standard under normal flow and wind conditions.

Louvres can be supplied in various materials and finishes, the most common being anodized or painted aluminium, since this provides good corrosion resistance and light weight. Other options are galvanized or pre coated steel or, for more rigorous conditions, stainless steel.

Most louvre systems have a pitch between 30 mm and 100 mm. Where noise control is required, louvres can be supplied either in the form of acoustic louvre with a pitch of 300 mm and acoustic material in the louvre blade or as standard louvre with an attenuator section behind it. A bird or insect guard (as applicable) is normally mounted behind the louvre.

17.4.2 Controllable ventilation

Controllable ventilation is normally provided by one of three types of ventilator: louvred, opening flap and weathered. The most common is the louvred ventilator which has a number of louvre blades controlled from a pneumatic ram or electric actuator which can be fully opened when ventilation is needed and fully closed to a weatherproof condition when it is not. These may normally be roof or wall mounted (Figure 17.7).

Opening flap ventilators have one or two hinged flaps (opaque or glazed) which are normally held closed but which may be opened to between 45° and 90°, depending upon design. Control is normally pneumatic or electric. Specific designs are available for roof or wall mounting (Figure 17.8).

Weathered ventilators need to have a complex air path in order to prevent rain entry so they therefore provide a restricted airflow. To overcome this, multifunctional ventilators are often used providing a direct airpath during dry weather and a restricted one during rainfall. These ventilators are normally only roof mounted (Figure 17.9).

Most ventilators are powered in one direction with spring return. Thus a pneumatic ventilator might be described as 'pressure to open' or 'pressure to close'. With

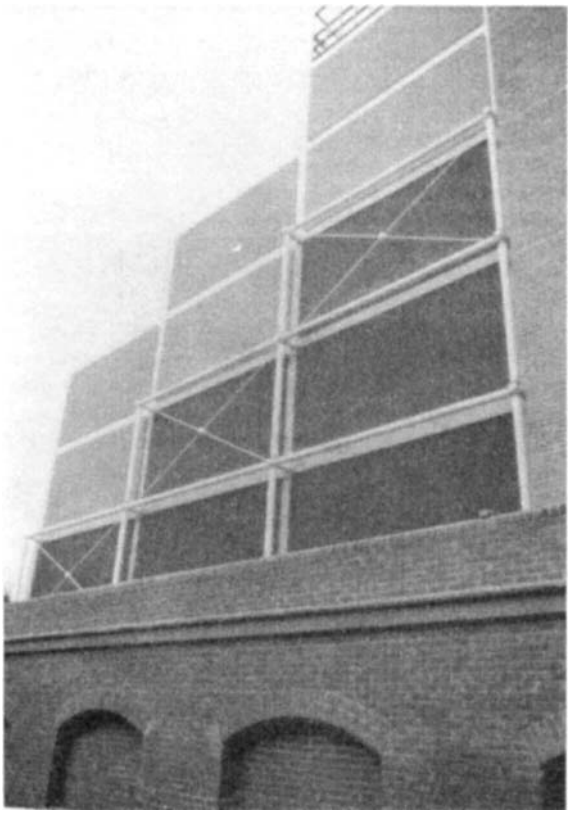


Figure 17.6 Fixed louvre system

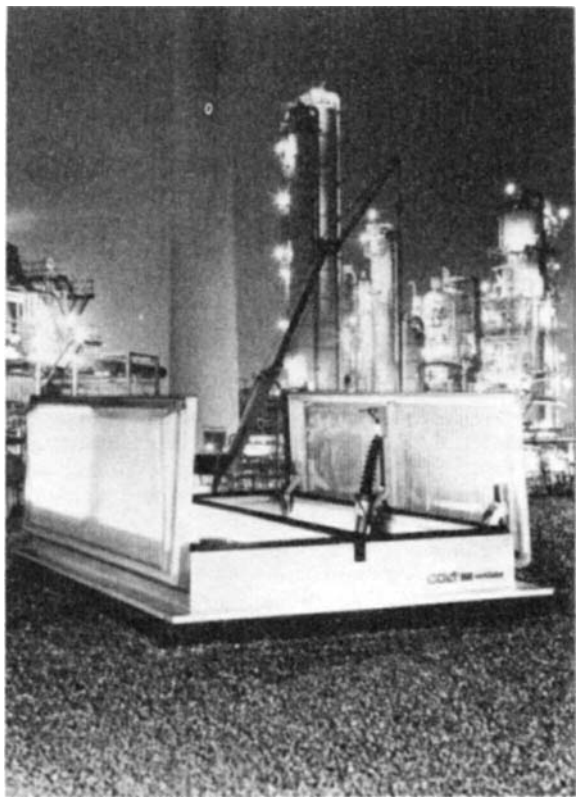


Figure 17.8 Flap type roof ventilator

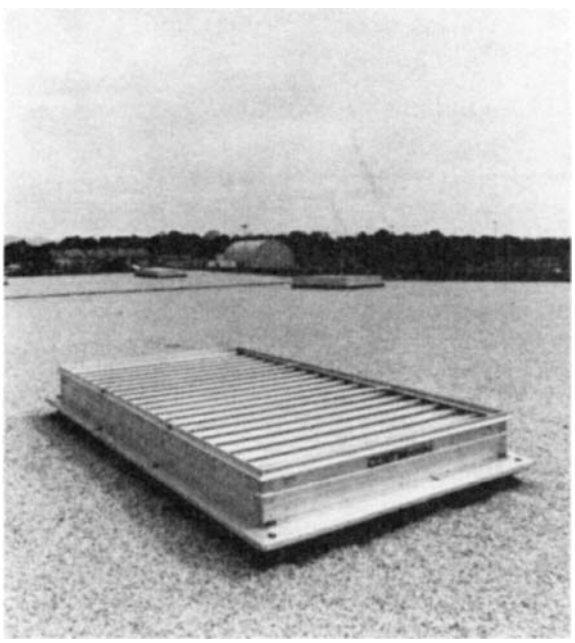


Figure 17.7 Louvred roof ventilator



Figure 17.9 Weathered roof ventilator

the pressure to open type the ventilator will fail to the closed position under the influence of the return spring, ensuring the building remains weatherproof. Where ventilators are installed mainly as smoke ventilators it is important that they fail to the open position, so pressure to close ventilators should be used. A fusible link is normally fitted into the controls so that in the event of fire, affected ventilators will open automatically to release smoke and heat.

Most ventilators are made of aluminium because of its good corrosion resistance and light weight. On industrial premises they are normally left in mill finish and allowed to oxidize. On commercial premises a polypowder paint finish is normally specified for aesthetic reasons.

Many older designs of ventilators are of single skin construction with poorly air sealed joints since winter heat losses through closed ventilators was not considered an important issue. Some of these designs have been updated with rubber or brush pile seals to reduce closed air leakage, since this was the major source of heat loss. As Building Regulations become ever more strict amid increasing concern for the environment, newer designs of ventilator have become available with insulated, and sometimes cold bridge free, construction and significantly improved seals.

A limited range of accessories may be provided, normally bird guard, insect guard or attenuators, but since airflow through the ventilators is driven by very small pressure differences (perhaps 5 Pa), great care has to be taken to ensure the ventilation remains effective.

17.5 System design

17.5.1 Overheating

Overheating can be due to a number of causes, but is usually from solar gain and machinery heat losses. If ventilating to provide thermal comfort in a space for humans or animals there are a number of considerations apart from simply air temperature:

1. Air temperature
2. Mean radiant temperature
3. Radiant temperature asymmetry
4. Air velocity
5. Humidity

Thus someone working near a window will receive hot solar radiation through the window in summer and cold radiation from the cold window surface in winter, causing uncomfortable radiant asymmetry even if the room temperature is perfect for personnel working away from the window. Ventilation will not be the correct solution for this problem – sun shading and double glazing would be more effective.

It is therefore important when considering ventilation design to consider the whole thermal environment and not to simply assume that limiting the air temperature will cure all problems.

17.5.1.1 Factories, warehouses, etc.

Two methods of preventing overheating are available: either general ventilation to provide fairly even conditions over the whole space at working level or local ventilation to give spot cooling for localized hot spots.

General ventilation is designed to keep air temperatures within a few degrees Centigrade of the outside shade temperature over the majority of the floor area. The ventilation rate required, which is not directly related to the space floor area or volume, is calculated from the formula:

$$\dot{V} = \frac{Q_T}{C_p \Delta t} \text{ m}^3/\text{s} \qquad (17.6)$$

where $\dot{V}$ = ventilation rate required (m^3/s),
Q_T = total heat load in the building (W),
C_p = specific heat of air
Δt = temperature difference between inlet (°C) and extract air.

The heat load (Q_T) includes all sources of heat in the building – electrical equipment, furnaces, people, solar gain, etc. The temperature difference (Δt) is selected to give the most economical design without compromising comfort and is generally found by allowing a 1.8°C temperature rise per metre height between inlet and extract ventilators. For natural ventilation the inlet and extract areas required can then be calculated from equation (17.3). Either powered or natural ventilation may be used. See Section 17.2 for a discussion of the benefits of each system.

The positioning of equipment is important to ensure that the whole space is ventilated without any significant dead spots of stagnant air. Generally, extract ventilators should be positioned as high as possible and spread evenly over the roof area with no more than 20 m between adjacent units. In smaller buildings the inlet is usually provided through existing openings such as loading-bay doors unless security precludes this. In larger buildings, inlets should be provided on at least two sides and, if any area is more than 20 m from an outside wall, consideration should be given to providing some local powered inlet to provide a positive airflow in that area.

If the heat load in the building is high enough for ventilation to be needed in autumn and spring, when air temperatures are fairly low, then the design must either ensure that airspeeds through the inlets are not high enough to be felt as a cold draught, which limits velocity to around 1 m/s, or provide for some heating of the inlet air to raise it to an acceptable temperature. (Partial recirculation can achieve this economically.)

Local ventilation is used where conditions in most areas are acceptable or unimportant but a small area or areas require cooling, generally because a workstation is close to a source of heat. In this situation there are three methods of treatment:

1. Reduce heat output or provide shielding. Radiant heat can be reduced by several methods such as insulating the equipment's hot surfaces, painting it with aluminium paint to reduce heat emission or by installing

a screen (two layers of expanded metal) between the workstation and the equipment.
2. Provide local air movement. Creating local air movement, even with warm air, provides a reduction in effective temperature and is inexpensive. A 'punkah' type fan may be used, although this can have the effect of drawing down warmer air from a high level, or a portable 'fan in a box'. It is advisable to have a multi-speed fan to allow the effect to be adjusted by the operator for maximum comfort.
3. Provide fresh air. For maximum effect, a ducted fresh-air inlet system will provide cool air in summer and, if fitted with a recirculation unit, allow a flow of tempered or warm air in winter. The air outlet should be positioned to ensure that the airflow does not cause a draught on the back of the neck.

17.5.1.2 Offices and public spaces

In factories, air movement can be generated by fairly unsophisticated equipment, since there is generally reasonable scope for equipment location and noise levels are often not critical. In offices and public spaces, the space, aesthetic, noise and air movement criteria tend to be much tighter. The ventilation rate needed can still be calculated using equation (17.6), although the acceptable temperature difference will be much lower (typically, 5°C).

While air conditioning is generally preferred to ventilation in modern spec built and city centre offices, there is a move back to ventilation due to environmental concerns. There is also generally a financial benefit in using ventilation.

When ventilation is used it is impossible to provide the same accuracy of temperature control that can be achieved by air conditioning, but recent research indicates that building occupants can be satisfied by the conditions in naturally or mechanically ventilated buildings, especially if they have a degree of local control of conditions – which can be as simple as having openable windows.

Natural ventilation is currently in vogue, but its use puts significant restrictions on the building design, requiring shallow floor plates, lofty rooms and thermally heavyweight construction with exposed floor or ceiling slabs as well as careful detailing to limit solar gain through glazing while providing good natural light. Careful detailing of the ventilation system is also needed to ensure that sufficient automatically operated and draught free ventilation is provided, that manually openable windows have fine control and cause limited draughts and that limited draught free winter ventilation is provided.

A CIBSE Application Manual[22] provides guidance on the design of natural ventilation systems for offices and public spaces.

Successful natural ventilation can be enhanced by use of night cooling to take advantage of the cool night air to pre cool the building structure and limit internal day time temperatures. This is a very energy efficient strategy which will typically reduce peak temperatures by 2°C, but it can cause security concerns. If these concerns cannot be adequately addressed then a mechanical system can be installed specifically for night cooling.

Post occupancy surveys have shown that naturally ventilated offices are viable and can be successful, but that the success is strongly dependent upon the quality of detail design of the ventilation system and its controls.

Mechanical ventilation, while less energy efficient than natural ventilation, is a simpler and more robust option which can be successfully used in a wide range of office buildings.

If sufficient opening window area is available, either an inlet or extract system alone may be satisfactory, but if optimum control of conditions is required, then both mechanical inlet and extract should be provided.

Inlet systems should incorporate heating if winter ventilation is needed and air filtration if the ambient air is not clean enough, as is common in city centres. Extract grilles are normally at high level and inlet may be high or low level. The design and position of the grilles or diffusers is critical for successful ventilation to avoid draughts and stagnant areas, and flow patterns will vary, depending upon whether the airflow is heating or cooling. ISO 7730 recommends that for light sedentary work the mean air velocity in the occupied area should not exceed 0.25 m/s in summer and 0.15 m/s in winter, and temperature gradients should not exceed 3°C between the ankle and neck.

Two design methods are commonly used: displacement ventilation, where clean air is introduced at low velocity at low level, picking up heat and odour as it passes through the room and rising by buoyancy up to ceiling extracts; and diffusion ventilation, whereby clean incoming air at higher velocity is mixed with the air in the space, with the resulting mixture extracted at ceiling level.

A combination of natural and mechanical ventilation is used in some buildings. This is referred to as 'mixed mode'.[23] It is generally used where natural ventilation is the preferred option but it either cannot provide sufficient comfort all summer or it is not suitable in some areas of the building. Mechanical ventilation is then provided in addition to natural ventilation with a control system which will automatically switch between systems as necessary.

It is not uncommon for small areas of ventilated offices to require air conditioning to cope with high local heat loads, e.g. computer rooms.

17.5.2 Fume dilution

17.5.2.1 Factories, warehouses, etc

Dilution of fumes in these areas is generally required for one of two reasons: either to reduce the level of harmful (toxic or irritant) fumes to a safe level, normally below the OES[18] (Occupational Exposure Standard) or to dilute offensive odours. Care must be taken to ensure that the problem is not merely passed on to neighbors. If it is, then a local extract with air-cleaning equipment will be preferred if it is practical. Indeed, a local extract system is always preferable, since it removes the problem at source, resulting in a cleaner environment within the building.

The starting point for design of a dilution ventilation scheme is normally a hygiene survey in which levels of pollutants and the ventilation rate are measured under worst conditions. The required ventilation rate is then

calculated by ratio of level of contamination measured and required, where

$$\dot{V}_r = \frac{\dot{V}_m \times C_m}{C_r} \text{ m}^3/\text{s} \quad (17.7)$$

where $\dot{V}_r$ = ventilation rate required (m³/s),
$\dot{V}_m$ = ventilation rate measured (m³/s),
C_r = contamination level required,
C_m = contamination level measured.

The ventilation should be designed so that airflow is directed from clean to dirty areas to keep the majority of the building as clean as possible. However, this form of ventilation does little for people working at the source of contamination.

Normal ventilation equipment can be used unless the fumes are corrosive or flammable. Powered equipment is employed to ensure that a steady airflow is provided.

Since the ventilation will be needed both summer and winter, there will be an energy penalty for the high level of airflow, and either the inlet airflow must be pre-heated or additional space heating will be required. The extra heat requirement is given by

$$Q = 1.2 \times (\dot{V}_r - \dot{V}_m) \times (t_c - -1) \text{ kW} \quad (17.8)$$

where Q = extra heat input needed (kW),
t_c = winter room temperature (°C).

17.5.2.2 Offices and public spaces

In these areas fume dilution is normally required to reduce body odour and tobacco odours and to minimise passive smoking risks. CIBSE[1] gives current UK recommendations for fresh air requirements for various rooms to overcome these, varying from 5 to 25 l/s per person. These figures give a balance between energy loss and air purity, and higher levels of ventilation may be needed if a clean atmosphere is of overriding importance.

In most older offices the natural ventilation achieved by infiltration is sufficient to provide reasonable conditions, but areas of high occupancy such as conference rooms, theatres, bars and restaurants normally require mechanical ventilation. Sufficient ventilation must be provided to match the highest demand, whether for odour dilution or summer overheating.

An alternative to ventilation to clear tobacco smoke is the use of electrostatic air cleaners which clean and recirculate air within a room. These provide smoke dilution without the energy penalty of extra ventilation but require frequent cleaning to keep operating at maximum efficiency.

The government is currently putting pressure on pubs, clubs and restaurants to provide a clean atmosphere with control of tobacco smoke. At present there is a voluntary code in place and a threat of legislation if the code is not effective. The code incorporates layout, ventilation and air cleaning guidelines to provide acceptable air quality.

17.5.3 Prevention of condensation

Condensation occurs whenever moist air comes into contact with a surface which is colder than the 'dewpoint' of the air. The dewpoint is the minimum temperature at which the air can contain the amount of moisture within it, and it will vary with moisture content. Condensation can also occur in the air when warm moist air meets cold air, when it is known as 'fogging'.

Condensation will appear on the inside surface of porous or impervious materials, forming first on the worst-insulated surfaces (normally glazing or steelwork). On porous surfaces condensation can occur within the material or at an internal boundary. This is known as interstitial condensation, and it is especially dangerous, since it is often not known about until it has caused noticeable damage.

Condensation can be avoided or reduced by several methods:

1. *Insulation* – Increase the insulation of surfaces to raise their temperature above the dewpoint of the internal air. This should be treated with care, since insulation of one surface may merely shift condensation to the next worst-insulated surface, or cause interstitial condensation.
2. *Reduce moisture emission* – If practical, this is always the best method of avoiding condensation. It can be achieved by good housekeeping, reducing steam leaks, covering open tanks when not in use or by changing working practices or modifying equipment either to contain the moisture more efficiently or remove it directly from the space.
3. *Ventilation* – Increasing the ventilation rate through a space while keeping the air temperature high will reduce the moisture content of the air without lowering surface temperatures and, by reduction of the dewpoint, will limit or avoid condensation. The hot, moist air exhausted takes a lot of energy with it, which it may be practical to recover using a heat-recovery system.
4. *Dehumidification* – Increasing the ventilation rate through a building has a high-energy penalty. Dehumidifiers do not increase the ventilation rate but recirculate air while removing the moisture from it by a refrigeration process. Their electrical cost is high, but since most of the energy is released into the room as heat, the overall running costs can be significantly lower than for a ventilation system.

Calculation for condensation problems is complex but is covered in the CIBSE Guide[1] in some depth.

17.5.4 Local extract

Local extract is used to remove contaminants directly from a process to the exterior without passing through personnel breathing zones. It thus provides a high degree of safety and because small volumes of air are extracted relative to a dilution ventilation system it is energy efficient.

Where dusts, grits, sawdust or other large particles are being extracted it is normally mandatory to include an air-cleaning device before the air is exhausted. Unless they are toxic or odorous fumes can normally be simply

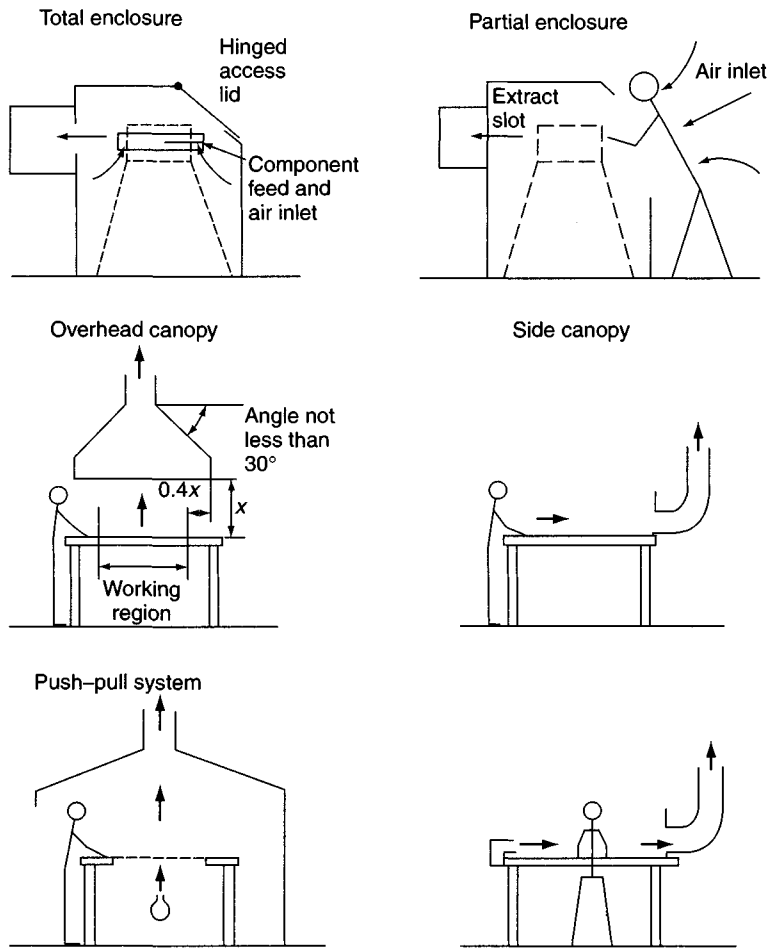


Figure 17.10 Typical local extract hoods and enclosures

exhausted into the atmosphere at a suitable location well away from anywhere with normal personnel access.

The design of a system can be broken into three main areas: capture, transport and cleansing. Capture of the contaminant is of paramount importance. Depending upon the source of the contaminant, capture may be via a hood, slot, booth or enclosure, with the airflow designed to take the contaminant from the source into the duct system without passing through the operatives' breathing zone. Some typical examples of good design are shown in Figure 17.10. To capture the contaminant, a minimum air velocity, referred to as the 'capture velocity', is needed at the source. The value of the capture velocity depends upon the type of source, enclosure and local air movement. Typical values are given in Table 17.1. Full guidance in the design of capture systems is given by the ACGIH.[12]

Once captured, the contaminant has to be carried along a duct system. If the duct velocity is too low, particles will tend to drop out of suspension and collect in or fall back down the duct. It is therefore essential that a suitable minimum duct velocity, referred to as the transport velocity, is maintained. Typical values are given in Table 17.2. Nothing is gained by velocities far in excess of the recommended transport velocity, and in some cases much is lost, since abrasion of particles on the duct can cause premature erosion and failure.

Table 17.1 Capture velocities

Condition of dispersion of contaminant	*Examples*	*Capture velocity (m/s)*
Released with practically no velocity into quiet air	Evaporation from tanks; degreasing, etc.	0.25–0.5
Released at low velocity into moderately still air	Spray booths; intermittent container filling; welding; plating	0.5–1.0
Active generation into zone of rapid air motion	Spray painting in shallow booths; barrel filling	1.0–2.5

Removal of particles from the airstream is generally carried out in a cyclone, positioned outside the building and taking particles from all sources in the building. Care

Table 17.2 Transport velocities

Contaminant	*Typical transport velocity (m/s)*
Vapours, gases	5
Fumes	7–10
Light dusts	10–12
Dusts	12–17
Industrial dusts	17–20
Heavy or moist dusts	20+

should be taken to position cyclones away from noise-sensitive areas since both ducts and cyclones can be noisy, especially if grits or chips are being carried.

Selection of fans and ducting for local extract must be more rigorous than for other systems. The fan must be capable of withstanding abrasion or corrosion from the contaminants, and if they are flammable must have a flameproof or out-of-airstream motor. The ducting also must be able to withstand abrasion or corrosion and must be fully sealed to prevent escape of contaminants within the building. For specialist applications such as fume cupboard extract, ducting and fans are often of plastic construction.

17.5.5 Smoke and heat exhaust ventilation (SHEVS)

SHEVS are designed to clear smoke and heat from a building in the event of fire. In large open spaces it is impossible to 'smother' a fire (as is often recommended in domestic situations) by closing doors and windows. The aim of a SHEVS is to minimize damage due to smoke staining and heat and to assist evacuation and firefighting by providing a layer of clear air below the smoke. Without a SHEVS a space can become 'smoke logged' from ceiling to floor in only a few minutes.

The actual design of a SHEVS is very complex, and although much published guidance is available[14–19] it should be left to experts. Where a SHEVS is installed for Building Regulations or fire regulation compliance the system design should be approved by Building Control or the Fire Brigade.

In discussing design or vetting tenders, there are a number of important points to consider:

1. *Design fire size* – An accurate assessment is needed of the maximum size of fire which is likely and which can be designed for. Since the whole design is based upon this value it is essential that this be carefully considered.
2. *Interaction with sprinklers* – The likely size of fire will be smaller in sprinklered buildings and the temperature of the smoke produced will be lower since the smoke is cooled by the sprinkler flow.
3. *Fire detection* – For efficient operation, control of the ventilation must be linked to a fire-detection system or sprinkler flow switch to ensure that the ventilators are operated as early as possible. Natural ventilators must incorporate a fusible link or bulb as a back-up fail-safe device, but this should not be considered as the main form of emergency operation.
4. *Fire resistance* – Fans, motors, cabling and controls which are expected to operate under fire conditions must be suitably rated for the temperature expected.
5. *Air inlet* – A suitable low-level inlet ventilation area must be provided for the expected air flow rate. Where personnel escape routes will be used for inlet, the inlet velocity must be low enough not to impede progress.

Smoke ventilation is not intended to replace other forms of fire prevention and control but to work as an important component in an overall scheme.

17.6 Legislation and codes of practice

17.6.1 Legislation

Most legislation regarding ventilation is aimed at controlling the environment within the workplace, and until very recently there was a plethora of assorted and outdated regulations in force. Most of these have now been repealed under COSHH.

Legislation regarding the state of the air exhausted into the external environment is limited, the Environmental Protection Act being the main Act in force. The major pieces of existing legislation are discussed briefly below.

17.6.1.1 Health and Safety at Work etc. Act 1974 (HASAWA)

This does not directly relate to ventilation but places duties upon employers and employees regarding health and safety and is an enabling Act for further Regulations.

17.6.1.2 Control of Substances Hazardous to Health Regulations 1988 (COSHH)

Enabled under HASAWA, these Regulations provide a requirement for adequate control of hazardous substances and therefore directly cover use of ventilation to keep the atmosphere clean within the workplace. Ventilation equipment installed to comply with COSHH must be regularly inspected and tested at no more than 14-month intervals, and monitoring may be required to ensure its continued effectiveness.

17.6.1.3 Factories Act 1961

This Act requires effective and suitable provision of ventilation to supply fresh air and render harmless, so far as practical, fumes, dusts, etc.

17.6.1.4 Highly Flammable Liquids and Liquefied Petroleum Gases Regulations 1972

These require mechanical ventilation to be provided, preferably by local extract from cabinets or enclosures, to avoid dangerous concentrations of vapours occurring in workrooms.

17.6.1.5 Woodworking Machines Regulations 1974

These Regulations require local extract to be provided at designated machines to remove sawdust, chips, etc. and for all solid particles collected to be discharged into suitable receptacles.

17.6.1.6 Offices, Shops and Railways Premises Act 1963

This Act requires that in all workrooms there must be effective and suitable means of ventilation.

17.6.1.7 Environmental Protection Act 1990

This Act controls emission of pollutants from ventilation systems by classification as 'Statutory Nuisances'. Local council environmental health departments acting on a complaint or otherwise can classify an emission as a statutory nuisance and issue an Abatement Order requiring emission to be stopped or reduced. This strengthens and supersedes the provisions of the Public Health Act 1936.

17.6.1.8 Control of Pollution Act 1974

This Act allows local authorities to require the occupier of any premises to provide estimates or other information as specified concerning emission of pollutants.

17.6.1.9 Workplace (Health, Safety and Welfare) Regulations 1992

These regulations build upon the Factories Act and Offices, Shops and Railway Premises Act to require reasonable environmental conditions within the workplace. The Approved Code of Practice to the regulations sets minimum winter temperatures but gives no guidance to reasonable maximum summer time temperatures.

Note: These synopses are the author's interpretation only. Neither the author nor the publishers can take any responsibility for any result of any actions taken as a result of reference to this section.

17.6.2 Codes of practice

17.6.2.1 BS 5925: 1980: Design of buildings: ventilation principles and designing for natural ventilation

This British Standard gives recommendations on the principles which should be observed when designing natural ventilation of buildings for human occupation and provides a basis for choice between natural and powered systems.

17.6.2.2 BS 5720: 1979: Code of Practice for mechanical ventilation and air conditioning in buildings

This deals with design, planning, installation, testing and maintenance of systems.

17.6.2.3 BS 6540: Part 1: 1985: Methods of test for atmospheric dust spot efficiency and synthetic dust weight arrestance

This gives standard test methods for filters used in ventilation and air-conditioning systems.

17.6.2.4 ISO 7730: Moderate thermal environments – determination of the PMV and PPD indices and specification of the conditions for thermal comfort

This gives a method of measuring and evaluating moderate thermal environments to which people are exposed.

17.6.2.5 EH22 (Revised May 1988): Ventilation of the workplace

This Health and Safety Executive Guidance Note provides information on standards of general ventilation and fresh air requirements in the workplace.

17.6.2.6 EH40: Occupational exposure limits

This gives advice on limits to which exposure to airborne substances hazardous to health should be controlled in workplaces. It is revised annually.

17.7 After installation

17.7.1 Commissioning and testing

Once any system has been installed it is important that it is properly commissioned to ensure that everything is working satisfactorily and to specification. A guide to commissioning ducted systems is available from BSRIA. Commissioning of other systems should be in accordance with the manufacturers' recommendations, but typical commissioning lists are shown below.

17.7.1.1 Natural ventilation systems

1. Check incoming electrical supplies to isolators.
2. Check pneumatic and electrical connections between panels and ventilators.
3. Check ventilators and ensure that any transport closure pieces and packing are removed and ventilators are correctly installed.
4. Commission compressor (if fitted) according to manufacturer's instructions.
5. Operate ventilators and check that all open and close correctly.
6. Check operation of all controls.
7. Check pneumatic system for leakage.

17.7.1.2 Powered ventilation systems

1. Check incoming electrical supplies to isolators.
2. Check electrical connections between panel and fans.
3. Check that fan blades rotate freely and ventilators are correctly installed.

4. Operate ventilators and ensure that all run correctly and in the correct direction.
5. Check full load current on all phases on all ventilators.
6. Check operation of all controls.

Once a system is installed, no specific regular testing of day-to-day ventilation systems is required unless they are installed to comply with COSHH Regulations. This testing would normally be carried out in conjunction with annual maintenance.

SHEVS must be regularly tested, since failure in an emergency cannot be allowed. The system must be fully tested in accordance with the manufacturer's instructions at intervals of not more than 1 month or as agreed with the fire authorities. Any faults found must be rectified immediately.

17.7.2 Maintenance

Most simple ventilation systems require only annual maintenance unless some form of air cleaning or filtration is incorporated, although where systems are pneumatically operated the compressor will need weekly checking. Air cleaners or filters will need regular emptying, cleaning or replacement to maintain efficiency and prevent clogging up. This can either be carried out on a regular schedule (based on the manufacturer's guidance and site experience) or when indicated by a pressure differential gauge or alarm. The cost of a gauge is easily repaid by savings in maintenance costs by maximizing intervals between cleaning or replacement. The task of maintenance can be made easier by taking care in design to provide good access.

Compressors will need a weekly oil level and receiver auto drain check and oil changes and filter cleaning at (typically) 500-hour intervals, although for compressors used only to operate ventilation this can be only an annual task due to the limited usage. Typical annual maintenance for systems are shown below.

17.7.2.1 Natural ventilation systems

1. Remove any debris (leaves, moss, etc.) from rain channels or drainage holes.
2. Check security of fixings.
3. Check operation of ventilators and, if necessary, clean or oil linkages.
4. Examine hinges, pulleys, cables, anchorages, etc. for wear.
5. Check pneumatics for air leaks and fully service compressor.
6. Check that all controls operate correctly.

17.7.2.2 Powered ventilation systems

1. Remove any debris from rain channels or drainage holes.
2. Check security of fixing.
3. Check that fan impeller turns freely.
4. Check electrical connections to fan.
5. Check operation of moving components (other than fan). Clean, oil or adjust as appropriate.
6. Run fan and check current against data plate.
7. Check that all controls operate correctly.
8. Check and clean filters, heater batteries, etc.

17.7.3 Running costs

Running costs of ventilation systems can be broken down into three main areas:

1. Maintenance costs;
2. Electrical costs;
3. Heat loss due to ventilation use during heating season.

17.7.4 Maintenance costs

Regular service checks such as filter cleaning and compressor oil level are normally carried out in-house and time can be allocated for these tasks once some experience has been gathered. Annual maintenance may be carried out in-house or by specialist service engineers employed either by manufacturers or HVAC service companies. A service contract can often include breakdown cover, which has the advantage of reducing risk of unexpected bills and ensuring that prompt repairs are effected at the cost of a higher annual premium.

17.7.3.1 Electrical costs

The only significant electrical cost involved in ventilation systems is operation of fans. Other electrical equipment such as dampers, compressors, etc. generally run for such short periods that costs are negligible.

Electrical costs for fans can be estimated from the following formula:

$$C = V \times \phi \times A \times \text{fuel cost} \times \text{hours run} \qquad (17.9)$$

where C = cost per annum (£),
V = motor voltage per phase (V),
ϕ = number of phases,
A = operating current (A),
Fuel cost = cost of electricity (in £/kWh),
Hours run = total running hours per annum.

17.7.3.2 Heat loss

Where a ventilation system is required to run during periods when heating is provided then there is an energy cost associated with the heated air being exhausted from the building. This is related to the extra heat input needed from the heating system to balance the heat loss through the extra ventilation. A calculation method is available in section B18 of the CIBSE Guide.[2]

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18 Air conditioning

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18.1 Basic principles and terms

18.1.1 Abbreviations

In addition to the abbreviations used in SI, the following are employed in air conditioning work:

db	Dry bulb temperature
wb	Wet bulb temperature
dp	Dewpoint temperature
rh	Relative humidity
μ	Percentage saturation
kg/kg	Kilograms water vapour per kilogram dry air (absolute moisture content)
TH	Total heat
SH	Sensible heat
LH	Latent heat
SHR	Sensible heat ratio
ON OFF	The condition of air or water entering or leaving a coil or heat exchanger
TR	Tons of refrigeration capacity
TRE	Tons of refrigeration capacity extracted
TRR	Tons refrigeration rejected (at final cooler)
HP	High pressure (refrigerant)
LP	Low pressure (refrigerant)
DX	Direct expansion cooling
ΔT	Temperature difference
ach	Air changes (room volumes) per hour
ahu	Air-handling unit
swg	Static water gauge
NR	Noise rating. One of a series of curves relating noise level and frequency to speech interference
NC	Noise criteria. Similar to NR, but differing, particularly at the low-frequency end

18.1.2 Terms

18.1.2.1 Mechanical ventilation

The movement of air by fan, conveying outside air into the room or expelling air or both. Filtration, heating and control of the distribution pattern may be included. It is not cooling in the sense of temperature reduction but can be used to limit temperature rise when the outside air is below that of the space being treated.

18.1.2.2 Full air conditioning

This necessitates plant capable of control of temperature by being able to add or subtract heat from the air and control humidity by being able to add or subtract water vapour. The system also comprises fan(s), filtration, a distribution system and may include noise control. Other terms such as 'cooling' or 'comfort cooling' may be met and these can be taken to mean an ability to lower the temperature of the air by refrigeration but without full control of humidity. Moisture may be removed as an incidental characteristic of the cooling coil. The term 'air conditioning' is sometimes used where control of humidity is not included. It is essential to employ clear specifications of performance.

18.1.2.3 Air

Atmospheric air is a mixture of gases, mainly nitrogen and oxygen together with water vapour. It normally carries many millions of dust particles per cubic metre.

18.1.2.4 Temperature

A measure of the average energy of the molecules of a substance. The heat intensity.

18.1.2.5 Heat

A form of energy which, when given to a body, raises its temperature or changes its state from solid to liquid or liquid to gas.

18.1.2.6 Heat flow

Heat flows from a body at one temperature to a body at a lower temperature. Materials have the property of resistance to the rate of heat flow. It differs from material to material.

18.1.2.7 Sensible heat

The heat energy causing a change in temperature, as in raising a kettle of water from cold to boiling point.

18.1.2.8 Latent heat

The heat necessary to change the state of a substance from solid to liquid or from liquid to gas, or the heat given up during the reverse process. There is no change in temperature during these processes. For example, continuing to boil a kettle of water previously raised to 100°C to steam requires the addition of latent heat, but there is no change in temperature if the pressure remains constant.

18.1.2.9 Total heat

The sensible heat plus latent heat in such a mixture as moist air. In air-conditioning work it is referred to a base of 0°C, not absolute zero.

18.1.2.10 Sensible heat ratio

Sensible heat flow divided by the total heat flow.

18.1.2.11 Enthalpy

The heat content of a substance per unit mass.

18.1.2.12 Dry bulb temperature

The temperature of air as indicated by a dry sensing element such as a mercury-in-glass thermometer.

18.1.2.13 Psychrometrics

The study of humid air. The psychrometric chart shows the relationship between the various properties of humid air in graphical form and can be used for the solution of problems.

18.1.2.14 Wet bulb temperature

The temperature of air as indicated by a thermometer when its bulb is enclosed by a water-wet wick. If the surrounding air is not saturated water will evaporate, taking the necessary latent heat from the thermometer bulb which then gives a lower reading than a dry bulb in the same air. The depression in wet bulb temperature is proportional to the amount of water vapour in the air.

Normal practice is to arrange a flow of air over the wick by using a sling (whirling) or fan-assisted instrument. If the thermometer is stationary an area of higher saturation builds up around the wick but the reading may be referred to tables for screen instead of sling readings.

18.1.2.15 Partial pressure

The contribution by each constituent gas to the total air pressure. Standard air pressure is 101.325 kPa (1013.25 mbar).

18.1.2.16 Vapour

A gas which is below its critical temperature and which can therefore be turned to liquid by an increase in pressure.

18.1.2.17 Saturation

There is a limit to the amount of water vapour that air can hold and this amount increases with an increase in dry-bulb temperature. When air at any temperature holds the maximum possible amount of water vapour the air is said to be saturated. It is common to express air humidity at any dry-bulb temperature as a percentage of the maximum.

18.1.2.18 Percentage saturation

This compares the mass of water vapour in a sample of humid air with the saturation mass at a given temperature expressed as a percentage.

18.1.2.19 Relative humidity

This compares the vapour pressure of the water vapour in a sample of humid air with the saturation vapour pressure expressed as a percentage.

The numeric difference between percentage saturation and relative humidity is very small and in practice the two terms are often used synonymously.

18.1.2.20 Dewpoint

The temperature to which a sample of air has to be reduced to bring it to saturation. It is fixed by the water vapour content of the air sample.

18.1.2.21 Absolute humidity

This measures the quantity of water vapour in a sample of air in kg moisture per kg air. This is the vapour content of the air although it is very frequently but incorrectly referred to as the "moisture content". The relative humidity then depends on the air dry bulb temperature. Air at 25°C containing 0.01 kg/kg is at 50% relative humidity (rh). If now cooled to 14°C the air would be at its dewpoint (i.e. saturated). If cooled further, moisture is condensed out, the sample remaining saturated as it cools. If now reheated back to 25°C its rh would be lower than 50%. If cooling had not been continued to condense moisture its rh would return to 50% at 25°C.

18.1.2.22 System resistance

The resistance to air flow which causes a pressure drop. It is similar to electrical resistance and voltage drop (see Section 18.5). The term 'resistance' is often used erroneously when pressure drop is meant. Resistance is the pressure loss for a given air flowrate.

18.1.2.23 Upstream, downstream

Used to denote positions earlier or later in the system relative to the direction of air flow.

18.1.2.24 Condensing unit

A refrigeration compressor and condenser on one chassis complete with controls.

18.1.2.25 Split system

As above but with a remote condenser.

18.1.2.26 Chiller

A compressor, water-chilling evaporator and condenser on one chassis.

18.1.3 The plant

These divide broadly into two types:

1. The direct expansion plant where the air-cooling coil is fed with cold refrigerant;
2. The chilled water plant where the cold refrigerant first chills water (or other liquor) which is fed to the air-cooling coil.

A block diagram of the DX system is shown in Figure 18.1. It has two main circuits – the air circuit and the refrigerant circuit. In the chilled-water system there are additional circuits:

1. Of chilled water between the refrigerant and the air-cooling coil;
2. Of water carrying heat from the refrigerant to the heat-rejecting device.

Figure 18.2 shows a block diagram of the system.

A temperature difference must exist between each stage to cause a heat flow from one to the other. The air and refrigeration side are described in further detail below.

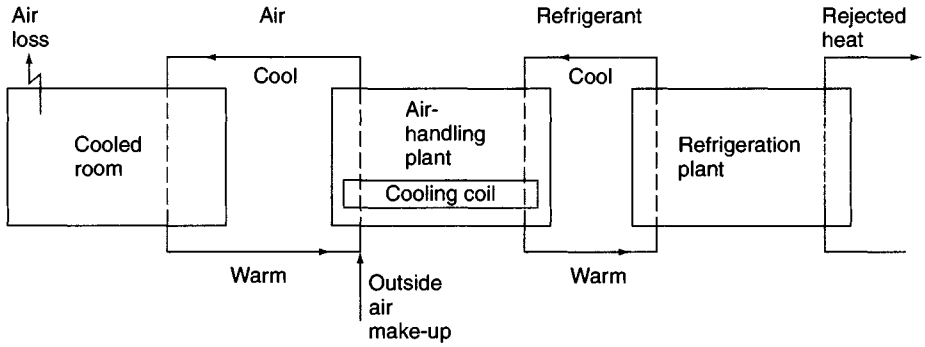


Figure 18.1 Heat flow paths in a direct expansion system

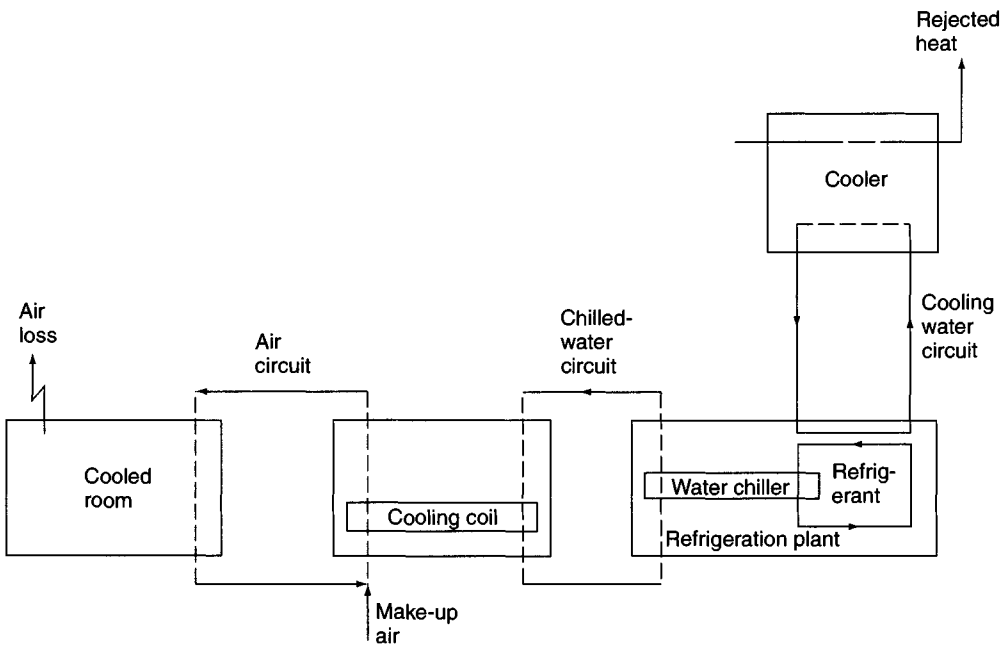


Figure 18.2 Heat flow paths in a chilled-water system

18.1.4 The air-handling plant

The plant may comprise one or more complete factory-made units or may be built up on-site from sub-assemblies. There can be variations from the arrangements discussed below and shown in Figure 18.3. The condition or quantity of air input to the conditioned space (referred to below as the room) must be varied such that after it has gained or lost heat or water vapour by the applied load its condition and therefore the room condition is as specified.

18.1.4.1 Outside air intake

During normal operation an air-conditioning system will introduce a quantity of fresh air for ventilation purposes. The quantity of air required to ventilate is usually considerably less than that required to cool the air-conditioned space and is discussed in Section 18.2. To economise on energy use it is usual to recirculate the major proportion of air being extracted and mix it with the required ventilation air. In most cases air-conditioned spaces are slightly pressurised to minimise the ingress of unconditioned air from outside or surrounding spaces and this is achieved by extracting a slightly smaller quantity of air than that supplied.

18.1.4.2 Mixing chamber

This is where the outside air intake and recirculated air are brought together before proceeding to the next stage of treatment. As shown in Figure 18.3, it is a low-pressure area which will induce outside air without the use of another fan if the route has low resistance.

When two samples of air are brought together the condition of the mixture may be arrived at arithmetically by

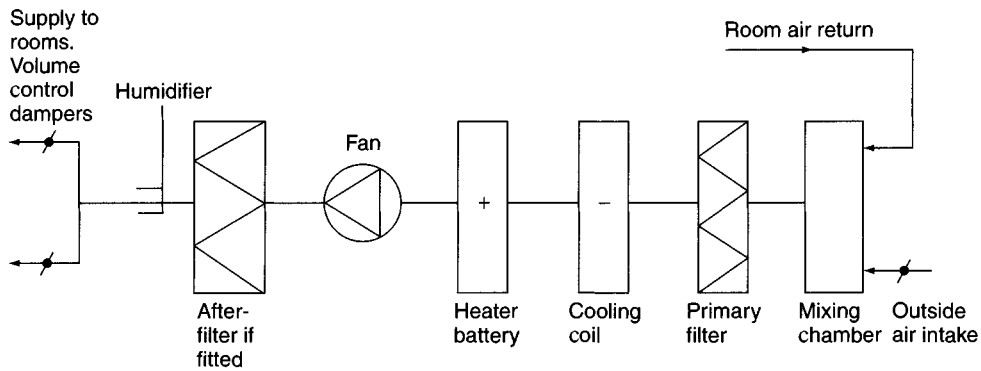


Figure 18.3 Air flow path in an air-conditioning system

adding the heat flow of each and dividing by the total mass flow; and similarly for the moisture flow. Alternatively, plot the condition of each onto a psychrometric chart. The mixed condition lies on a straight line between the two in a position proportional to the two quantities.

18.1.4.3 Pre-filter

Where a high degree of cleanliness is not required it could be the only filter in the system. The subject is covered in more detail in Section 18.7.

18.1.4.4 The cooling coil

This is the exchanger where heat flows from mixed air to cold refrigerant or to chilled water. It is an arrangement of finned tubes normally of aluminium fins on copper tubes, but copper fins can be specified for corrosive atmosphere. Performance characteristics are controlled by fin and tube spacing. If the room humidity is too high it can be dehumidified by operating the cooling coil at a temperature below the room dew-point temperature. This may result in the room becoming too cool in which case the heater battery must be brought into operation. Obviously it is undesirable from an economic point of view to operate the cooling coil and heater battery simultaneously but this is unavoidable at times if full control of both temperature and humidity is to be achieved.

18.1.4.5 Heater battery

This is used when (1) the room needs heating instead of cooling or (2) for reheat as described above. When and air-conditioning plant is required to serve more than one space where the load profiles for the spaces are significantly different it is common to install separate reheat batteries in the branch ducts to the different spaces.

The main plant then controls the dehumidification and humidification as an average of the spaces whilst the reheat batteries enable each space to be maintained at its correct temperature. This will mean less accurate control of the humidity in the individual spaces but for most practical cases the variations are not significant.

18.1.4.6 The fan

This drives the air around the system against its resistance (see Section 18.6).

18.1.4.7 Humidifier

The humidifier is a means of increasing the absolute humidity of the air although usually controlled from a relative humidity sensor. (see Section 18.8).

18.1.4.8 Air flow

The quantity supplied must be matched to the load on the plant (see Section 18.2). After leaving the plant it is distributed to match loads of the rooms or zones to be served.

18.1.5 The refrigeration plant

The basic circuit is shown in Figure 18.4 and the principal items are described below.

18.1.5.1 Evaporator

This is the device where the air or water being cooled gives up its heat to provide the latent heat of evaporation to the refrigerant. Superheat is also added to the refrigerant at this point to prevent damaging liquid forming on the way to the compressor.

18.1.5.2 Compressor

A compressor circulates the refrigerant around the system, raising its pressure such that the refrigerant can be condensed by removal of latent heat. It may also be considered as raising the temperature of the refrigerant above that of the final cooling medium to which heat is rejected. Lubricating oil is contained in the crankcase but, being miscible in the refrigerant, is carried around the system and returned.

18.1.5.3 Condenser

This is the vessel where the refrigerant rejects its heat to waste or reclaim, turning back to liquid in the process.

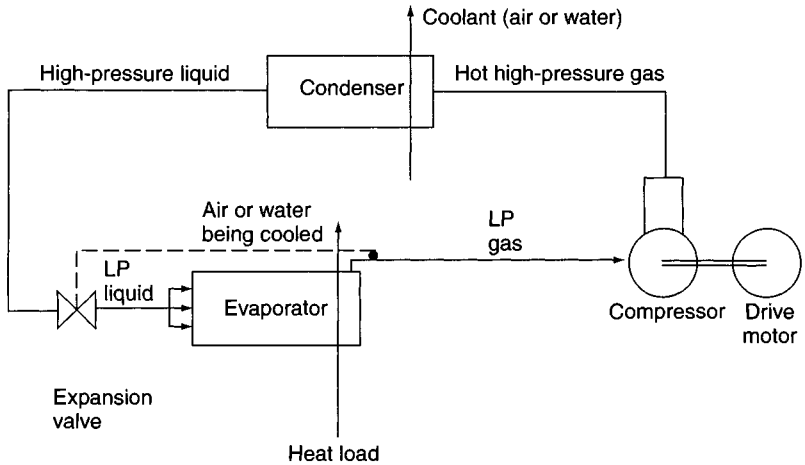


Figure 18.4 Refrigerant flow path in a cooling system

Sub-cooling is practised by the removal of further heat. This prevents liquid flashing back to vapour on return to the evaporator.

18.1.5.4 Expansion valve

A reduction in pressure and hence in temperature takes place across this item before the refrigerant re-enters the cooling coil via distributor pipes.

18.1.6 Controls

18.1.6.1 Room condition

Dry bulb temperature This is sensed by a thermostat in the conditioned space or in the return duct. Where underfloor air return is practised it is strongly recommended that the sensor be placed close under a return grille to prevent changes of condition occurring between the room and the sensing position. In large rooms separate thermostats can be arranged to give an average signal but individual zones of control each separately treated are much better. Dry bulb sensors may be bi-metal strips, thermistors or refrigerant-filled phials or bellows responding to pressure differences caused by temperature change. These, in turn, provide an electrical or mechanical signal. The mechanical items are used to alter the value of potentiometers or make-or-break contacts. The signals are transmitted to amplifiers which respond to the degree of error. An important feature is the proportional band of temperature over which the controls call for up to full plant capacity.

Humidity Humidity sensors may be animal or plastic skins varying in length with changes in rh or lithium chloride coating changing in electrical resistance. The former are prone to lose calibration. Other comments above apply equally to rh control.

Control at the evaporator A phial senses the temperature of the outlet suction line to the compressor and controls the expansion valve opening to maintain a constant temperature in the coil.

18.1.6.2 Control at chilled water coil

A three-way motorized valve is modulated between full flow to the coil and full bypass to satisfy the room thermostat.

18.1.6.3 Control of water-chilling compressors

Being large multi-cylinder machines, the chilling capacity is controlled in steps by rendering cylinder valves inoperative. Control is initiated by sensing water temperature in a storage buffer tank or by sensing return water temperature from the air-cooling coil. Small (DX) compressors are run on a start–stop basis on call from the room thermostat. Safety devices associated with compressors include:

High (gas) pressure cut-out;
Low (gas) pressure cut-out;
Oil differential cut-out (oil feed pressure to be above the crankcase pressure);
Freeze thermostat (low water temperature limit);
Single-phase protection (preventing attempts to start with loss of one phase of a three-phase electrical supply);
Time out (preventing too-frequent starting and motor burn).

Until all the switches in the interlock train are satisfied and closed the compressor will not start or will not continue to run.

18.1.7 The load on the plant

The unit of heat is the joule (J). The unit of heat flow rate is the watt (W) or J/s. However, the imperial unit should be understood as it will still be met, particularly outside Europe. The ton of refrigeration is derived from an ability to remove sufficient heat from a short ton (2000 lb) of water at 32°F to turn it to ice at the same temperature in the course of 24 h. This amounts to a heat extraction rate of 3.517 kW.

The load presented by the room is first transmitted to the room air which, in turn, passes it to the cooling coil.

Other gains will occur as detailed below. The total load is best considered in two parts – sensible and latent.

18.1.7.1 Machine heat

All electrical energy fed to the room will appear as heat. This presents a load to the plant unless power is conveyed out of the room by cable or hot items are physically removed. Parts of some large computers are cooled by a direct supply of chilled water presenting a load on the refrigeration plant but reducing the load on the air side. Cold outside conditions will result in some of the internal cooling load being met by fabric loss.

18.1.7.2 Fabric losses or gains

In winter in cold climates heat will be lost through fabric of the building. This will be advantageous at times of high internal load but will need to be considered as a heater battery duty at times of low internal load. In winter there can be considerable loads for humidifiers if the structure is not adequately vapour sealed. Weather-tightness is insufficient. For example, a computer room in the UK held at normal conditions may experience up to 1200 Pa vapour pressure difference, forcing moisture out. During high summer in temperate and hot climates the external water vapour pressure will be higher than in the conditioned space.

18.1.7.3 Personnel

People give off both sensible and latent heat. During light work such as in a computer suite or laboratory they emit approximately 110 W sensible 30 W latent and while seated, 90 W sensible 20 W latent.

18.1.7.4 Air ducts

A duct carrying cool air through a warm space such as a loft will gain heat before entering the conditioned room, contributing to the load on the plant. Ducts passing through the conditioned space do not add to the load. Similarly, there will be losses in winter if they carry warm air through cold spaces and moisture gains and losses if leaky. Insulation and vapour-tight joints are necessary.

18.1.7.5 Fan heat

The power fed to the fan shaft (or the total electrical power fed to the motor if within the duct) appear as sensible heat in the system. During a heating cycle this is useful. This commonly lies between 2% of the cooling duty for small systems to 10% for large systems.

18.1.7.6 Compressor heat

Friction (or, if within the refrigerant path, as in hermetically sealed or semi-hermetic machines, the whole of the input to the motor) increases the amount of heat to be rejected by the final cooler or available for heat recovery. It is uneconomic to operate refrigeration plant at unnecessarily high temperatures in order to assist recovery.

18.1.7.7 Pump heat

In chilled-water systems pump shaft power adds to the heat of the circulating water. Similarly, if the chiller has a water-cooled condenser pump heat is added to that handled by the final cooler. Power is proportional to the flow and pressure:

$$\frac{\text{Volume flow}(m^3/s) \times \text{Pressure (Pa)}}{\text{Efficiency}} = \text{watts}$$

Efficiency can vary between 35% for very small pumps and 80% for large ones, and may be found to lie between 3% for small heating circuits and 10% of the heat conveyed for large systems.

18.2 The air quantity required

18.2.1 Air change rate

Air change rates (room volumes per hour) are sometimes used to specify the duty of mechanical ventilation systems. The same may also be applied to air-conditioning plants but care must be taken as to whether these air changes are meant to apply to the total air in circulation or just the ventilation air. Recommendations and regulations are given in Chapter 17.

18.2.1.1 Volume to be supplied

The volume of air required to remove the heat gains from a space to be air-conditioned may be calculated from the following formula:

$$\text{Heat Gain} = \text{air flow mass} \times \text{air specific heat capacity} \times \text{temp. difference}$$

Where the specific heat capacity for air is approximately 1.02 kJ/kg°C and the temperature difference is the difference in temperature between the air supplied to the room and the room itself and a typical value for a temperate climate would be 8°C (e.g. air at 14°C supplied to a room at 22°C). For spaces with high ceilings and/or tropical climates higher temperature differentials may be acceptable. It is often necessary to know the air volume flow rather than the air mass flow and this can be calculated by dividing the air flow mass by an average air density value of 1.2 kg/m^3.

In ventilation systems the temperature rise calculated on the basis of specific heat alone will be pessimistic by one or two degrees because of the effect of building mass. Unless an extract is specifically designed to remove heat from hot spots or lights, the extract and room temperature can be taken to be the same.

18.2.1.2 Outside air intake

When temperature limitation is more important than close control of conditions, a considerable economy of refrigeration plant operation results from arranging to draw in outside air when it is sufficiently cool and rejecting this back to outside after having gained heat from the room.

However, where close control of temperature and humidity is required accuracy and economy ensue from minimizing the outside air intake. Ideally the ventilation air quantity should be based on the number of occupants. A rate of 8 l/s (0.008 m^3/s) being typical. Alternatively where occupancy is not defined a value of 2 l/m^2 (0.002 m^3/m^2) of floor area may be used as a guide. It is usually desirable to maintain a room pressure of 10 to 20 Pa above the surrounding spaces to minimise the ingress of unconditioned air and this is achieved by extracting slightly less air from the space that was supplied. The exact amount depends on the air tightness of the space and will usually need to be determined during the commissioning stage but would normally be between 2 and 5%.

18.2.1.3 General considerations

The relative position of air intakes and air outlets needs careful consideration.

Ideally they should be located on the same aspect of the building but not adjacent to each other. This arrangement minimizes the destabilizing effect of wind forces without a significant risk of short-circuiting between inlet and outlet. Air intakes should be located as far away as possible from any source of pollution such as vehicle exhausts, flues, kitchen or toilet discharges.

Air-lock entries should be used where close control of conditions is required and for clean rooms, but conventional doors with close fit and self-closures are sufficient.

Fire authorities may stipulate pressurization of certain areas such as stairways and may require smoke-extract systems to be brought into operation automatically in the event of a fire. They should be consulted at an early stage of the design.

18.3 Heat losses and gains

18.3.1 Heat losses

Heat transfer through a partition is a function of resistance to heat flow, the temperature difference driving the heat through and the surface area. The function of heating systems is to provide the heat lost in maintaining the temperature difference. Thus

Heat flow (watts) is $U \times$ TD $\times$ area

where U is a coefficient for the partition in watts per m^2°C. For each room served the loss through each wall, ceiling and floor should be calculated and for each part of those surfaces where differences occur, such as windows in walls or cantilevered structures of upper floors.

The U values of many partitions or composite constructions can be found in standard references but others may have to be calculated where no data are available or changes are contemplated. The resistivity (r) of each element of the partition encountered by the heat in passing through must be found and multiplied by the thickness in metres. Manufacturers are usually able to give resistivities. The sum (R total) of all the elements, including the inner and outer surface resistances and the resistance of any interleaf air gap, is found. The U value is the reciprocal of R total. For example, for a wall:

Outer surface (normal exposure)	0.055
112 mm brick skin 0.12 × 0.112	0.01344
50 mm uninsulated air gap	0.180
150 mm lightweight block skin 5.88 × 0.15	0.882
15 mm rendering 2.5 × 0.015	0.0375
Inner surface	0.123
R total =	1.29094
$U = 1/R$ =	0.775

If this is insufficient to meet the building regulations (e.g. the external wall of a dwelling house) the problem could be reworked using additional insulation.

The temperature at any intermediate point is proportional to the R total to that point. This may be used to decide whether that point is above or below the dewpoint of penetrating air.

In maritime climates such as the UK the lowest external temperatures are not sustained for long periods. The mass of the structure has a slugging effect, and it is safe to use a relatively high external design temperature (e.g. −1°C in the south of the UK and −4°C in the north). These figures do not apply to an outside air intake where the full effect of low temperature is felt immediately nor to lightweight structures. When choosing a design temperature difference, one must take into account that adjacent rooms may not always be heated to their design temperature. Heat bridges, which are weak points in the insulation, must also be considered in proportion to their areas.

Cold outside air introduced to the system by infiltration or by design of the plant will require heat to be added by the plant or directly in the room to maintain the room temperature. The heat required is

kg/s × 1.02 × °C TD kW

For infiltration it is convenient to use $m^3/h \times 0.33 \times$ °C TD watts, but where air conditioning is employed infiltration should not be allowed. Air lost from the space by pressurization carries heat away but this is not an additional load beyond that mentioned above.

The available heating capacity should exceed the calculated figure, this being sufficient only to balance the losses under steady conditions. A 25–50% excess capacity is recommended to provide warm-up from cold and good response to controls but without excess overshoot. It is important in close control air-conditioning design to have sufficient heating capacity to raise the room temperature from cold following plant stoppage. If the room is cold the controls will see high rh and call for dehumidification upon restarting. Unless this is countered by sufficient reheat the control of conditions will not recover automatically.

18.3.2 Internal gains

Any heat liberated within the room reduces the heating effort required by the plant. At any time these gains

exceed the loss more than marginally, cooling is required. Heat sources are:

1. The total electrical input to the room unless power is carried away by cable or heat by pipe. This includes lighting and it should be remembered that the input to fluorescent fittings is greater than the tube ratings. Some luminaires are designed as air-extract fittings, in which case their heat is a load on cooling plant, but does not contribute to room heating unless the plant is in a non-cooling recycling mode;
2. Heat from other processes unless carried away by pipe or items are taken out of the room;
3. Heat from personnel (see Section 18.1);
4. There should be no space heating within air-conditioned rooms but some gains may arise from hot water pipes passing through to other areas;
5. Gains from adjacent spaces held at a higher temperature;
6. Heat gains into ducts where these pass through warm areas *en route*;
7. The shaft power of fans will appear in the system as heat. Where the drive motor is in the airstream the whole of the motor input will appear as heat.

18.3.3 Heat gains

The calculation of heat gains through the building fabric is more complicated than for heat losses, taking into account the gains from both the air-temperature difference and from solar intensity. The gain varies during the day with the movement of the sun and changes in air temperature. Heavily glazed buildings are susceptible to large gains from low sun elevations at all times of year and here building orientation can have a considerable effect on plant loads.

A structure with a large mass will result in the peak gain appearing on the inside some hours after the external peak, and the gain will be attenuated since the outside condition will be reduced before that time. The time of peak gain will differ for each of the enclosing surfaces, so it is necessary to calculate each for several hours to find the peak for one room and to repeat this for each room to find the peak load on a plant serving several rooms. Computer packages are available to undertake this laborious task but the broad method is shown below.

To avoid temperature shock and for economy, the control of comfort air conditioning may be allowed to drift with extremes of external temperature. However, where the design is to maintain specified internal conditions under virtually all external conditions data may need to be adjusted upwards.

18.3.3.1 Gains through walls

$(A \times U \times (M - T)) + (A \times U \times F \times (P - M))$ watts

where A = area (m),
U = W/m^2°C)
M = mean solair temperature (°C) (solair temperature is a composite temperature taking into account outside dry bulb temperature and solar radiation),
T = fixed room temperature (°C),
F = factor depending on wall thickness (varies from 1 at zero thickness to approximately 0.05 at 0.5 m thick),
P = solair intensity at the sun time considered.

The delayed time at which this gain is manifest depends on the structure thickness and density and varies from zero for zero thickness to 15 h for 0.5 m thickness.

18.3.3.2 Gains through windows

$A \times ((C \times I) + U \times (O - T))$ watts

where A' = area (m),
U = W/m °C,
$\acute{C}$ = solar gain factor,
I = direct radiation intensity,
T = room temperature (°C),
O = outside temperature (°C).

The gain is immediate.

18.3.4 Heat of outside air intake

The outside air brought into the system for ventilation purposes will add a significant sensible and latent heat loads to the air-conditioning plant. The total load can be calculated by multiplying the mass flow rate of outside air by the difference in enthalpy (total heat) between the design room condition and the design outside condition to give a kW rating.

18.4 Air conditioning for computers

18.4.1 The computer

In the context of this section a computer is a large mainframe machine standing in its own room. The machine is housed in cabinets 1–2 m high with a metre or so clearance all round. Some items are purely electronic, others handle magnetic tape, magnetic discs or paper. The function may be printed output following calculations, information storage and retrieval or electronic control of a remote process. In the largest configurations output printers and communications equipment may be housed in their own adjacent rooms but with similar environmental control. Other associated rooms which require air conditioning if included in the suite are: Job Assembly, Operations Control Room, Magnetic Media Store, Computer Engineer's room, Ready-Use Stationary Store. The main stationary store and store for master tapes are not normally conditioned although are heated in cool weather. The items can be conditioned in the Job Assembly room before use. Reserve master magnetic media can be housed in a remote building or room where, in temperate and warm climates, conditions are maintained by building mass.

The computer will dissipate large amounts of heat which have to be removed to prevent temperature rise. There is usually a contractural requirement to provide conditions within fairly close limits to ensure reliability and to allow handling media at high speed. The requirements are specified by the computer manufacturer, and

are typically 21°C ± 2°C and 50% rh±5% together with a filter performance of 80% average arrestance Euro 4/5 or 80% average efficiency Euro 4/5, at least in the outside air intake (see Section 18.7). The control should centre on the specified figures and only touch limits (if at all) with changes of load. In spite of developments in design, heat concentrations tend to rise and configurations expand.

Modern telecommunications equipment is very similar, but environmental tolerances are normally much wider, with particular emphasis on reliability.

18.4.2 Air supply

Cooling air to the cabinets is normally introduced from the room at low-level front or back with fan-assisted discharge to the rear or top. The normal practice is to introduce room-cooling air at high level. This mixes with rising hot air to give a near-uniform condition in the occupied levels. The distribution of cooling air must be carefully matched to heat load around the room. A large room (say, over 300 m^2) should have separate zones of control with their own sensors. The ceiling void should nevertheless be common. The recirculation of air will confine itself to the zones fed by individual units when all are running but will be redistributed by a ventilated ceiling in the event of partial failure of plant modules.

The easiest and most flexible method of introducing air is by a ventilated false ceiling. A great advantage of a ventilated ceiling supply is that the layout of the computer or indeed its make and heat pattern may not be known at the time of air-conditioning design, and will most certainly alter during the life of the plant. The distribution of supply air can be altered to match the load providing sufficient cooling capacity and air volume are installed.

Upward air flow is also practised. The cable void formed by the raised floor is used to supply air which enters the room via floor grilles. These can be moved to meet the pattern of heat distribution and are normally placed close to the computer cabinets, but consideration must be given to changing air conditions, intended to meet changing room load, entering the computer compartments. Care has to be taken to avoid the updraught lifting dust into the occupied space.

The extracts may be in the ceiling with the advantage of taking up the heat of lights without it passing to the room. Greater use can thus be made of a given air flow. Care has to be taken in the choice of grilles if trolley traffic is going to be present. Low supply temperatures may cause discomfort to staff.

18.4.3 Air extract

Air extract can be at one wall or, in the case of ceiling diffuser supply, extract grilles can be interleaved. The normal for all but the smallest computers is to use the underfloor cable void as a return path. This void is formed by proprietary 600 mm or 2 ft square interchangeable tiles standing on corner jacks. Some of these may be perforated or they may be fitted with grilles. A maximum velocity of 2.5 m/s over the grille face or through perforations is recommended. Depending on the detail of the tile chosen, a pressure drop of about 10 Pa can be expected, but in the case of carpet-covered tiles where the holes tend to become obstructed a downrating to 70% is recommended.

18.4.4 Chilled water

Some very large machines have a direct supply of chilled water to a heat exchanger in the central processor or its store, the final distribution within the machine being part of its design. The user's responsibility is the provision of half couplings (often Hanson, USA) and the chilled water supply rate, temperature, pressure, pH and other analyses. Welded pipe and vapour-sealed insulation are essential. End-stop valves should be installed and consideration should be give to fitting bypasses to compensate for changes in demand and to allow one computer (if there is more than one) to be fed while another is uncoupled. Consideration should also be given to the installation of moisture detectors underfloor.

The plant should be replicated for reliability and to allow maintenance (say, 3 × 50% capacity). Proprietary units are available specifically for this function.

The final connection to the computer is by flexible pipe, but it is still necessary to liase with others to know the position to terminate and, in due course, which floor tile is to be cut and precisely how. This can be expected to entail extra floor jacks.

18.4.5 Computer heat

Ideally, the air-conditioning designer is given the heat loads to be catered for at the outset. However, in the fast-moving field of computers this may not always be the case. Also, the life of the plant is likely to outlast more than one computer configuration but need not itself require more than re-zoning. Particularly where a computer has a number of peripherals (input and output devices), it is unlikely to dissipate fully to the maker's data at any one time, but it is strongly recommended that further diversity on that for individual items given at the maker is not allowed in the design of the cooling capacity of the plant. It is unwise not to allow for expansion of the computer configuration. An initial design on a basis of an overall heat dissipation (say, 500 W/m^2 overall average) unevenly distributed about the room is not unreasonable for large computer halls. In this field the design engineer should not be afraid to question his brief if the client is to be well served. Flexibility to cater for changes has already been covered above.

18.4.6 Telecommunications

Much telecommunications equipment is designed for overhead cabling, which can be very extensive and dense. Any modern equipment which relies on cooling to function should have breaks in the cabling layout partly to allow cool air to fall. In the case of naturally ventilated racks the air discharge should be directed down gangways (the racks being arranged in long suites) and not directly over the racks. A ventilated ceiling supply can be confined

to the racked area to allow other services to pass without breaking the ceiling. Except in smaller cases, for modern systems duct and diffuser designs may be insufficiently flexible and may not be able to meet the concentrations of heat without discomfort to attendants. However, in small installations (150 m^2) air-handling units may be employed directing air freely over the top of the cabling.

While the air distribution must match the heat distribution, the position of extracts is not important. Direct return to air-handling units mounted around the room in numbers necessary for reliability is common practice. In the event of loss of one or more cooling modules a well-designed ventilated ceiling adds to reliability by distributing the reduced amount of air in the same proportions throughout the room.

18.5 Air distribution and system resistance

18.5.1 Duct sizing

Ducts convey conditioning air from point to point at a variety of speeds. Slow speeds results in large ducts, costly in themselves and in building space. High speeds result in noise and the need for high fan powers. A good basis for air conditioning is 6–7 m/s adjacent to the plant but, as discussed below, less at distant points.

When we refer here to static pressure we mean the difference between internal and external pressure causing air to tend to flow into or out of ducts. Velocity pressure is that due to the air's forward movement. The sum of the two is total pressure.

18.5.2 Duct design

Simple runs of a few metres may be designed for a constant velocity. A supply duct is thus reduced in steps at each outlet or a return or exhaust duct similarly increased in section in the direction of flow.

A large system with branches, several inlets or outlets and some tens of metres long will be more easily controlled at the end distant from the plant if velocities are reduced as we progress down the length of the duct. If air is slowed in a controlled way with the duct sides diverging at not more than 15° included angle its velocity pressure will reduce and (ideally, without loss) its static pressure will rise to maintain a constant total head to compensate for pressure loss as the air progresses down the duct. However, at least by manual methods, design for static regain is laborious and the duct shape unconventional. It is seldom practised.

A method commonly used is that of equal surface friction per unit run. If rectangular ducts are being considered their equivalent circular diameter must be found. This may be obtained by

$$1.3 \times [(w \times d)^{.625}]/[(w + d)^{.25})]$$

Here w and d are width and depth and the units may be metres or millimetres. Alternatively, the diameter may be found from published charts. Using Figure 18.5 a pressure gradient (Pa/m) is chosen and with each change of volume flow a new diameter is found. This is converted to a convenient rectangular section equivalent to the round section. It will be seen that the velocity reduces.

Where practicable, the large surface area of wide shallow ducts should be avoided to keep pressure gradients to a minimum. There can be no hard-and-fast rule, 4:1 being a suggested limit. The system may, of course, be designed to use only round-section ducts.

18.5.3 System pressure drop

The point of interest is the path of highest pressure drop or index leg. Other parallel branches can be designed of appropriate size to pass the required amount of air, those of lower resistance than the index leg being throttled by dampers. The pressure drop is the sum of the drops caused by the following and is calculated to determine the pressure against which the fan must operate:

Surface friction of duct as discussed above (Pa/m × length);
Changes in section;
Bends;
Branches;
Obstructions;
Grilles, meshes, etc.

Pressure drop is calculated by $\zeta \times$ velocity pressure, where ζ is the resistance factor for the above items other than duct friction and is found from Table 18.1 or similar references. Velocity pressure is found by 1/2density × velocity^2, taking standard density at 1.2 kg/m^3, or from Table 18.2.

18.5.3.1 Plant resistance

In the design of tailor-made plant it is necessary to calculate the above as they occur within the plant and add the pressure drop of all other items such as air filters at their dirty conditions, coils, etc. In the case of proprietary units it is normal for the manufacturers to quote an external pressure against which they will deliver the specified air quantity.

18.5.3.2 Duct resistance

The basis of good duct design is to arrange gradual changes to section and direction. It is sometimes necessary to construct a 90° elbow with no inside radius. The pressure drop and noise generation can be greatly reduced by incorporating turn vanes which split the air into a number of near-parallel paths. The information given in Table 18.3 assumes simple (non-aerofoil) turn vanes (see also Figure 18.6).

18.5.4 Ventilated ceilings

A ventilated ceiling is an alternative to ducts, diffusers and grilles as a means of distributing air within a room. It is suspended below the structural ceiling forming a shallow void. One type consists of perforated metal trays or tiles. Each is supplied with a bagged acoustic pad which is removed from those trays or tiles which are to

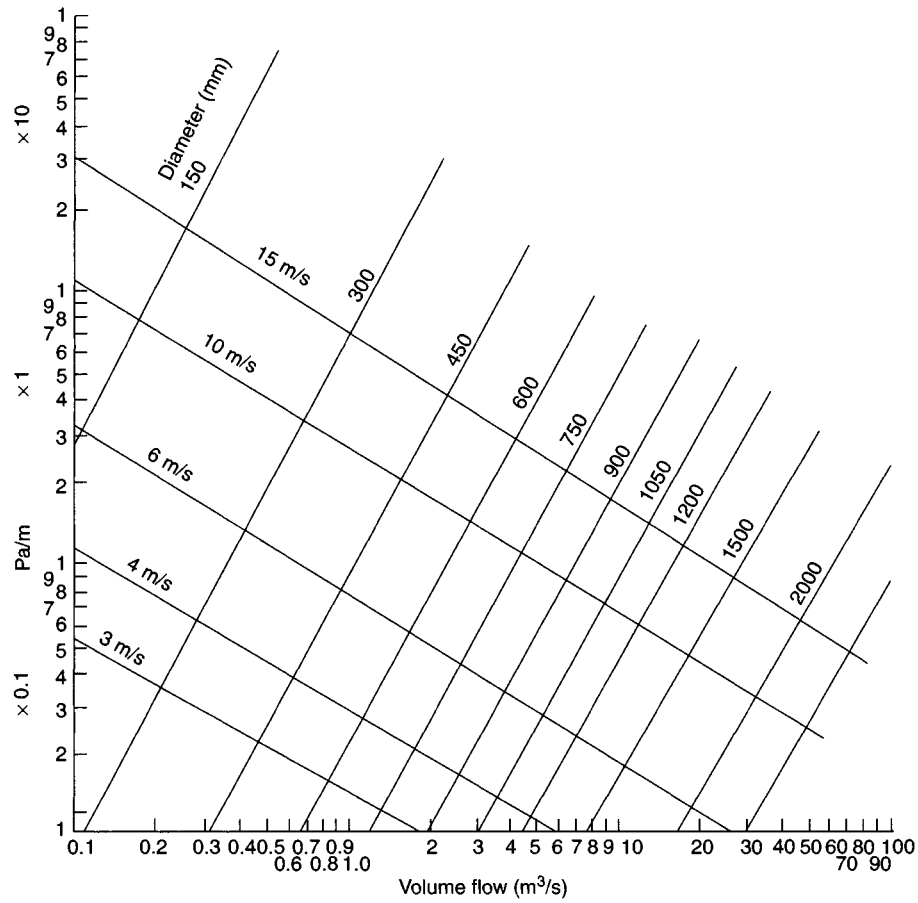
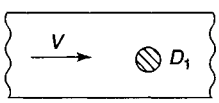
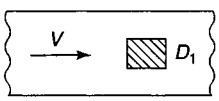


Figure 18.5 Pressure gradient in circular steel ducts

Losses at obstructions

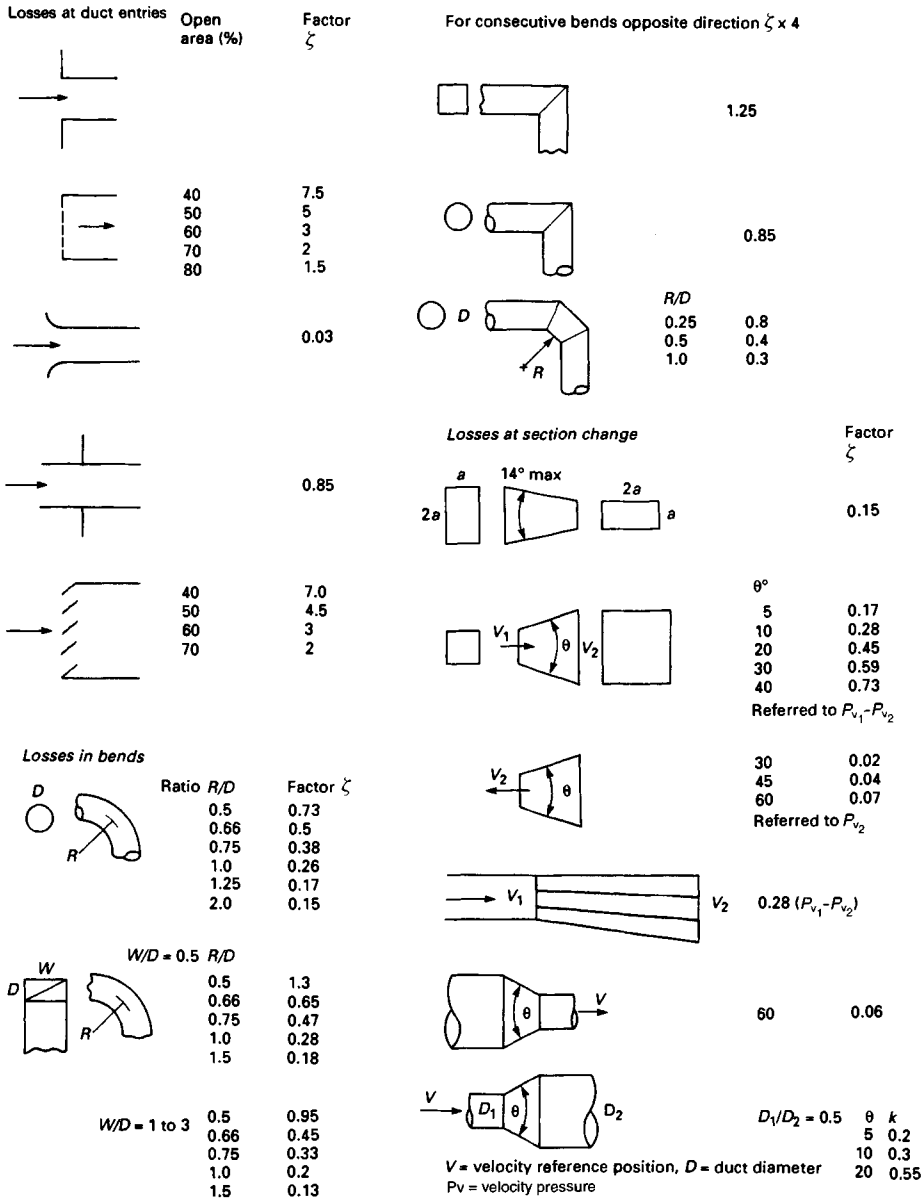
	Ratio D_1/D_2	Factor ζ
	0.1	0.16
	0.25	0.5
	0.5	1.6
	0.1	0.5
	0.25	1.1
	0.5	3.0
Idle stage of axial fan		0.1
Electric heater battery 80% free area		1.0
Finned-tube coils (referred to face velocity)		2 to 6

ventilate. Another consists of tiles with single-row slot openings at intervals between runs of tiles, the openings being controlled by dampers integral with the slots. Any type of tile which can shed dust or is combustible should be avoided. Rising hot air and descending cold air mix a few hundred millimetres below the ceiling, giving a near-uniform condition in the occupied levels. The availability of very small areas of control can be advantageous where electronic apparatus with mild chimney effect would have its natural cooling upset by strong downdraughts, by confining air supply to gangways.

The method is useful where large quantities of air are to be introduced without draughts; where the distribution of heat load is unknown at the time of design or is likely to alter; and where, as a measure of reliability, it is required to redistribute the remaining air in the original proportions in the event of partial failure of the plant.

Ventilated ceilings can cater for 1 kW load per square metre and in excess of 100 ach. Lighting and power tracks can be incorporated and fire-detection heads fitted. In computer suites (see Section 18.4) it is normal to combine a ventilated ceiling supply with an underfloor extract, which is then not critical as to layout of grilles and assists any heating mode. The pressure and slot velocity are, for all practical purposes, uniform throughout the ceiling area, and the air pattern is finally set by checking the room temperature from point to point. Pressure drops are of the order of 20 Pa. Void depths are seldom critical, being a function of the throw required and the presence of obstructions such as beams or pipes. Depths of 200–1000 mm are common, with throws from the entry point of up to 20 times void depth.

Table 18.1 Resistance factors



The air supply is introduced by stub ducts penetrating the void by 0.5 m or less and simply cut off square. However, where there are obstructions across the void it can be advantageous to convey a proportion of the air to or past this by extended ducts. Equally, it can be advantageous to duct air part-way if it is to double back round a corner. In general, however, the system is very tolerant, including positioning air entries about the room. Stub velocities should be 3.5–5 m/s but individual manufacturers will give their own requirements.

Unless beams are present at the entry the stubs should be close to the structural ceiling. Beam fairing may be used where the void has to be shallow and this can reduce the risk of re-entrainment due to local high-velocity pressure. Zone barriers are fitted within the void where separate rooms are to be fed. The ceiling need not cover the whole room.

18.6 Fans

18.6.1 Fan selection

Fans propel the air through the system, and must be chosen to be capable of delivering the required volume

Table 18.1 *(continued)*

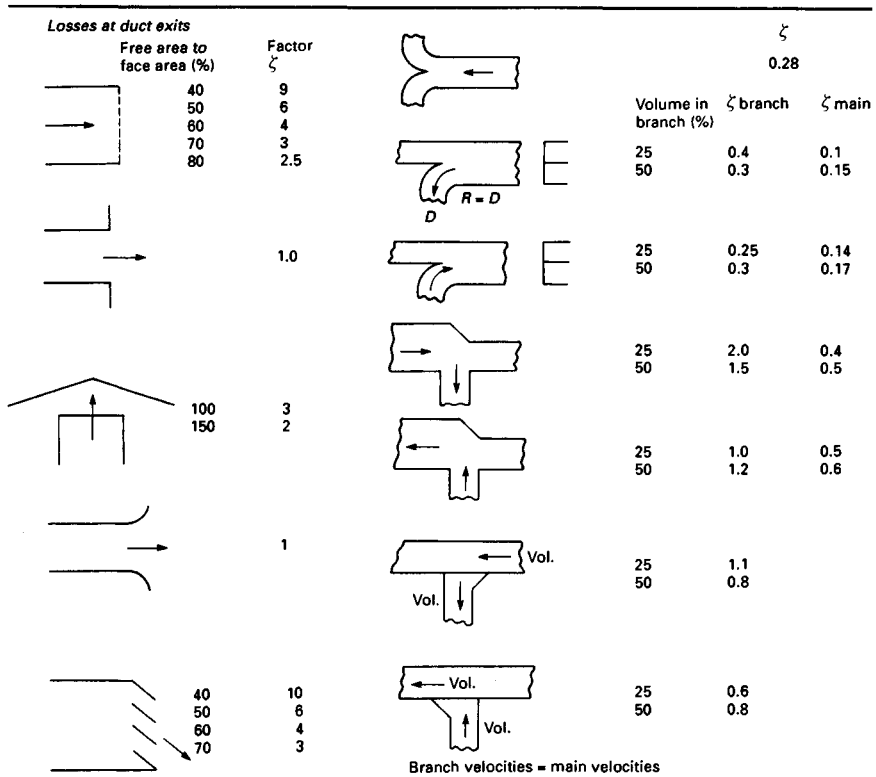


Table 18.2 Velocity pressure (Pa)

m/s	0	1	2	3	4	5	6	7	8	9	10
0.0	0.0	0.6	2.4	5.4	9.6	15.0	21.6	29.4	38.4	48.6	60.10
0.1	0.01	0.73	2.65	5.77	10.09	15.61	22.33	30.25	39.37	49.69	61.21
0.2	0.02	0.86	2.90	6.14	10.58	16.22	23.06	31.1	40.34	50.78	62.42
0.3	0.05	1.01	3.17	6.53	11.09	16.85	23.81	31.97	41.33	51.89	63.65
0.4	0.1	1.18	3.46	6.94	11.62	17.5	24.58	32.86	42.34	53.02	64.90
0.5	0.15	1.35	3.75	7.35	12.15	18.15	25.35	33.75	43.35	54.15	66.15
0.6	0.22	1.54	4.06	7.78	12.7	18.82	26.14	34.66	44.38	55.30	67.42
0.7	0.29	1.73	4.37	8.21	13.25	19.49	26.93	35.57	45.41	56.45	68.69
0.8	0.38	1.94	4.7	8.66	13.52	20.15	27.74	36.5	46.46	56.62	69.98
0.9	0.49	2.17	5.05	9.13	14.41	20.89	28.57	37.45	47.53	58.81	71.29

flow against the calculated system pressure, advisedly with a small margin.

Individual fans are capable of operating over a range of volumes and pressures which are interrelated, the performance being shown in manufacturers' tables and curves. Venturing outside the recommended area of operation may, depending on the type of fan, result in motor overload, motor undercooling, vibration or stall. Selection should be made for minimum power input, which is also likely to be the quietest fan for the duty. Performance is usually quoted for a standard condition of 1.2 kg/m^3. Calculations of system resistance are best carried out at the same condition. The user may find only the static pressure quoted. If total or velocity pressure are also quoted or the outlet velocity can be calculated the designer can calculate how much pressure can be recovered after the exit. Any mismatch due to difficulty in calculating system resistance will cause the volume to rise or fall, to settle on the fan characteristic curve.

18.6.2 Types

The broad range of types used in air conditioning is:

1. Centrifugal
2. Axial
3. Propeller
4. Cross Flow
5. Mixed Flow

Table 18.3 Where to place splitters

Duct width (m)	*If one split r1* (mm)	*If two r1 r2* (mm)	*If three r1 r2 r3* (mm)
0.5	110	65, 190	50, 110, 230
1.0	155	85, 280	60, 150, 380
1.5	190	100, 380	65, 190, 520
2.0	226	110, 470	70, 230, 660
2.5	255	115, 540	75, 255, 790
ζ factors:			
If none			
1.25	0.65	0.5	0.45

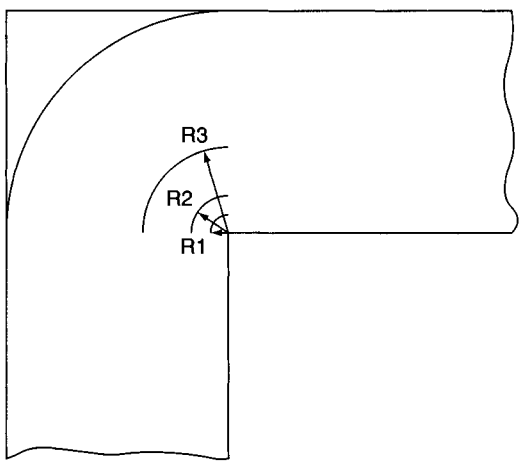


Figure 6 Splitters in mitre bends

The centrifugal fan has an inlet on the axis of rotation and outlet from a scroll casing 90° from the inlet. The centrifugal fan is not reversible. The characteristics of the fan are determined by blade shape, i.e.:

1. Straight blades or paddle wheel: Low efficiency; used for conveying particle-laden air.
2. Forward-curved blades: Moves large volumes for a given size; the driving power required rises markedly with increased volume, necessitating an adequately rated drive motor.
3. Back-curved blades: Highest efficiency of the group; more stable characteristic of volume against pressure; capable of developing higher pressures; non-overloading, i.e. the power does not rise to a peak as the flow tends to zero or free flow.
4. Many developments of the centrifugal fan exist, the most commonly employed being the double-width double-inlet fan moving twice the volume for a given wheel diameter. It is possible in large purpose-made plants to arrange for the drive motor (and hence its efficiency losses) to be external to the airstream.

Axial fans have a cylindrical casing and the fan blades are mounted on an extension of the shaft on the centre line. The blades are normally of aerofoil section. Axial fans are available with adjustable blade angles which allow differing characteristics from one construction or alteration on-site by specialists. The power characteristic is usually non-overloading. In the working range the developed pressure increases with reduced volume. Stall is said to occur when the fan can no longer develop the pressure to deliver the required air volume. This is a feature of high blade-angle fans. It is best not to attempt to use such a fan to deliver too small a volume.

They are reversible with varying degrees of efficiency. Air leaves the blades with rotary motion and can be straightened by downstream vanes, leading to increased pressure development. Two-stage contra-rotating fans develop more than twice the pressure of a single stage. Further staging may be arranged.

When using conventional induction motors the available range of speeds is restricted by the fixed-supply frequency and the number of field poles in the motor. It should be noted that, outside Europe, supply frequencies other than 50 Hz are used, resulting in induction motors operating at proportionally different speeds, and that this applies to all types of fan.

Special versions are available, such as hazard-proof and for high-pressure operation, but these are not normally applicable to the field of air conditioning. Fans are available with fewer blades (part-solidity) to allow the use of smaller higher-speed motors. There are also fans with short casings having a length little more than that to accommodate the blades for use in confined spaces.

Propeller fans are of low capital cost for the volume moved but are used in applications where the resistance is very small such as unducted openings through partitions. The power required increases with resistance. Their pressure–volume characteristic changes with the relative position of the blades and mounting plate.

Cross-flow fans have a blade arrangement similar to that of a back-curved centrifugal fan but the casing arrangement allows the incoming air to enter along the width of the blades, avoiding the 90° turn. Long narrow shapes can be arranged, making them suitable for use in small air-handling units, fan heaters or air curtains.

Mixed-flow fans have the appearance of an axial fan but has an impellor that has similar characteristics to those of a backward curved centrifugal fan. This would be an excellent combination but for their low efficiency.

18.6.3 Multiple arrangements

Fans are sometimes operated in parallel where relatively large volumes are required to be delivered against a relatively low resistance. Ideally they should be identical or similar characteristics to avoid instability. In the event of failure of one the effect of reduced pressure drop in the system is to give a flow of about two thirds that of two. Non-return dampers should be fitted.

Fans are installed in series where a relatively small volume of air needs to be delivered against a relatively high resistance. This arrangement is very common with axial fans which develop and inherently low total pressure compared with centrifugal fans. Axial-flow fans are available having two (contra-rotating) impellers and motors in the

one casing. Further staging may be arranged. If one stage fails or is switched off it will idle round with loss, but since similar losses in centrifugal fans are much higher, these are not usually operated in series. However, supply and extract fans in a recirculating system effectively in series may differ.

18.6.4 Fan laws

The laws quoted here are selected as those appropriate to the practicable applications of fans:

Volume flow varies as the speed of rotation;
Pressure varies as the square of speed of rotation;
Power varies as the cube of the speed of rotation;
At constant speed a fan delivers constant volume (m^3/s) into a fixed system in spite of change in density;
Pressure and power absorbed vary as change in density.

18.6.5 Volume regulation

This falls under two headings:

1. Where a permanent change is found to be needed during commissioning or change of duty. The volume may be changed:
   (a) By variation of system resistance by damper action. Care is needed to prevent axial fan motors overheating or reaching the stall point;
   (b) By changing the speed of the drive. In centrifugal fans the common practice is to change or adjust belt drive pulleys, taking care not to exceed the power capability of the motor. In axial fans the pitch of the blades may be adjustable by swivel mountings on the hub.
2. Where frequent change is required in the normal operation of the plant variable speed fans would be used. Some axial fans are available with blades which can have their pitch adjusted during operation.

18.6.5.1 Mounting

It is common practice to support the fan on anti-vibration mountings and connect the fan casing to the duct by short lengths of flexible non-combustible material. Care should be taken during installation to see that these are aligned to prevent entry turbulence and noise generation.

18.7 Dust control and filtration

18.7.1 Dust control

Dust is continually being introduced to the conditioned space by clothing fibres, skin particles, shoe dirt, room processes and the outside air make-up. Dust particle sizes range from 1 μm to 75 μm, smaller particles being described as smoke. In an apparently clean office there may be as many as 30 million particles per cubic metre.

Control is by filtration in the plant but smoke can be removed by local recirculation through fan filter units.

For Clean Rooms (rooms of a very high standard) dust count per unit volume will be specified, but other specifications for room cleanliness are usually in terms of filtration performance against a standard test dust. Other important features are resistance to air flow and dust-holding capacity, leading to the fan energy required and filter life.

By number count the great majority of particles in the outside air are likely to be less than 1 μm. By weight these small particles will account for a very small proportion of the sample. A filter with a high efficiency measured by weight of particles trapped may be almost transparent to the small ones. Very high counts can be found in rural areas from pollen or agricultural activities.

Where a high cleaning efficiency is required it is sound practice to install a filter of lower performance upstream to trap the larger particles and prolong the life of the more expensive High Efficiency Particulate Arrestance (HEPA) Air Filter. Two filters of equal merit placed in series will not be materially more efficient than one.

The action of most filters is mechanical. These are normally scrapped when fully loaded but may, for lower efficiencies, be washable. Another type uses electrostatic charges.

18.7.2 Electostatic filters

These are usually provided with a mechanical pre-filter to remove the larger particles and serve to even out the flow over the face. The air then passes between plates positively charged at 10 or more kV and the dust thus ionized is attracted to downstream plates charged at a lower voltage negatively. A mechanical after-filter may also be fitted in case electric flashover at the plates releases dirt. Cleaning is by hot water wash, necessitating drying procedures, or by mechanical agitation. Their resistance to air flow is low and their efficiency good against small particles. They are not often employed in general air-conditioning work.

18.7.3 Tests

Different test methods produce numerically different results and comparisons should only be made of results using the same test method. Tests fall into three categories: gravimetric tests, which measure ability to trap and retain dust; those which measure staining power of contaminants before and after filtration; and those measuring the concentration of a test aerosol either side of the filter by photoelectric methods. The tests which will be met most often are as follows.

BS 2831 has been withdrawn. The No. 1 test for high-grade filters has been superseded by BS 3928 for absolute filters (those having an efficiency of better than 99.9% in that or similar tests) and by ASHRAE 52–76.

18.7.3.1 ASHRAE 52–76

This forms the basis of Eurovent 4/5. There are two tests. The atmospheric dust spot efficiency test, assessing the reduction of staining power of atmospheric dust, is generally used for the higher efficiencies as well as the synthetic dust weight arrestance test, using an artificial dust. In both cases averages are quoted from a series of tests.

Filters are classified in BS 6540: Part 1–Eurovent 4/5 but without statements of airflow rate or final pressure drop. From the lower performance upwards:

Average arrestances (Am) EU1 <65%; EU2 ≥ 65 to <80%; EU3 ≥ 80% to <90%; EU4 >90%
Average efficiencies (Em) EU5 ≥ 40% to <60%; EU6 ≥ 60% to <80%; EU7 ≥ 80% to <90%; EU8 ≥ 90% to <95%; EU9 >95%
Higher cleaning ability is tested to Eurovent 4/4.

18.7.3.2 BS 3928

This test uses a cloud of sodium chloride particles. The size distribution is from below 0.1 μm to approximately 2.0 μm and a figure for percentage penetration is obtained. Since the test does not materially load the filter it can be used to assess the quality of each unit before despatch. This test forms the basis of Eurovent 4/4, which differs a little in procedure.

18.7.4 Standards required

For many applications filters with an average arrestance of 80% against Eurovent 4/5 will serve, but in more critical situations and, for example, in the outside air intake of computer rooms or laboratories 80% average efficiency would be chosen.

18.7.5 Clean rooms

The dust count to be achieved may be specified in terms of US Federal Standard 209b. There are three standards: 100, 10 000 and 100 000, which are the maximum counts per cubic foot of 0.5 μm and larger particles. Maxima for 5 μm particles are also given. BS 5295 has four classes: 1 is the most stringent and calls for a marginally lower count than US Federal Standard 209b, class 100. It carries details for a range of particle sizes, room construction and air flow pattern. Laminar flow is required for the cleanest areas, which can be achieved when the ceiling or one wall of the room is composed of a louvered filter bank. Filter efficiencies ranging from 70% to 99.995% are recommended.

18.7.6 Filter life

Filter life varies with make and type, and may be limited by the ability of the fan to operate against pressure drop. It is a function of the dirtiness of the air and the amount of material packed into the filter bank. Life may be quoted in terms of dust held in g/m^2 face area. For fan selection a knowledge of pressure drop is required. Typically, a panel filter might be quoted as operating from, say, 75 Pa initially at 2.5 m/s face velocity to 250 Pa when loaded and a HEPA might operate up to 700 Pa. The pressure drop across a bank of filters is kept within bounds by changing a proportion in rotation.

18.7.7 General

Care should be taken during installation to see that there is no edge leakage. For tailor-made plants it is best if filters are kept sealed in their delivery containers until after the plant has been completed and vacuumed out. Unfinished duct ends should be covered during the progress of other work, since cleaning is difficult and expensive.

Filters should meet at least the requirements of (in the UK) BS 2963 and in some cases be non-combustible to BS 476: Part 4, although construction methods render this difficult.

18.8 Humidification

The ability to add water vapour to the air to raise humidity is an essential part of close control air conditioning. The need may be brought about by a change in the condition of the outside air, fabric losses or a change in the gains within the room or in plant operation.

18.8.1 Humidifier capacity

The humidifier is sized to meet the load of the outside air intake quantity. It is necessary to know the rh to be achieved, outside air intake rate (kg/s) and its lowest winter moisture content (kg/kg). This can be taken as 0.0027 kg/kg in the south UK and 0.002 for the north, corresponding to −4° and −7°C saturated, respectively. Since the capacity will be reduced by blowdown time, allowance is necessary for control, and there will be leaks from the plant and building fabric, an addition of about 30% above the calculated value is recommended.

18.8.2 Types of humidifier

These may be Direct (i.e. installed within the conditioned room) or Indirect (i.e. installed in the conditioning plant). Water may be introduced (a) as a spray or mist or (b) as steam generated separately or by a device within the plant.

In most air-conditioning work the humidifier will be indirect. The psychrometric operation of various types is described below.

18.8.3 Pan humidifier

There are a high legionella risk and are not recommended. The steam is generated in a pan of water by electric elements. High-temperature hot water or steam coils could also be used. About 30% of the input appears as waste sensible heat, giving a sensible heat ratio of 0.3.

Where the pan is in the airstream the condition downstream of the pan has an increased moisture content (kg/kg) found from the air flow and moisture input. On a psychrometric chart this will lie on a line of sensible-to-total heat ratio of 0.3. Thus the psychrometric plot shows a steep rise in moisture content with a small rise in dry bulb temperature. The latter is a disadvantage when cooling is required. Regular blowdown is needed, preferably controlled by a timer, to prevent furring when mains water is used, and open pans should not be utilized where the

conditioned space is to be dust controlled. A small water volume is an aid to quick response.

18.8.4 Steam jet

Where it is available the source can be a separate boiler plant, but common practice is to employ purpose-made electrode boilers within or adjacent to the plant. The latter reduces sensible gains to the plant but, being essentially saturated steam, condensate return pipes are required. In addition to the rise in vapour content of the air (kg/kg) being dependent on air-flow and steam-injection rates, there is a very small increase in dry bulb temperature by the cooling of the vapour to the air temperature. The rise in total heat is: total heat of steam (kJ/kg) × quantity supplied per kg air.

Proprietary units are supplied with automatic blowdown cycles and can be matched to the broad water analysis. Cylinders have a limited life.

18.8.5 Spray humidifiers

Water is injected into the airstream in a fine mist by pumped jets or spinning disc. For practical purposes, the psychrometric plot follows a wet bulb line. The air provides the latent heat of evaporation, resulting in a fall in dry bulb temperature. If water were to be supplied at up to 100°C the humidified condition would be at a correspondingly higher total heat of 420 kJ per kg water supplied.

Where dust control is important the system should only be used with a supply of demineralized water to avoid solids being passed into the conditioned space. The temperature of the air must be sufficient to hold the quantity of moisture being supplied, any excess being deposited in the duct. Unless drained away, this can give rise to corrosion and to incorrect control by reevaporation when the humidifier is switched off under control.

18.8.6 Direct Injection humidifiers

Used in industrial applications for many years in "direct" applications they have now been adapted for use in ducted systems. Water is supplied through nozzles with compressed air such to atomize the water droplets and ensure complete evaporation.

18.8.7 Ultrasonic humidifiers

A reservoir of water has an ultrasonic acoustic source located in the water and the energy from this causes water molecules to be shed from the water surface in the form of a fog which is absorbed by the air.

18.8.8 Air washers

Banks of sprays discharge water into the airstream with the object of achieving saturation of the whole air flow. Excess water falls into the base tank of the washer from which it is pumped back to the sprays. Downstream eliminator plates entrap any remaining free moisture, acting best within a specified velocity range. Cleanliness is essential to avoid bacterial growth. A constant bleed and make-up is normally arranged to control the accumulation of waterborne solids, but this, in turn, dilutes bacteriocides and inhibitors. The washer does not fully wash the air in the normal sense but does have the cleaning efficiency of a low-grade filter.

If the temperature of the water is not controlled it will come to the wet bulb temperature of the air passing through. Ignoring pump heat, the process is adiabatic. The psychrometric plot follows a wet bulb line.

If heat is added to the water the condition for 100% saturation takes the new wet bulb temperature of the incoming air.

If the water is chilled, cooling of the supply air takes place together with control of dewpoint and hence humidity of the room treated. Saturation efficiency is given by:

$$\frac{\text{Entering air db} - \text{leaving air db}}{\text{Entering air db} - \text{entering air wb}} \times 100\%$$

Due to bypass, a single bank of sprays might achieve 60% saturation and a capilliary washer (one where the air passes through a wetted mat) might achieve 95%.

This type of humidifier is obsolescent.

18.8.9 Humidifier run time

Humidification is an expensive process and it is useful to be able to assess energy costs when considering its inclusion in a plant. It is possible from meteorological records for any particular area to find the time in hours per year and extent to which the external moisture content is, on average, at or below a required absolute value. As an example, in the southern UK humidification would be required in varying degrees for 6700 h per year if 21°C 50% rh was to be maintained. If the characteristic of cooling coils is to dehumidify when only sensible cooling is required then the humidifier load will be greater. For comfort purposes it is usually regarded as acceptable to maintain a minimum rh of 30%.

18.9 Test procedure for air-conditioning systems

18.9.1 Object and application

This is an on-site test following installation. The procedure is designed to find any weaknesses in the plant and its implementation, while not cheap, is worthwhile where performance is important or in doubt. It is essential to have contractually agreed its use, who is to make the various provisions and what action is to be taken if any faults are shown and to allow sufficient time for testing and any remedial work.

It is recommended that a contractor demonstrating to a client should have tested the plant previously and should not use the test to supplant commissioning. The acceptance that individual items of plant have the necessary capacity does not necessarily mean that the whole will perform as required. Indeed, the test can find proprietary items lacking.

18.9.2 Conduct of the tests

The necessary skills should be on-site to attend to any minor faults but must not be allowed to alter settings from one test to another, except as required by the test procedure. Dummy loads should be ready for use. If sensitive equipment is to be present (as might be the case in upgrading computer room plant) then the interested parties must agree limits previously. This may also apply to parts of the plant itself such as humidity-detecting elements. The latter can be protected physically. The job specification should state which parts of the procedure apply (if not all).

The plant is tested to hold limits in the specified external conditions and is not (unless exceptionally so agreed) tested beyond them. The plant should not be overdesigned just to pass the test. For the duration of the test external conditions can never span those for which it is designed. To fully load the plant in cool weather it may be necessary to dissipate twice the design process load. The dummy load should simulate the design load, and in the case of electronic equipment rooms this may best be done by arranging fan heaters directed upwards and in the same layout as the equipment. Ideally, simulation of the heat of outside air make-up should be in the intake duct. If impractical, then it may be placed in the room close to a return grille. Room-temperature readings should not be taken near to dummy loads, and in heavily loaded rooms it may be necessary to confine readings to extract positions. Except in test houses, it is not possible to apply the full range of external conditions at the final cooler. It will therefore be appreciated that a plant should easily pass its test on a cold day. Resort could be made to certified performance curves if a doubt exists.

Misleading results can be obtained from tests of limit 'stats' and sensors if their set point is adjusted to the current conditions to bring about operation. The control points should be set and conditions adjusted until operation occurs, opportunities arising during the test procedure.

The following is an outline of the test procedure:

1. *Pre-test performance.* An assessment of whether the plant is ready for a full test.
2. *Recorders and alarms.* Continues 1 and checks the calibration of recorders and alarms.
3. *Air balance.* To check overpressure and outside air intake.
4. *Background heaters.* Checks control and capacity of back-up heating.
5. *Heating and humidification.* The plant is called upon to perform at its maximum winter design capacity.
6. *Cooling and dehumidification.* The plant is required to perform at its maximum summer capacity.
7. *Limits, interlocks and inspection.* Cut-outs, limiting controls and interlocks are tested.

Compliance with specified details and good practice are checked.

18.9.3 Pre-test performance

Allow the plant to run automatically for a period of some days either with no artificial load or with a small one of fixed value. If no means of recording are built into the plant than recorders should be introduced and placed in representative positions in the various zones for the duration of the tests. Periodically examine the traces or monitor printouts. These will give an indication as to whether the plant is controlling correctly on light load.

Observations of external wet bulb and dry bulb air temperatures or similar assessment of other forms of load may be combined with simple observations of what the plant is doing. If it were using its refrigeration capacity under cold no-load conditions then clearly something is wrong. A common fault is finding the plant calling for large amounts of humidification when the requirement as indicated by external readings is for dehumidification, this perhaps being due to incorrect SHR of the cooling coil. Periodic excursions may be found and these are often caused by external influences which might be identified by their time of occurrence.

Make no excuse for checking whether the sun shines on the thermostats or someone has washed the floor. Another common occurrence is that while the room is not being controlled as specified, the plant appears to be operating correctly. Here a series of simultaneous readings of air flows and wet and dry bulb temperatures should be taken around the whole of the air circuit – on and off coil, condition after fan, condition at inlet grilles, etc. Referring these to a psychrometric chart will usually indicate where the fault or leak lies.

18.9.4 Recorders and alarms

These are important, since they may be used in part using the remainder of the procedure and may be the only indication for future operatives as to whether conditions are correct.

1. With the plant still operating as for test 1. With hand instruments, check conditions as close as possible to the recorder's heads:

Recorder no.	Time		Date
	DB	WB	RH
Recorder reading		–	
Test sling (or other)			

   Note that some recorders have a clock time difference between the dry bulb and rh to allow for pen overlap.
2. Where this can be done, moving the alarm-indicating arms to the room condition will indicate whether the alarms operate but much more satisfactory results are obtained by causing the controlled condition to swing beyond the alarm points and at the rate that would be expected in practice.

Recorder no.	Time	Date

	DB	WB	RH
Recorder reading		–	
Test sling (or other)			
Alarm occurred		–	

18.9.5 Air balance

Room overpressure can conveniently be tested during this period. Produce a single line sketch of the conditioned space(s) including doorways. Test for air-flow direction with hand smoke tubes, both at the top and bottom of closed doors, and record the direction of flow. Crack the doors open if fully sealed.

Measure the outside air make-up quantity, taking a pattern of readings across the area of the duct or grille:

Average flow velocity m/s × area m^2 = m^3/s

18.9.6 Background heaters

The function of these is to prevent the room becoming cold and humid in the event of the main plant being off for any reason other than power failure. For a small input they can protect the conditioned space to a large degree and greatly reduce reconditioning time upon restoration of the main plant. They would require a comparatively small input from a standby generator.

With the main plant switched off:

1. Set the humidistat (if fitted) downwards and note when the heater(s) come on. As before, more accurate results are obtained by swinging room conditions, but (a) we will have ascertained that the direction of operation is correct and (b) the method is sufficient for the relatively coarse control required. Reset.
2. Set the thermostat upwards noting when the heater(s) come on and continue to the limit of the thermostat. Take a set of readings.

Room	Date
Time	Dry bulb temperature

Assuming the heaters are electric (i.e. have a high surface temperature) and the conditioned space is uniformly surrounded by rooms or the outside then the temperature that should be achieved is the design lift in temperature from the surrounds to room temperature, above whatever the surrounding temperature happens to be on the day of the test.

If there is a mix of external walls, heated or cold surrounding rooms and rooms under similar control to the one being tested the temperature elevation of the tested room (°C) should be:

Design heat input (watts) + sum of (surface constants ×TD to outside at time of test) for each surface ÷ sum of constants for all other (outside) surfaces
where the surface constant is *U* value × area.

3. Since any background heaters must now be allowed to operate during the cooling cycle their control must be set below the lower limit for the conditioned space. An interlock with the main plant may be included. These features should be checked and noted at this time.

18.9.7 Heating and humidification

The plant should be able to hold the room at the desired temperature when heat is not being dissipated in the room. The plant should also be able to raise the temperature of the room from cold under winter conditions (e.g. after a power failure or an outage). In considering the temperature to be achieved under test the comments given in test 2 of Section 18.9.6 also apply here. If hot water heating is used, full temperature elevation will not be achieved because high return air temperatures will reduce the coil output. For instance, where the design rise was 22°C above an external of −1°C; 19°C, 16°C and 14°C are satisfactory with ambients of 5°C, 10°C and 15°C, respectively.

If it is variable, set the outside air intake quantity to the winter value. Set the desired temperature up to a maximum, leaving the humidity setting alone. It will be appreciated that as the room temperature rises during the heating test the rh tends to fall. However, since the humidity setting remains unaltered the humidifying system will be called upon to operate until at one condition it is working at peak winter rate. Due to the faster characteristic of heaters, the rh will be found to fall but absolute moisture should be found to steadily rise. The duration of the test is normally about 3 h and final conditions should be held for half an hour to prove the moisture source.

Calculation of test condition *kg/kg*
Absolute moisture in the room at design temperature and humidity;
Absolute moisture content of winter outside air intake at design condition;
Design difference to be made up by humidifier =
Add absolute moisture content outside at time of test;
= Room moisture content to be achieved in test.
(Neglect gains from test personnel)

Room	Date		
	DB	WB	= kg/kg
Time			

Under steady conditions the plant should be able to hold the design room rh up to the temperature given in psychrometric tables or a chart where the design room rh and test absolute moisture content (kg/kg) coincide. At the end of the test restore the temperature set point to the design value and any control of outside air volume to automatic. Observe that operation.

If the plant is now shut down for a period of 1 or 2 h with the conditioned space remaining closed, a slow

Room Date

Supply Air	Sens. load kW	Lat. load kW	Position 1 Dry Wet RH	Position 2 Dry Wet RH	Position 3 Dry Wet RH
Time					

the remainder of the test load which represents the missing summer building gains is now applied.

Design sensible heat of outside air intake kg/s × kJ/kg
Less actual on day of test kg/s × kJ/kg

Room design conducted heat gain kW

less: $\frac{\text{(design gain)} \times \text{actual TD}}{\text{design TD}}$ kW

Design solar gain less actual gain (under site conditions this will have to be estimated) kW

Total kW

Plus
Design outside air moisture content (kg/kg)
Less actual moisture content on day (kg/kg)
× air flow (kg/s) = kg water/s

(it will be found that kg water per hour ×2/3 closely approximates to the power in kW of test load kettles required).

reduction in absolute moisture content will be observed. A rapid fall will indicate a significant leak in the building or plant, would account for any difficulty in achieving the test result and should be investigated. The design vapour pressure difference may amount to several tens of millimetres water gauge acting on the vapour sealing and equally leads to moisture ingress during summer conditions.

18.9.8 Cooling and dehumidification

The test load must be calculated and is applied in two parts. The lights should be as in normal use and all plant controls normal and automatic. The background heaters (if installed) can be called as load but it is essential that thermostats and overloads do not reduce the applied load unobserved. Electrical measurements should be taken, particularly at the full-load condition, and for this purpose, trust not put in rating plates.

The test load: watts
Sensible equipment or process heat;
Sensible heat of personnel;
(Less number present)
Latent heat of process;
Latent heat of personnel;

In the case of electronic equipment rooms there will be no call for a latent test load at this stage.

Starting from zero, take a set of readings, then increase the load in increments of about 20%, repeating at 15-min intervals. Note that if the supply air passes over a structural slab its elevated temperature from test 18.9.7 will briefly add load.

To avoid unnatural conditions the latent load is applied in steps with the sensible load until full summer conditions are simulated. This should be held or 1 h or more. If the pattern of temperature readings around the space is satisfactory we have a check on the suitability of the air distribution. If any doubt exists as to the duty achieved, simultaneous readings of air flow and wet and dry bulb temperatures across the cooling coil or supply to extract can be taken and the duty calculated.

Observations should be made that the plant is not being manually coaxed, that it is not humidifying and that the compressors have not tripped but are cycling under part-load conditions. Instruments should be indicating correctly. In cases where it is impractical to fully load the plant, ascertain that an appropriate amount of refrigeration is being employed. This situation is best avoided, as much of the plant is not being demonstrated to full capacity.

18.9.9 Limits and interlocks

The items for test under this group will vary from plant to plant and with specified requirements. It is assumed that the Clerk of Works is satisfied with the following:

Interior of plant clean before run;
Interior of ducts clean before running or blown out to bags;
Ducts sealed;
Lagging sound, non-combustible, no loose material in airstream;
Vapour sealing sound;
Filters of correct grade;
Filters kept clean before installation;
Filters installed without leaks;
Water circuits leak tested;
Water circuits flushed;
Water circuits dosed;
Refrigerant circuits vacuumed and dry;
Refrigerant circuits leak tested;
Crank case oil level correct;
Plant Room ventilated;
Humidifier drainage and deep U-trap correct.

18.9.9.1 Test

For each compressor:

HP cut out;
HP cut in;
LP cut out;
LP cut in;
Oil Differential cut out;
Oil Return functioning (sight glass);
Low water temperature cut out;
Recycling timer;
Loss of phase protection;
High room humidity override;
High room temperature override;
Plant heat high temperature cut out;
Plant low air temperature cut out;
Air flow interlock;
Automatic changeovers;
Room emergency power off buttons
Emergency power off buttons reset (only when so manually operated).

19 Water and effluents

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This page has been reformatted by Knovel to provide easier navigation.

19.1 Introductory warning

Water is an essential service to any facility. The amount and quality needed vary considerably between different plants, but the essential fact important to all engineers who have to deal with water technology is that the subject of water quality and treatment is highly specialized. It deals with chemistry and microbiology, and even within those fields the technology is specialized and in the hands of experts. It is therefore a field in which plant engineers cannot be expert, and are forced to take advice from specialists. These are usually suppliers of plant or chemicals, or professional consultants.

These specialists are in a position of great responsibility, because plant engineers are so dependent on their advice. In these circumstances it is possible for 'cowboy' organizations to thrive. Past and present experience shows that these are too common. *Plant engineers must not automatically accept the lowest offer for materials or advice in this field but must first be satisfied with the specialists' competence and integrity.*

There are many sad examples of installations which have gone disastrously wrong, and these are by no means limited to small facilities or those in which water is a relatively unimportant service. For example, manufacture of microchips is wholly dependent on a supply of highly purified water. In recent years two of the largest UK manufacturers, sited at opposite ends of the country, have had to shut down and send the workforce home because their purified water facility had failed.

The golden rule, therefore, is to deal only with consultants, contractors, plant suppliers and water-conditioning experts whose experience and standing are known to be good.* If there is any doubt, references should be sought and followed up. Water and effluent installations are a relatively minor cost item in any plant, but their failure can be disastrous. It is foolish to make false economies on so essential a service.

19.2 Requirements for water

Any plant will need water for domestic purposes: in most cases this can be provided by public supply and discharged to the public sewer. Most plants have some steam-raising equipment for space heating, and steam is often required for other purposes. Steam raising always requires water conditioning and usually external treatment of some kind. Many operations require water of a specified quality, which varies over a wide range: from cooling and washing water to softened or demineralized and (in extreme conditions) ultra-pure water.

For food and drink, medical, pharmaceuticals and cosmetics production the microbiological quality of the water becomes paramount. Even in applications where biological quality is not directly important, uncontrolled growth can be a damaging nuisance. Warm-water systems and cooling circuits in particular are a potential hazard (e.g. from *Legionella*). Some water treatment or conditioning is commonly required.

Water from public supply costs money, as does that discharged to the public sewer. Except for water which is incorporated into the product of the plant or evaporated to the atmosphere, any water which enters the plant is returned to the environment as an effluent. It may be necessary to improve the quality of this before disposal to surface water or into a public sewer, and for acceptance into the public sewer the sewerage authority may levy a charge dependent on the quality. This is levied per cubic metre of water discharged, and this volume, in turn, is normally estimated on the basis of the metered incoming mains supply flow, minus some agreed factor for water retained in the product or lost by evaporation. There is therefore a double financial incentive to reduce the plant's water consumption.

For many years water costs have been rising faster than inflation, and are set to rise even faster in the future. The belief that water is 'free' must be combated: it is usually possible to make more economical use of water.

In some cases sensible design can lead to re-use of water, which reduces both water and effluent costs. This is best achieved by intelligent routing of the water rather than by treatment before re-use. Effluent treatment is best avoided wherever possible. For example, very slightly contaminated process wash water can be recovered for washing down floors. This reduces charges for both incoming water and effluent.

19.3 Water chemistry

Raw water analyses are normally obtained from the local water supply organization. Water analysis is a specialized trade, and analysts who do not routinely carry this out can prove unreliable. Most water suppliers provide 'typical' or 'average' analyses, which do not show the range of variations which can be expected. At the end of a hot dry summer, for example, a water which originally comes from a river will probably contain a higher level of impurities than the 'typical' value, while a deep well water will stay much the same. Some supplies are blended from differing sources, and the proportion of the blend will affect the product. Some waters receive run-off from roads which are salted at times of frost, which can cause massive and sudden changes. It is important to find out about such variations from the 'typical' analysis.

19.3.1 Units of measurement

Analyses usually give concentrations in milligrams per litre (mg/l) or parts per million (ppm). For practical purposes these units are the same.

Most minerals in water exist as ions – electrically charged particles which give them an electrical conductivity. The different systems of units which measure their concentration can cause much confusion. For any calculation involving adding different ions to one another it is vital to use one of two systems of 'equivalents'.

The traditional British method is to calculate the concentration 'equivalent to calcium carbonate' and give the

*Most reputable plant suppliers are members of BEWA (British Effluent and Water Association).

results as 'mg/l as $CaCO_3$'. A more modern unit, widely used throughout Europe, is the milligram equivalent or milliVal, abbreviated as meq/l or mVal. This gives the same information as 'mg/l as $CaCO_3$' but the values are one-fiftieth of those expressed 'as $CaCO_3$'. Explaining these systems is lengthy, and usually increases the non-chemists' confusion. The system 'mg/l as $CaCO_3$' is used below and the rules are as follows:

1. Concentrations of individual constituents, such as calcium, 'hardness' or 'alkalinity' should be brought to mg/l as $CaCO_3$ for any comparisons or calculations.
2. There should be a statement on the analysis sheet which makes it clear what system of units has been used. Hardness and alkalinity are often given 'as $CaCO_3$', which makes life simple.
3. Alternatively, the analysis may state that concentrations are given 'as the ion' or 'as such', or each individual constituents may say (for example) 'calcium as Ca'. In that case one must use the following conversion table:

To convert from mg/l as such	*To mg/l as $CaCO_3$ multiply by*	*To meq/l multiply by*
Calcium (Ca)	2.5	0.050
Magnesium (Mg)	4.17	0.083
Bicarbonate (HCO_3)	0.82	0.016

4. Total Dissolved Solids (TDS) and Silica (SiO_2) are normally given 'as such' and do not require any conversion.

19.3.2 Hardness and alkalinity

Many analyses quote 'Total Hardness'. Some give 'Temporary Hardness' (or 'Carbonate Hardness') and 'Permanent Hardness (or 'Non-carbonate Hardness'), usually in consistent units so that the values can be added together to give the total hardness. The total hardness is actually the quantity of calcium (Ca) + magnesium (Mg) in the water. If the total is not given directly, the values given for these two constituents must be added, after conversion to mg/l as $CaCO_3$ if necessary.

Hardness in water varies widely, and as an arbitrary classification:

Hardness less than 50 mg/l as $CaCO_3$	Soft
50–200 mg/l as $CaCO_3$	Medium
More than 200 mg/l as $CaCO_3$	Very hard

19.3.2.1 Temporary hardness

Temporary or carbonate hardness and alkalinity frequently, but not always, mean the same thing (see below). 'Bicarbonate' or 'hydrogen carbonate' is a more scientific term since 'alkalinity' is actually the concentration of the bicarbonate (HCO_3^-) ion in the water.

If acid is dosed into a water-containing bicarbonate, the ion becomes converted to carbon dioxide (CO_2) gas, while the water becomes only slightly acidic. (Sodium bicarbonate taken against acid stomach uses this property.) The drop in pH from a given acid dose is much smaller than would result from the same amount of acid dosed into a water containing no bicarbonate. When enough acid has been added to convert all the bicarbonate to CO_2, further acid dosing leads to the sharp drop in pH, which is expected from a water containing no bicarbonate.

Another reaction of bicarbonate is that in boiling water it combines with any hardness present to produce scale, while releasing CO_2 into the steam. This hardness is called the 'Temporary Hardness'. Its concentration therefore depends on the amounts of both hardness and bicarbonate, whichever is the less. Most waters contain more hardness than bicarbonate, so that the temporary hardness is usually equal to the bicarbonate content. The 'Temporary Hardness' quoted in analyses is often the only information available on the bicarbonate content of the water.

19.3.2.2 Permanent hardness

After the temporary hardness has been removed, any calcium and magnesium which remains is still capable of forming a scum with soap, and can also react to form boiler scale. This is called the 'Permanent Hardness'.

19.3.2.3 CO_2 release

When the steam is condensed, any CO_2 released in the boiler redissolves in the condensate, making it slightly acidic and corrosive. Normally, boiler feedwater is softened and the boiler water pH is raised by addition of caustic soda. Both these measures reduce the degree to which bicarbonate breaks down and releases CO_2. Even so, very large amounts of bicarbonate entering the boiler should be avoided.

19.3.3 Total dissolved solids (TDS)

Water contains various other salts which are generally unimportant in medium-pressure boilers, except for the contribution they make to the total solids in the boiler water. They can therefore be grouped together, and since dosing water-conditioning chemicals also contributes to the boiler contents, even the total need not be known exactly. Most analyses give a figure for TDS in mg/l, but analytical methods differ and the result is not always particularly reliable. TDS is usually given as the actual weight of dissolved materials, which is 10–15% higher than the TDS measured 'as mg/l $CaCO_3$'.

Another method of estimating TDS is to measure the electrical conductivity of the water, which is usually reported as 'μho' or 'μS'. This figure is roughly double the TDS in mg/l as $CaCO_3$.

19.3.4 Silica

For feedwater to medium pressure boilers the silica content of a water only becomes important if it is a large proportion – say, more than 10% – of the TDS. This is unusual in normal water supplies, but can result from external water treatment (see 19.7.6 below).

19.3.5 Types of water

Most waters contain more total hardness than bicarbonate (both in equivalent units) – that is they contain both temporary and permanent hardness. Most of the mineral content of water from chalk or limestone measures consists of hardness and bicarbonate, and most of that is in the form of temporary hardness. Table 19.4 shows such a water.

Many waters from mountainous uplands such as Wales, Scotland, Yorkshire, or the moors of south-west England are surface runoff and have not percolated through mineral strata. They are low in minerals generally, and in hardness and alkalinity in particular, though usually even there the hardness will be greater than the alkalinity. Many of these waters have picked up large quantities of organic matter (the product of decaying peat bogs). This gives the water a faintly acidic character, and a yellowish tinge which is best seen by looking down a measuring cylinder or some such glass container. Many such soft and peaty supplies have lime added at the waterworks to make them less corrosive.

Some potable supplies are treated surface waters from rivers, etc. These originally derive from any of the above, but will also contain the products of human activities, which lead to increased mineral contents and possibly some undesirable materials such as detergents.

Potable water is not (and should not) be sterile. In fact, potable water mains always have a layer of living matter clinging to the walls. Any change in the flow, temperature or chemical quality of the water passing through the pipe will cause some of this to become detached. Quite large living organisms (such as freshwater shrimps, waterflies and even leeches) can occasionally be found in a potable supply. They are aesthetically disturbing but usually unimportant.

The important quality criterion is absence of pathogens, a term which covers all disease-bearing bacteria. This criterion is usually determined by test for *Eschericia coli*, a species of bacteria so common in the gut that it is a reliable indicator of any pathogenic contamination.

Some plants have to rely on a private supply, usually taken from a borehole. The water first must be tested by a competent authority. Water analysis is a specialized procedure and is preferably undertaken by an analyst who does this regularly, such as a local water supplier's laboratory. Water from a spring or a deep well which appears potable is usually found to be of reasonable quality, but it may occasionally contain some constituents (e.g. iron or manganese) in unacceptable concentrations. The nitrate content of groundwaters is generally rising throughout the UK, and if it is found to be near the legal limit (see Table 19.1) further samples should be analysed at, say, six-monthly intervals.

Table 19.1 Drinking-water quality standards (EC, 1980)

Colour	Pt/Co	20
Turbidity	JTU	4
Threshold odour no.		3
Anionic detergents	mg/l Manoxol	0.2
Pesticides	mg/l	0.5
PAH	μ/l	0.2
Phenols	μ/l	0.5
Aluminium	mg/l Al	0.2
Ammonia	mg/l NH_4	0.5
Arsenic	mg/l As	0.05
Barium	mg/l Ba	0.1 (GL)
Calcium	mg/l Ca	100 (GL)
Cadmium	mg/l Cd	0.005
Chloride	mg/l Cl	200
Chromium	mg/l Cr^{6+}	0.05
Copper	mg/l Cu	0.1 (GL)
Cyanide	mg/l CN	0.05
Fluoride	mg/l F	1.5
Hydrogen sulphide	mg/l H_2S	–
Iron	mg/l Fe	0.2
Lead	mg/l Pb	0.05
Magnesium	mg/l Mg	50
Manganese	mg/l Mn	0.05
Mercury	mg/l Hg	0.001
Nitrate	mg/l NO_3	50
Selenium	mg/l Se	0.01
Sodium	mg/l Na	150
Sulphate	mg/l SO_4	250
Zinc	mg/l Zn	5.0
Coliforms		Zero in 95% of samples
		GL = Guide Level (i.e. no MAC applies)

19.4 Building services

19.4.1 Potable water

Most plant sites in the UK have access to a public supply of water. Water suppliers are now responsible for meeting the EC's Directives (see Table 19.1). Wherever possible, all drinking-water taps should be served directly from the incoming main, and the plant engineer's sole responsibility is to ensure that no deterioration takes place within his system.

The water supplier normally insists that (for uses other than drinking-water taps) their main should discharge into a break-pressure vessel, after which the water quality becomes the consumers' responsibility. The water tank should be covered against tramp dirt and access by birds, etc., and it must be shielded from sunlight to avoid the growth of algae. Nevertheless, access must be maintained for easy inspection. The distribution pipework is preferably all-plastic and lead must be avoided altogether. The use of copper is doubtful with some corrosive waters, and soldered joints in it can lead to unacceptable concentrations of lead in the water.

The removal of such impurities is relatively simple at a waterworks, but a typical plant cannot provide the chemical expertise needed to keep the process in good working order. Treatment should therefore be avoided if there is any reasonable economical alternative.

If the water is found fit for consumption with respect to both its mineral and biological content, the problem of sanitization can still arise. Public supply invariably has a very small residual chlorine level. This suppresses

biological growth and maintains water quality even when the line is stagnant. As with other forms of treatment, the scale of private supply is usually too small to allow good control of chlorination equipment.

The traditional method of maintaining good quality in an unchlorinated supply is to allow it to run permanently to drain. This is what antique drinking fountains do, and overcomes the danger of bacterial growth in stagnant pipelines. (It also avoids freezing.) Dead legs in the piping system are always undesirable, especially when not chlorinated.

Employers may provide drinking water in containers, either buying bottled water, or by contract with suppliers of purified water. Some such suppliers fit refrigerators designed to hold the large plastic bottle in which the water is supplied. Sometimes this system is used even where good public supply is available, as a service to the staff who thereby receive a superior grade of drinking water.

19.4.2 Domestic effluent

All plants produce domestic effluent, which is most simply discharged into the public sewer. If no sewer is available the plant needs a septic tank or a similar device sized for the demand based on the number of people whom it will serve. Architects and competent building contractors have rules of thumb which apply to the design and sizing of these. Septic tanks need regular pumping out of sludge and access must be provided. Many industrial effluents interfere with the biological activity of a septic tank and must therefore be kept separate and discharged by other means.

19.4.3 Domestic water

Domestic hot and cold water, for WC flushing, hand washing, etc., will normally be supplied within a factory from the break-pressure tank fed by the incoming water main or private supply. Although these supplies do not need to conform to potable water quality standards they can provide a breeding ground for a variety of bacteria, including *Legionella*. As a precaution, many plant engineers dose sodium hypochlorite into the break tank to maintain about 0.2–0.5 mg/l of free chlorine in these supplies. Bacteria breed most prolifically at temperatures between 10° and 60°C and, wherever possible, hot water should be maintained above and cold water below this range. If the raw water is hard then consideration should be given to softening at least the hot water to prevent scale formation in calorifiers, pipework and sanitary ware.

19.4.4 Closed circuits

Closed water circuits, such as chilled water, or medium- and high-pressure hot water systems, should be initially filled with the best quality water available – de-ionized for preference but at least softened. They should then be conditioned by dosing with suitable corrosion-inhibiting chemicals and biocides. Make-up needed for closed systems is usually very small and raw water will often suffice, although, of course, higher-purity water is better. Routine sampling to check on inhibitor levels and bacterial growth is vital to the operation of such circuits, and most reputable conditioning chemical suppliers undertake this work on a contract basis.

19.4.5 Open cooling-water systems

Although direct air-cooled systems are now preferred there are still many evaporative cooling towers in operation, and open systems of this type can represent the most difficult of all the water-treatment situations the plant engineer is likely to meet. The systems work as follows: heat from the heat exchanger is taken up by the circulating water which is then sprayed into the top of a packed cooling tower with a forced or natural draught of air flowing through it. Some of the water evaporates, taking latent heat from the bulk of the water which, consequently, cools down. The cooled water collects in a sump below the tower and is pumped back to the heat exchanger. The water which evaporates from the tower leaves behind its non-volatile content – i.e. its dissolved minerals, and so the concentration of minerals rises. If this effect is not properly controlled, salts (especially hardness salts) become over-concentrated and deposit as scale in the pipework, the heat exchanger, or in the cooling tower itself. There the deposit can cause blockage, and its added weight can lead to mechanical damage. A proportion of bleed-off controls the concentration in the circulating cooling water. 'Windage', which is water lost by spray, is another cause of water loss from the circuit. Make-up water has to be supplied to compensate for all these losses.

In the cooling tower the circulating water comes into contact with large volumes of atmospheric air and washes from it a variety of airborne contaminants, including pollutant gases such as oxides of sulphur and nitrogen, dust and soot particles and spores of bacteria, fungi and algae. The dissolved gases may give rise to acidic conditions which contribute to corrosion, algae can grow in the sump where warmth and sunlight provide ideal conditions while fungi may appear on the dead algae. Aerobic bacteria, including *Legionella*, grow in the circulating water and contribute, with algae and fungi, to the formation of slimes which not only cause physical blocking of plant but also set up areas of differential aeration around the system, which can promote intense corrosion. This process is aggravated by the deposition of scale and corrosion products below which corrosion takes place and anaerobic bacteria multiply.

19.4.5.1 Water losses

The rate of evaporation from a cooling tower is approximately 1% of the circulation rate for each 5°C drop in temperature across the tower, or about 7 l/h per tonne of refrigeration. Windage losses will obviously depend on the prevailing wind conditions and the design of the tower. Typically, these are about 0.2% of the circulation rate.

The amount of bleed-off required will depend on the nature of the make-up water and the type of conditioning chemicals used. The specialist tower manufacturer, conditioning chemical supplier or water-treatment consultant

will advise the maximum concentration factor (the ratio of circulating water concentration to make-up water concentration) which can be allowed. The necessary bleed-off is then given by:

$$B = E/(C - 1) - W$$

where

B = bleed-off

E = evaporation rate,

C = concentration factor (typically 2–5),

W = windage.

The bleed-off may be set by a simple manual valve running continuously to drain or by an automatic valve controlled by the conductivity of the circulating water.

19.4.5.2 Make-up water

The required make-up water, M, is given by:

$$M = B + W + E$$

Many towers operate with hard water make-up, and scale-inhibiting chemicals are dosed to prevent the formation of hard, adherent scale. These chemicals allow the hardness salts to precipitate in the form of a mobile sludge, rather than an adherent scale. While they do reduce the danger of scale formation, the ideal solution is to make up the circuit with soft water. However, naturally soft or artificially softened water tends to be corrosive in the conditions encountered in open cooling systems, and it is necessary to dose a corrosion-inhibiting chemical to protect metal surfaces. In either case, the accurate control of chemical dosing is absolutely critical to the reliability and integrity of the cooling system. The selection of the correct conditioning chemical(s) and operating regime will depend on many factors, including the make-up water quality, concentration, materials of construction of the system and environmental conditions. It is a task for a specialist, and chemicals should only be purchased from reputable suppliers who will provide a continuing service of monitoring and control.

19.4.5.3 Biocides

Biocides are added to cooling water to control the growth of bacteria, fungi and algae in the system. Chlorine, dosed in the form of sodium hypochlorite, is probably the best broad-spectrum biocide and, at residual levels of 0.5 mg/l, chlorine is effective against most bacteria, including *Legionella*. However, a recirculatory system means that bacteria are exposed continuously to the same chemical conditions, and resistant strains with a natural immunity to the biocide will eventually appear and colonize the system. To prevent this, a regular 'shot dose' of an alternative biocide is advisable, and most chemical suppliers have a range of biocides, both broad spectrum and specific, for this purpose.

19.4.5.4 Filtration

Insoluble suspended matter, either picked up from the atmosphere or formed by deposition and corrosion within the system, together with slimes will, if not removed, cause blocking and abrasion problems. The build-up of such material can be controlled by 'side stream filtration', in which about 2–5% of the circulating water flow is filtered continuously. A sand filter is commonly used for this type of duty.

19.5 Boilers

19.5.1 Water for steam raising

Most plants have medium pressure boilers producing steam for space heating: many need steam for other purposes as well. Boiler water requirements for boilers have changed radically over recent years. The old 'Lancashire' and 'Economic' boilers had large heating surfaces and low heat transfer rates: scale deposits would do no more harm than reduce their thermal efficiency.

Modern packaged boilers use the heat transfer surfaces intensively, and are endangered by scale. The boiler water acts as a coolant without which the metal of the tube overheats. Thin films of scale can obstruct heat transfer sufficiently to bring about tube failure in this way – especially if the scale deposit is siliceous, which is a particularly good insulator. Alternatively, the scale deposit may slow down heat transfer from the hot combustion gases to such an extent that the temperature at the back of the boiler rises excessively and causes tube plate cracking.

A survey shows that poor boiler water quality remains the main single cause of boiler failure. Good water treatment plant and boiler-water conditioning and control are still vital not only to the boiler's performance but also to its integrity.

The important chemical factors in the steam–water circuit are: Hardness, TDS, Oxygen, and CO_2. In a few cases Silica is also important (see 19.7.6 below).

High pressure boilers, especially in power stations, require totally deionized water (see 19.7 and 19.8).

19.5.2 Managing the steam-water circuit

The boiler and its steam user form a circuit in which water and steam circulate. Loose use of nomenclature sometimes leads to confusion, and it is therefore useful to define the various waters in it:

Raw water: The mains supply or other external source used to prepare make-up.
Treated water: The water leaving the external treatment plant, if there is one.
Make-up: The amount of raw or treated water added to the feed.
Condensate: The water returning from the steam user(s).
Feedwater: The water entering the boiler feed heating system, which will normally be a blend of treated water and condensate.
Boiler water: The contents of the boiler.

Blowdown: The water blown down from the boiler in order to maintain its total dissolved level below the specified limit.

In order to maintain good boiler operation, the most important rules to follow are:

1. The boiler water should be within the limits specified for that type of boiler by British Standards, DIN etc. In a conventional shell type factory boiler the most important criteria are that hardness should be present only in very small concentrations, and the TDS should be below 3000 mg/l.
2. The boiler water must at all times contain a positive residual of oxygen scavenger (usually sodium sulphite).
3. The chemical regime should include phosphate or tannin dosing to counter any residual hardness.
4. The boiler water pH must be raised to about 9 or over to avoid corrosion, to maintain silica in solution, and to reduce the release of CO_2 into the steam.
5. The bicarbonate content of feed should be moderate to avoid excessive liberation of carbon dioxide in the boiler.

Clearly, these matters are interdependent.

19.5.3 Condensate return

Condensate normally contains no hardness and is very low in dissolved solids. Unless it has been excessively exposed to the atmosphere, condensate is also very low in dissolved oxygen. It represents the ideal feedwater, and the higher the proportion of recovered condensate in the feed, the easier it will be to maintain the boiler water within the desired limits. The percentage condensate return is thus basic to all considerations of water management for the boiler circuit.

In some process applications condensate becomes contaminated: in sugar refining it may contain sugar, in paper manufacture and some other processes it may be contaminated with raw water, and where it feeds turbines or other machinery it is liable to contain oil or grease. In all these cases the condensate may still provide a better source of boiler feed than the available raw water, but it may need condensate filtration or softening plant before re-use.

19.5.4 Raw water quality

This varies widely within temperate zones, and even more so in hot countries. A wide range of possibilities therefore exists: high hardness, high alkalinity, and/or high TDS need correction. However, the degree to which this is necessary is also dictated by the percentage of condensate return – if it is high, the need for external treatment is accordingly reduced. The processes used for external treatment are described below.

19.5.5 Oxygen scavenging

Water at ambient temperature in contact with air contains about 10 mg/l of oxygen. To avoid corrosion, boiler water must contain no oxygen, and have an excess of oxygen-scavenging chemical (usually catalysed sodium sulphite) to ensure this. Ideally, sulphite is dosed into the feed heating system with the feedwater to give the hot well, etc. some protection, with a second dosing point into the boiler itself to ensure that the residual is actually maintained.

The removal of each milligram of oxygen requires about 8 mg of sodium sulphite, so that the dose should be adjusted to suit the amount of oxygen introduced, which corresponds roughly to 80 mg/l of cold make-up. A high level of condensate return therefore reduces the scavenger demand, and this is not only an economy in itself but can also mean a considerable reduction in the amount of total dissolved solids introduced into the boiler with the feedwater.

Oxygen can also be removed from feedwater by thermal de-aeration, or partially removed by skilful design of the feed heating system and blowdown recovery. These processes run without cost to the operator, but save chemicals, and, by reducing the required dose of sulphite into the system, decrease the amount of non-volatile solids added into the boiler.

19.5.6 Blowdown

All non-volatile impurities entering the boiler build up in the boiler water. This includes the TDS in the feed, plus most of the conditioning chemicals, of which the sodium sulphite used as oxygen scavenger is usually the major contributor. To maintain the boiler water within its permitted limits some boiler water must be blown down. The rate (as a percentage of the steaming rate) is calculated by:

$$x = \frac{f \times 100\%}{b - f}$$

where f is the concentration of an impurity in the feedwater and b is its permitted concentration in the boiler water. This calculation should be made for each individual impurity specified. In practice, the TDS is usually the controlling factor in blowdown but if the make-up is treated by partial de-ionization, silica may be more important.

Blowdown costs money in terms of heat, water and chemicals, and should therefore be minimized. Control of blowdown and recovery of heat from it are important aspects of boiler operation.

Where sodium sulphite addition is a large contributor to the non-volatiles in the boiler, thermal means of reducing the oxygen can make a significant improvement in the overall operation. (see 19.5.5 above).

19.5.7 External water treatment

In an ideal case the condensate return is high, and the raw water low in dissolved solids, hardness and alkalinity. It is then possible to operate the boiler without external water treatment, relying on conditioning of the boiler water with phosphates, tannins or other chemicals to cope with the small amount of hardness introduced with the raw water.

In practice, especially with modern boilers, it is considered essential at least to soften the raw water. Conventional softeners do not, however, remove hardness

completely but allow a very small concentration to pass through.

Where the feed contains a large proportion of treated water, softening is a minimum requirement and the raw water quality dictates whether a more sophisticated form of external treatment would be preferable. If the water has a high alkalinity it calls for de-alkalization and base exchange. De-ionization is the ideal water treatment, but is usually avoided if possible because of its cost, use of corrosive chemicals and associated effluent problems. Membrane processes giving partial de-ionization are not normally installed at present, but are certain to become important in the future.

External treatment process plant should be installed only after a specialist's advice has indicated the best process, and plant should only be purchased from reputable manufacturers. The operational characteristics of the different processes are described below.

19.6 Specified purities for process use

Many industrial processes need waters of a quality better than the public supply, or whatever source is available. Demands vary widely. Pharmaceutical and cosmetics production generally require good biological quality. So do food and drink manufacture, but brewing and soft drink manufacture often requires a specified mineral content as well. In brewing it is becoming common for water to be largely de-ionized and a wholly synthetic water to be reconstituted by chemical dosing. Membrane processes such as reverse osmosis and electrodialysis, which do not completely de-ionize the water, are increasingly used. Table 19.2 gives details of the BEWA Water Quality Classification and Table 19.3 shows typical water characteristics.

Textile products are particularly sensitive to iron, which discolours the product. Many washing operations, as in metal finishing, require softened water to avoid staining of the product. Others are more sensitive and use de-ionized water.

De-ionized water is required for high-pressure boiler make-up and in many chemical process applications. Where a process has a large-scale steam demand, high-pressure turbine generators are often installed to generate power before providing the process with pass-out steam, thus making the most efficient use of the fuel. If the process does not return the steam as condensate, the boiler feed will be entirely treated water. With 100% make-up to the boiler the quality of the product water is particularly critical, and the flow is usually very high. The biggest industrial water treatment plants may be found doing this type of duty.

De-ionized water itself has a wide range of grades. The lowest is that obtained by a simple cation–anion unit, which may contain up to 5 mg/l TDS. The highest grade is ultra-pure water, which is necessary for making microchips and has maximum total contents four orders of magnitude lower. The specifications for suspended and dissolved matter in ultra-pure water are always at the limits of detection, and are steadily becoming more stringent as chemists devise more sophisticated methods of analysis.

The plant engineer should not be expected to select the correct process for any of these: good professional advice must be taken – and followed. The account below of the processes available therefore concentrates largely on external process characteristics which affect the general operation of the facility.

19.7 Water-purification processes

19.7.1 Filtration (Surface Filters)

This deals with all equipment used for the removal of particulate matter and represents a wide range of possibilities. Several books cover this subject and only a few typical examples are quoted here.

Simple strainers remove gross materials. These should not normally occur in public supply, but strainers are sometimes fitted to protect sensitive equipment or processes against breaks in the main, etc. The commonest form contains a stainless-steel wedge wire screen and is piped with a bypass so that the screen element can be isolated and removed for cleaning when necessary. If the load on the filter makes this kind of cleaning burdensome a self-flushing filter can be used. These can incorporate strainer elements down to 50 μm.

Smaller particles can be removed by cartridge filters which can be rated for various particle sizes down to 10 μm. These are typically candle filters whose filter elements are bobbins of nylon or similar string wound onto a former. When clogged, they must be replaced.

19.7.2 Sand filters (Depth Filters)

Sand filters are widely used in water purification and remove suspended matter by a completely different mechanism. Instead of the water passing through small orifices through which particles cannot pass, it runs through a bed of filter medium, typically 0.75 mm sand 750 mm deep. The orifices between such sand particles are relatively large, but dirt is adsorbed onto the large surface area presented by the medium. The pressure loss rises as the dirt builds up and the filter must be cleaned when it reaches about 3 m WC, otherwise the dirt can be pushed right through the filter.

Filter backwashing normally needs low-pressure compressed air and a flow of filtered water about ten times the rated filter throughput. These backwashing arrangements are critical, and providing the large flow of backwash water, as well as drainage for its disposal, can often create difficulties. Given good backwash arrangements, and on a water low in suspended matter, sand filters are simple, reliable, cheap and have low operating costs.

Sand filters vary in sophistication. A simple filter will remove most particles down to 5 μm. Multi-media filters which use sand and anthracite, and possibly a third medium, in discrete layers, can yield very efficient filtration down to 2 μm. Granular activated carbon can be used instead of sand to add some measure of organic removal to the filtration process. The quality produced by any filter

Table 19.2 BEWA water quality classification

Class	*Type*	*Typical applications*	*General notes*	*Relevant standards*
1	Natural water	Once-through cooling systems Outside wash down Irrigation Fisheries Firefighting Recreational Natural mineral waters	Level of salinity may restrict use for irrigation and fisheries Brackish water has TDS up to 10 000 Seawater has TDS up to 50 000 All characteristics highly variable	Dept of Environment (DoE) Circular 18/85 EC Directive 75/440/EEC EC Directive 78/659/EEC EC Directive 79/923/EEC EC Directive 76/160/EEC EC Directive 80/777/EEC
2	Potable water	Drinking Domestic use Food and soft drinks Cooling systems Irrigation Firefighting		WHO (ISBN 92 4 154 168 7) EC Directive 80/778/EEC DoE Circ 20/82 DoE Circ 25/84
3	Softened water	Recirulatory cooling systems Low-pressure boilers Laundries Bottle washing Closed recirculatory systems Domestic use		Industrial Water Society (IWS) BS 2486: 1978 BS 1170: 1983 BEWA: COP.01.85
4	De-alkalized water	Medium-pressure boilers Recirculatory cooling systems Brewing Food and soft drinks		IWS BS 2486: 1978
5	De-ionized water	Medium-pressure boilers Humidifiers Renal dialysis Glass washing Battery top-up Laboratories Plating industry Spirit reduction	For renal dialysis aluminium must be less than 0.01 mg/l as Al Silica removal may be required for some applications	BS 2486: 1978 BS 4974: 1975 BS 3978: 1966 American Society for Testing and Materials (ASTM) EEC Draft 85/C 150/04 Association for the Advancement of Medical Instrumentation (AAMI)
6	Purified water	Pharmaceuticals Cosmetics Laboratories Chemical manufacturing	United States Pharmaceopeia (USP) also specifies pH = 7.0	British Pharmacopoeia (BP) European Pharmaceopoeia (EP) USP US Food and Drug Administration (FDA) BS 3978: 1966
7	Apyrogenic water	Vial washing Parenteral solutions Tissue culture		BP, 1980 EP USP FDA
8	High-purity water	High-pressure boilers Laboratories	De-aeration may be required	BS 2486: 1978 BS 3978: 1966 National Committee of Clinical Laboratories Standards (NCCLS) PSC-3
9	Ultra-pure water	Microelectronics Supercritical boilers Nuclear applications Analytical instrumentation	De-aeration may be required Readily picks up contamination from pipework and environment	BS 2486: 1978 Integrated Circuit Manufacturers Consortium Guidelines (ICMC) ASTM D 1193-77

depends largely on the efficiency of the backwash. Sand filters in some form provide a satisfactory solution for the majority of water-filtration problems.

Sand filters are typically designed to give 24 hrs or more between backwashing. Trouble follows quickly if for some reason filter runs become short, because then the filtered water used for backwashing uses up a large percentage of the filtered water and the net output of water falls sharply.

19.7.3 Coagulation

Still smaller particles and some of the organic matter in a water can, if necessary, be removed by coagulation, in

Table 19.3 Typical characteristics of water

Class	*Conduct. µs/cm*	*Resist. MΩ – cm*	*TDS*	*pH*	*LSI*	*Hardness*	*Alkalinity*	*Nitrate*	*Sodium*	*Heavy metals*	*Silica*	*Suspended solids*	*Turbidity*	*SDI*	*Particle count*	*OA*	*TOC*	*Micro-organisms*	*Pyrogens*
2	750		Max. 500	6.5 to 8.5			More than 30	Max. 50	Max. 150	Less than 0.1		Less than 1.0	Max. 5			Max. 5		Less than 100	
3					– 1 to +1	Less than 20													
4					– 1 to +1		Less than 30												
5	20	0.05	Max. 10	5.0 to 9.5		0.1					0.5	Less than 0.1	Less than 0.5	Less than 5					
6	5	0.2	Max. 1	6.0 to 8.5		Max. 0.1					0.1	Less than 0.1		Less than 3		Less than 0.1		Less than 10	
7	5	0.2	Max. 1	6.0 to 8.5		Max. 0.1					0.1	Less than 0.1		Less than 3	1	Less than 0.1		Less than 1	Less than 0.25
8	0.1	10	0.5	6.5 to 7.5							0.02	Less than 0.1		Less than 1.0	1			Less than 1	
9	0.06	18	0.005			0.001	0.001	0.001	0.001	0.001	0.002	ND		Less than 0.5	0.1		0.05	Less than 1	Less than 0.25

Definitions

Conductivity: the electrical conductivity of the water measured in microSiemen/cm is the traditional indicator for mineral impurities.
Resistivity: the reciprocal of conductivity, measured in Megohm-cm. It is used in some industries instead of conductivity particularly for ultra-pure water.
TDS: total dissolved solids determined by evaporating the water and weighing the residue. Units are mg/l.
pH: the acidity or alkalinity of the water expressed on a scale of 0 (acid) to 14 (alkaline). pH is considered neutral.
LSI: (Langelier Saturation Index): an indication of the corrosive (negative) or scale-forming (positive) tendencies of the water.
Hardness: the total dissolved calcium and magnesium salts in water. Compounds of these two elements are responsible for most scale deposits. Units are mg/l as $CaCO_3$.
Alkalinity: the total concentration of alkaline salts (bicarbonate, carbonate and hydroxide) determined by titration with acid to pH 4.5. Units are mg/l as $CaCO_3$.
Nitrate: concentration is in mg/l as NO_3^-.
Sodium: concentration is in mg/l as Na^+.
Heavy metals: the total of chromium, lead, copper and other toxic metals expressed in mg/l.
Silica: soluble or 'reactive' silica concentration in mg/l as SiO_2.
Suspended solids: the concentration of insoluble contaminants in mg/l.
Turbidity: a measure of the colloidal haze present in Nephelometric Turbidity Units (NTU).
SDI: the Silt Density Index, a measure of the rate at which the water blocks a 0.45 µm filter.
Particle count: the number of particles greater than 0.5 µm in 1 ml of water (maximum particle size is 1 µm).
OA (Oxygen Absorbed): a measure of organic contaminants determined in a 4-hour test at 27°C and measured in mg/l as O_2. (Other indicative tests could be Permanganate Value (PV) or Chemical Oxygen Demand (COD).)
TOC: (Total Organic Carbon): another way of expressing organics, in this case in mg/l as C.
Microorganisms: used here to mean the number of colony-forming units of total bacteria present in 1 ml of water.
Pyrogens: the endotoxins responsible for febrile reaction on injection, determined either by the rabbit test or the **LAL** test. Units are Endotoxin unit/ml (EU/ml).

Note: There are many different tests and different versions of the same test for water analysis. If there is any doubt as to method or interpretation consult a reputable water-treatment supplier. The letters ND in the table indicate 'not detectable'. Parts per million (ppm) is also commonly used to express concentration and is essentially identical to mg/l.

Standard tests for water analysis

For further information including test procedures the following are recommended.

BS 2486, Treatment of water for land boilers.
BS 2690, Methods of testing water used in industry.
Methods for the Examination of Waters and Associated Materials, HMSO.
ASTM Standards, Vols 1101 and 1102 (1983)
American Public Health Association, *Standard Methods for the Examination of Water and Waste Water*, 16th edn.

which a chemical coagulant is dosed into the water before the filter. Unlike simple filtration, this process requires chemicals and careful control. Dosing directly before the filter will only cope with small concentrations of dirt. Larger amounts of dirt require coagulation to be followed by sedimentation and then filtration. It is a difficult process and is to be avoided if at all possible, especially on small flows. When coagulation processes go wrong, they can severely damage downstream equipment.

19.7.4 Membrane filtration

Microfiltration and ultrafiltration have recently been introduced for the removal of particles down to any desired size. Their capital cost is relatively high. Experience with them is limited, and a short trial with a small-scale pilot element is advisable. Prediction of full-scale performance from such trials is normally quite reliable, because the full-scale unit generally consists of a number of the same element as was used in the trial.

Dead-end filtration through membrane filters is common in some industries where high purity is imperative, and the filters serve as a final polisher. When clogged, the membrane has to be replaced. They are unsuitable for applications where they have to remove any significant concentration of particulate matter, as the cost of membrane replacement can become very high.

19.7.5 Water softening

Traditional water-softening processes add lime, or lime and soda ash, to the water. This produces a precipitate in the form of a sludge, which must be settled out and the clarified water filtered in a sand filter. The chemicals are cheap, but the problems of handling solid chemicals and of sludge disposal have largely made the processes obsolete. They are, however, simple and robust, suitable for low-technology supervision, and cope well with changing water analyses. They should not be forgotten when considering projects in underdeveloped countries.

19.7.6 Ion-exchange processes: general

Ion-exchange units physically resemble sand pressure filters, and are almost as effective in removing, and therefore accumulating, suspended matter. As they are backwashed much less vigorously they must not be fed with water containing more than about 2 mg/l of suspended matter or they will become progressively fouled with suspended material. Public supply quality is usually (but not always) good enough for the water to be put directly onto ion exchange though strainers are often fitted upstream to guard against accidental contamination.

Ion exchangers are synthetic resins in the form of beads – small spheres of 0.5 to 1.0 mm in diameter. Good backwashing of the bed is important to obtain a uniform bed in which the different sizes are graded to give the minimum pressure loss. The resins have a limited life. Cation resins, used in softening and also in the first stage of de-ionization, can last for 10 or even 20 years, but anion resins used in de-ionization rarely give more than 3–5 years of use.

The 'capacity' (in terms of equivalents per unit volume) of ion exchangers is limited, and depends in part on the amount of excess regenerant chemical which is applied. The design of ion exchange plant consists of matching the amount of impurity in the water which is to be exchanged per run against: the working capacity (per unit volume of exchanger) and the volume of exchanger installed. This calculation must take into account the worst conditions likely to be met – hence the importance of finding out about variations in the raw water (cf 19.3 above).

If the unit becomes badly fouled with suspended matter (for example, after a pipe break has introduced excessive suspended matter into the system) it must be taken out of service and cleaned. This is done with an extended backwash, possibly at higher flow rates. If this does not remove the dirt, the manhole should be opened and the resin agitated with an air lance. Non-ionic detergents can be used, but not at the same time as the air lance or the resulting froth will be impossible to control.

Ion exchangers in general and cation resins in particular are liable to chemical attack by chlorine. The very small residual of chlorine in public supply (typically, 0.2 mg/l) has only a minimal effect, but if more chlorine has been added it must be removed (e.g. with an activated carbon filter) before ion exchange.

The anion resins used in de-ionization are prone to fouling if the water contains organic matter. The soft peaty waters mentioned in 19.3.5 above are particularly bad in this respect, and, at worst, can reduce resin life to a few weeks.

The handling, storage, measuring and dilution of regeneration chemicals requires serious consideration, especially in de-ionization, which requires strong acid and alkali. For dilution and pumping the actual regeneration solution most systems use ejectors, which avoids moving parts in corrosive solutions.

All ion-exchange processes produce contaminated waste water from backwash, regeneration and rinse. The proportion of waste depends on the concentration of hardness or to TDS being removed, and can be as high as 15% of the product flow. Any pretreatment has to take this additional flow into account.

19.7.6.1 Base-exchange softening

This is the simplest and commonest ion-exchange process. It uses cation resins which are regenerated with strong brine to remove calcium and magnesium ions from water in exchange for sodium ions. Well-designed standard plant is available in a wide range of sizes and operates with a minimum of supervision. Conventional softeners allow 1–3% of the incoming hardness to leak through. As the hardness is exchanged for sodium the TDS remains substantially unchanged. The softened water is at the same pH as the incoming water but is rather more corrosive to steel.

Salt is easily purchased and handled in bulk, and causes no corrosive or noxious effluents. The run/regeneration cycle on automatic softeners is normally governed by a multiport valve, which is the only moving part on the

plant. This can fail and so feed brine into the boiler, but fitting a conductivity meter on the make-up line can guard against this.

The operation of a base exchanger is chemically inefficient, and the spent regenerant contains large amounts of excess salt which may occasionally be difficult to dispose of. Factory softeners make a major contribution to the chloride content of the UK's industrial rivers, and pressure from environmentalists to reduce the amount of salt being discharged is growing.

19.7.6.2 De-alkalization/base exchange

This three-stage process is used for waters of high alkalinity and hardness. It actually removes most of the temporary hardness and so reduces the TDS of the water. The first stage is Dealkalization, which removes temporary hardness while converting the bicarbonate into dissolved CO_2 gas. The second stage is an air-blown degassing tower to reduce this CO_2 to about 5 mg/l, and the third is a conventional softener to remove the permanent and any residual temporary hardness. These stages are illustrated in Table 19.4, which shows that another important advantage is that the TDS of the water is reduced. However, that may make silica the critical impurity in the feed. (Cf 19.5.1)

The raw water silica is 22 mg/l as SiO_2, and therefore becomes a major constituent of the treated water. Silica scale must now be avoided by raising the boiler water pH and letting silica rather than the TDS control the necessary blowdown. Silica scale not only has a tenth of the heat conductivity of calcium carbonate scale but it is glassy, adherent, and extremely resistant to boiler-cleaning chemicals.

De-alkalization resins are regenerated with sulphuric or hydrochloric acid. Sulphuric acid is cheaper and easier to store and handle, but its dilution with water is potentially dangerous and must be carefully engineered. The regenerant solution must be extremely dilute to avoid the precipitation of calcium sulphate, which would clog the unit. This leads to long regeneration times and a high production of waste water. Hydrochloric acid is usually preferred on the smaller scale, where easier operation is more important than the annual cost of chemicals.

De-alkalization resins must not be over-regenerated or the product water becomes strongly acidic. The system therefore needs some measure of skilled supervision, and may depend on a pH meter – an instrument which, in turn, needs regular and skilled maintenance.

Table 19.4

	Raw water	*De-alkalized*	*Base exchanged*
Total Hardness[a]	290	50	1
Alkalinity[a]	265	25	25
TDS[a]	334	94	94
Silica	22	22	22

[a]All as mg/l $CaCO_3$.

The acid regeneration is very efficient, and the amount of free acid going to drain is small. Given a reasonable amount of dilution, it may be unnecessary to take special precautions against it. Although acids are more expensive than salt, the efficiency with which they are used means that the operating cost of a de-alkalization/base exchange plant is similar to that of a simple softener. The capital cost, on the other hand, is much higher and of the same order as that of a simple de-ionizer.

The tower in which CO_2 is stripped out must run into a break-pressure tank with subsequent repumping. It will load the water with any dust, and living organisms or other particles in the atmosphere, which leads to trouble in dirty environments or in pharmaceutical works.

The de-alkalized and degassed water has a pH of 4–5 and (having just passed through an air-blown tower) is laden with oxygen and extremely corrosive. Normal practice is to dose NaOH into the degasser tower sump, at a level sufficient to approach the desired boiler water pH. If this dosing fails, severe corrosion in the degassed water pump, the softener and the feed system will result.

19.7.6.3 De-ionization

De-ionization is a two-stage process which removes all dissolved ions from water. First, the water passes through a bed of cation-exchange resin, regenerated with sulphuric or hydrochloric acid, where all the cations are removed in exchange for hydrogen and dissolved salts are thus converted into their equivalent mineral acids. This acidic water is passed through a bed of anion exchange resin, regenerated with caustic soda, which removes all the anions in exchange for hydroxyl. The resulting water contains, except for a small leakage of dissolved salts (typically less than 1–5 mg/l), only hydrogen and hydroxyl ions which, together, form water. On large plants, above about 20 m^3/h, it is quite common to include a degassing tower between the cation and anion exchange stages. This is a purely economic measure; it removes carbon dioxide which would otherwise have to be removed on the anion resin and consequently reduces the amount of caustic soda needed for regeneration.

De-ionization plant has a lower capital cost than membrane plant, but on a highly mineralized water its operating costs are higher. It also involves storage, handling and discharge of acid and alkali, which Health and Safety regulations, as well as environmental restrictions, are making more and more difficult. The spent regenerant from a cation unit contains large quantities of excess acid, and that from an anion unit excess caustic, which must be neutralized before discharge. Self-neutralizing designs are the norm.

These factors are making membrane processes progressively more favourable. They add practically nothing to the environment, and do not involve corrosive chemicals. They are also more tolerant of some changes in the raw water analysis. Ion exchange and membrane processes can be combined in the treatment train, either for economy (if the flow is large) or to obtain the highest levels of purity, especially with respect to colloids and bacteria. Since ion exchange units work batchwise and membrane plant is continuous, this involves problems of storage and control.

19.8 Membrane processes

Falling costs and greater experience are making membrane processes more and more attractive. Their advantages over ion exchange are described in 19.7.6 (above): the disadvantages are greater capital cost, and their great sensitivity to fouling impurities in the water being treated. Elaborate pretreatment may be necessary to protect the membrane plant.

Membrane plant performance improves sharply with rising temperature. Very cold water should be preheated, especially if it will eventually serve as boiler feed, but maximum permissible operating temperatures are not high. They vary with different plant, but are never above 50°C. Development of high-temperature plant is in hand.

19.8.1 Reverse osmosis (RO)

In reverse osmosis water is forced by pressure through a very fine-pore membrane, which has the property of rejecting dissolved salts. The process thus removes both particulate and dissolved matter. Generally, the flux of water is extremely slow, so that large membrane areas have to be installed to achieve the desired output. Different grades of membrane show different rejections and fluxes.

A 'tight' membrane will remove over 99% of dissolved salts but requires pressures of the order of 30 bar or more to function economically. A 'loose' membrane may only take out 90% of the salts but will function at around 5 bar or even less. Both types of membrane will remove all particulate matter, colloids, bacteria and large molecules. Small, undissociated molecules such as silica and dissolved gases (i.e. oxygen and CO_2) pass through unchanged.

The ability to remove particulates has made RO indispensable in the production of ultra-pure water for microchip washing. Its ability to remove large molecules enables it to produce pyrogen-free water for the pharmaceuticals industry.

For conventional water purification, RO may be economical for removing the bulk of the dissolved salts in a water before ion exchange, but only if the raw water has a high dissolved solids content. In practice, substituting two processes for one is uneconomical except for large throughputs.

Recently developed 'softening' membranes reject most of the hardness in water while passing sodium salts, and operate at pressures of about 5 bar. This can be used to provide substantially softened make-up water for shell boilers. About 5–10% of the raw water hardness remains in the water but, for example, if there is a sufficiently high condensate return to the system this residual hardness may be acceptable.

RO has some intrinsic disadvantages:

1. The water wastage tends to be high, especially on small plants where a complex water-saving flow sheet is inappropriate.
2. RO membranes are very sensitive to fouling by particulates, colloids and macromolecules. The Silt Density Index test for raw water is an empirical test which shows the rate at which a 0.45 μm filter disc becomes plugged, and gives a good indication of the fouling properties of the water. It should be carried out by an experienced person. Seasonal and other variations which might lead to fouling must also be considered.

   Pretreatment to avoid fouling is always complicated and risky: if it fails, rapid fouling of the whole membrane complement of a plant will result. Cleaning procedures are ineffective against severe fouling and membrane replacement is very expensive. On bad fouling waters RO should be avoided unless, for example, its use is essential to produce ultra-pure water.
3. Some anti-scaling treatment is necessary on most waters, using, for example, pH reduction, hexametaphosphate, phosphonates or polyacrylic inhibitors. The action of the various compounds available is not yet fully understood, so this can be a hit-and-miss technique.
4. As CO_2 passes through the membrane, while bicarbonate is rejected, the product water tends to be acidic and may need pH correction.

19.8.2 Ultra-filtration

As RO membranes become 'looser' their salt rejection falls (see 19.8.1). Eventually a point is reached at which there is no rejection of salts, but the membrane still rejects particulates, colloids and very large molecules. The membrane pore size can be tailored to a nominal molecular weight cut-off. The resulting filtering process is called ultra-filtration.

In this process good hydrodynamics on the membrane surface are required to scour away the accumulated solids and prevent the membrane being blinded. This cannot be totally effective, and in practice the nominal membrane cut-off is often masked by the tendency of particulates to form a thin layer on the membrane surface whose effective pore size may be smaller.

The process is used mostly for industrial separations, such as the removal of yeast from beer or the recovery of emulsified cutting oils. It has been proposed as a pretreatment to RO for fouling waters, but the economics are doubtful.

19.8.3 Electrodialysis (ED)

This process uses membranes which remove salts from water by passing an electrical current through it. It was originally developed for the conversion of brackish water to potable (i.e. for a product of 300–500 mg/l). As the salts are removed, the conductivity of the water falls, the power used in the process increases and the cost rises. It is therefore potentially economical primarily for pretreating a highly mineralized water (say, 300 mg/l or more) before ion-exchanger de-ionization.

Unlike RO, which is essential for producing ultra-pure water, there is little experience of ED in industry. The process has some potential advantages over RO: it is less liable to fouling and it can be engineered to waste much less water. Electrical Deionization is based

on the ED principle, using a treatment cell which is filled with ion exchange resin to facilitate the passage of electrical current. This allows the process to produce very high purity water suitable for pharmaceuticals, microelectronics etc. The process initially gained ground over ion exchange deionization for smaller flows, when the nuisance of corrosive regenerants is relatively higher. Its success on this small-scale applications, together with increasing environmental difficulties with ion exchange regeneration chemicals and effluent, is now moving it into larger scale operations.

19.8.4 Retrofit of membrane processes

As with RO, de-ionization by ED before ion exchange is rarely feasible because of the complication of two processes instead of one. A different situation arises where an existing ion exchange installation is overloaded, either because the plant needs to treat more water or because the TDS in the raw water have risen above the original design level. In such cases the simplest and most economical solution can be to install RO or ED to take up a large part of the ionic load and allow the existing ion-exchange plant to be uprated.

19.9 Effluents

Industrial effluents are a particularly difficult problem to discuss in general terms: their nature is very diverse, possible methods of treatment vary correspondingly and their acceptability depends as much on the receiving body as on their flow and contents. There are, however, some common factors which are worth mentioning.

19.9.1 Domestic sewage

Industrial plants also discharge domestic sewage. It is vital to keep this separate from any industrial effluent which may have to be treated, so that it can then be disposed of by conventional means (to the public sewer, septic tank, etc.).

19.9.2 Surface drainage

Most of the surface drainage due to rain falling on roofs, roadways, etc. will be normal, acceptable floodwater and can run off to a soakaway, storm drain, etc. in a conventional manner. Surface drainage from areas contaminated with spillage or with material deposited from a locally polluted atmosphere creates a particularly difficult effluent problem, characterized by unpredictable and violent variations in flow and concentration of pollutant. The best approach to this is to avoid conditions in which the area becomes loaded with contaminant.

Alternatively, the contaminated surface drainage must be segregated from the normal stormwater drains and may, for example, be led into a balancing tank. This tank must be large enough to even out the variations and to allow the contents to be added to the works effluent (treated or untreated) over a period of time. Provision must be made for periodically removing the inevitable accumulation of silt in the bottom of the tank.

19.9.3 Noxious effluent

Almost any impurity added to water leaving a works can, in certain circumstances, become noxious, and with some of these impurities it is not immediately obvious that they are unacceptable. The main examples are:

- Corrosive conditions – not only high or low pH, but also high levels of sulphate, which is corrosive to cement and therefore unacceptable in the public sewers. High temperatures can be unacceptable;
- Toxic constituents such as heavy metals, cyanides, etc.;
- Organic materials whose decay consumes oxygen, which includes various harmless materials (e.g. domestic sewage, all vegetable matter, milk wastes, cellulose, sugars, etc.);
- Inert material which may settle to the bottom of a body of water and coat its beds (clay, alum sludge, etc.). Also dyestuffs which discolour the water and are aesthetically unacceptable.

Unlike potable and industrial waters, for which quality specifications are laid down, there can be no universal regulation as to the concentration or degree to which any of these is acceptable. The receiving body, who have to use their judgement in each case, will lay down allowable limits.

The sewerage authority decides on the level of contamination which it is prepared to accept into its sewer. The amount of sulphate and of biodegradable matter which can be allowed will depend, first, on the quantity and quality of the flow already in the sewer and available to dilute the effluent. The second decision concerns the limits of contaminants which are acceptable into the sewage works.

If the effluent is within acceptable limits, the sewerage authority is entitled to make a charge for receiving and treating it (see below). The Environmental Authority in England has similar decisions to make if the effluent is to be discharged directly into the environment. The acceptable limits will, of course, be much lower but no charge will be levied.

The receiving body is entitled to take samples of effluent at all times to ensure that the conditions under which they have agreed to receive it are being met. They may insist on some kind of continuous or regular monitoring by the discharger, but for almost every kind of effluent this is difficult to automate and standardize, and is always an unsatisfactory aspect of the system.

19.9.4 Charges for effluent

Sewerage authorities normally leavy a charge on industrial effluent. The conventional system of charging uses a formula which takes into account the volume, its concentration of suspended solids and its oxygen consumption (which is a measure of the load it will put on the treatment works). Typical figures for the flow and quality of the discharge are ascertained and agreed between the sewerage authority and the plant.

The flow of effluent is often calculated on the assumption that, say, 90% of the incoming water (metered by the water supplier) will re-emerge as effluent. This is, of course, not the case at a brewery, for example, where direct metering or different methods are used to ascertain the effluent flow. Direct metering of the flow is, however, always difficult and therefore uncommon.

19.9.5 Effluent management

If a works produces any effluent liable to be unacceptable, or liable to raise an effluent charge, it is important that the whole effluent system should be properly managed. This means knowing where the drains run and in which of them each effluent flows. This information is often unavailable and is difficult to ascertain. Good management often means that if treatment or tankage is required, different flows should be segregated from one another. Diluting a noxious effluent with another of a different type, or with a non-noxious one, generally aggravates the problem.

19.9.6 Effluent treatment

Where the effluent is outside the limits acceptable for discharge it has to be treated first by the works. Generally, effluent treatment is an unsatisfactory operation because it requires skills different from those available on the works, and because it is a nuisance and is not seen to be productive.

Effluent-treatment plants fail most commonly because the design is based on an inadequate or faulty definition of the effluent problem. In an existing works it may take months of painstaking research to establish the true patterns of flow and contamination. Predicting these for a new project can be extremely difficult, and serious mistakes are common.

Treatment processes vary widely, and in themselves are reasonably well understood, but even if the nature and pattern of effluent is properly defined, problems often arise from wide variations in contents and flow of the effluent. Factories may produce several different types of effluents, each at different times or at variable flow rates. To cope with this needs a large bulking tank, and/or a grossly over-sized effluent plant. A cheaper effluent unit may result in limitations being imposed on the operation of the main plant – for example it may limit the rate at which a process tank can be discharged to drain. (The operators will quite probably ignore this need and so cause a noxious discharge.)

The best solution to any effluent problem is to avoid treatment by the works altogether. Even if it appears initially to be more costly, it will save trouble and expense in the long term.

If the process cannot be modified to avoid the effluent the sewerage authority may be persuaded to take over its treatment. Various financial arrangements have been made for this over the years, from a charge based on the volume flow to a capital contribution towards an extension to the sewage works capacity. By this means the responsibility is handed over to an organization whose purpose and technical skills are devoted to the subject.

19.9.7 Water economy and re-use

Water is historically thought to be free, which often leads to pointless waste. Water usage is rarely measured at the point of consumption, and so its cost is never brought home to the people there.

As an example: workers at a foundry kept a 1/2" hose running into a bucket to cool a bottle of milk kept there for making their tea. At 1201/h, 24 h/day, this led to the waste of 86 m^3/month of water. Water + effluent discharge cost £1.50/m^3, so cooling the milk bottle cost £130 per month. The expense of a small refrigerator was recovered within a couple of months.

Occasional spot estimates of water usage (which may be possible without installing meters), with direct debiting of water cost to the operation, can do much towards water economy. In such an exercise it is important to add the cost of effluent discharge to that of water intake.

Much lip-service is paid to water re-use, which, on the whole, is more fashionable than practicable. Better opportunities arise from simple economy in water consumption at each point of use. Water re-use after effluent treatment is not often practicable. It appears, if at all, most favourable in the re-use of a slightly contaminated water for some low-grade purpose such as washing down.

Acknowledgement

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20 Pumps and pumping

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20.1 Pump functions and duties

Pumps impart energy to the liquids being transferred by mechanical means using moving parts. They can be classified as rotodynamic or positive displacement. Rotodynamic pumps cause continuous flow, and the flow rate and discharge pressure are effectively constant with time. Positive displacement pumps deliver fixed quantities at a rate determined by driving speed. The main types of pump commonly used are listed in Figure 20.1.

Pumps are used to transfer liquids, moving blood and other biological fluids, delivering measured quantities of chemicals as in dosing in water treatment, in firefighting, in irrigation, moving foods and beverages, pumping pharmaceutical and toilet products, in sewage systems, in solids transport, in water supply and in petrochemical and chemical plant. They are utilized in power transfer, braking systems, servomechanisms and control, as well as for site drainage, water-jet cutting, cleaning and descaling. Pumps thus give a wide range of pressure rises and flow rates with pumping liquids which vary widely in viscosity and constituency.

20.2 Pump principles

20.2.1 Rotodynamic pumps

Taking a typical centrifugal pump (Figure 20.2) the Euler equation can be written, at best efficiency flow, in the form

$$gH = u_2^2 - Qu_2 \cot \beta_2 / A_2 \qquad (20.1)$$

where $u_2 = \omega D_2/2$, $A_2 = \pi D_2 b_2$, Q is flow rate and H is head rise. This ignores flow losses, so that actual performance is less than the Euler (Figure 20.3). Figures 20.4–20.6 give typical pump performance curves for a constant driver speed. The inflections in the mixed and axial flow curves are due to flow instability over blades and through impeller passages. Centrifugal Pumps usually have an almost straight line relation between flow rate and power, with power rising with flow rate. Axial pumps take more power at low flows than at high levels of flow rate.

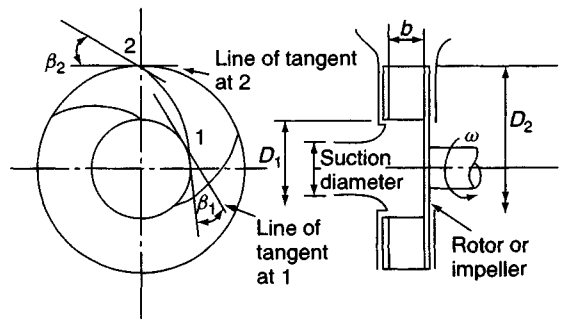


Figure 20.2 A simple centrifugal pump

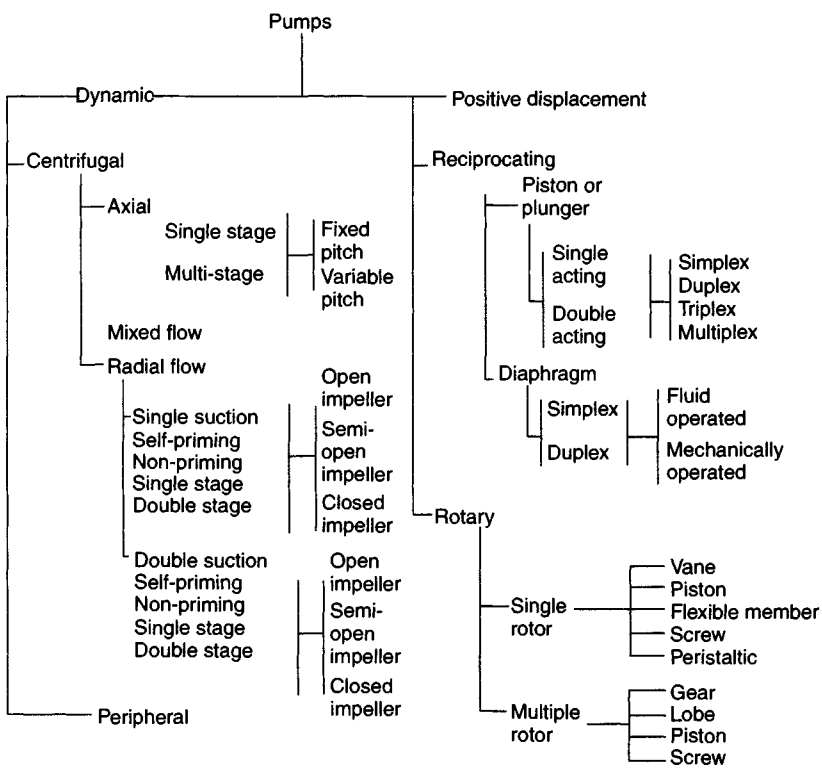


Figure 20.1 Pump family trees

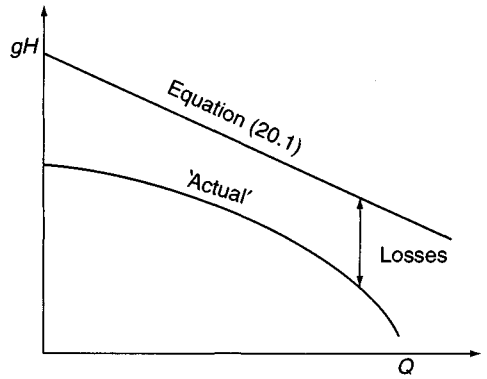


Figure 20.3 A pump's ideal and actual characteristics

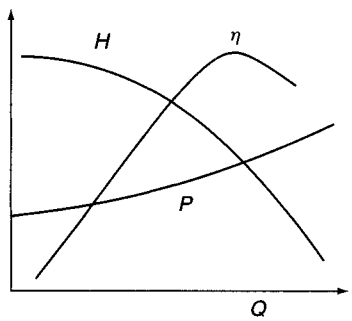


Figure 20.4 Centrifugal

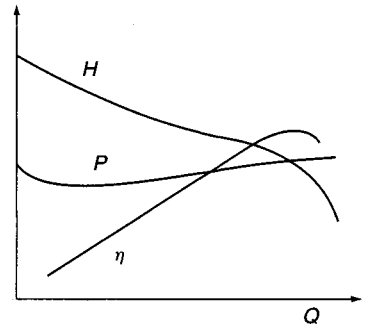


Figure 20.5 Mixed flow (bowl pump)

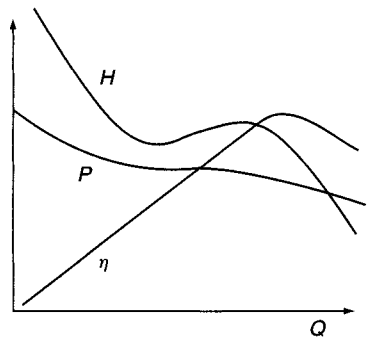


Figure 20.6 Axial flow

The hydraulic efficiency

$$\eta_H = \frac{g H_{\text{Actual}}}{g H_{\text{Ideal}}} \qquad (20.2)$$

and

$$\eta_0 = \frac{\text{Hydraulic power}}{\text{Input power}}$$

or

$$\eta_0 = \dot{m}\, g H / P_{\text{in}} = \rho Q\, g H / P_{\text{in}} \qquad (20.3)$$

($\dot{m}$ is the mass flow rate)

Typical pump cross-sections are shown in Figures 20.7–20.10. Figure 20.11 illustrates two layouts of multistage pumps, pump (a) has the stages stacked together and the casings clamped by 'pinch bolts' to give a seal; pump (b) encloses the stages in a pressure casing and is typical of high pressure machines used in modern large power stations for boiler feed, and in oil field re-injection duties among other applications.

20.2.2 Scaling laws and specific speed

If a simple pump is considered, it is possible to state that there must be a working relation between the power input,

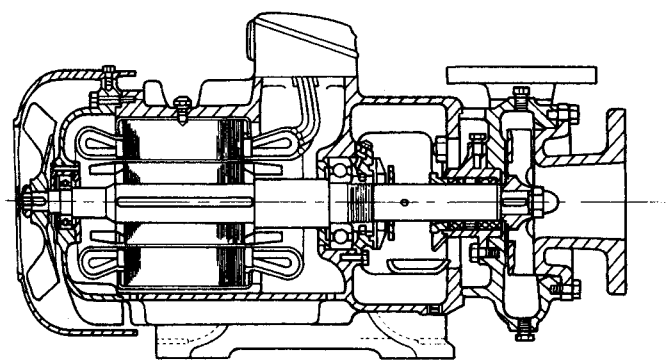


Figure 20.7 A monobloc design

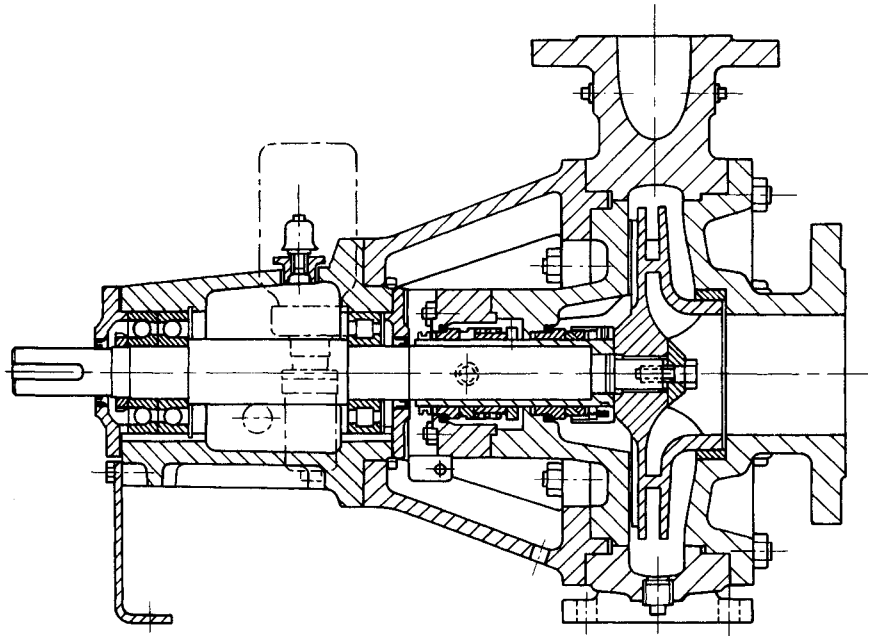


Figure 20.8 A back pull-out design

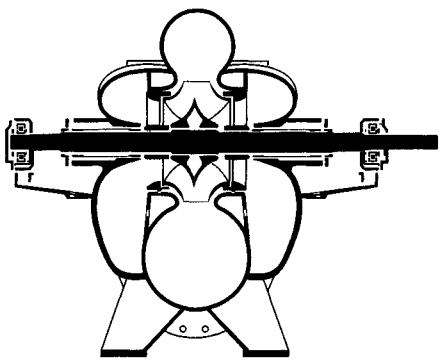


Figure 20.9 A double-suction design

and the flow rate, pressure rise, fluid properties, and size of the machine. If a dimensional analysis is performed it can be shown that a working relation may exist between a group of non-dimensional quantities in the following equation:

$$\frac{P}{\rho\omega^3 D^5} = f\left[\frac{Q}{\omega D^3} \cdot \frac{gH}{\omega^2 D^2} \cdot \frac{\rho\omega D^2}{\mu} \cdots\right] \qquad (20.4)$$

(1) (2) (3) (4)

Term (1) is a power coefficient which does not carry any conventional symbol

Term (2) can easily be shown to have the shape V/U and is called a flow coefficient (the usual symbol being ϕ).

Term (3) similarly can be shown to be gH/U^2 and is usually known as a head coefficient (or specific energy coefficient) ψ.

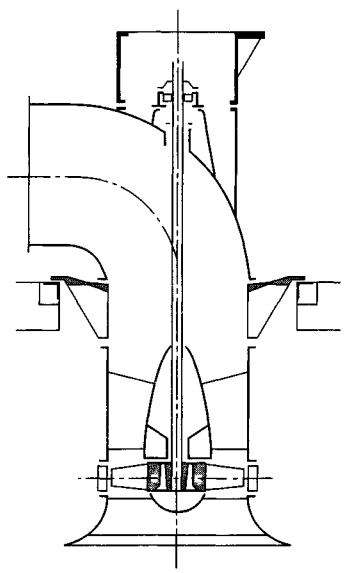


Figure 20.10

Term (4) is effectively a Reynolds number with the velocity the peripheral speed and the characteristic dimension being usually the maximum impeller diameter.

Since these groups in the SI system are non-dimensional they can be used to present the results of tests of pumps in a family of pumps that are geometrically and dynamically similar. This may be done as shown in Figures 20.12 and 20.13, and Figure 20.14 shows how the effect of changing speed or diameter of a pump impeller may be predicted,

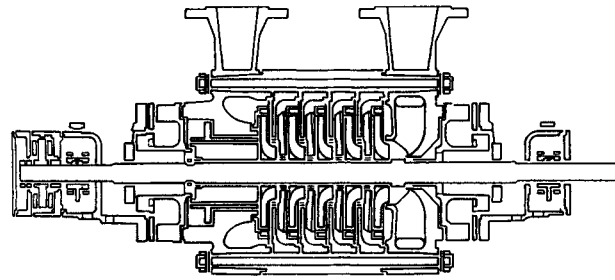


Figure 20.11(a) A multistage pump

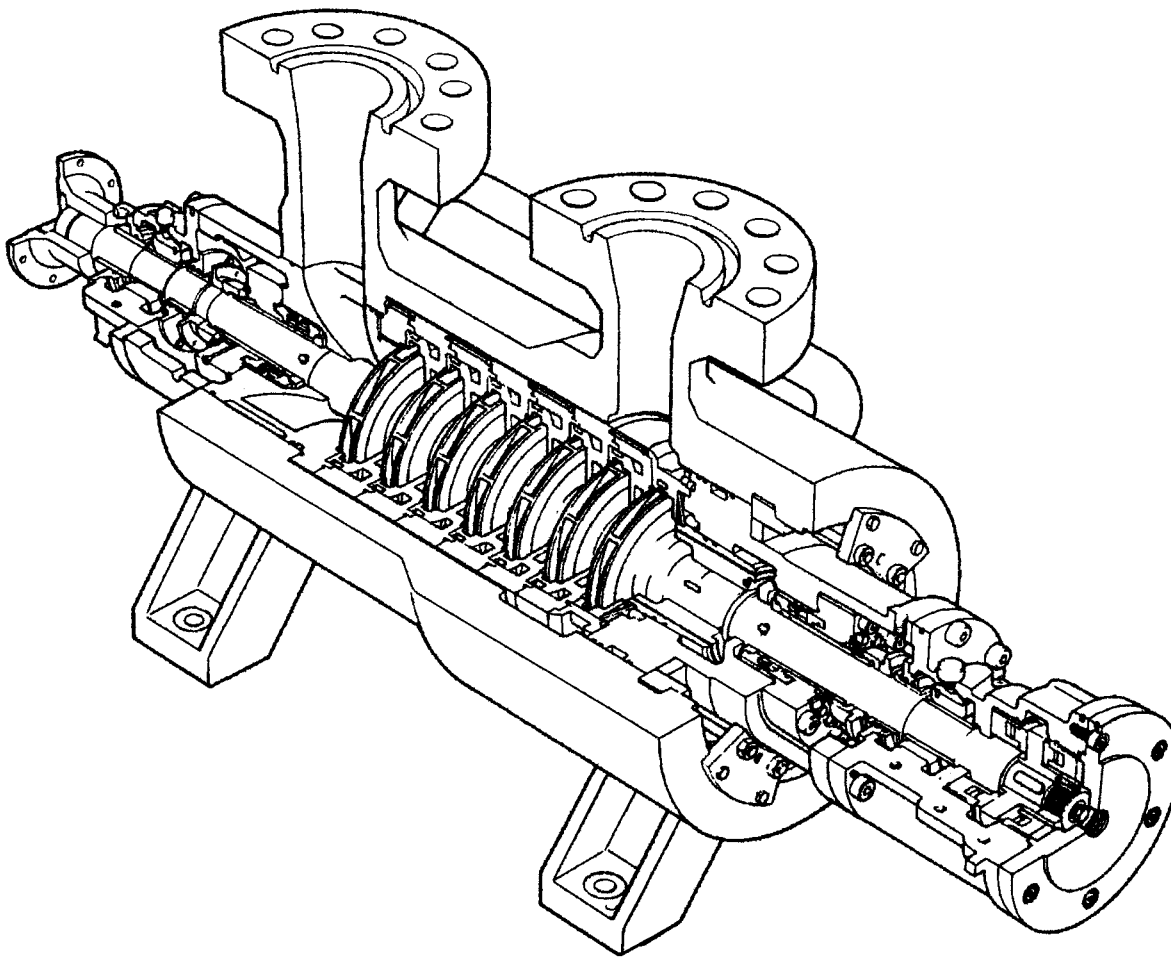


Figure 20.11(b) Multistage barrel casing pump

using the scaling laws:

$$\left.\begin{aligned} \frac{P}{\rho\omega^3 D^5} &= \text{const} \\ \frac{Q}{\omega D^3} &= \text{const} \\ \frac{gH}{\omega^2 D^2} &= \text{const} \end{aligned}\right\} \qquad (20.5)$$

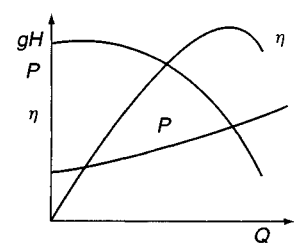


Figure 20.12 A pump's characteristic at fixed speed

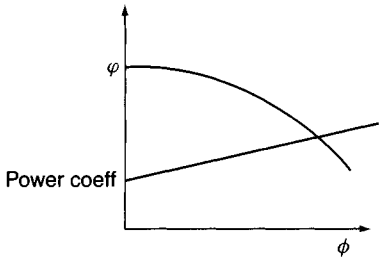


Figure 20.13 A non-dimensionalized plot

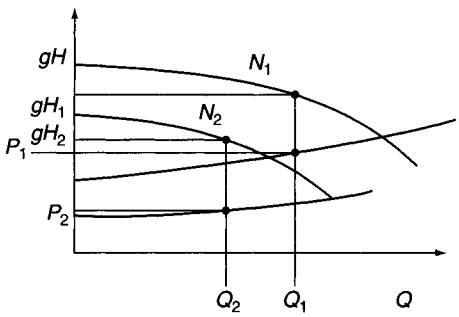


Figure 20.14 Prediction of speed change using equation (20.5)

The classical approach to the problem of characterizing the performance of a pump without including its dimensions was discussed by Addison,[1] who proposed that a pump of standardized size will delivery energy at the rate of one horsepower when generating a head of one foot when it is driven at a speed called the Specific Speed:

$$N_s = K\frac{N\sqrt{Q}}{H^{3/4}}$$

The constant K contains fluid density and a correction factor, and it has been customary to suppress K and use

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}} \qquad (20.6)$$

Caution is needed in using data, as the units depend on the system of dimensions used, variations being litres/minute, cubic metres/second, gallons per minute or US gallons per minute as well as metres or feet. Plots of efficiency against specific speed are in all textbooks based upon the classic Worthington plot, and Figure 20.15, based on this information, has been prepared using a non-dimensional statement known as the characteristic number

$$k_s = \frac{\omega\sqrt{Q}}{(gH)^{3/4}} \qquad (20.7)$$

This is based on the flow and specific energy produced by the pump at its best efficiency point of performance following the approach stated by Wisclicenus: 'Any fixed value of the specific speed describes a combination of operating conditions that permits similar flow conditions in geometrically similar hydrodynamic machines.'

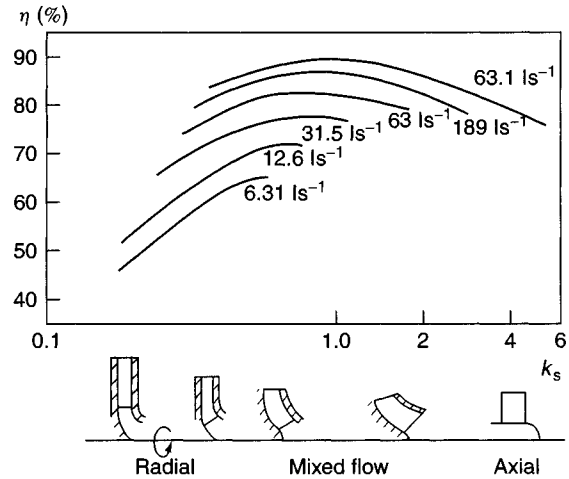


Figure 20.15 Variation of overall efficiency with non-dimensional specific speed[3]

Figure 20.16 presents on the basis of the characteristic number the typical impeller profiles, velocity triangle shapes, and characteristic curves to be expected from the machine flow paths shown. This indicates the use of the number as a design tool for the pump engineer.

The scaling laws (equation (20.5)) may be used to predict the performance from change of speed, as indicated in Figure 20.14. As will be discussed in section 20.9.1 pump makers can adjust the output of a given pump by reducing the impeller diameter as indicated by Figure 20.17. This illustrates the maximum reduction that can be used without an substantial reduction in maximum efficiency. Karrasik *et al*[2] discuss this and present equations called the 'scaling laws' that are used to predict the performance changes resulting from diameter reduction:

$$Q_1/Q_2 = N_1D_1/N_2D_2$$
$$H_1/H_2 = N_1^2D_1^2/N_2^2D_2^2$$
$$P_1/P_2 = N_1^3D_1^3/N_2^3D_2^3 \qquad (20.8)$$

Other methods of adjusting the output while keeping the speed constant consist of modifying the profiles of the blades at the maximum diameter of the impeller. This technique has been used for a long time and is often used to obtain a small energy rise when the pump is down on performance when tested. The reader is referred to reference 2.

20.2.3 Positive displacement pump principles

Whether the pump is a reciprocator or a rotary design, liquid is transferred from inlet to outlet in discrete quantities defined by the geometry of the pump. For example, in a single-acting piston pump (Figure 20.18) the swept volume created by piston movement is the quantity delivered by the pump for each piston stroke, and total flow rate is

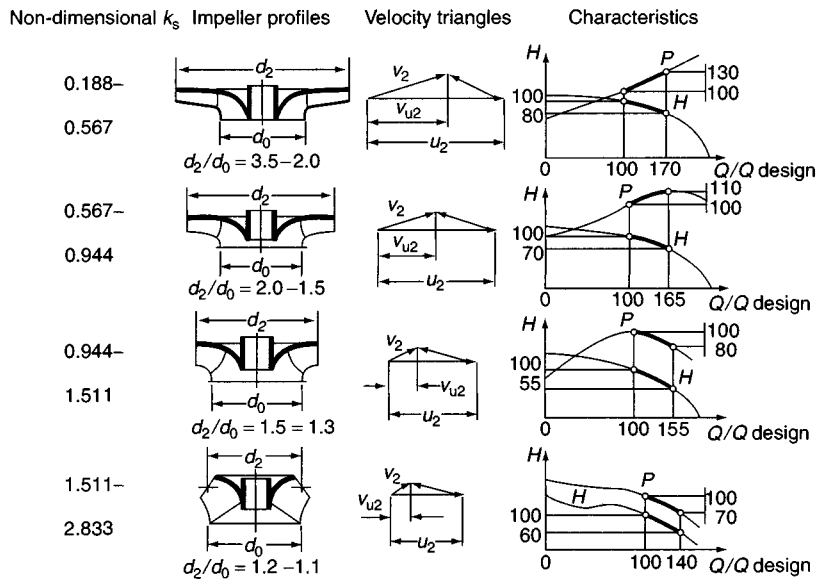


Figure 20.16 Flow path shapes, velocity diagrams and characteristics

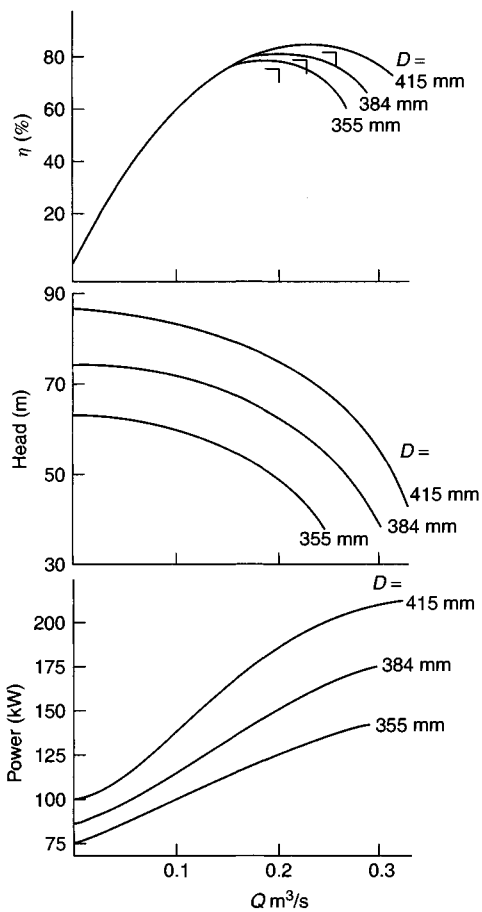


Figure 20.17 Scaling laws applied to diameter change (after Karassik *et al.*[2])

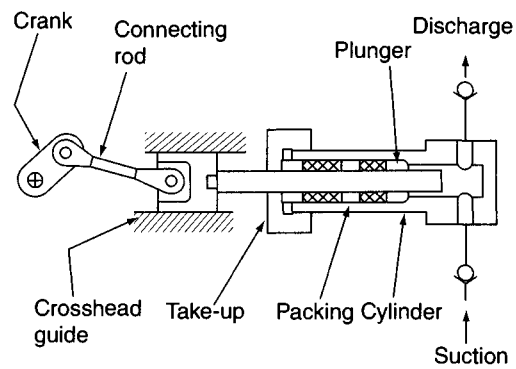


Figure 20.18 Plunger pump

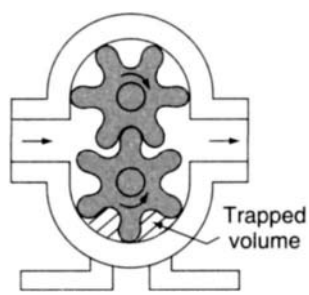


Figure 20.19 External gear pump

related to the number of strokes per unit time. Similarly, the spur-gear pump (Figure 20.19) traps a fixed quantity in the space between adjacent teeth and the casing, and total flow rate is related to the rotational speed of the gear wheels.

The maximum possible flow rate,

Q_0 = displacement × speed

as shown in Figure 20.20. The actual flow is reduced by leakage, flow Q_L,

$$Q = Q_0 - Q_L$$

The volumetric efficiency

$$\eta_v = \frac{Q}{Q_0} = 1 - \frac{Q_L}{Q_0} \tag{20.9}$$

and

$$\eta_0 = \frac{\rho Q g H}{P_D + P_L} \tag{20.10}$$

P_D and P_L are defined in Figure 20.20. Table 20.1 gives typical values of η_v and η_0 for a number of pump types.

Since discrete quantities are trapped and transferred, the delivery pressure and flow varies, as shown in Figure 20.21, which also illustrates how increasing the number of cylinders in a reciprocating pump reduces fluctuations. In the case of lobe and gear pumps the fluctuations are minimized by speed of rotation and increasing tooth number, but where, for control or process reasons, the ripple in pressure is still excessive, means of damping pulsations has to be fitted. Dampers (often called accumulators) are usually fitted to absorb or attenuate the pulses; Figure 20.22(a) sketches two simple systems one used where the gas used to provide the pressure can be allowed to pass into the fluid, the other uses a diaphragm to seal the gas off. Figure 20.22(b) compares the effectiveness of four different designs of accumulator that are used. The capacity of the accumulator is important, and one formula based on experience for sudden valve closure is

$$Q_A = \frac{QP_2(0.016L - T)}{(P_2 - P_1)} \times 0.25 \tag{20.11}$$

Here Q_A is the accumulator volume (m^3), Q is flow rate (m^3/S), L is pipe length (m), T is valve closure time (s), P_1 is the pressure in the pipeline (N/m^2) and P_2 is the maximum pressure desired in the line (N/m^2) ($P_2 = 1.5P_1$ in many cases).

Table 20.1 Some values of η_v and η[4]

Pump	η_v(%)	η(%)
Precision gear	→ 98	→ 95
Screw	–	75–85
Vane	85–90	75–80
External gear	–	20–60
Radial – multi-piston	>95	>90
Axial – multi-piston	>98	>90

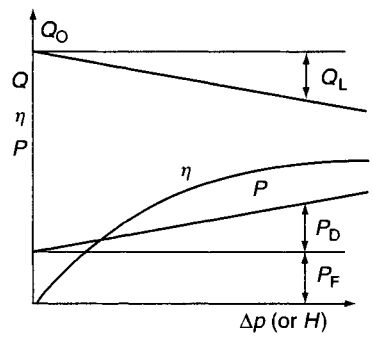


Figure 20.20 Typical characteristic at constant *N*

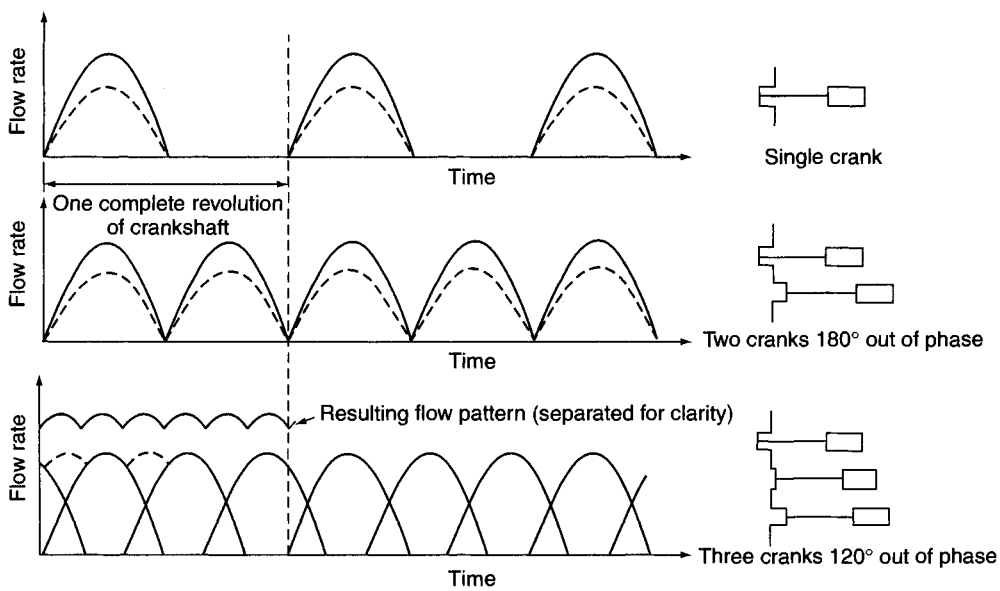


Figure 20.21 Reciprocating pump: variation of flow rate with numbers of cylinders

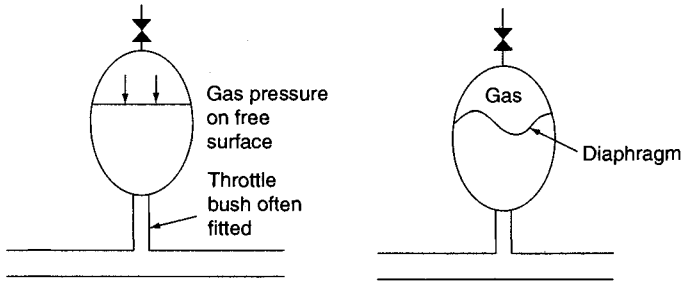


Figure 20.22(a) Simple Damper designs

RELATIVE DAMPENER PERFORMANCE

	DIVERTER	APPENDAGE	GAS-OVER LIQUID	ACOUSTIC
ATTENUATION:				
HGIH FREQUENCY	FAIR	POOR	POOR	EXCELLENT
LOW FREQUENCY	EXCELLENT	EXCELLENT	EXCELLENT	POOR
BACK PRESSURE ON PUMP	SLIGHT	NONE	NONE	NONE
EFFECTIVENESS AT:				
VARIOUS PUMP rpm	EXCELLENT	EXCELLENT	EXCELLENT	POOR
VARIOUS PUMP gpm	EXCELLENT	EXCELLENT	EXCELLENT	POOR
VARIOUS PUMP PRESSURES			EXCELLENT	FAIR
INTIAL COST	HIGH	LOW	MEDIUM	HIGH
REPAIR COST	MODERATE	MODERATE	NONE	NONE
MAINTENANCE COST	LOW	LOW	MEDIUM	NONE
SLURRY CAPACITY	POOR	EXCELLENT	GOOD	POOR

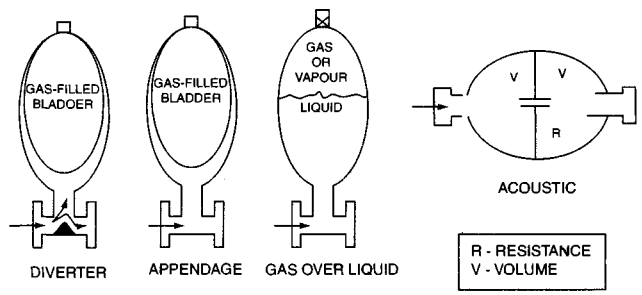


Figure 20.22(b) A comparison of damper performance

20.3 Effects of fluid properties on pump behaviour

Two effects on pump performance must be discussed: viscosity and gas content. Figures 20.23 and 20.24 illustrate the effects of viscosity change on centrifugal and positive displacement pumps, respectively. Figure 20.23 shows the deterioration of centrifugal pump performance, and it may be noted that if v is greater than 100 centistokes, water performance must be corrected. Figure 20.24 indicates that in a positive displacement pump the volumetric efficiency improves and power requirement increases (with increasing viscosity).

Table 20.2 summarizes the effects of liquid changes (effectively, viscosity and density changes) on pump performance and Figure 20.25 presents material presented by Sterling,[5] which illustrates how efficiency falls away with

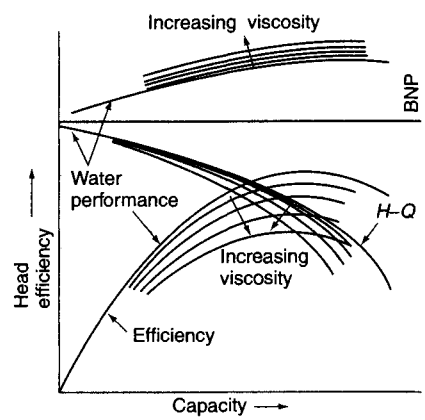


Figure 20.23 Effect of viscosity on centrifugal pump performance

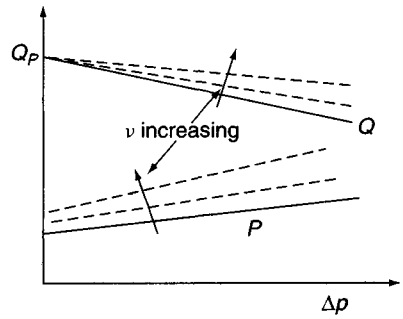


Figure 20.24 Effect of viscosity on positive displacement performance

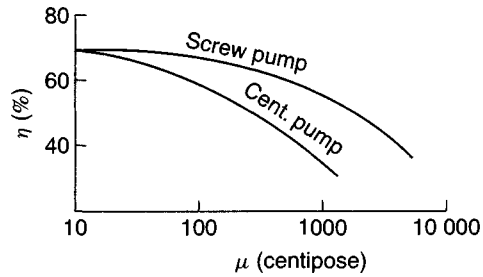


Figure 20.25 Effect of μ on screw pump and centrifugal pump compared (after Sterling[5])

viscosity for two pumps working at the same duty point, graphically showing the rapid fall-off of efficiency as μ increases in a centrifugal pump.

Figure 20.26 demonstrates a well-known method of correcting for fluid change from water for a centrifugal pump. This allows an engineer to predict change in performance if the kinematic viscosity of the liquid to be pumped is known and the water test data are available.

Gas content is another important effect. It is well known that centrifugal pumps will not pump high gas content mixtures, as flow breaks down (the pump loses 'prime') when the gas/liquid ratio rises beyond 10%.

Table 20.2 Effect of fluid viscosity

Type of pump	*Significant[a] viscosity levels*	*Effect of viscosity level*	*Treatment and/or notes*
Centrifugal	20	–	Performance maintained similar to water performance up to this level
	20–100	Lowering of H-Q curve increase in input hp	General lowering of efficiency but may be acceptable
	Above 100	Marked loss of head	Considerable reduction in efficiency, but high efficiencies may still be attainable from large pumps
Regenerative	Above 100	Marked loss of performance	Pumps of this type would not normally be considered for handling fluids with a viscosity greater than 100 centistokes
Reciprocating	Up to 100	Little	Performance generally maintained. Some reduction in speed may be advisable to reduce power input required
	Above 100	Performance maintained but power input increased	Speed is generally reduced to avoid excessive power inputs and fluid heating
	Above 1000	Flow through valves may become critical factor	Larger pump size selection run at reduced speed – e.g. 3 × size at 1000 centistokes running at one-third speed. Modification of valve design may be desirable for higher viscosities
Plunger	–	–	For very high-pressure deliveries only
Sliding vane	Above 100	Sliding action impaired: slip increased	Not generally suitable for use with other than light viscosity fluids
External gear	None	Power input and heat generated increases with increasing viscosity	May be suitable for handling viscosities up to 25 000 centistokes without modification. For high viscosities: (a) Clearances may be increased (b) Speed reduced (c) Number of gear teeth reduced
Internal gear	None	Power input and heat generated increases with increasing viscosity	For higher viscosities: (a) Speed may be reduced (b) Number of gear teeth reduced (c) Lobe-shaped gears employed
Lobe rotor	250	None	(a) Speed may have to be reduced
	Above 250	Cavitation may occur	(b) Modified rotor form may be preferred
Single-screw	None	–	Nitrile rubber stator used with oil fluids
Twin- or	Up to 500	Little or none	–
multiple-screw	Above 500	Increasing power input required	Speed may be reduced to improve efficiency

[a]Viscosity in centistokes

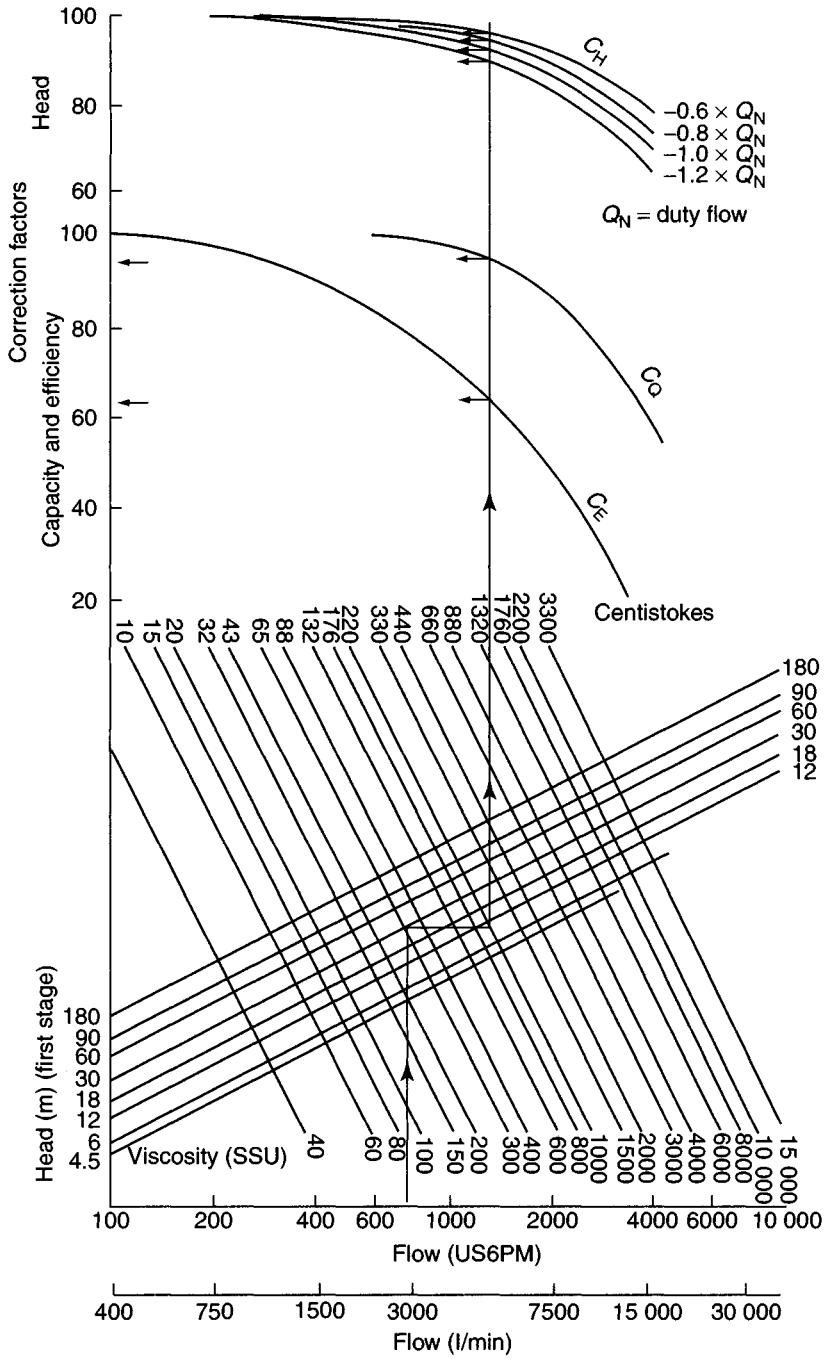


Figure 20.26 Viscosity correction curves (adapted from *Hydraulic Institute Standards, 12th edition, Hydraulic Institute Cleveland Ohio 1969*). A pump delivers water at a rate of 750 USGPM against a head of 30 m with an efficiency of 75%. It is to deliver a liquid with a viscosity of 1000 SSU. Predict the probable performance. From the figure $C_E = 0.64$, $C_Q = 0.95$, $C_H = 0.92$ at the duty ($1.0 \times Q_N$). Thus ηoil = $0.75 \times 0.64 = 48\%$ Q oil = $0.95 \times 750 = 712.5$ USGPM, H oil = $0.92 \times 30 = 27.6$ m.

Figure 20.27 shows how a centrifugal pump is affected, particularly at low flow rates, and the behaviour is typical of conventional centrifugal pumps. Figures 20.28 and 20.29 present well-known information on the effects of dissolved and entrained gas on the volumetric efficiency of a positive displacement pump.

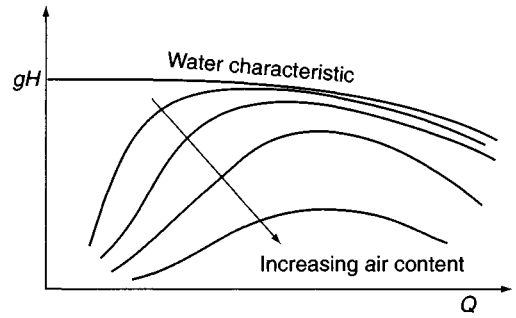


Figure 20.27 The effect of air content on pump behaviour

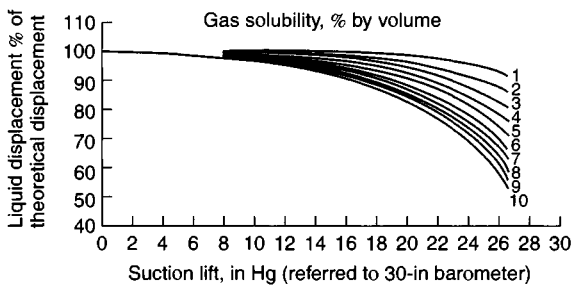


Figure 20.28 Effect of dissolved gas on liquid displacement

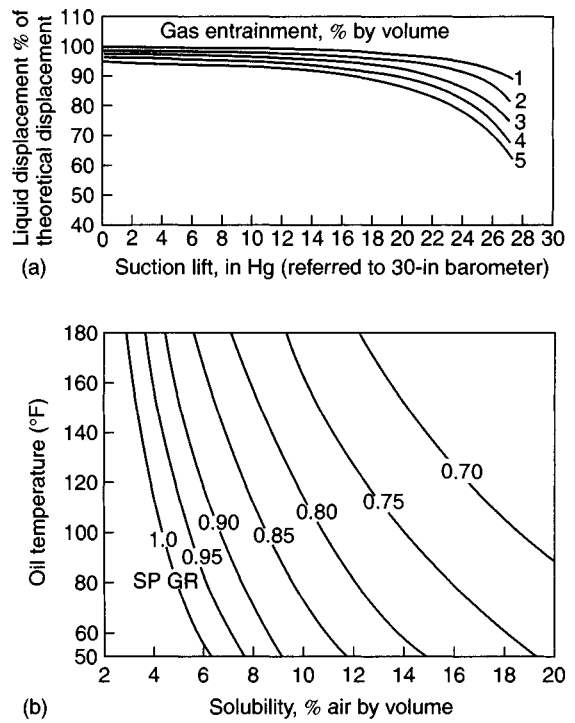


Figure 20.29 (a) Effect of entrained gas on liquid displacement; (b) solubility of air in oil. *Example*: At 5 in Hg with 3% gas entrainment by volume, pump capacity is reduced to 84% of theoretical displacement

20.4 Flow losses in systems

20.4.1 Friction losses

The most common method of friction loss estimation is based on the D'Arcy Weisbach equation:

$$(gH)_{\text{friction}} = f\frac{L}{D}\frac{V^2}{2} \tag{20.12}$$

The friction factor f is plotted in Figure 20.30 against the Reynolds number, based on the pipe inner diameter D for circular pipes and the hydraulic diameter (= 4 × flow area/wetted perimeter) for non-circular pipes. Table 20.4

Table 20.3 Some equivalent lengths for typical fittings (clean water)

		$\frac{L_E}{D}$
Gate valve (wedge:disc:plug disc)	Fully open	13
	Half open	160
	Quarter open	900
Ball and plug valves	Fully open	3
Conventional swing check valve	Fully open	135
Footvalve with strainer (hinged flap)	Fully open	75
Butterfly valve (200 mm up)	Fully open	40
90° Standard elbow		30
90° Long-radius elbow		20

Table 20.4 Hydraulic roughness of commercial pipes

Type of pipe	*Hydraulic roughness K* (mm)
Coated cast iron	0.127
Uncoated cast iron	0.203
Galvanized steel	0.152
Uncoated steel	0.051
Coated steel	0.076
Asbestos cement (uncoated)	0.013
Spun bitumen and concrete lined	
Drawn brass, copper, aluminium	
Glass plastic	
Concrete cast on steel forms	0.203
Spun concrete	0.076
Riveted steel – four transverse rows of rivets and six longitudinal	4.064
Two transverse rows of rivets, longitudinal seams welded	0.127
Single transverse rows of rivets	0.508
All welded	0.076
Flexible pipes	Roughness varies considerably with construction. Smooth rubber hose corresponds approximately with steel pipe. Head loss when curved can be 30% higher than when straight

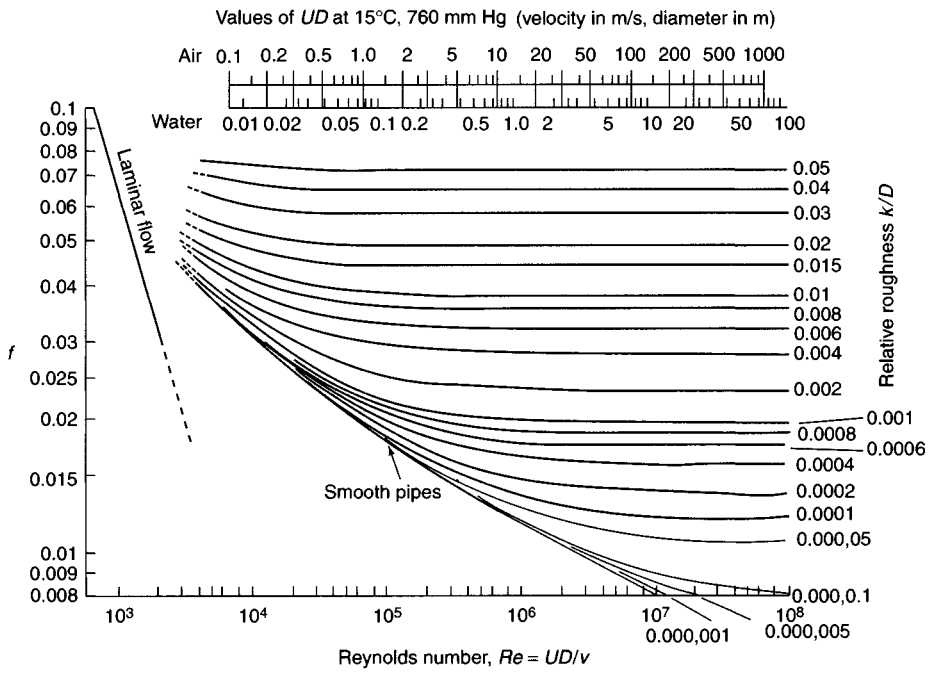


Figure 20.30 Friction factor f plotted against Re (after Miller[6])

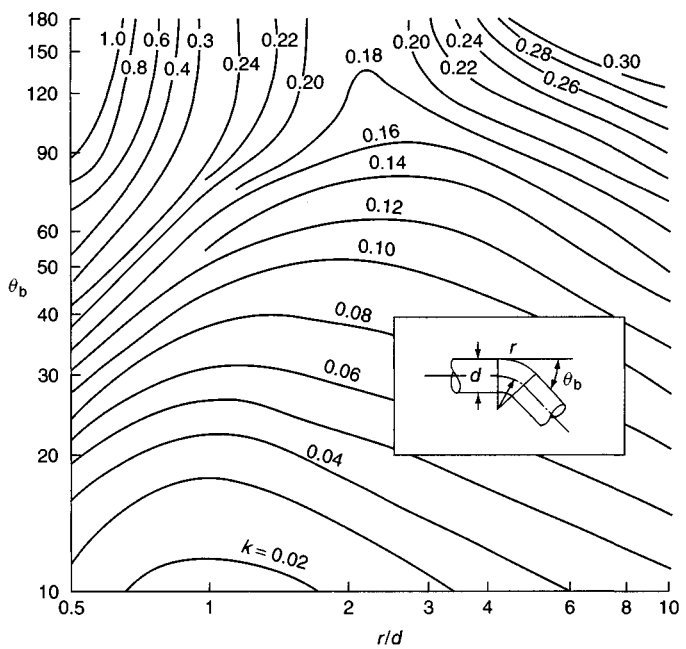


Figure 20.31 Bend loss coefficients[6]

gives typical surface roughness. Figure 20.30 is thus used to find f as follows:

Mean velocity 7 m/s, mean diameter 50 mm, water kinematic viscosity, therefore $UD = 0.35$

$R_E = 3 \times 10^5$

Roughness for galvanized pipe = 0.152, therefore $k/D = 3 \times 10^{-3}$

Hence in Figure 20.30 the lines drawn illustrate $f = 0.016$

20.4.2 Losses in bends, valves and other features

20.4.2.1 Loss factor method of estimating losses

A common method of estimating losses is to use a factor K, so that energy loss for a feature is given by

$$\Delta(\mathrm{gH}) = \mathrm{K}\ V^2/2 \qquad (20.13)$$

Figures 20.31–20.33 give loss factors for a range of common fittings. Most fittings do not occur in close proximity to one another, but bends frequently do. The effect of putting bends close together is presented in terms of the spacing between bends and a correction factor K_p. The equation used is for two bends:

$$\Delta(gH) = K_p\left(K_1\frac{V^2}{2} + K_2\frac{V^2}{2}\right) \qquad (20.14)$$

(bend 1 loss) (bend 2 loss)

Figures 20.34–20.36 give information on K_p values for the configurations shown in Figure 20.37.

20.4.2.2 Equivalent-length method

As the name suggests, the loss a feature causes is replaced by the loss due to a length of straight line which gives the same value of energy loss. Table 20.3 gives typical values of L_E, which are then added to the D'Arcy Weisbach equation to give

$$\text{Total loss in energy} = \frac{f}{D}\frac{V^2}{2}(\text{pipe length} + \text{sum of } L_E \text{ components}) \qquad (20.15)$$

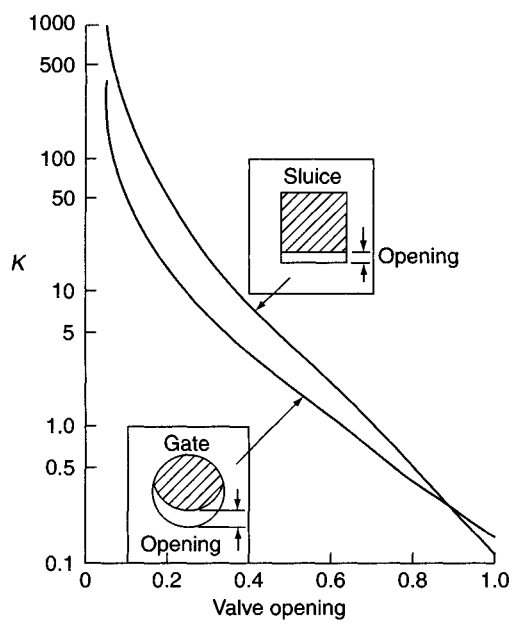


Figure 20.32 Gate valve losses[6]

Thus for a simple line 100 m long with a bend ($L_E = 30$) a valve ($L_E = 13$) the total loss $= (fv^2/D^2)(143)$.

20.4.3 Presentation of system loss

The flow loss in a system varies as (velocity)^2 or (flow rate)^2, so the total loss imposed by a system on a pump can be shown to vary with flow rate in the way shown in Figure 20.38(a). Figures 20.38(b) and 20.38(c) illustrate how system curves vary with the proportions of static and dynamic losses. Figure 20.38(d) illustrates a common tanker loading/unloading system with no static lift, and Figure 20.38(e) shows the less common site where a hill allows the use of gravity to assist flow.

20.5 Interaction of pump and system

20.5.1 Steady-state matching of pump and system

If the constant speed characteristic of a pump is superimposed on a system curve there is usually one intersection point, shown in Figure 20.39. If a flat system curve is being matched with a mixed or axial flow machine there can be flow instability, as illustrated in Figure 20.40, which is only corrected by changing pump speed or the static lift, or selecting a different pump.

20.5.2 Flow control

The simplest flow control is by valving (Figure 20.41). The dynamic loss is changed by either opening or closing a valve in the line. The valve could be pressure controlled. A method much used in boiler feed systems because it ensures full flow through the pump and thus reduces risk of vapour locking in the bypass (Figure 20.42). In this case the pump supplies the system and bypass flow, so match point flow is higher than system demand and power demand is higher. A third control, commonly used for PD machines (and increasingly for centrifugals as prices reduce), is speed control (Figure 20.43). If Figure 20.44 is considered, achieving 90% of designed flow by speed control will happen with little sacrifice in efficiency (and probably 25% power reduction), valve control will result in a 3–4% reduction in pump efficiency (and probably 7–8% increase in pump head), bypass will probably require 15% more flow, the pump efficiency will drop 7% or 8%, and the pump may also cavitate.

20.5.3 Multiple-pump layouts

If the flow range in a system is larger than can be achieved with a single machine, several similar pumps may be installed in parallel. Figure 20.45 illustrates possible layouts for centrifugal pumps and match points on a system curve for one, two or three pumps operating. Non-return valves must be installed as shown to avoid pump interaction. Note that three pumps do not give three times

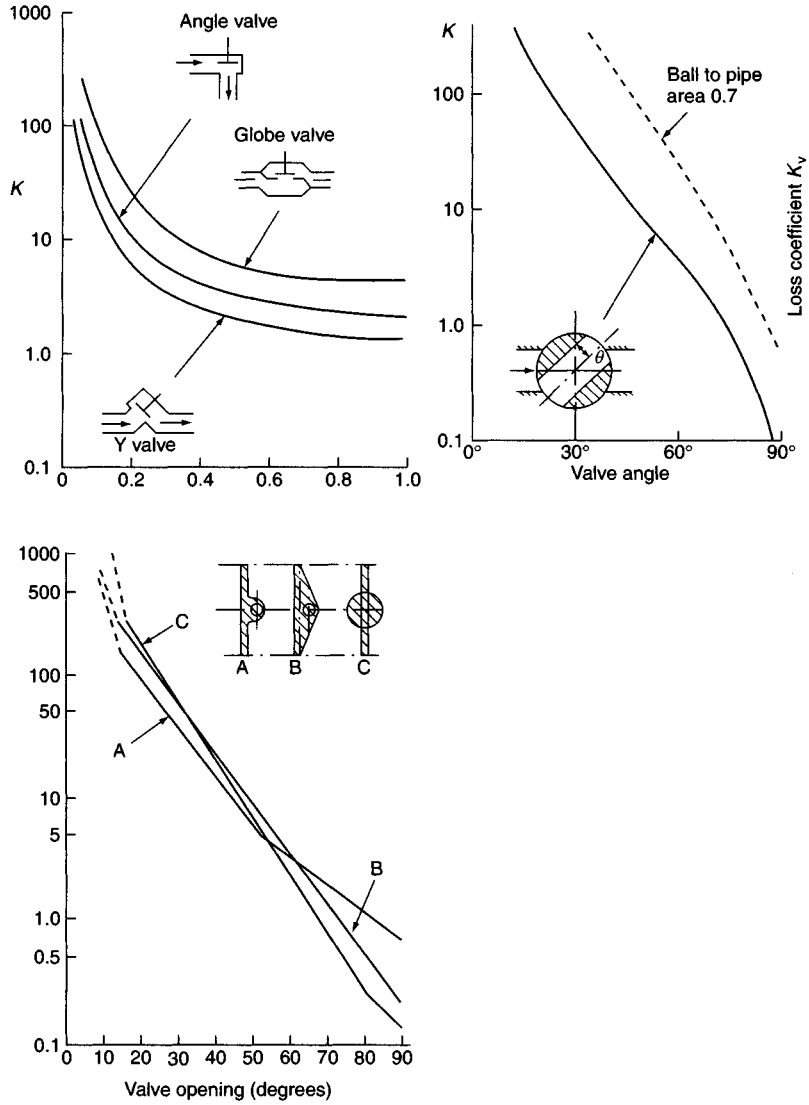


Figure 20.33 Some typical valve loss characteristics[6]

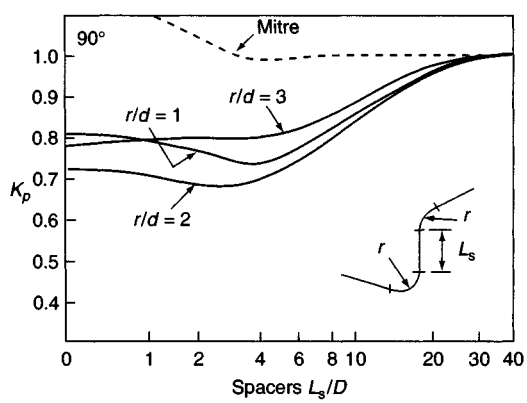


Figure 20.34 Interaction coefficient: combination bends (after Miller[6])

single-pump flow, due to the square law nature of the system curve. Figure 20.46 demonstrates how variable-speed drives will give a wide range of flows. Systems supplied by positive displacement pumps do not usually need wide flow ranges, but the same principle of parallel operation will apply.

Dissimilar pumps may be used. As Figure 20.47 shows, the resulting combined curve indicates that pump 2 will not begin to deliver until the specific energy from pump 1 drops below its shut-valve energy rise, therefore if the non-return valve for pump 2 does not seat, pump 1 can cause it to turbine.

20.5.4 Suction systems

Poor intake layout can give rise to pump problems, unstable running, losing prime, and cavitation. If the pump

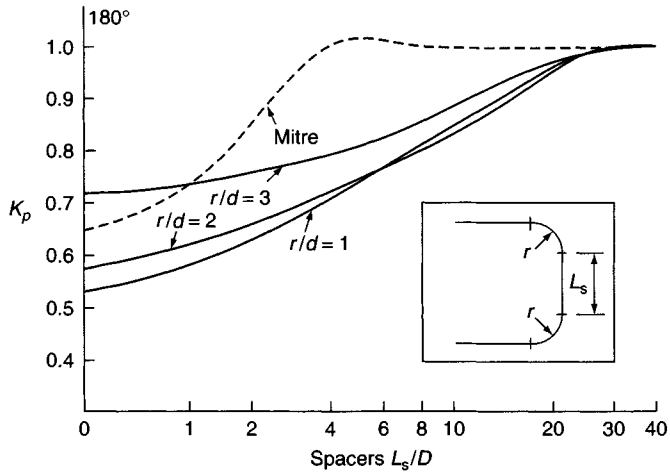


Figure 20.35 Interaction coefficient: 180° combination (after Miller[6])

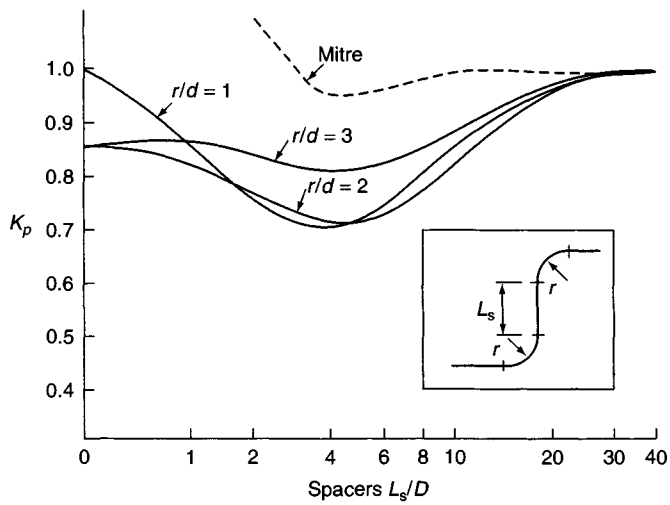


Figure 20.36 Interaction coefficient: S-bend combination (after Miller[6])

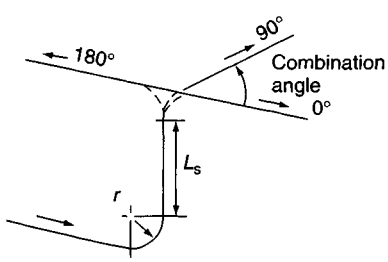


Figure 20.37 The combinations shown in Figures 20.33–20.36

is drawing water from a sump the position of the intake and the shape of the sump must be chosen to avoid vortex formation and resultant air ingestion and pump instability. Figure 20.48 shows the proportions for PD and centrifugal pump suctions and Figure 20.49 gives details of baffles that can be fitted in tanks to reduce vortexing. If large flow

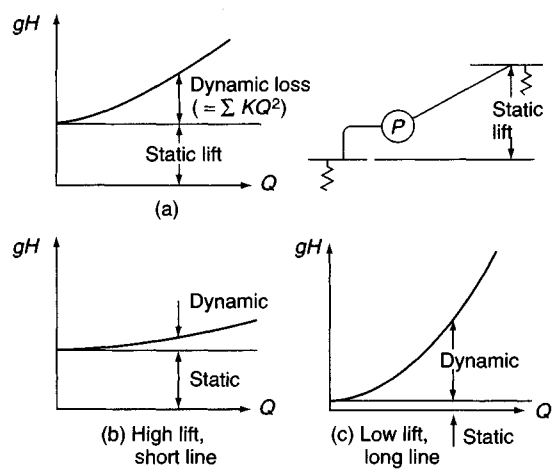


Figure 20.38(a,b,c) System loss characteristics

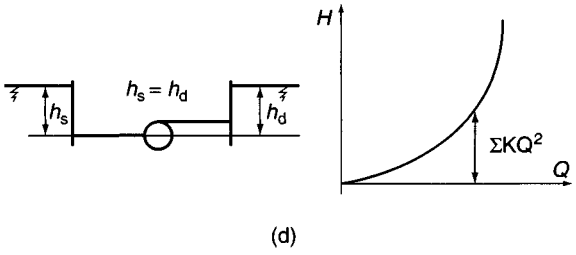


Figure 20.38(d) A zero lift system

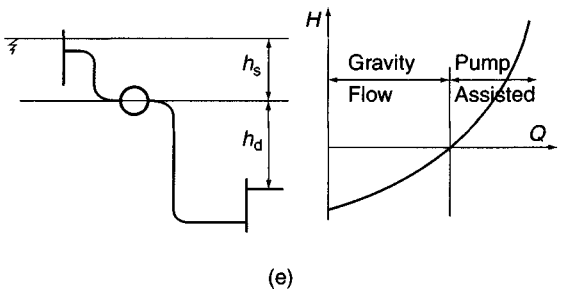


Figure 20.38(e) A Gravity assisted system

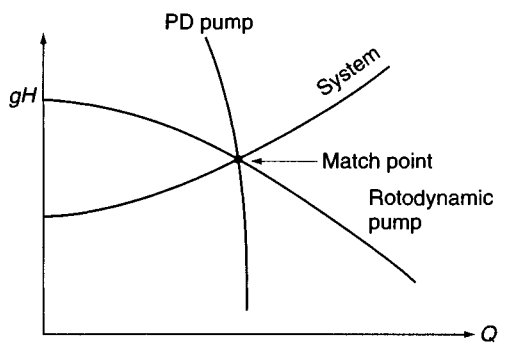


Figure 20.39 Matching constant-speed pumps to a system

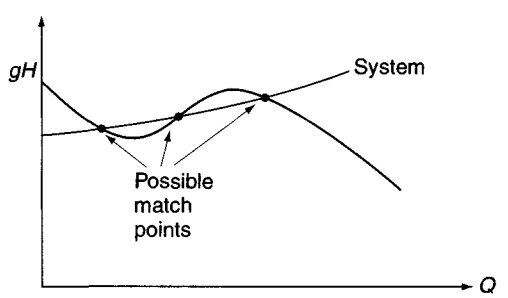


Figure 20.40 Combination of a flat system curve and an inflected pump curve

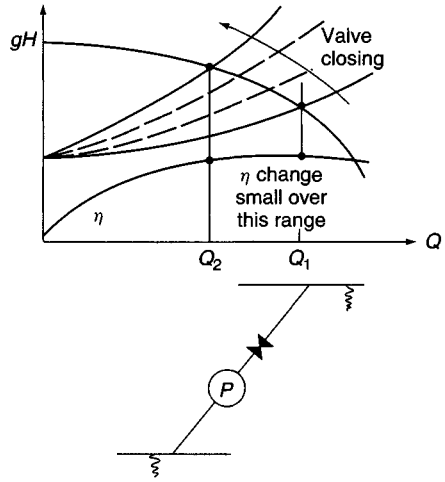


Figure 20.41 Valve control

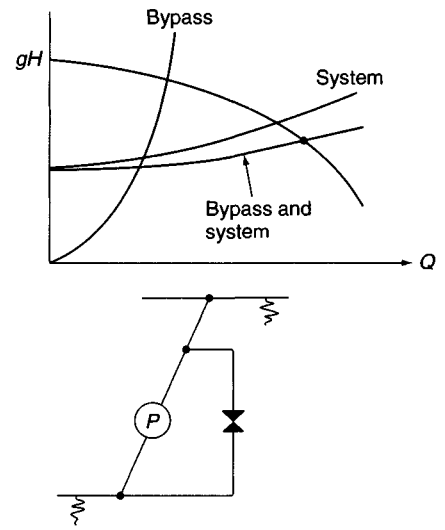


Figure 20.42 Bypass control

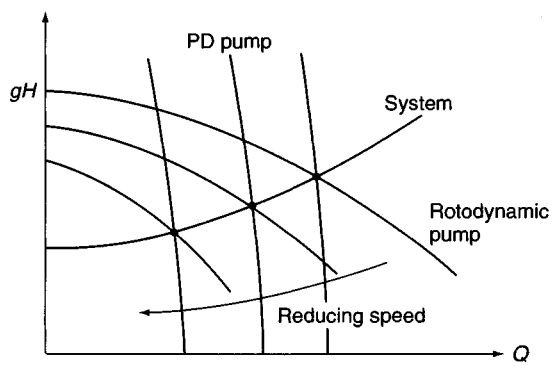


Figure 20.43 Speed control

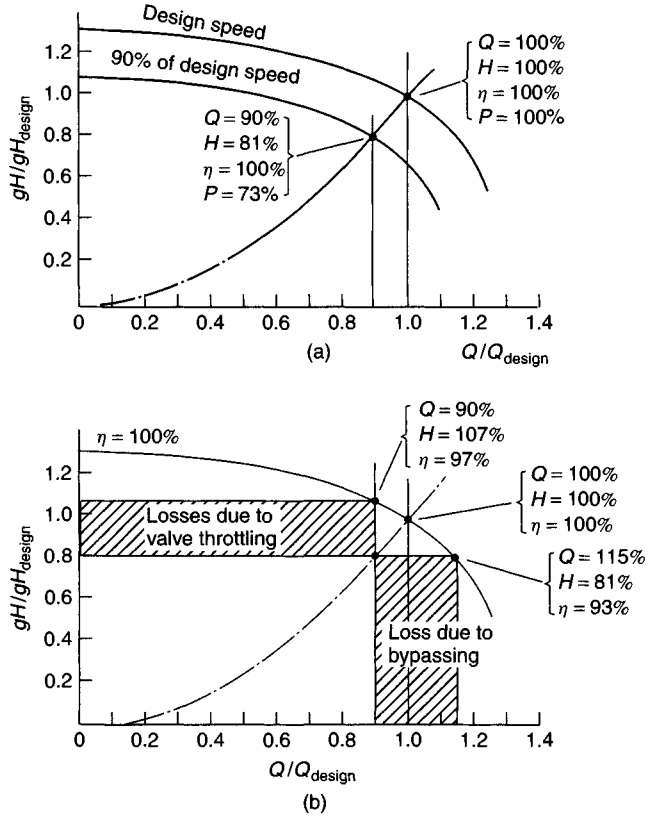


Figure 20.44 Comparison of speed, bypass and discharge regulation. (a) Speed control: (b) bypass or throttle

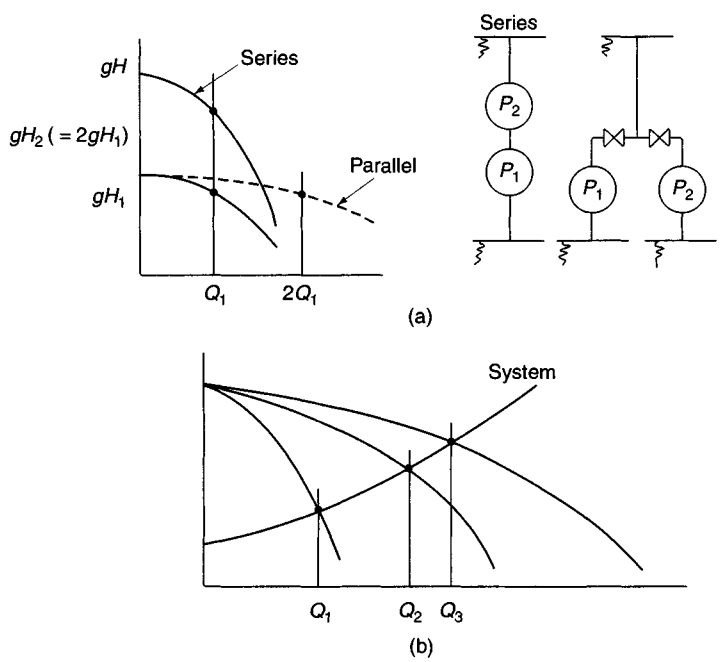


Figure 20.45 (a) Pumps in series and parallel; (b) three identical pumps running in parallel

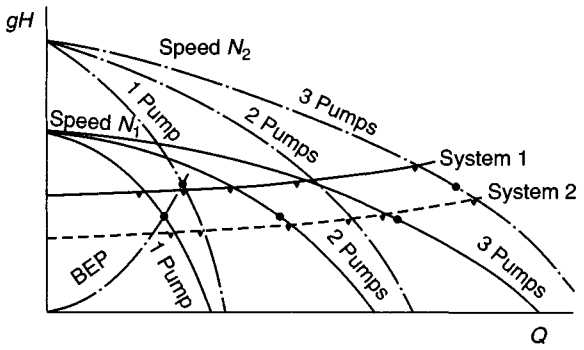


Figure 20.46 Variable-speed pumps in parallel

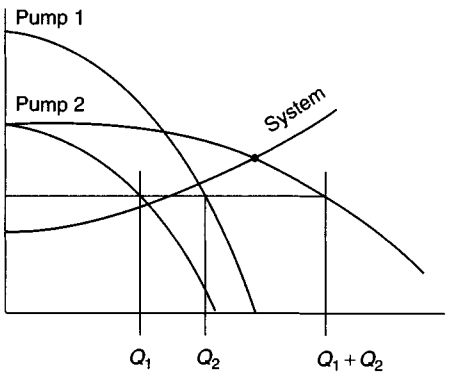


Figure 20.47 Dissimilar pumps in parallel

rates and numbers of pumps are involved it is advisable to commission model tests to ensure that pump behaviour is not affected for all flow rates and pump combinations.

20.6 Cavitation

Cavitation is the term used to describe the formation of bubbles in liquid flow when the local pressure falls to around vapour pressure. Two effects are experienced in the pump: a reduction in flow rate (accompanied, particularly in centrifugal pumps, by additional noise) and in surface damage and material removal. In general, cavitation occurs in the suction region of a pump or the inlet port and valve area of a positive displacement pump. Figure 20.50 shows how reduction of suction pressure (which gives rise to cavitation) affects the characteristic of a typical centrifugal pump.

20.6.1 Net positive suction head (NPSH)

When drawing liquid through a suction a pump generates a low pressure in the suction area, which, if it reaches vapour pressure, gives rise to gas coming out of solution and causing bubbles to form. An estimate of the margin above vapour pressure, used for many years, is Net Positive Suction Head. Two forms are used: NPSHavailable and NPSHrequired.

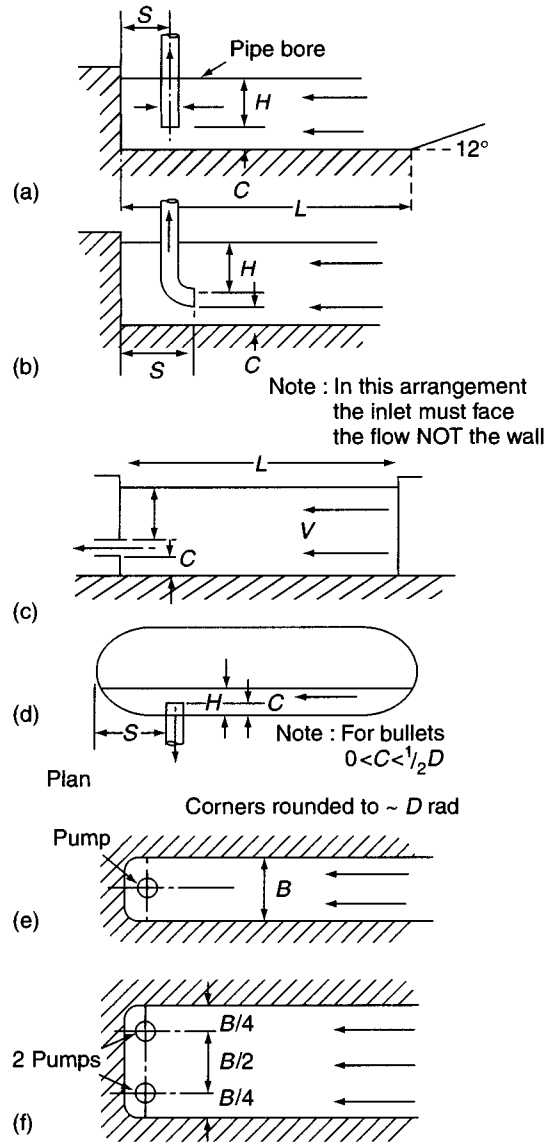


Figure 20.48 Suction bay and tank proportions (based on reference 7). Possible suction arrangements: (a)–(c) open suction layouts commonly used; (d) tank intake system (recommended limits: $3 > (S/D) > 1$; $2/3 > (C/D) > 1/2$; $(H/D) > [(V^2/3) + 1.5]$; $[(L - S)/D] > 5$); (e) single-suction cell in plan ($5 > (B/D) > 2$); (f) double-suction cell in plan ($4 < (B/D) < 10$)

NPSHavailable ($NPSH_A$)

$NPSH_A$ = Total head at suction flange − vapour pressure head

Figure 20.51 illustrates how system NPSH or NPSH-available is calculated for the usual suction systems outlined. For a centrifugal pump, the basic NPSH is calculated from[7]

$$NPSH_A = h_s - h_f \frac{10.2}{\rho}\left(\frac{B}{1000} + P_i - P_v\right) \qquad (20.16)$$

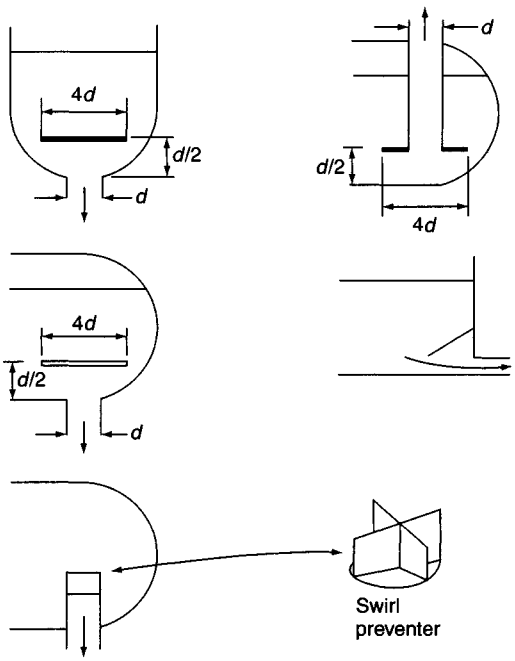


Figure 20.49 Vortex-prevention devices for tanks

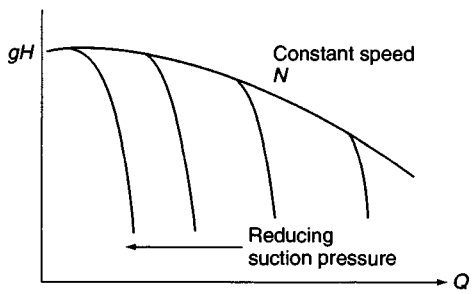


Figure 20.50 Effect of suction pressure on pump performance

where

h_f = flow losses in suction system (m),
B = minimum barometric pressure (mbar) (use 0.94 of mean barometer reading),
P_i = minimum pressure on free surface (bar gauge),
P_v = vapour pressure at maximum working temperature (bar absolute).

In the process industries h_f is calculated for the maximum flow rate and the NPSH at normal flow allowed for by using the formula

$$\text{NPSH}_A = 0.8(\text{NPSH}_{basic}) - 1) \tag{20.17}$$

This gives a 'target' value to the pump supplier that is 'worst' condition. In general, for cold water duties equation (20.16) can be used for the duty flow required. Equation (20.16) is employed for reciprocating and rotary positive displacement machines with allowance made for acceleration effects.

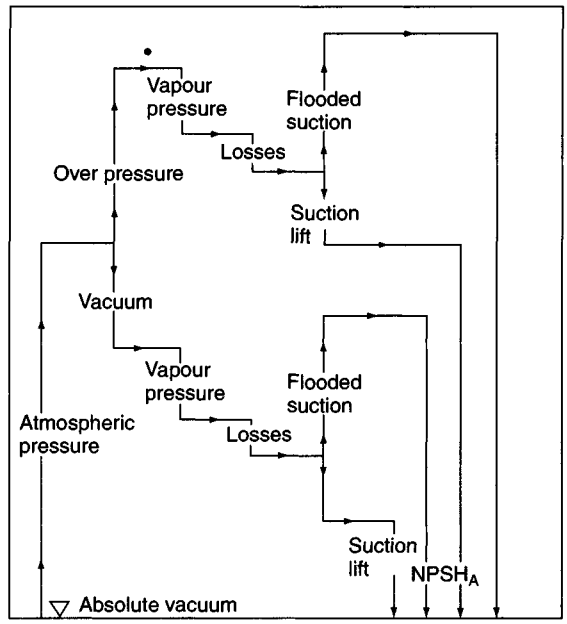


Figure 20.51 Visualization of NPSH$_A$ (with acknowledgements to Girdlestone Ltd)

In reciprocators h_f is calculated at peak instantaneous flow, including maximum loss through a dirty filter, and an additional head 'loss' to allow for pulsation acceleration is used:

$$h_A = \frac{700\,N\,Q}{Z}\sum\frac{L}{d^2} \tag{20.18}$$

and

$$\text{NPSH} = \text{NPSH}_A - h_A \tag{20.19}$$

For *metering pumps*:

$$\text{NPSH}_{basic} = h_s + \frac{10.2}{\rho}\left(\frac{B}{1000} + P_i - P_v\right) \tag{20.20}$$

h_f is as for the reciprocating pump based on peak instantaneous flow and

$$h_A = \frac{6\delta P_i}{\rho} \tag{20.21}$$

δP_i = pressure pulsation at pump inlet (bar)
$= K_1 \rho C Q/D^2$

where

K_1 = 40 for simplex, 20 for duplex, 3 for triplex, 1 for quintuplex,
C = velocity of sound in liquid ms^{-1} (for water at normal temperature $C = 1000\,\text{ms}^{-1}$)

$$\text{NPSH}_A = \text{basic NPSH} - (h_f^2 + h_A^2)^{1/2} - 1 \tag{20.22}$$

for simplex and duplex pumps and

$$\text{NPSH}_A = \text{basic NPSH} - (h_f + h_A) - 1 \tag{20.23}$$

for triplex and quintuplex pumps.

For *rotary pumps*:

$$h_A = \frac{\delta P}{\rho} \tag{20.24}$$

where

δP = pressure pulsation at pump inlet bar
$= K_{2\rho} C Q / D^2$,
K_2 = 2 for three-lobe pumps
5 for two-lobe pumps,
5 for a monopump,
1 for a spur-gear pump,
5 for a vane pump,
10 for a peristatic roller-type pump,
0 for a screw pump.

NPSHrequired (NPSH$_R$)

This is a statement of the NPSH that the pump can sustain by its own operation, so that the operating requirement is that $NPSH_R < NPSH_A$. $NPSH_R$ is more difficult than $NPSH_A$ to determine. Reference 7 suggests working relations for positive displacement machines which are outlined below.

For reciprocating metering pumps, $NPSH_R$ is related to valve loading, as shown in Figure 20.52:

$$A = \frac{24 v Q \rho}{Z d_v^3} + 5 \times 10^5 \frac{\rho Q^2}{Z^2 d_v^4} \tag{20.25}$$

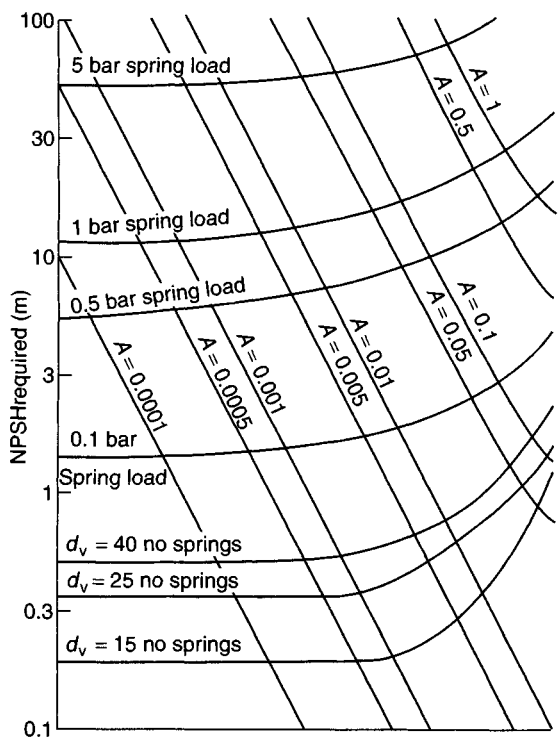


Figure 20.52 NPSH required for a reciprocating metering pump[7]

(where d_v = nominal valve size (mm)) for single valves, and

$$A = \frac{80 v Q \rho}{Z d_v^3} + 1.5 \times 10^5 \frac{\rho Q^2}{Z^2 d_v^4} \tag{20.26}$$

for double valves. It is recommended that for hydraulically operated diaphragm pumps the extra losses imposed by the diaphragm and support plate are treated as a single unloaded valve.

For other reciprocators

$$NPSH_R = 5U^2 + \frac{0.12(P_d)^{0.75}}{\rho} \tag{20.27}$$

where

U = mean plunger speed (ms^{-1}),
P_d = discharge pressure bar (dbs).

For the centrifugal pump two terms are in common use, the Thoma cavitation number σ and the suction specific speed S_N:

$$\sigma = \frac{NPSH_R}{\text{Pump head rize}} \tag{20.28}$$

Figure 20.53 gives a typical plot of σ against k_s that may be used as a first 'design' estimate of $NPSH_R$, but in many applications test data are required:

$$S_N = \frac{N\sqrt{Q}}{K(NPSH_R)^{3/4}} \tag{20.29}$$

where K is a constant = 175 if $g = 9.81$ ms^{-2}, Q is in l/s, N is in revolutions/second and $NPSH_R$ is metres of liquid. An older form of S_N using USGPM, feet and rpm is

$$S_N = \{N\sqrt{Q}\}/(NPSH_R)^{0.75} \tag{20.30}$$

An acceptable design value for this for a centrifugal pump is 9000. $NPSH_R$ here is usually based on a 3% head drop, defined in Figure 20.54, for the pump tested with cold water at design flow rate and rotational speed.

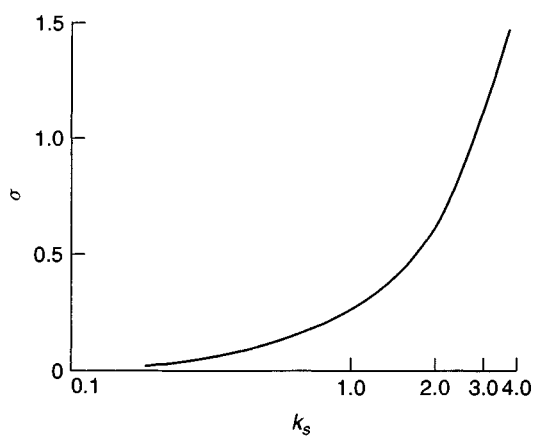


Figure 20.53 Variation of Thoma's cavitation parameter with specific speed for pumps[3]

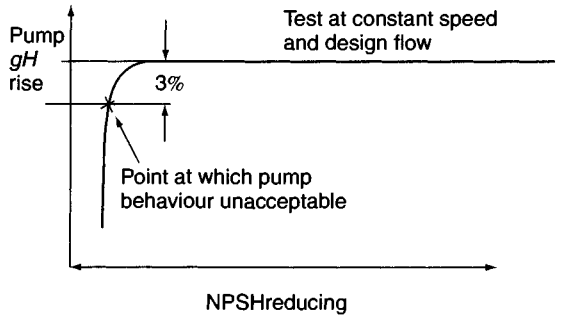


Figure 20.54

20.7 Priming systems

If the suction level is above the pump there is usually no problem in 'priming' (that is, ensuring that the pump suction system is full of liquid) unless it is pumping a volatile and vapour locks when stationary. In many applications the pump is above the suction vessel or main, and the static pressure at the take-off point is too low to provide the static lift required. In these cases centrifugal and positive displacement pump suction lines are often provided with non-return valves so that, once filled they do not lose liquid on shutdown. If their operation is intermittent, a priming tank or 'jerry' is provided (Figure 20.55) to allow priming to take place. This is only possible with small machines because of the sizes needed. It is general practice that no pump should be started or run dry to avoid metal-to-metal contact and seizure. The only exceptions to this are pumps designed to provide priming – 'self-priming' machines, used in installations where the suction line empties, as in tanker-unloading bays or site-dewatering applications.

Positive displacement pumps are self-priming by their normal operating action and are designed to cope with running dry. Centrifugal pumps are not inherently self-priming, and need to be provided with assistance in the form of ejectors, as in Figure 20.56 or dry vacuum pump systems, where a dry vacuum pump allows air to be drawn out and where an automatic valve prevents liquid entering the pump, or wet vacuum pumps, such as the liquid ring pump (Figures 20.57 and 20.58), may be used to extract the air. Such devices are common on portable fire pumps, the liquid ring pump being driven from the pump main driver in such a way as to allow disconnection when the pump is fully priming, thus avoiding extra power loss during normal operation.

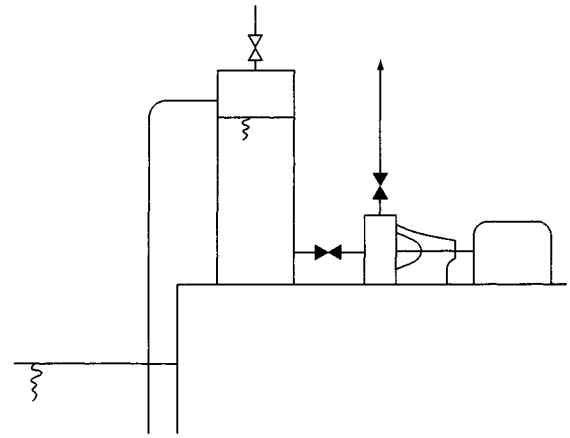


Figure 20.55 Priming tank arrangement

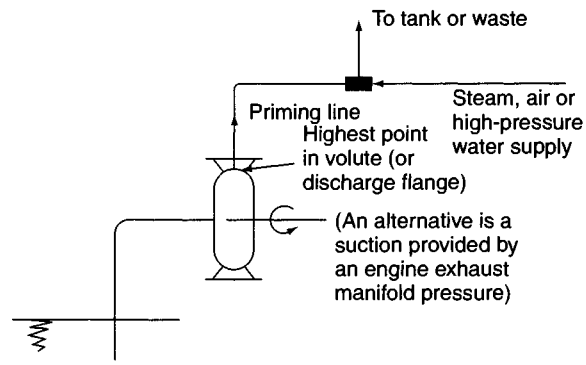


Figure 20.56 An ejector priming system

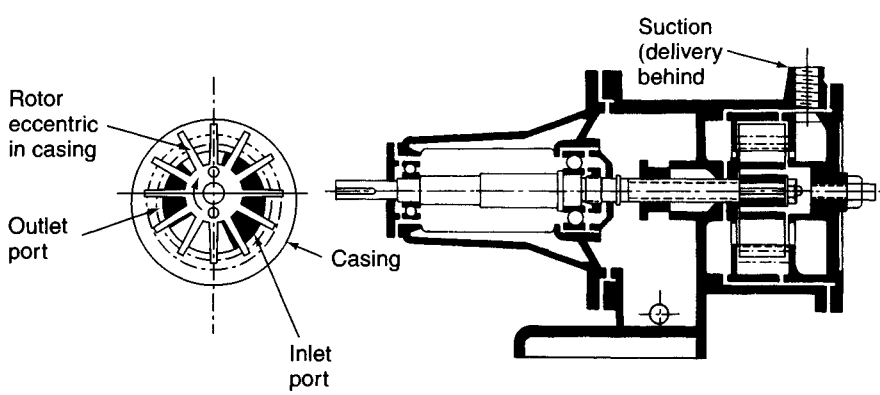


Figure 20.57 Schematic of a liquid ring pump

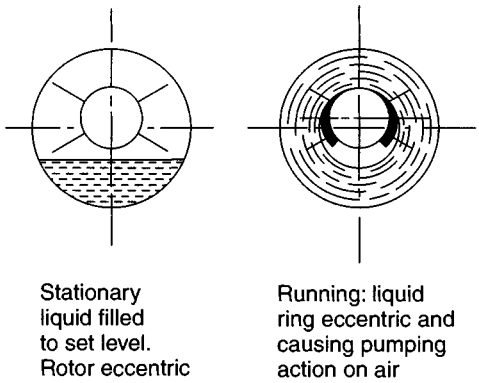


Figure 20.58 Principle of liquid ring pump

Self-priming centrifugal pumps do not rely on any assisting system, but are provided with a special casing system that allows liquid retained in the pump on shutdown to recirculate to draw air from the suction line until that is full of liquid and the pump is primed. There are several designs which will pull suction lifts up to 7 m with cold water. All the designs impose a penalty of lower efficiency when in the normal pumping mode, but are effective alternative solutions to an auxiliary priming system which do not require additional equipment as bolt-on extras requiring maintenance.

One class of self-priming pumps which are rotodynamic but not centrifugal in operation is the side-channel or peripheral pump (Figure 20.59). The circulating motion results in a transfer of energy from the liquid leaving the rotor to the stator, and as the fluid proceeds to 'corkscrew' round the periphery from suction to discharge, energy builds up so that it is claimed that the pressure rise is 2.5 times that produced by a conventional centrifugal pump with the same peripheral velocity, although efficiency is much lower (up to 50%).

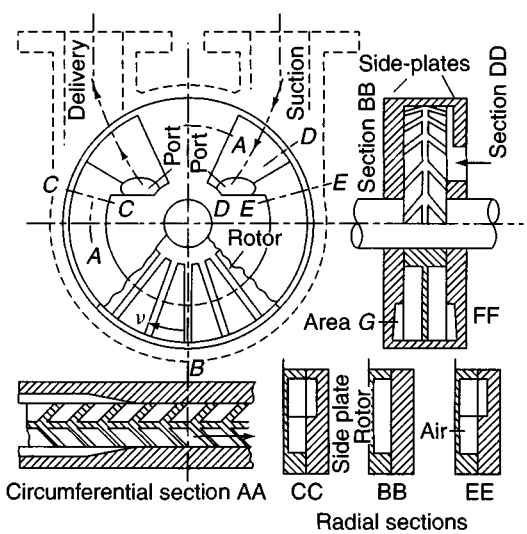


Figure 20.59 Peripheral pump layout and operating principle (after Addison[1])

20.8 Seals: selection and care

Static seals are standard provision from many suppliers, therefore seals for the moving elements in pumps will be discussed. For centrifugal pumps both stuffing box and mechanical seals will be considered and the discussion will be extended to reciprocating and rotary machines.

20.8.1 Centrifugal pump and rotary pump seal systems

The stuffing box, or packed gland, has been used for many years, typical layouts being shown in Figure 20.60. Usually, since a very smooth shaft surface is needed a sleeve of hard bronze or chrome plated is used for water services finished to 0.8 μm. For normal duties soft packings are selected to deal with both seal surface speed and temperature. Figures 20.61 and 20.62 give typical materials and their capacities, and manufacturers' data sheets should be consulted when selecting the number of rings and the compression needed. When properly adjusted and 'run in', the leakage rate on a cold water duty could be about 1 l/day, which may be lost as vapour. Overtightening the packings can give rise to overheating and shaft failure or seizure. Typically, a four-ring gland will seal 3.5 to 4 bar, and absorb about 0.15 kW when run in and fitted to a 50 mm shaft.

The mechanical seal is now a standard fitting of high reliability and tends to be fitted instead of a packed gland. A typical mechanical seal is shown in Figure 20.63. The conventional design has a spring, rotating with the shaft, which holds a rotating seal ring against a stationary ring to provide a sealing interface. Stationary fluid seals are provided as shown. For water and general non-corrosive duties the design is internal, so that the liquid being sealed both cools and provides a supply for the film which separates the rotating and static seal rings. Simple seals are designed to be 'balanced' or 'unbalanced'. Referring to Figure 20.64, it can be seen that a balanced seal will give a lower closing hydraulic force and thus lower contact pressure, therefore a higher sealed pressure can be sustained. Too little load, and the seal will leak, and too large will reduce life. An unbalanced seal gives a simpler shaft or sleeve design, and will seal up to 10 bar gauge, and above this, balanced seals are required. Materials often used for standard water duties are carbon for the face and ceramic and, if condensate, carbon with a nickel–iron static seat could be fitted. The seal manufacturer will quote the appropriate materials, and will usually suggest circulation as shown in Figure 20.63. The mating

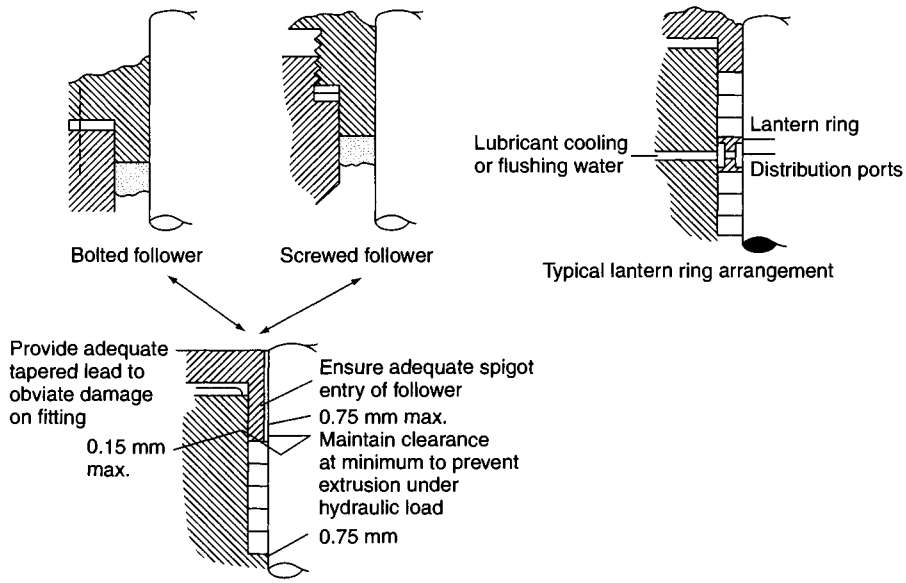


Figure 20.60 Stuffing box details

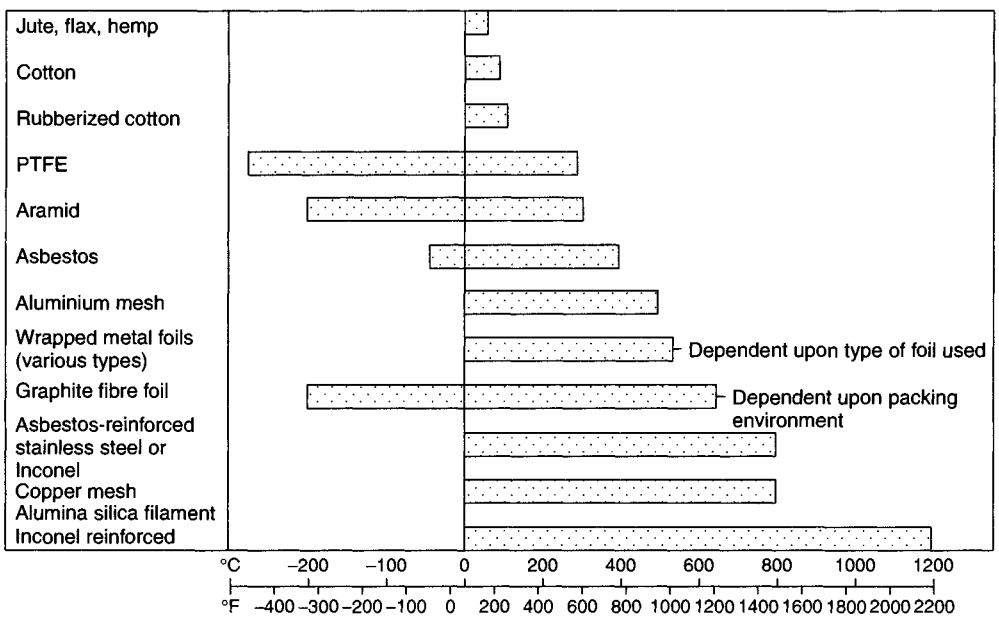


Figure 20.61 Soft packings – temperature range

sealing surfaces are lapped to within 0.5 μm, shaft run-out should not exceed 0.125 mm, and shaft finish where the seal ring has to pass should be 0.4 μm to avoid damage.

If a mechanical seal or a packed gland is fitted properly a good life can be expected if the liquid is clean. If grit is in suspension the seal manufacturer should be consulted about appropriate materials and system design.

20.8.2 Reciprocating pump seal systems

The comments on packed glands apply for shaft and rod seals. Piston-to-cylinder seals may be arranged like the packed gland, but are provided with end rings which locate and prevent the sealing rings from extrusion. Surface finishes for rod or piston will be the same as those given above with leakage rates of the same order.

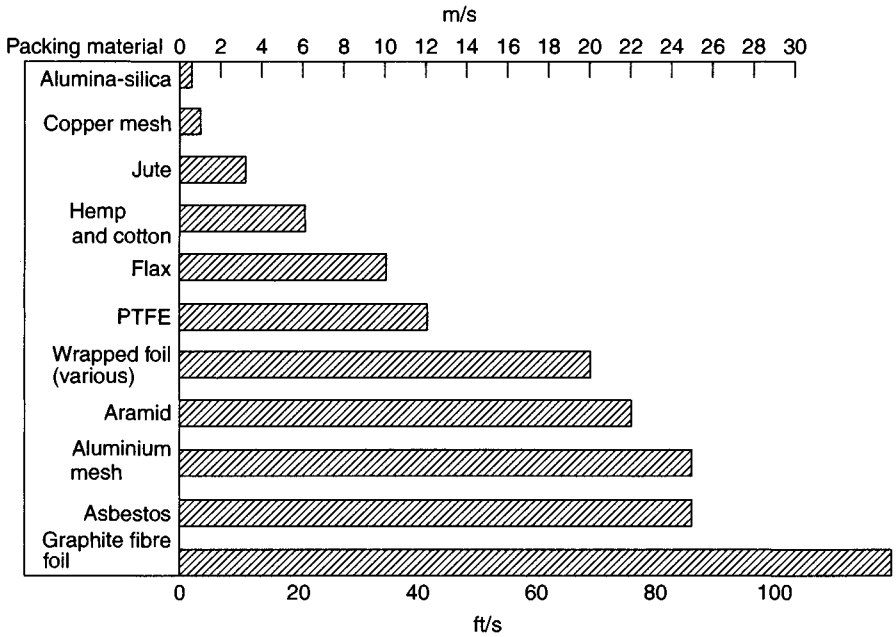


Figure 20.62 Soft packings – speed range

20.9 Pump and drive selection

20.9.1 Pump selection

Since pumps are the essential element in a flow system, the selection of the correct machine is crucial to the success of a plant. It must be constructed from the appropriate materials, run at the right speed, be compatible hydraulically with the system at all flows, economical in first cost and in operation, and 'user-friendly'. To place the process of pump selection in the plant decision tree it is necessary to follow the iterative way a complete plant evolves.

From the initial statement of need a preliminary design brief evolves containing flow rates and attendant component pressures and temperatures. From this an initial design layout is produced, the pressure losses and probable inlet and outlet pressures and attendant flows for all pumps needed estimated, and a first assessment of possible pumps made. Considerations of cavitation (and perhaps a need to rationalize on pump designs) lead to a second look at the systems. A revision of flow schedules, pressures and temperatures results, and, by iteration, a 'final' design layout appears from which pump and equipment specifications begin to be formulated and initial enquiries are made to suppliers. Pump manufacturers will check possibilities and tender if their pumps will give the duties specified or, if invited tendering is used, will propose changes to suit their pumps.

In the consultant's design office the selection of pumps (and hence of makers) to tender must be done at the project design stage, and considerations of cost, complexity and suitability will influence the choices made. An important consideration at this stage is that the design point specified is the corrected one. A common practice is the 'add a bit for ageing, add a bit for the unknowns' at the early design stage and then the next engineer in the process also 'adds a bit' since they may be on the low side, and thus a margin of flow is added. This process can sometimes ensure that the pump size is such that, even though the design point is that quoted, the pump will be running at low flow when the system is commissioned, and this may be in a region of instability, giving running problems on the plant. It cannot be too much emphasized

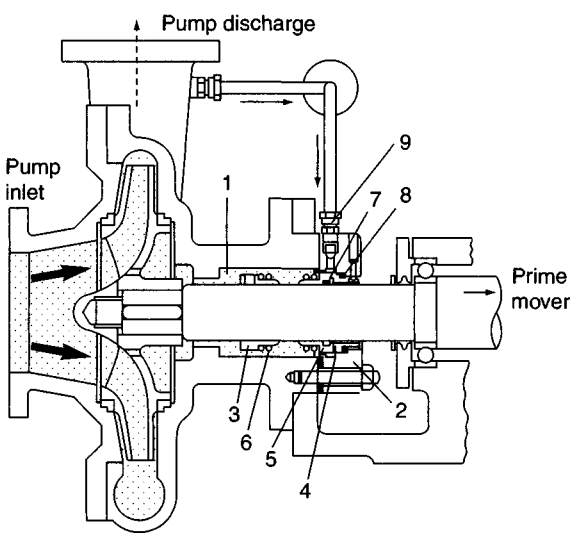


Figure 20.63 A typical mechanical seal installation. 1 Seal chamber; 2 seal plate; 3 spring sleeve; 4 seat; 5 seal ring; 6 spring; 7 dynamic secondary seal; 8 static secondary seal; 9 flush connection

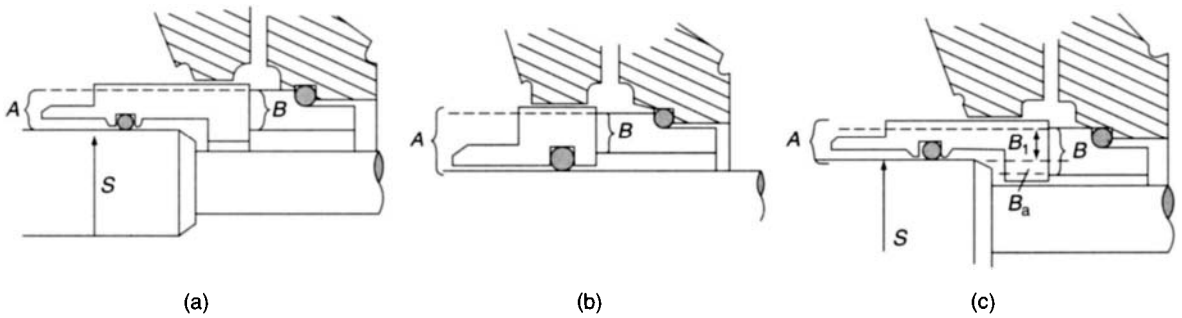


Figure 20.64 Seal balance arrangements. S = Sliding diameter or effective sealing diameter; A = hydraulic piston area of sliding ring; B = face contact area. (a) All area B is outside effective sealing diameter and areas A and B are equal. Average face contact pressure equals product pressure, i.e. seal is 100% out of balance. (b) Unbalanced seal. All area B is outside effective sealing diameter and area A is greater than area B. Average face contact pressure is greater than product pressure, i.e. seal is more than 100% out of balance, depending on the relative area ratios. This condition exists in most unbalanced seals. (c) Balanced seal. Here part of the face contact area, B_1, is outside. The sliding diameter S carries the product pressure acting on area A. The face contact area, however, equals $B_1 + B_2$, and so the unit face loading will be less than product pressure, in accordance with the area ratio, i.e.

$$\frac{B}{B_1 + B_2} = \frac{A}{B}$$

$$\text{Balance} = 1 - \frac{A}{B}$$

Generally, 0.2–0.35

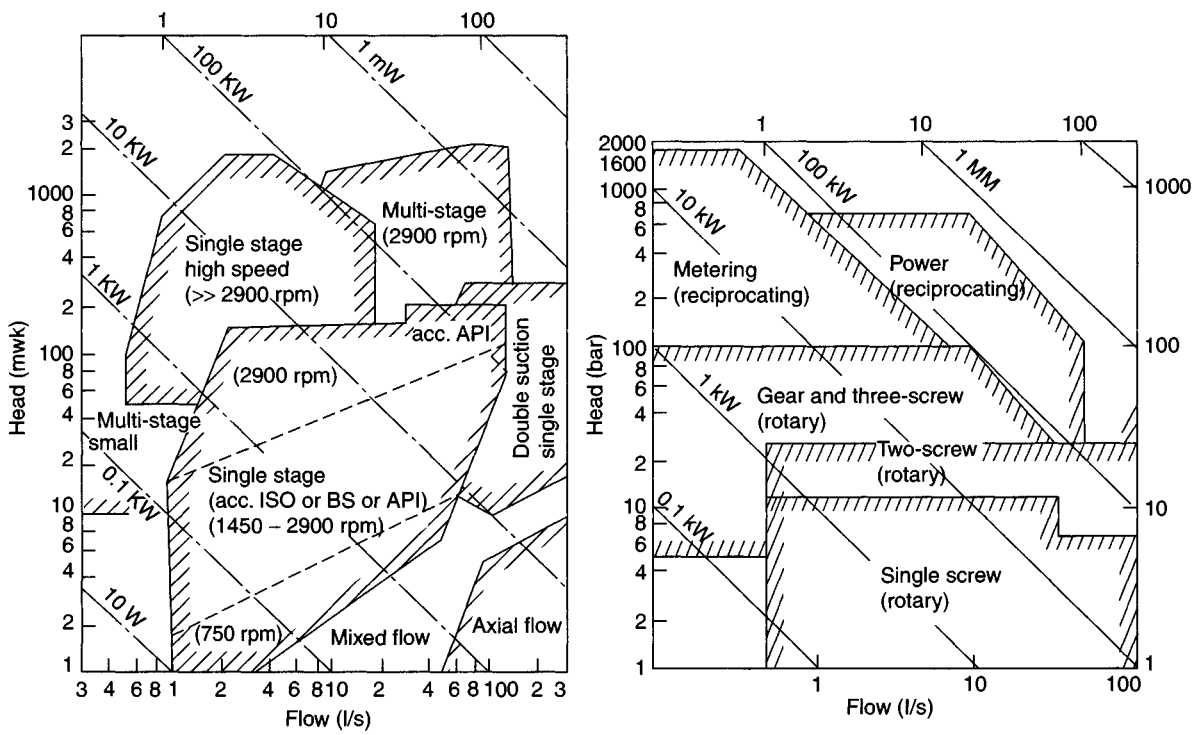


Figure 20.65 Pump range chart (courtesy Nederlandse Aardolie MIJ BV)

that accurate estimation of the duty flow and head will assist pump application and life.

Examination of Figure 20.65 will reveal that in many cases the choice of centrifugal or positive displacement pump is dictated by the head and flow specified. Where, however, the choice may be either type, other considerations must enter the selection process. For example, first cost is an important factor. Sterling[5] has demonstrated

that a screw pump and a centrifugal would give the same duty, that the screw pump would have an $NPSH_R$ less than the centrifugal, have a lower fall-off in efficiency as fluid viscosity increased, but would cost twice more than the centrifugal and be more expensive to maintain. He concluded by stating the centrifugal as being the most preferred for price and maintenance in 80% of pumping duties.

A probable selection procedure could take the following form:

If possible, a standard centrifugal pump shall be selected, but the effect of high viscosity must be considered (see Table. 20.2). If flow is low remember the efficiency fall-off, and look at alternative designs. If flow rate is important, metering pumps should be preferred, as centrifugal pumps will not give accuracy. If solids are in suspension consider working clearances, need to avoid blockage and the flushing for seals.

A drive speed of 2900 rpm is preferred to give higher efficiency and smaller size and first cost (but remember noise risks). Appropriate codes (API 610, for example) should be observed.

If a centrifugal is not suitable, select a rotary positive displacement pump. The design usually selects itself, but for flow rates in the centrifugal pump range, screw pumps, monopumps and wide-tooth gear pumps may be considered. Remember that if particles are present the screw pump will lose volumetric efficiency, and the mono type of machine should be selected.

If the duty is metering, piston or diaphragm pumps should be selected.

When looking at manufacturer's data sheets a selection like that shown in Figure 20.66 is often given to assist in choosing the frame size of the machine. A set for all the common driving speeds for 50Hz and 60Hz supply is usually supplied. In the figure the frame size [125–100 – 315] gives the suction size: delivery size: nominal impeller diameter, and the prominent dot on each 'fishscale' indicates the best efficiency operating point for that frame size, and the right hand cut off line gives the limiting flow at each head rise for reliable cavitation damage free operation.

20.9.2 Drive selection

For most centrifugal pumps the drive will be a synchronous motor, running at 2900 rpm for 50 Hz supply to minimize pump size and cost. Large boiler feed pumps use steam turbines which give economic output regulation since steam is available. In most plant variable-speed drives may be used to give economic flow control. A wide range of possibilities are available (Table 20.5). Bower[8] writing from the viewpoint of a pump designer, has given some comparative costs. He commented that a 10 kW drive pump running for 10 h per day will cost more than the first cost of the unit in a year. He showed that if a 75 kW pump running at 2900 rpm is to run at half flow, a variable-speed drive giving 1450 rpm will use 39 kW if supplying a low static lift system, where flow losses are important. There is thus an economic argument for a higher first-cost pump plus drive if such savings are possible.

20.9.3 The economics of pump selection and running maintenance

With the operating economics of pump-supplied system such as the water industry networks receiving attention, it is of interest to note that recent work[9] makes two points: pump performance does fall off with time and there should be consideration of the economics of refurbishment as part of system pricing. Cullen reported a WRc study of basing figures on 50% utilization and a 3p per kilowatt hour tariff. One case involving 12 pumps, capital value £120 000, with an efficiency fall-off of 5–9%, could be refurbished for about £48 000 to give 5% efficiency uplift and show an electricity saving of £13 400 per year and a return on investment of 35% per year. A further example covering eight pumpsets, capital value £80 000 with a serious efficiency fall-off of 15–19%, could be refurbished at cost of £112 000 to give an uplift of 15%, resulting in a £31 200 per year saving and an annual investment of 25%. These examples and others emphasize that traditional oversizing is expensive in running cost, that pump mismatch should be avoided and that pump replacement or refurbishment can be economic in large installations.

20.9.4 Reliability considerations

As a further consideration of the overall system design it is necessary to examine the choice of the number of pumps installed. In the petrochemical and process industries availability is an important factor in plant operation. The Institution of Mechanical Engineers suggests several classes of pumps linked to availability:[7]

1. A Class 1 installation achieves high availability using a single pump upon which the system is completely dependent is in a single process stream where pump outage means a large loss of output. The process here demands that continuous operation is possible for at least three years without enforced halts for inspection or correction and where components must have a life expectancy of more than 100 000 h.
2. A Class 2 system is as Class 1 but, with process recovery short after shutdown, infrequent pump outage can be tolerated and an interval of about of about 4000 h for continuous operation can be tolerated.
3. If in a Class 1 and 2 installation a deterioration in pump operations can be tolerated or easily corrected by operators it may be categorized as Class 3.
4. A Class 4 installation is different from the first three by having standby pumps that can take over immediately a pump fails. Main pump and the standby need not be identical but should both have life expectancies exceeding 25 000 h.
5. A Class 5 installation follows the Class 4 concept, but is characterized by having pumps operating with identical spares and have one or more pumps operating in plant bays where product storage gives time to

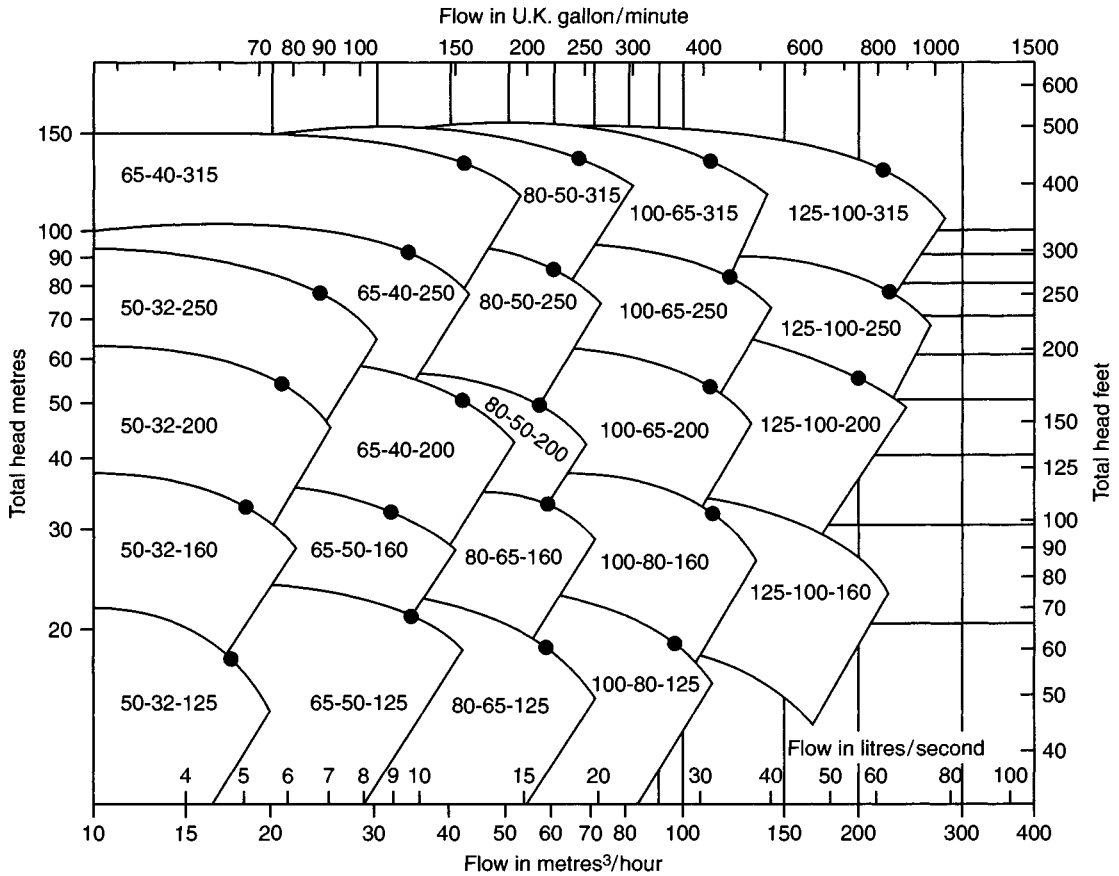


Figure 20.66 Pump Selection chart

assess the problem and to take action to get the pump back on-line.

6. A further Class 6 is suggested for pumps intended for batch or intermittent duty. (If high availability is essential the machine should be placed in Class 4.)

For many process pumps the L10 life is less than 8000 h, so they usually fall in Classes 4, 5, and 6. A typical system uses a running pump rated at 100% duty with an identical spare either installed or carried in store. This consideration affects the total system design if installed spares are to be used as well as the overall cost of the installation.

20.10 Pump testing

Pump tests are needed to establish the performance of a machine before delivery to the user so that contract conditions may be satisfied. They are also required to establish the health of the pump at intervals in its service life. When a new pump is delivered the pump manufacturer will supply data required either as a set of performance points or a plot as a certificate of suitability. Ideally, the pump should be tested in the system configuration that it is intended to supply, but usually tests are performed in the test bay in a standardized manner laid down by national and international codes. When a pump is installed a simple test may be performed to establish a performance point in a similar way to periodic tests to establish how the machine's performance is being affected.

20.10.1 Factory tests

Factory tests establish the pressure head, power, efficiency and NPSH over the complete flow range the pump can deliver running at design speed. The manner of test procedure is laid down by British Standard, DIN standard or ANSI standard codes or national variations from such main codes, and a minimum requirement is quite often defined by industry codes such as API 610. This is not the place to discuss instrument accuracies, as the codes lay down the limits possible from conventional instruments. There are two main classes of test: the commercial requirements normally possible in the maker's test plant and high-accuracy tests that are only possible by using 'substandard' instruments and very sophisticated techniques available from, for example, the National Engineering Laboratory at East Kilbride in Scotland. Such tests are very much more expensive and are only needed in special cases.

Table 20.5 Main characteristics of speed changing drives related to centrifugal pumps[8]

Type of drive	*Power range (kW)*	*Speeds*		*Drive efficiency (%)*		*Overall efficiency (%) including motor*				*Power factor*		*Main characteristics related to pump drives*	
		Max. rpm	*Ratio*	*Maximum speed*	*Half speed*	*Max. speed*		*Half speed*		*Max. speed*	*Half speed*	*Advantages*	*Limitations*
						4 kW	*150 kW*	*4 kW*	*150 kW*				
'V' belts or flat belts	Up to 750	5000 at limited power	8:1	'V' belts 85–90 Flat belts 90–95		70 75	80 85	40 45	65 70	0.9	0.3 with same motor	Low cost possibility if speed changes are infrequent	Increased floor space. Not suitable for outside application. Reduced bearing life if jack shaft not used
Timing belts	Up to 350	6000 at limited power	9:1	95+		80	87	50	75	0.9	0.3 with same motor	Similar to V belts but give reduced shaft loading and greater efficiency	
Gear box	Any	Any, but standard units usually step down		95+		80	87	50	75	0.9	0.3 with same motor	A robust, compact drive for infrequent changes or for matching drive speed to pump requirement. Any power available. Efficient	Correct maintenance importance
Variable-speed pulleys	Up to 125	Up to 4500 but at limited power	4:1 Std	85–90		70	N.A.	40	N.A.	0.9	0.3	Low cost. Housed-belt belt versions available	Limited power range. Automatic control difficult. Limited belt life
Eddy current coupling	Up to 1500	Up to 4200 with belt drive	Above 10:1	96	45–50	80	87	25	35	0.9	0.35	Reliability and life good. Automatic control easy	Low efficiency at reduced speed. Water cooling required for higher powers. Slip-in drive reduces pump maximum speed. Only speed reduction possible
Fluid couplings	15 to 12 000	3500 Std	4:1	95	45–50	80	87	24	35	0.9	0.35	Reliability and life good. Available to very high powers at which they become more cost effective	Low efficiency at reduced speed. Heat exchanger required for higher powers. Slip reduces pump max. speed. Automatic control expensive. Expensive for low powers

Positive infinitely variable chain drives	Up to 120	Up to 5500 but at limited power	10:1	85–90		70	N.A.	45	N.A.	0.9	0.3	Speed increase possible	Limited power range. Careful maintenance essential. Life limitations
Mechanical variators	Up to 75	4200 at 10 kW 2600 at 75 kW	Up to 12:1	85–95	85–85	70	N.A.	40	N.A.	0.9	0.3	Speed increase possible	Limited power range. Limited life. Careful lubrication and maintenance essential
DC motor and thyristor voltage control	Up to 2500	1500 Std 3500 avail. higher-special	Up to 30:1	See overall efficiency		80	90	45	65	0.9	0.3	Good range. Relatively good low speed efficiency. Automatic speed control easy	TEFC Expensive. High speed expensive. Harmonics generation needs consideration. More maintenance induction than motors
Voltage control of induction motor	Up to 50	3000	4:1	See overall efficiency		80	N.A.	25	N.A.	0.9	0.3	Low cost. Can use squirrel cage induction motor. Automatic control easy	Limited power range. Low efficiency at reduced speed. Only speed reduction possible. Requires at least 30% derating of motor
Schrage AC commutator motor	Up to 500	2500	4:1 Std up to 20:1	See overall efficiency		80	90	45	70	0.95	0.5	Good efficiency and power factor. Speed increase possible	Automatic control expensive. Movable brush gear increases maintenance. TEFC expensive
Stator-fed AC commutator motor	Up to 2500	2000	up to 10:1	See overall efficiency		80	90	45	70	0.9	0.4	Improved life over the Scharge motor and increased supply voltages possible. Good efficiency	Automatic control expensive. TEFC expensive
Frequency control of induction motor	Up to 75 Std 2000 special	5000	10:1	See overall efficiency		75	87	40	65	0.95	0.95/0.3	Can use squirrel cage induction motors with minimal derating. Good power factor (with most designs). Speed increase possible	High cost. Electronics more complex (and less reliable?) than other types

20.10.2 Scale-model testing

Scale-model testing is used with very large pumps such as water feed pumps for thermal power stations. The problems posed by such tests in establishing the full-size machine performance are well discussed in a paper contributed by workers studying pumps for the Central Electricity Board.[10] This is a specialized area of work covered by ISO codes of practice, and any engineer wishing to study these must check the current codes.

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21 Cooling towers

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21.1 Background

The use of water as a cooling medium has been long established, but its importance, in an industrial sense, was emphasized with the introduction of steam power. Cooling ponds are still widely used and spray ponds, which incorporate a degree or so of evaporative cooling, can be found, but the increasing requirement for control on water-cooling temperatures heralded the development of the modern cooling tower. The cost of land and the increasing expense of abstracting and of returning water, as well as its availability, ensured that the engineering and design techniques employed were sufficient to satisfy the economic factors imposed by these constraints.

The state of the art in cooling tower design is being constantly improved. Correctly designed, installed and maintained, today's cooling tower still remains the optimum selection in the great majority of cases where heat dissipation is required.

Historically, the first pack designs were random timber, to be followed rapidly by ordered timber splash bars. The concept of filming water as opposed to splash or concrete originated in England in the 1930s. The introduction of plastic packings dates from the 1950s, but this was confined to mechanical-draught towers until the 1970s, when experiments started with plastic packs in natural-draught cooling towers. Asbestos cement in flat sheets, corrugated sheets and flat bars, although widely used in the past, are now out of favour on health grounds in most developed countries. Plastic-impregnated paper is used in certain Eastern countries in air-conditioning towers, but has been unsuccessful in the West. In most cases the changes have been due to economics, but water quality and type of process can significantly affect the selection in individual cases.

Developments over the years have brought about the necessity for very close control over the water quality. This important subject is referred to later, but at this stage, it is important to draw attention to the latest publication from the Health & Safety Executive – the new issue of the L8 – APPROVED CODE OF PRACTICE – (ACOP) which incorporates in Part 2 'Guidance on the control of Legionella in water systems' which replaced the separate HS(G)70 document.

21.2 Theory

Water cooling in towers operates on the evaporative principles, which are a combination of several heat/mass transfer processes. The most important of these is the transfer of liquid into a vapour/air mixture, as, for example, the surface area of a droplet of water. Convective transfer occurs as a result of the difference in temperature between the water and the surrounding air. Both these processes take place at the interface of the water surface and the air. Thus it is considered to behave as a film of saturated air at the same temperature as the bulk of the water droplet.

Finally, there is the transfer of sensible heat from the bulk of the water to the surface area. This is so slight in terms of resistance that it is normally neglected. Radiant heat transfer is also ignored for all practical design purposes.

Thus the two main processes are evaporation of water and convective cooling. The first is based on the difference in partial vapour pressure and the second upon the temperature difference.

Merkel's analysis in 1924–1925 demonstrated that for pure counterflow it is possible to combine these processes into a single term by using the enthalpy difference as a driving force. Experience over many years supports this, and cooling tower design in counterflow is universally represented by temperature–enthalpy diagrams.

For crossflow designs the additional factor of the horizontal depth of packing has to be included in the basic calculations. The accuracy of the design is directly related to the number of calculations in the selection programme. Whereas counterflow can be dealt with as a single entity, crossflow has to cope with the changes that occur at every level of pack, both vertically and horizontally.

21.3 Design techniques (see Appendix 21.1)

The performance of any cooling tower can be assessed against the following:

$$\frac{KaV}{L} = \frac{C}{(L/G)^n}$$

where KaV/L is normally given as the performance index or is quoted as KaV/L demand. L/G = water/dry air mass ratio and, taking n as average value 0.6, the constant C is proportional to the height of packing. This would cover most design requirements. Excessive temperatures and extremely high air rates will require further factors which are not necessary in the great majority of cases.

The Cooling Tower Institute (CTI) publishes sets of graphs which give demand in terms of three design temperatures and L/G. The CTI graph first published in 1967 gives KaV/L demand plotted against L/G with the approach temperature as a parameter. Each curve applies to a specified combination of wet bulb temperature and cooling range. Each cooling tower pack has its own KaV/L and responsible suppliers will supply performance graphs similar to those of the CTI.

Having selected a type and height of pack, the above equation can be plotted to intersect with the required demand curve to obtain the L/G. With the L/G and the given amount of water to be cooled, the air requirement can be calculated for:

$$\text{Air} = \frac{\text{Design water flow}}{L/G}$$

The following steps should then be:

1. Correct calculated air volume to conditions at the fan.
2. Select the air rate and calculate the plan area of the tower.
3. Select a fan and calculate the power requirements from the known air volume and the pressure drop characteristics of the selected pack.

4. Assess the cost factors applicable, in terms of fan, pump cost, price of land, maintenance and treatment costs.
5. Optimize all known factors in terms of efficiency and then economy.

21.4 Design requirements

The factors which should be applied at the design stage cover the water flow rate, the design wet bulb figure, the required return temperature at the design point, the cost of power and land, and the water analysis. Water flow is normally determined by the equipment that the cooling tower is serving (for example, heat exchangers). Process designers historically leave the cooling tower until last (it is, after all, the final heat sink). When water costs were negligible, this was acceptable, but with the increase in costs and, in certain cases, the restrictions on availability of water, this approach has had to be modified. Greater consideration must be given to the overall system. Experience in the last ten years has shown that economic optimization can lead to a more efficient cooling tower, with a corresponding drop in the cost of heat exchanger. This is particularly true in power generation and industrial processes.

Design wet bulbs can be determined from published meteorological data for the area concerned. The difficulty is deciding how to relate the annual coverage to the tower performance at any given time.

For some years it was common practice to quote three different figures, based on the tower's performance as a percentage of the year. For example. in air conditioning it could be shown that the tower would achieve its design for 95% of the year. Alternatively, a tower costing 15% less could obtain its design parameter for 85–90% of the year. Only the operator would know whether the 85–90% or less was acceptable, while the economists would welcome the saving of financial capital.

The tendency nowadays is to design direct for the three warmest months of the year or as specified by the requesting purchaser, or to meet the specified by the requirements of the plant supplier's necessity. The selection of a tower no longer gives the 3 wet bulb alternatives, as the selection of the final specification may influence the obtaining of an incorrectly suited tower. The economic argument therefore no longer enters into the selection process.

The frequent failures to achieve even the quoted reduced percentage figures led to a reappraisal, and current design is more accurate. In some respects this is also due to the improvement in pack designs, particularly in the European and American markets. However, it must be said again that in optimizing cooling tower selection the designer must be advised of all appropriate factors. Discussions with cooling tower designers at the outset can save time and money in the future.

Water quality is important, not only from an environmental point of view but also in relation to the type of packing to be specified. Analysis of the circulating water is simple to obtain, but it is very seldom offered to the cooling tower designer. The quality, or lack of it, will determine the type of pack to be used, the selection of structural materials and whether the tower should be induced or forced draught, counterflow or crossflow. Water treatment, in the shape of chemicals to control pH and to act as counter-corrosion agents or as biocides, all have a bearing on tower selection.

Modern film packs can be offered for a range of 'Total Suspended Solids' (TSS) levels in recirculating water i.e. typically using the most efficient pack designs. TSS concentrations should not exceed 50 mg/l.

Alternative film flow designs can be supplied for concentrations levels up to 100 mg/l and 180 mg/l. Obviously other factors may modify these parameters, but are good enough for a general rule. Over 180 mg/l splash pack designs would be required And such designs would be required and such designs are now based on plastic splash grids, rather than timber splash bars/laths.

The '*Legionella* syndrome' has resulted in health authorities in the UK applying statutory regulations, which are directly reflected in terms of capital cost and tower material selection. To safeguard against this, responsible designers have already produced cooling tower designs which not only meet the regulations but anticipate future, more stringent, legislation.

The following list of information factors should be made available to any supplier so that discussions on the technical requirements can be carried out prior to optimization (see Appendices 21.1 and 21.2).

21.5 Materials and structure design

The great majority of towers available fall into one of two categories: counterflow or crossflow (co-current flow is available but is seldom used) (see Figure 21.1).

Natural Draught Towers, once associated with the generation of electricity, this type has not been installed in the UK for some years, although they have been installed abroad. This is primarily because they are considered as 'Visual Pollution', and do tend to give the uninitiated the impression that they are also environmentally polluting the atmosphere, although they are not.

21.5.1 Counterflow

Counterflow designs are used throughout the entire design field, i.e.:

Natural draught – hyperbolic concrete shells
Mechanical draught – induced draught
Forced draught

21.5.2 Crossflow

Crossflow designs are also used throughout the entire field, i.e.:

Natural draught – hyperbolic concrete shells
Mechanical draught – induced, single and double sided and circular
Forced draught
Advanced fan-assisted natural draught.

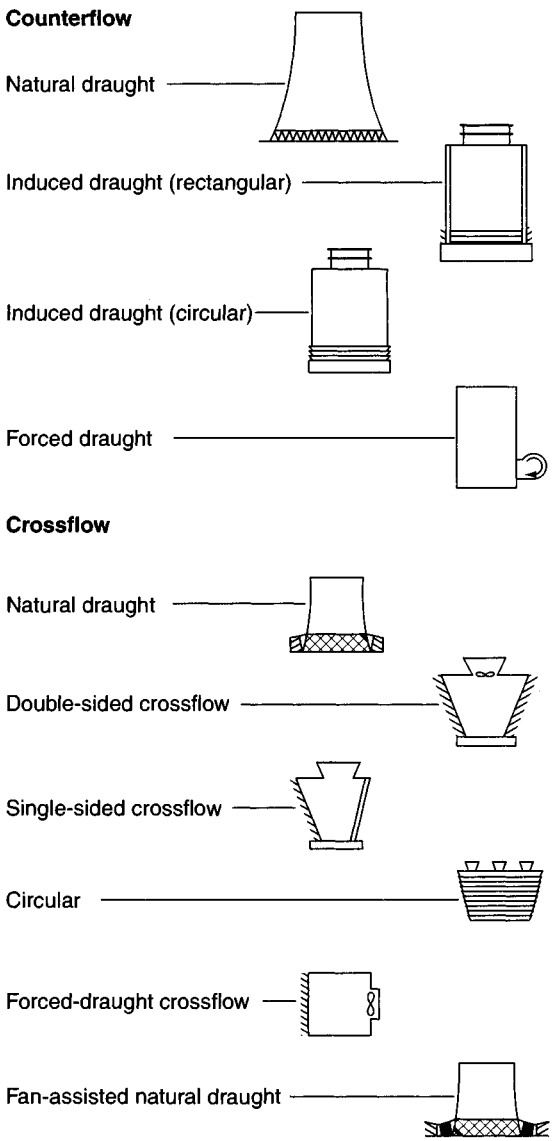


Figure 21.1 Counter- and crossflow modes

Axial or centrifugal fans can be applied in most cases and are significant factors in the final selection and optimization (Figures 21.2 and 21.3).

Hybrid towers, combining wet and dry cooling, are designs to meet specific problems and require expertise from specialist suppliers. Structural materials include concrete, timber, various forms of metal (including galvanized and alloys), GRP, PVC and, again, variations and combinations of other materials. Packing materials have an almost similar pattern but must include compressed paper and compressed asbestos cement paper, but the great majority of towers currently employ plastic, in some form or another, unless the water conditions are such that timber (or even concrete) must be used as alternatives.

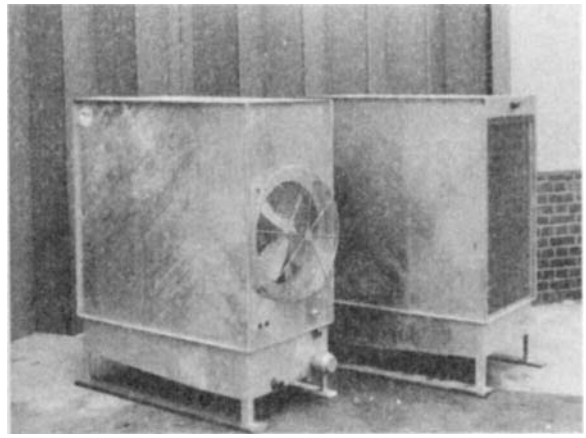


Figure 21.2 Basic crossflow units

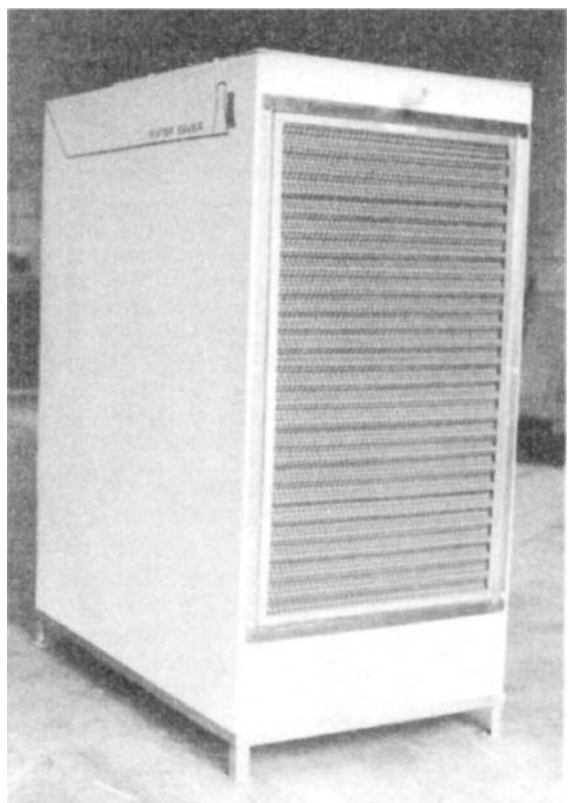


Figure 21.3 Improved design of crossflow unit (note easy-removal panel)

21.6 Specification

The purchase of the cooling tower is, in most cases, a once in a decade operation. Where towers are bought on a regular basis, specifications are determined either by the user or by the consultant, incorporating their experience of operation and any changes required as a result of production/process alterations.

In air conditioning circles, the tower normally represents the final heat sink in a turnkey package which would include compressors/condensers, pipework, ducting, fans, pumps, control gear, etc. Where consultants and experienced contractors are concerned, the tower specification is well defined and the purchases based upon economics related to efficiency.

Where a tower is to be purchased for a one-off situation, it is worth considering the various factors which can affect the final choice:

Location (both geographically and in elevation)
Restrictions (i.e. planning, structural, physical and environmental)
Design wet bulb
Design dry bulb
Water flow rate
Water quality
Water treatment to be used/cycles of concentration?
Process
Constant or cyclic heat load
Criticality of return temperature
Noise restrictions
Additional local environmental factors
Water discharge regulations (quantity and quality)

For the periodic or once-off buyer it is essential to obtain advice from a reputable supplier or a consultant with experience of cooling tower usage (Figure 21.4).

As an example, the reputable cooling tower designer would establish most of the above parameters from his own experience. In addition, he could determine with his client the economic factors which could influence his selection, i.e. low capital cost with high running costs, or a higher capital cost with more acceptable power costs (a 12-month or a 5-year payback period). This particular factor is often understandably ignored by turnkey contractors, and end users should always obtain alternative designs to make their own selection.

The costs of water, energy and land are all contributing factors in economic assessment. The emphasis placed on each differs from the varying viewpoints, but it is the end user who has to 'foot the bill'. It is therefore in his own interests to acquire some knowledge of the cooling towers being offered.



Figure 21.4 Architect-designed tower (note water pattern in basin). The office windows are affected by chemicals in carry-over

21.7 Water quality and treatment

As, in most cases, the circulating water in any system incorporating a cooling tower is recycled (the loss being made up as a percentage of total flow), the subsequent concentration will affect the water condition. This, in turn, determines the type of treatment required to maintain pH and to control any potential biogrowth. Acidic or alkaline waters pose their own problems in terms of corrosion and material attack. The larger users probably employ their own chemical specialists, while others rely on consultants to determine the type of treatment the system requires. However, the majority of tower users have very little knowledge of the chemistry involved and depend on water-treatment organizations.

The following definitions are useful for reference to familiarize the end user with the terminology currently employed:

pH	The acidity or alkalinity of the water expressed as a scale of 0 (acid) to 14 (alkaline). pH 7 is regarded as neutral.
TDS	Total dissolved solids, expressed as ppm (parts per million) or as mg/l (milligrams per litre). Evaporate the water from a sample and the residue can be weighed.
TSS	Total suspended solids: expressed in similar terms to TDS but representing a concentration of insoluble particles.
Conductivity	Used as a measure of mineral impurities.
LSI	Langelier Saturation Index: indicates the corrosive (negative) or scale-forming (positive) characteristics.
Hardness	Expressed as $CaCO_3$, this is the total calcium and magnesium salts in the water. Hardness figures given as ppm or mg/l are important, as the compounds of these two elements are responsible for most scale deposition.
Alkalinity	Expressed as $CaCO_3$, this is the total concentration of alkaline salts (i.e. bicarbonate, carbonate and hydroxide).
BOD	Biological Oxygen Demand: expressed as ppm or mg/l, it is used as a measure of pollution.
COD	Chemical Oxygen Demand: as above, but related to chemical impurities.
Oxygen Sag	The level of oxygen in a polluted water system. Normally shown in a graph form.
Fouling Factor	This is generally applied to plastic packs in natural-draught towers but can relate to larger mechanical draught and to the biological fouling that can occur. It also reflects on the thermal performance of the packing (In the days when the natural draught towers associated with the generating industry the CEGB published

fouling factors for certain high-density packs where the supply of water was prone to seasonal biological growth and silt deposition, along with calcium hardness deposition).

While other terms are, of course, employed, the above can be useful for most end users.

21.8 Operation

Having selected and purchased a cooling tower, it needs regular maintenance, as does any other part of the plant. This is true of every cooling tower, from the largest natural-draught tower to the smallest packaged unit.

All cooling tower operators should keep a full maintenance and working log to enable proper control to be maintained on the water quality and treatment and the operating efficiency, enabling planning of maintenance and operating procedures to be continually be monitored and updated as required. In air-conditioning installations, with the experience of *Legionella*, it is now mandatory to keep such a log, as well as a record of hygiene testing to determine the non-existence of bacteria. Chlorine dosing, as recommended by certain local authorities (including London), is essential. Tower materials have to be assessed in regard to chlorine residuals which can be damaging to galvanized metals and timber. Mechanical equipment requires regular checks, apart from the commonsense ordinary maintenance (it is surprising how often this is ignored).

The fault-finding chart (Figure 21.5) was originally produced by the Cooling Water Association (which subsequently became the Industrial Water Society and then The Water Management Society), and it is practical and simple to follow. Water treatment checks (apart from the *Legionella* requirements referred to earlier) must be carried out and water samples should be analysed on a regular basis. How frequently this takes place depends on the criticality of the tower for the end user. Cooling towers are water-conservation tools as well as heat dissipators: with water costs increasing, continuous tower performance is essential. In any case, a down-time caused by lack of maintenance is costly and careless.

Remember that outside influences (for example, new building work in the vicinity of the installation) can increase air-based pollution, such as cement dust entering the tower at air inlet levels or via the forced-draught fan. Extra cleaning of the tower pack and distribution system should be undertaken under these circumstances and close checks kept on the efficiency of the overall system.

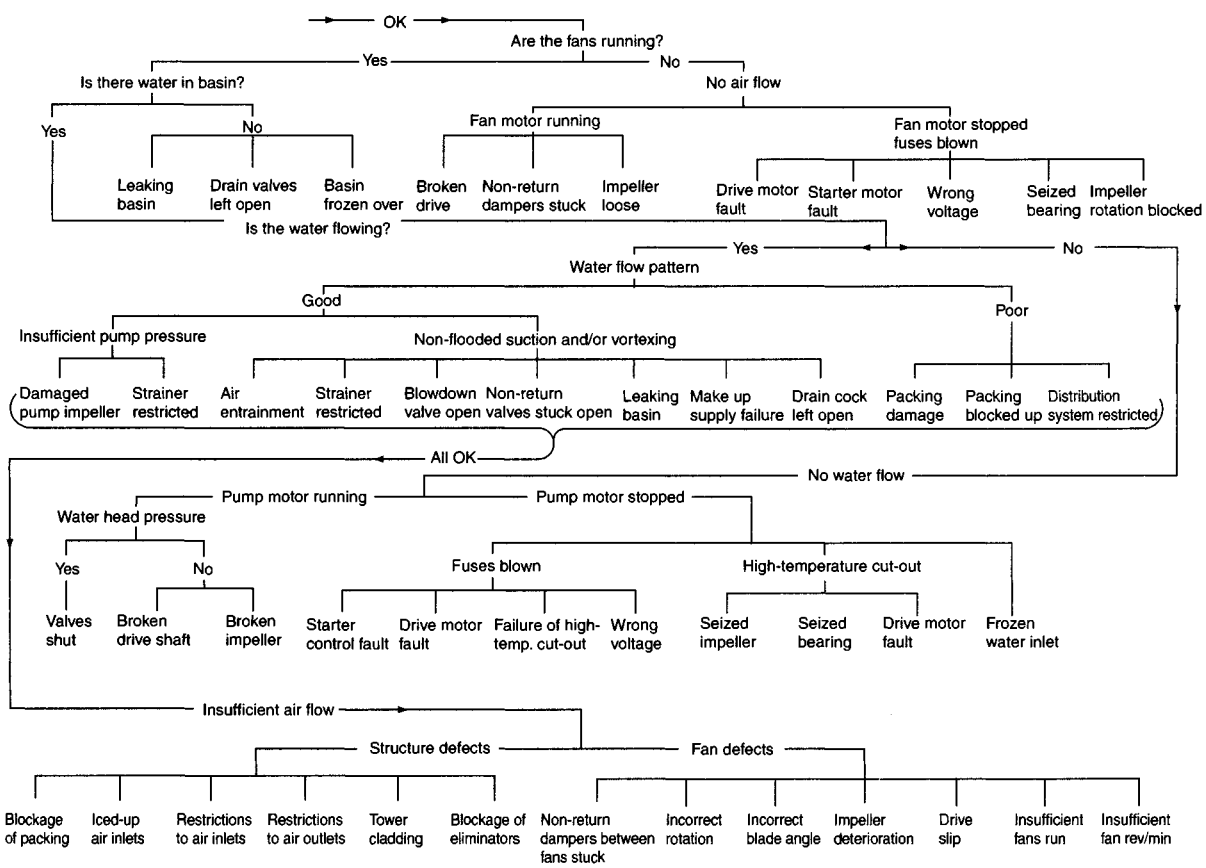


Figure 21.5 Fault-finding chart

Changes of process or modification to the product can introduce new design parameters, which can affect the tower. Overloading the tower in both a thermal and hydraulic sense may be acceptable as a temporary measure, but 'temporary' is the critical word. Too long exposure to an increased temperature can affect plastic packings, unless they have been designed to withstand such an increase. (Remember to discuss future predicted problems with the cooling tower designer before installation.)

Excessive water loads can lead to malfunction of the distribution system. Higher loadings in one area can lead to pack collapse and rapid fall-off in performance.

In the majority of cases common sense, combined with basic engineering principles, should be sufficient to ensure good service from the tower on a continuous basis. The reputable supplier will always be ready to help and advise. If the advice is sought in time, many of the problems associated with the changes mentioned need never arise.

21.9 Modifications – retro-fits

Changes in circumstances will frequently require modifications to an existing cooling tower. Additional heat loads may be needed, and changes in the end process may cause the return temperature to increase, necessitating a new thermal load on the tower. Most frequently it is a requirement for an increase in hydraulics.

21.10 Consultation

All too often, the supplier is not consulted at the planning stage, with the inevitable result of a tower failure, not only in performance but also in pack collapse, structural failures and total shutdown. The original tower was supplied against a design water and thermal load, and changes to those parameters will affect the performance. It is possible to change existing towers, and not only is it possible, it is well-established practice. The successful amendments are those where the tower designer has been advised (in advance) of the proposed changes. He knows the limitations of his product and can advise on what can or cannot be done.

There is one area where improvements can be achieved, namely the increase in thermal performance by changing to a more advanced design of packing. Care has to be taken to ensure that the new pack configuration is compatible with the quality of water as well as its quantity. The water treatment conditions could change, and almost certainly the distribution system will need amendments. The benefits to be obtained can be listed as follows:

1. Improvement in thermal load.
2. Possible reduction in pumping head (e.g. the change from a splash pack to a high-density film-type pack can save power by installing the new pack at the bottom of the former splash area and lowering the pump inlet). If the correct design is used it may be possible to leave existing fans, thus incurring no additional power penalty. Even if fan changes are required, the economics have to be studied, but in most cases such changes will be beneficial.

Changes to a distribution system can be of assistance in minor improvements. Nozzle designs are under constant review but it is in the context of pack changes that amendments are important.

21.11 Environmental considerations

The principal areas where cooling design is affected by environmental requirements are visual and audible (i.e. aesthetic (plume) and noise).

21.11.1 Aesthetic

Planning regulations can be rigid in their attitude to the visual impact that a cooling tower may have on the surrounding area. This is not, however, confined to air-conditioning installations. Certain industrial areas, within the UK and elsewhere, limit the number of towers, their height and configuration in relation to the existing background situation. While this is understandable in environmental amenity terms, it leads to major design difficulties on the part of the supplier.

Consultations with all interested parties is essential at the planning stage. Solutions can normally be found, but the cooling tower designer must be included in these discussions. Towers can always be designed to meet the planning regulators and the demands of architects. Low towers, tall narrow towers, circular towers, multi-faceted towers, towers built into the buildings, even towers installed under ground, are all practical examples of modern installations (Figures 21.6–21.8). Obviously,



Figure 21.6 Cooling plant, including towers, installed as a separate unit on a supermarket satisfies the architect, town planners and the end-user

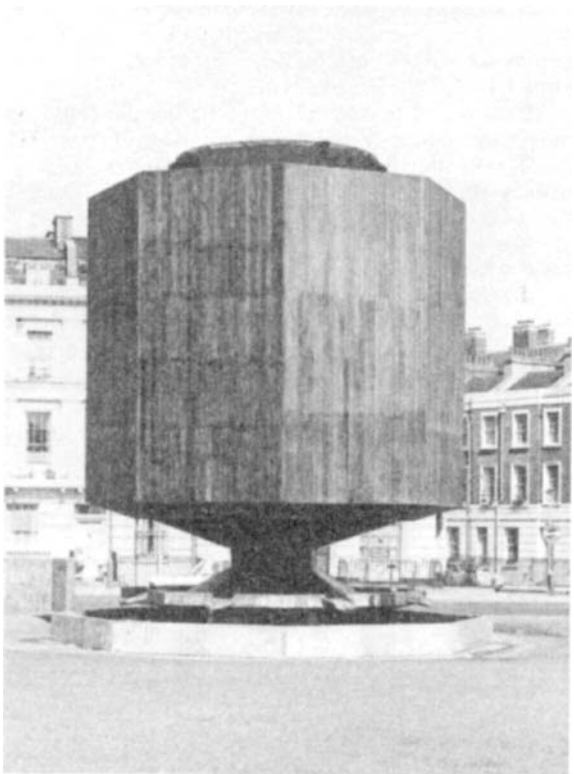


Figure 21.7 Design requested by architect – low plume, no splash (note catchment tray), clear of office block



Figure 21.8 Cranes can be eliminated!

the design characteristics have to be reassessed. Hence the emphasis on cooling tower designers' involvement from the outset.

As cooling towers operate on the evaporative principle, at certain temperature conditions the discharged heat vapour will appear as a plume. The amount of the pluming can be accurately assessed against the temperature conditions (both inside and outside the tower), the volume of air and the velocity of the discharge. The extent to which this can be classified as a 'nuisance' depends entirely on the location of the tower and its proximity to sensitive areas (i.e. housing, office blocks, roads etc.). There have been cases where medium to large conventional wet towers have been installed, and under certain atmospheric conditions, the plume can fall down to ground level, causing poor visibility or even icing on neighbouring roads or thoroughfares. In such cases, Hybrid towers should be considered.

However, as with commercial considerations made when selecting the wet bulb temperature for the tower design, such a commercial evaluation is required when deciding on the plume point for Hybrid towers. To supply a Hybrid tower that would not plume under all climatic conditions would be expensive, if not uneconomical.

Looking towards the smaller towers, there have been quite a few smaller towers used in dry cleaning installations, within sensitive areas, where the location of a tower has been very restricted, not only because of the availability of space, where inlet has been ducted into the tower, and the outlet, has been combined with warm ventilation extract fan discharge air, thus avoiding all possibilities of moisture deposition and the associated problems. Necessity being the driving force of the decision, sometime brought about by aesthetic considerations, especially where the location has been in the newer shopping precinct location.

One variation is the natural-draught tower, where geographical location may cause the plume to affect ambient conditions downwind, such as moisture deposition on roads (Figure 21.9) or, in one instance in Switzerland, where the plume from a large natural-draught tower located in a narrow valley restricted sunlight on the farming area downwind. (The predicted 7% restriction was accurate.) The drift can normally be confined within more than acceptable limits by the use of efficient drift eliminators.

The height of the discharge is important, and in air-conditioning projects it can be critical in relation to surrounding buildings. Consideration has to be given to

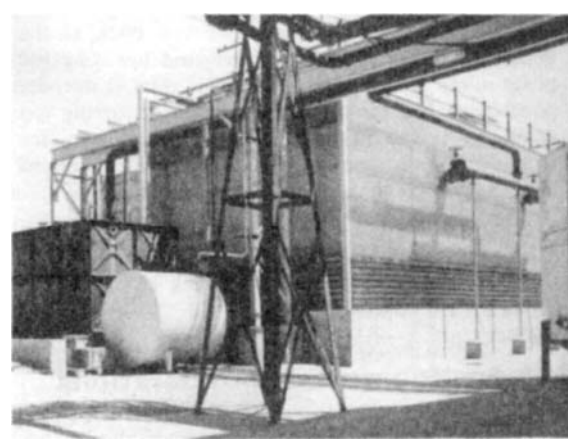


Figure 21.9 Congested site. Restrictions on air inlet, increased pressure and air velocity results in drift deposition on road

the volume of discharge, the possibility of entrainment of water-treatment chemicals in the drift (these can cause 'etching' on glass windows), the siting of the tower in relation to the fresh air inlets to the building and the visual impact, in architectural and aesthetic terms.

Eliminator design can vary from the non-existent to an efficiency which can limit drift to 0.00005% of flow. Whilst such a level can be achieved, in certain cases, it would be rare that any manufacturer would offer a guarantee of anything better than 0.001% whilst achieving a more common level of around 0.0005%. Such drift eliminator levels would normally be offered for towers to be installed in a sensitive area or for sea water cooling towers. A more typical (as specified by clients) guarantee level would be 0.005%. In other words, drift can be almost undetectable, but the difference is obviously in the economics involved.

Pressure groups in the environmentally aware political parties can make excessive demands. Often these can be met by good public relations meetings, but the more reputable cooling tower suppliers can be invaluable in dealing with such matters.

Plume abatement is possible, even to the point of 'invisible plumes'. While this is not a problem in hot countries, the temperate zones (for example, Europe and the USA), will always have seasons when the plume is normally visible. To change this situation to a non-plume effect is again possible but it is expensive. As an example, one installation in the centre of a North American city, where non-pluming throughout the year was a mandatory clause in the planning permission, resulted in the tower cost being increased by a factor of 3! (A not-insignificant amount in the overall cost of the project.) Plume control can be achieved at the expense of larger installations and possible changes in the temperature levels, all of which require prior consultation with the designer.

The other source of possible drift or precipitation from cooling towers is caused by windage or blow-out from the air inlets, noticeably under strong or gusty conditions. This can occur in both mechanical- and natural-draught cooling towers, but the effect is normally localized to the immediate tower area. In the natural-draught cooling tower the extent of the problem varies according to the design of the packing.

In the case of pure counterflow packing, where the entire packing is positioned above the air inflet, the large air inlet opening can give rize to discharge of water by air entering the air inlet on the windward side, then being sucked out in the vortex depression, which generally occurs at approximately 90° to the wind direction. The resulting spray is carried as a fairly narrow band for a distance of perhaps 20 to 30 m downwind of the tower. In a mixed-flow packing, where the cooling tower packing extends down into the air inlet, there is considerable resistance to the free passage of air through the air inlet. Therefore the depressed area of the vortex is reduced and the resulting spray tendency is likely to be restricted to a fine spray, literally being blown off the peripheral pack laths. Various techniques have been adopted to minimize this effect, such as external radial baffles, internal baffles and louvres. All of these will, of course, incur additional cost and some of them may also increase the pressure drop through the air inlet and thus affect the thermal performance. Additionally, they can increase the overall dimensions of the installation.

Mechanical-draught cooling towers are normally supplied with either central baffles or inlet louvres. This depends on the tower dimensions. On these towers the wind or spray blow-out is generally confined to relatively small single-cell units where an inlet may be provided on all four faces. In this case the major remedy is to provide internal diagonal baffles to prevent crossflow of air through the air inlets.

On larger multi-celled mechanical-draught towers of both counterflow and crossflow variety, the air inlets are confined to the two opposing faces and windage or drift loss is unlikely to occur, except under exceptionally high wind conditions. Here again, remedial work, depending upon the location, can be applied but at additional cost (see Figure 21.10).

21.11.2 Noise

Perhaps the most common environmental requirement in modern cooling tower installations is that of noise. Cooling tower noise is generated by the fan equipment and the falling water. In large mechanical- or natural-draught cooling towers the water noise is at a level where it could exceed the noise generated by the fan equipment (particularly if steps have been taken to reduce fan noise to a minimum). In the case of smaller cooling towers the prediction of noise intensity at a distance in excess of between 30 and 50 m can be taken as a hemispherical radiation from a point source, i.e. a reduction in the level of 6 dB for every doubling of the distance. However, with the large multi-cell mechanical- and natural-draught cooling towers the noise is radiating from a considerably larger area, and therefore the sound pressure level falls by only 3 dB for every doubling of the distance up to $\frac{1}{2}d$ (where $\frac{1}{2}d$ = pond diameter of the hyperbolic shell in a natural-draught tower or the tower length for the multi-cell mechanical-draught type). For distances greater than $\frac{1}{2}d$ the sound pressure will then fall by 6 dB for every further doubling of the distance.

Fan noise is likely to be more obtrusive than the so-called 'white sound' emitted by falling water due to the presence of discrete frequencies arising from blade-passing frequency, tooth frequency on the gearboxes bearing and rumble from the gearboxes and motors and other electrical noises. It can, of course, be minimized by correct choice of fan. In general, the use of broad-cord multi-bladed fans enables the fan to be operated at a minimum possible speed compatible with the duty performance. Reduction of bearing noise in gearboxes can be eliminated, as far as possible, by careful design in the mounting system, and motor noise can always be shielded by acoustic enclosures. For extremely quiet operation on mechanical-draught towers recourse may have to be made to the use of silencers or attenuators on the air inlets to the cooling tower to minimize the water noise, radiation and mechanical noise break-out, with further acoustic attenuators on the fan discharge.

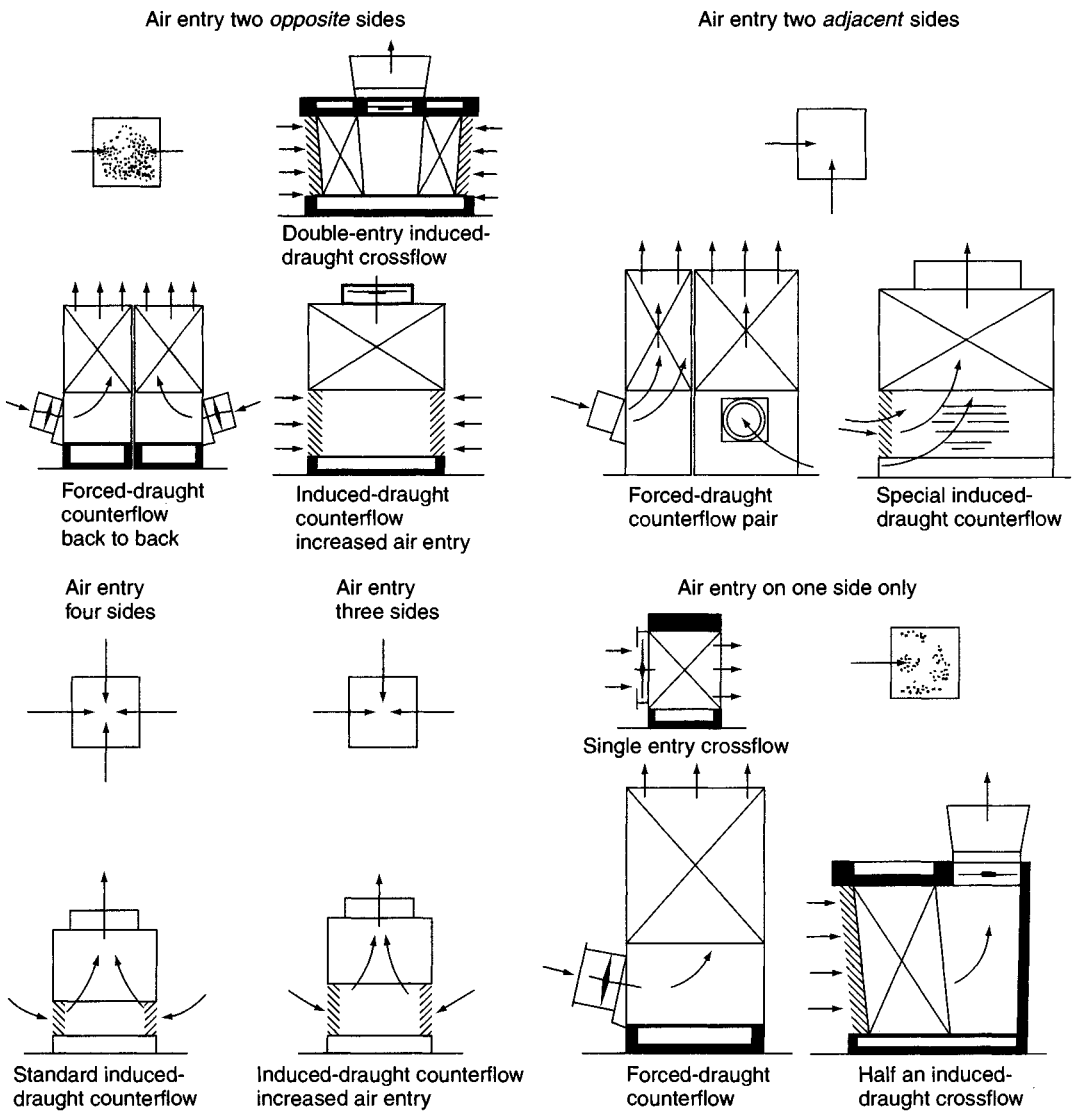


Figure 21.10 Configurations of cooling tower air flows

Any acoustic treatment on the fan discharge is required to operate under potentially corrosive conditions, with warm moist air passing through the attenuators. Precautions are needed to ensure that these are adequately treated to prevent risk of condensation and that the structural media are also protected against water pick-up and potential damage.

In the case of natural-draught towers the total noise source is very considerable and has to be assessed as a large-area source relating from the whole diameter, through the entire height of the air inlet. Falling water noise in that situation can be as high as 85 dB. The noise level at 70 m reduces to 66 dB and at 480 m it is approximately 46–47 dBA. On the largest natural-draught towers the figures increase. For example, at the pond level and at the side of the tower they can be in excess of 91 dBA and can actually reach 55 dB at 500 m.

Sound is defined as any pressure variation that the human ear can detect. This variation can occur in air, water and other media. To determine noise, it is necessary to assess the frequency of the variation which, in turn, can be related to the speed. For most applications the speed of sound is expressed at 340 m/s. Speed and frequency give the wavelength, i.e. the physical distance in air from one wave to the next. For example, at 20 Hz this gives 17 m while at 20 KHz one wavelength is 1.7 cm.

For convenience, the usual measurement of sound is expressed in decibels (dB), and ratings go from 'threshold of hearing' to 'threshold of pain' (135 dB). Figure 21.11 illustrates the common noise criteria, which can be expressed in sound-pressure levels (SPL). The human ear can detect 1 dB but 6 dB represents a doubling of the SPL, although it would need a 10 dB increase to make it 'sound' twice as loud.

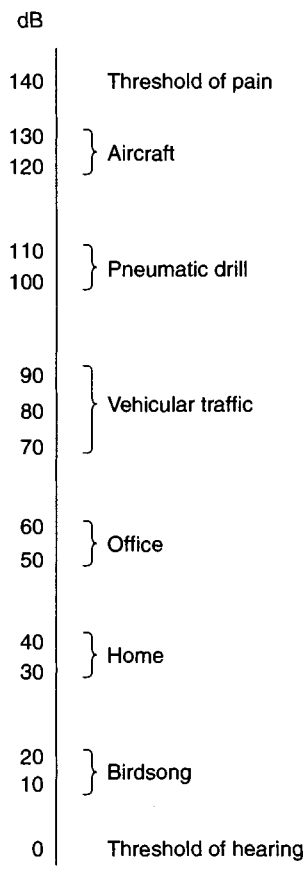


Figure 21.11 Threshold ratings for sound

In assessing the noise emanating from a cooling tower it is necessary to measure the main points of emission – the fan, the motor, the gearbox and the falling water. As noise bounces and can be absorbed by certain materials, it is usual, where noise restrictions apply, to map the area and calculate the SPL at a large number of points, taking into consideration interferences, bounce and absorption. The number of points measured is reflected in the accuracy of the resultant topograph.

Remember also to take background noise into your calculation. Too frequently, specifications are made which ignore this, with the result that equipment is applied to a more rigid design than is absolutely necessary.

The siting, as well as the selection of type of tower, can be critical. Rotating the tower, shielding the motor, use of baffles can all help in meeting environmental noise requirements. If in doubt, consult your cooling tower designer.

21.12 Problem areas

21.12.1 Installation

Cooling towers have been called the Cinderella of the plant scene – usually unnoticed (if not even unseen), forgotten and sadly ignored. While cooling tower designers may have other ideas, they generally recognize this as being true in many cases. Designers therefore try to achieve the impossible, i.e. to build a piece of mechanical equipment that can be left alone and perform its function without fuss and attention.

While designers can claim some degree of success, there are many occasions when their products are misinstalled.

21.12.1.1 Don'ts

Mix products – placing a forced-draught tower beside an induced-draught one causes problems for both designs (Figure 21.12).
Place access panels incorrectly – the access panel is for the user's benefit. Ensure that it is accessible (Figure 21.13).
Starve the air inlets – insufficient air results in poor performance (Figure 21.14).
Ignore the bleed – inadequate bleed means concentration of salts, change of pH and pack fouling.
Forget about make-up – water starvation means poor performance, vortexing, pump and motor failure.
Fail to check on water treatment – inadequate treatment and haphazard slug dosing can lead to poor performance, damage to associated equipment and failure to meet discharge requirements.
Forget to install safety cut-outs, for overload and ambient changes – ice damage can be disastrous (Figure 21.15).
Allow corrosion to develop – metal failure can be costly and, at times, dangerous (Figure 21.16).

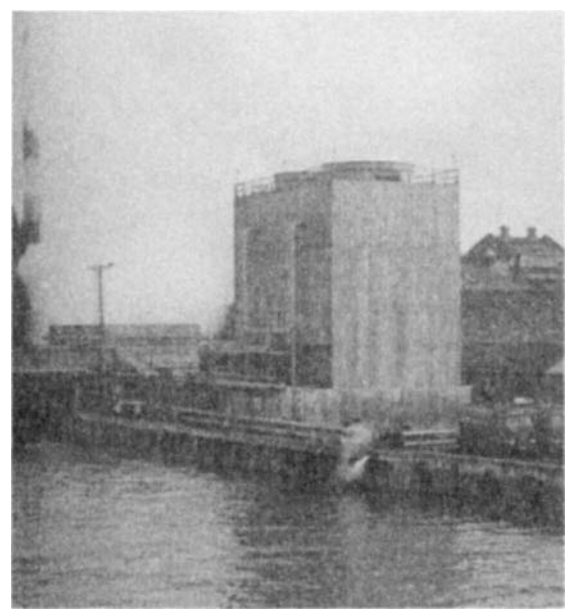


Figure 21.12 Mixing forced draught with induced. The overloaded forced-draught tower with excess plume results in elevated wet bulb at air inlets on new tower. The problem is resolved by removing the forced draught and adding one more cell to the induced draught

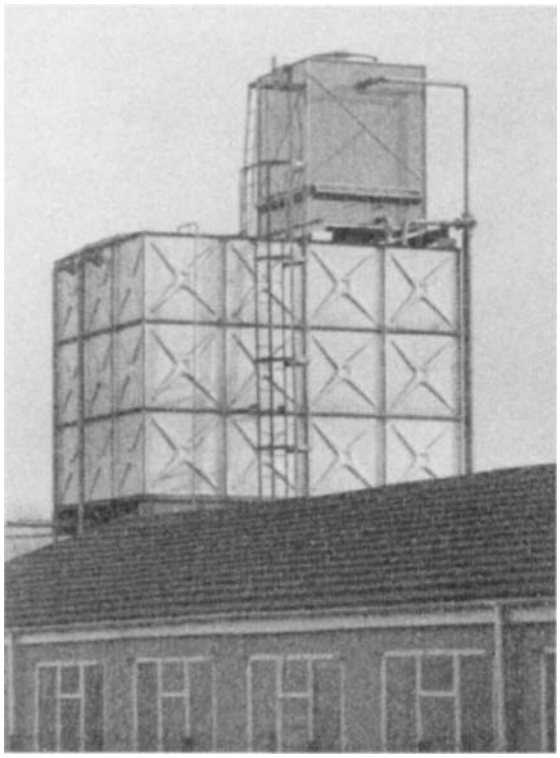


Figure 21.13 Cyclic heat load using small tower and large water storage. This is a good idea and sound engineering, but the access panel is on the wrong side (30 ft drop to ground level)

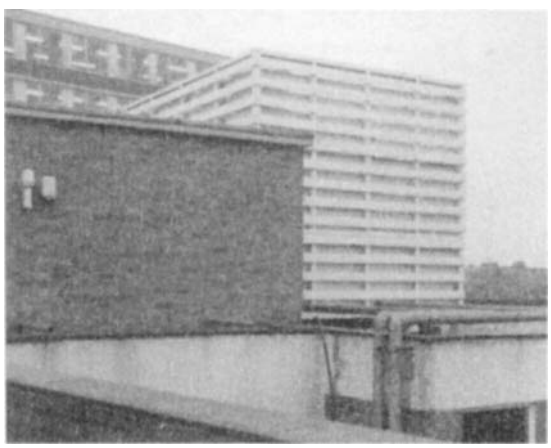


Figure 21.14 An attempt to conceal tower and reduce noise, resulting in starvation of air and failure in performance

Do not locate the tower, where access can be made by members of the public as many a tower has had a bottle of detergent emptied into the water with disastrous effect.

21.12.1.2 Do's

Ensure maintenance checks are carried out.
Check on power consumption, water usage, water costs.

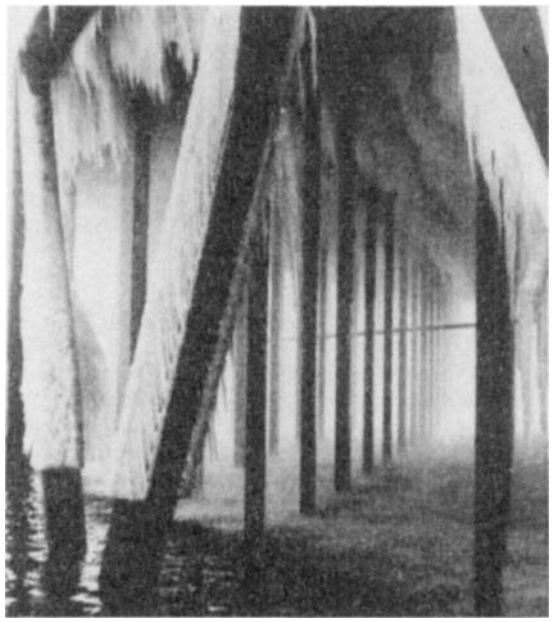


Figure 21.15 Ice on natural-draught tower (no de-icing ring fitted)

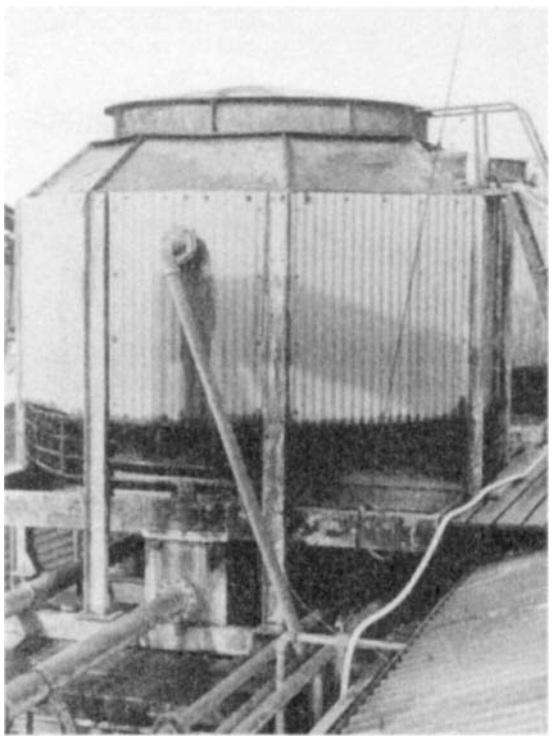


Figure 21.16 The effects of corrosion. Structural failure is visible (holes in fan casing)

Carry out monthly inspection – inside and out, where possible.
Check water analysis; the frequency depends on individual cases but it should be no less than quarterly.

Check mechanical equipment (i.e. fans, motors, drives). (Remember to check belt tensions where applicable.)
Check for vibration, both mechanically and structurally.
Ensure that access panels are used and replaced correctly.
Make certain that repairs, when necessary, are carried out efficiently and quickly.
If it in doubt, call the cooling tower designer.

21.13 Summary

While the majority of cooling tower installations work efficiently, the normal requirements of maintenance and good efficiency practice have still to be applied. This may not always be the case. Time for maintenance is limited, and plant engineers have other pressing problems or, as is well known, forget about the towers! With the increasing economic and environmental pressures on the use of water, this situation must change.

It may be appropriate to quote the old engineering term of 'KISS' (Keep It Simple, Stupid!) and, recognizing that the cooling tower designer does his utmost to comply, it is the responsibility of the operator to 'co-operate'!

Regular checks and an efficient logging system will ensure that the cooling tower, correctly planned, efficiently installed and adequately maintained, will give valuable service for many years. The economic returns justify a little more thought and attention than has been given to the subject in the past.

Appendix 21.1 Theoretical calculations

$$L\,dT = Ka\,dV(h_L - h_G)$$

where K = the coefficient of heat transfer for the packing in question,
a = the effective transfer surface area per unit pack volume,
V = depth of packing,
h_L = enthalpy of boundary air layer in contact with and at the same temperature as the water, and
h_G = enthalpy of bulk air passing through the packing.

Integrating this for the full depth of packing, the expression becomes:

$$L \cdot \Delta T = KaV \cdot \Delta h_m$$

where Δh_m is the mean enthalpy difference, otherwise known as the *Mean Driving Force (MDF)* (see Appendix 21.2).

This can be rearranged as:

$$\frac{KaV}{L} = \frac{\Delta T}{MDF}$$

which is the form in which it usually appears. KaV/L is commonly called the 'tower characteristic'.

Now let us refer to the right-hand side of the above expression. The mean driving force varies with the specified design temperatures and also the ratio of water/air loading (L/G). If we take a low air flow, the air soon rises in temperature and tends to reach equilibrium conditions with the boundary layer. Thus the driving force is reduced. On the other hand, excess air is unnecessary. Therefore we must adjust the air flow that supply just meets demand. A plot of L/G versus $\Delta T/MDF$ is shown in Figure 21.17. This is known as a demand curve.

The left-hand side of the above expression is a measure of the quality and quantity of the packing being used, and has been shown empirically to obey the law $(KaV/L) = c(L/G)^{-n}$ for counterflow applications only.

Cooling in the crossflow mode requires an incremental 'trial and error' technique, best suited to computer analysis. The tower characteristic KaV/L can then be plotted against varying L/G ratios, and this gives a measure of the ability of the packing to effect the transfer (Figure 21.18).

We have already equated KaV/L with $\Delta T/MDF$, therefore we can superimpose the 'supply' curve over the 'demand', the intersect being the optimum L/G ratio for the packing being considered for the duty (Figure 21.19).

It is interesting now to examine the effect of using greater or lesser depths of packing, and to consider their suitability for duties of different degrees of difficulty. In Figure 21.20 we can see the effect of using three different pack depths on a moderately easy duty. By changing from

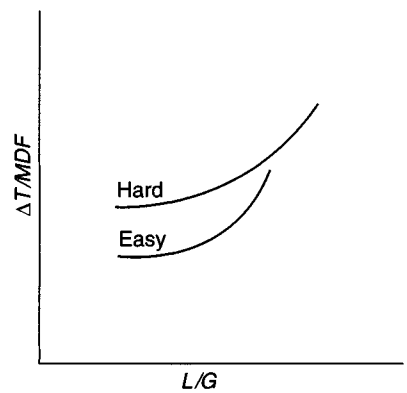


Figure 21.17

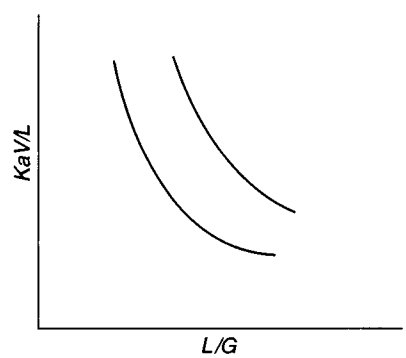


Figure 21.18

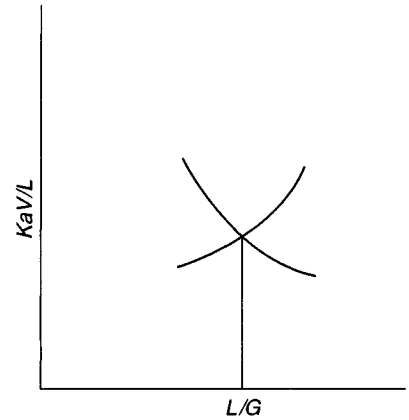


Figure 21.19

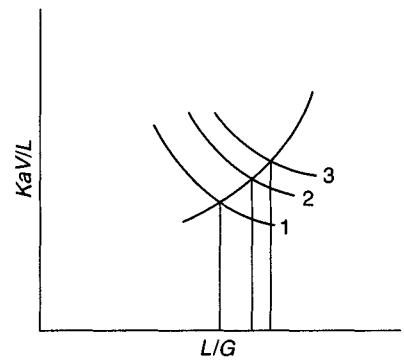


Figure 21.20

pack depth (1) to pack depth (2) we are able to use a much higher L/G ratio (which, in turn, means less air and/or a smaller tower). The increment from depth (2) to depth (3) gives a less significant increase in L/G, and therefore suggests that the optimum depth has perhaps been exceeded.

Now let us examine the same pack depths but applied to a more difficult duty (Figure 21.21). The increase in L/G is almost constant from (1) to (2) and from (2) to (3), showing that the optimum depth has not been passed, and may not yet have been reached.

Thus there is an optimum depth of packing for each individual duty and, in practice, it is usually found that an intersection near the knuckle on the demand curve produces the most economic selection.

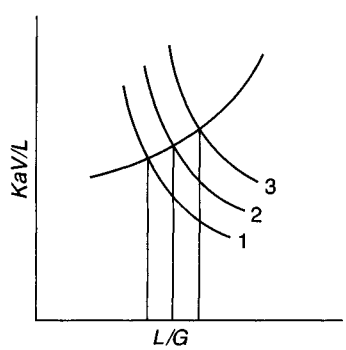


Figure 21.21

Appendix 21.2 Evaluation of the MDF

Several methods for the evaluation of the MDF have been put forward, notably that processed by Tchebycheff, which gives a high degree of accuracy in the case of large cooling ranges. In the form in which it is most commonly used, it reads:

$$MDF = 4/(1/\Delta h1 + 1/\Delta h2 + 1/\Delta h3 + 1/\Delta h4)$$

where $h1$ = value of $h_L - h_G$ at $T_2 + 0.1\Delta T$,
$h2$ = value of $h_L + h_G$ at $T_2 + 0.4\Delta T$
$h3$ = value of $h_L + h_G$ at $T_1 + 0.4\Delta T$
$h4$ = value of $h_L + h_G$ at $T_1 + 0.1\Delta T$

Graphically, this can be represented as in Figure 21.22. The expression for determining KaV/L is

$$(\Delta I/4)(1/\Delta h1 + 1/\Delta h2 + 1/\Delta h3 + 1/\Delta h4).$$

Appendix 21.3 Technical requirements

Location
Meteorological data
Wind rose
Water flow rate
Temperature to tower (T_1)
Temperature from tower (T_2)
Cooling range
Approach
Design wet bulb
Design dry bulb
Water analysis – circulating
– make-up
Cycles of concentration
Blowdown/purge rate

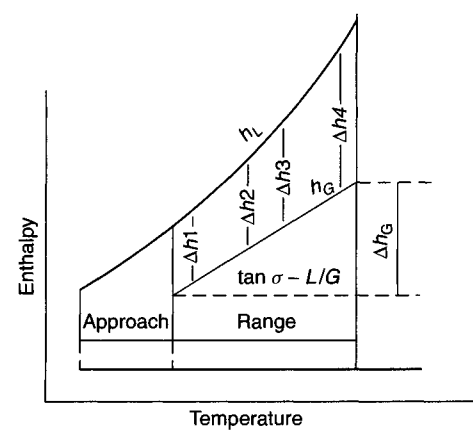


Figure 21.22

Power cost analysis
Drift loss requirement
Local authority requirements
Discharge qualities
Structural specifications
Pack specifications
Mechanical specifications (if applicable)
Noise specification
Impedance by adjoining structures (if applicable)

Acknowledgements

The authors wishes to thank the following for their considerable input: Mr Richard Clark and Mr Anthony Kunesch (FCT Ltd), The Cooling Water Association (now The Industrial Water Society), Mr John Hill (Director of BEWA) and the many understanding people who gave permission for publication of the photographs.

22 Electricity generation

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22.1 Introduction

Electricity is one of the key energy sources for industry and commerce. It is normally provided by the electricity supply companies, being generated from large fossil-fuelled, gas or nuclear central power stations and distributed throughout the country via high-voltage transmission systems. It can be fair to say that the electricity supply companies play a very important part in meeting the demands of the consumer efficiently, reliably and at an economic cost. However, there will always be a role for the private generation of electrical power, either to meet the needs for security of supply or to provide the electricity more economically. For the latter this is particularly the case for the concept of combined heat and power (CHP), where the local use of a heat demand can make private generation of electricity more competitive when compared with purchase from the local grid.

This chapter aims to convey the basic technical principles involved in electricity generation for industrial and commercial applications, with supporting technical data giving examples of the performance and efficiency of various schemes. A general guide is provided on the factors which have a major bearing on choice of an electricity-generating scheme with further details of the plant, its layout and descriptions of actual installations.

22.2 Generation of electrical power

Diesels, gas turbines and steam turbines are the more commonly used prime movers for the generation of electrical power. Additionally, the steam turbine can be employed in combination with either the diesel or gas turbine for combined cycle operation. The following describes the basic operation of each of these prime movers in relation to its associated power-generating scheme and reviews the more significant factors affecting performance and efficiency. Further information on the actual plant and installation is given later in Section 22.6.

22.2.1 Diesels

Diesels are used in many industrial applications (for example, for base-load generation in mines, cement plants and in remote regions of the world). In addition, they are often utilized to provide standby power for hospitals, telecommunications, banks, computer centres and office complexes which must have full independent power capability. The diesel can be started rapidly, making it ideal for peak lopping duties to meet maximum load demands, or for emergency use in cases of power supply interruptions.

Manufacturers offer a very wide range of diesel engines, all of which fall into categories depending upon crankshaft speed. The three categories are as follows:

Low speed: below 400 rev/min
Medium speed: 400–1000 rev/min
High speed: above 1000 rev/min

The speed of a diesel engine basically dictates its cost in relation to output. The choice is an economic consideration, taking into account the application of the engine and needs for reliability and security of supply.

The diesel has a good efficiency of approximately 40% with a flat fuel consumption curve over its operating range. With a competitive capital cost this gives the diesel a distinct advantage over its competitors.

22.2.1.1 The compression ignition cycle

The diesel is an internal combustion reciprocating engine which operates in the compression ignition cycle. The familiar reciprocating mechanism consists of a number of pistons, each running in a gas-tight cylinder with connecting rod and crankshaft. The connecting rods are set at angular positions so that they contribute their power stroke in a regular sequence.

In the compression ignition cycle the air is compressed and the fuel is injected into the compressed air at a temperature sufficiently high to spontaneously ignite the fuel. The heat released is converted to mechanical work by expansion within each cylinder and, by means of the reciprocating motion of the piston, is converted to rotary motion at the crankshaft.

There are two basic cycles, the two-stroke and four-stroke, each of which is illustrated in Figures 22.1 and 22.2 with their appropriate indicator diagrams. The two-stroke engine is mechanically simplified by the elimination of the mechanically operated valves. For the same rotational speed the two-stroke engine has twice the number of working strokes. This does not, however, give twice the power. In the down-stroke of the two-stroke cycle both the inlet and exhaust ports are cleared, which allows some mixing of fuel air charge and exhaust gases, resulting in less thrust. For similar reasons, this also gives the two-stroke engine a slightly higher fuel consumption.

The overall efficiency, η_b of a reciprocating engine is the product of the thermal efficiency, η_i and its mechanical efficiency η_m. Thus:

$$\eta_b = \eta_i \times \eta_m$$

An engine of good mechanical design has a mechanical efficiency of around 80–90% at full load. The overall efficiency of a compression ignition engine depends on the type, but ranges from 30% to 40%.

One of the main reasons for the good performance of the diesel, compared with alternative machines, is due to the fact that the design is not restricted by metallurgical considerations which, for instance, limits the higher gas temperature in the gas turbine. This is because the cylinder wall is only subject to intermittent peak temperature due to combustion and its average temperature is much lower than the mean gas temperature. Therefore, the cyclic temperature can be maximized.

22.2.1.2 Turbocharging

Supercharging the inlet air by use of exhaust gas turbocharging raises the volumetric efficiency above that which can be obtained from normal aspiration. This gives increased output without change to the speed or capacity of the machine. The full potential of the increase in

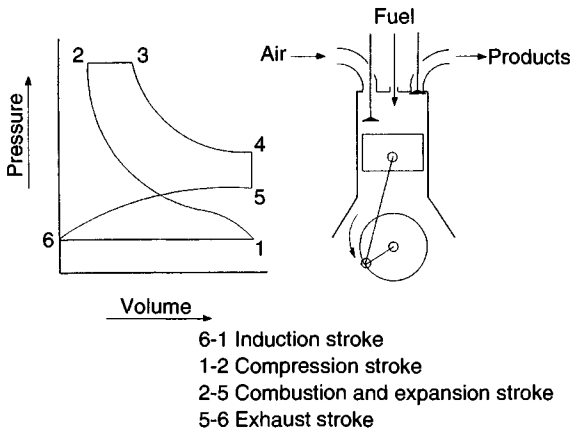


Figure 22.1 Four-stroke cycle for an internal combustion engine

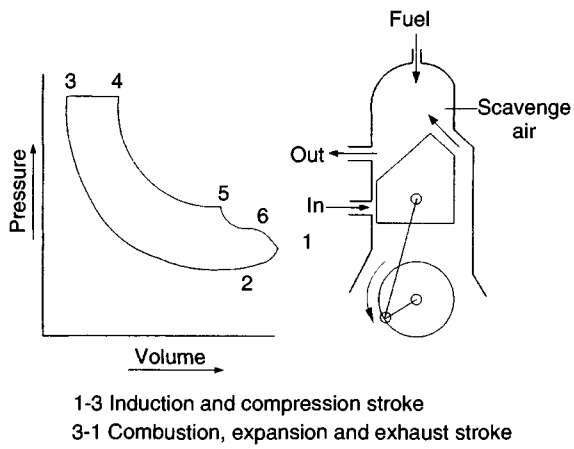


Figure 22.2 Two-stroke cycle for an internal combustion engine

air density is affected by the use of intercooling placed downstream of the turbocharger. Naturally, the use of turbocharging also improves performance at high altitudes.

22.2.1.3 Site conditions

The site conditions can have significant effect on the output of the diesel engine. For example, British Standards set out the de-rating method for internal combustion engines and establishes a datum level from which engine manufacturers relate their de-rating factors. Most engine manufacturers will give certain percentage reduction in power output for a certain increase in temperature and altitude above datum level.

One of the most important factors is the intercooler cooling water which has a profound effect on air manifold temperature. Use of a closed-cycle air cooling system will increase the cooling water temperature with de-rating of output. In addition, the radiators can add significantly to the parasitic load. The altitude above sea level at which the engine will be located also affects the output due to

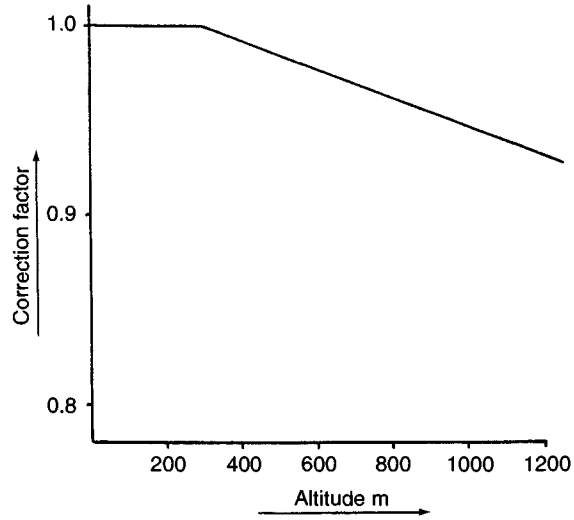


Figure 22.3 Correction to diesel power output for changes in ambient conditions

lower air density. Figure 22.3 illustrates the effect upon power output for changes in ambient conditions.

22.2.1.4 Oil consumption

One of the disadvantages of the diesel engine is its high lubricating oil consumption which, typically for a 3.6 MW engine, will be 0.0351/kW h. Added to this quantity must be the oil changes at routine service intervals.

22.2.2 Gas turbines

The role of the gas turbine is more familiar to many of us in the aircraft field. However, since Sir Frank Whittle invented the jet engine in the early pioneering years before the Second World War there has been rapid development in both output and efficiency of these machines, and today the gas turbine is a popular choice for electricity generation.

The gas turbine is widely used by electrical supply companies for peak lopping and standby generation. Additionally, it is increasingly being employed for base-load operation within a combined cycle (see 22.2.4) or combined heat and power (see 22.3) configuration.

The major disadvantage of the gas turbine is its low efficiency when compared with other machines. However, the gas turbine is compact, is subject to short delivery and erection period, has a competitive capital cost, and has virtually no requirement for cooling water. It can be started rapidly on fully automatic control.

22.2.2.1 Open-cycle operation

The basic gas turbine generates in the open-cycle mode and Figure 22.4 illustrates this diagrammatically. Air is drawn into a compressor and after compression passes into a combustion chamber. At this stage energy is supplied to the combustion chamber by injecting fuel, and the

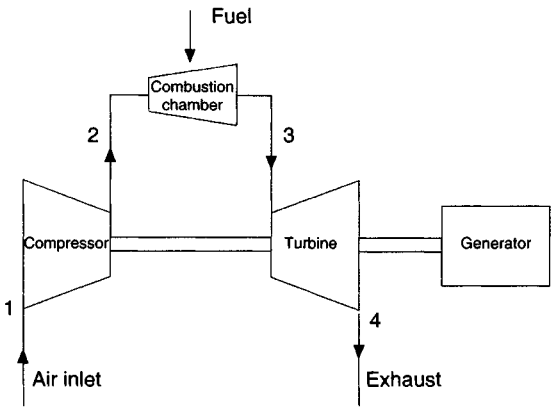


Figure 22.4 Basic gas turbine in open-cycle mode

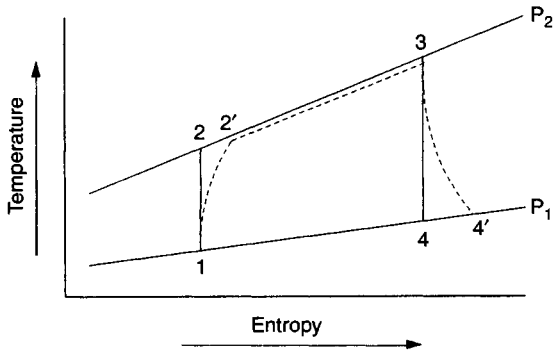


Figure 22.5 The gas turbine, or Brayton Cycle

resultant hot gases expand through the turbine. The turbine directly drives the compressor with remaining useful work which drives a generator for electricity generation.

Figure 22.5 shows the ideal open cycle for the gas turbine which is based on the Brayton Cycle. By assuming that the chemical energy released on combustion is equivalent to a transfer of heat at constant pressure to a working fluid of constant specific heat, this simplified approach allows the actual process to be compared with the ideal, and is represented in Figure 22.5 by a broken line. The processes for compression 1–2′ and expansion 3–4′ are irreversible adiabatic and differ, as shown from the ideal isentropic processes between the same pressures P_1 and P_2:

$$\text{Compressor work input} = C_p(T_2' - T_1)$$

$$\text{Combustion heat input} = C_p(T_3 - T_2')$$

$$\text{Turbine work output} = C_p(T_3 - T_4')$$

Therefore

$$\text{Net work output} = C_p(T_3 - T_4') - C_p(T_2' - T_1)$$

$$\text{Thermal efficiency} = \frac{\text{Net work out}}{\text{Heat supplied}} = \frac{C_p(T_3 - T_4') - C_p(T_2' - T_1)}{C_p(T_3 - T_2')}$$

By introducing isentropic efficiencies of the turbine n_t and compressor n_c the turbine work output is given as:

$$\text{Net work output} = C_p[T_3(1 - 1/k)n_t - T_1(k - 1)n_c]$$

where

$$k = \left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma}$$

The efficiency of the gas turbine depends on the isentropic efficiencies of the compressor and turbine, but in practice these cannot be improved substantially, as this depends on blade design and manufacture. However, the major factor affecting both efficiency and output of a given machine is the turbine inlet (or combustor) temperature, and this is dictated by metallurgical considerations. The turbine blades are under high mechanical stress, and therefore the temperature must be kept to a minimum, taking into account the design life of the machine. The introduction of blade cooling does allow use of higher turbine inlet temperatures.

22.2.2.2 Factors affecting performance

1. *Efficiency* Typical performance figures for gas turbines ranging in size from 3.9 MW to 17 MW are given in Table 22.1. These demonstrate that the open-cycle operating efficiency is in the region of 25–35%, depending on output.

When compared with similar rated diesel or thermal plant this efficiency can be considered low. It can be seen from Table 22.1 that this low efficiency is attributed to the relatively large amount of high-grade heat in the exhaust gas which is discharged to atmosphere at temperatures in the order of 400–500°C.

2. *Output* One of the major factors affecting gas turbine output is the ambient air temperature. Increasing the air temperature results in a rapid fall in the gas turbine output. Figure 22.6 shows a typical correction to power output curve for changes in ambient temperature.

Additionally, although to a lesser degree, output can be affected by inlet and outlet gas system pressure losses, which would be due to inlet filters and inlet and outlet ductwork and silencers. This fact must be borne in mind to ensure that in development of layout the ductwork design maintains the gas pressure losses within limits set down by the manufacturer.

3. *Part load* As the gas turbine operates with a fixed inlet air volume, its efficiency at part load deteriorates

Table 22.1 Typical performance data for industrial gas turbines

Engine	*TB 5000*	*GT 35*
Output, kW based on ISO Ratings	3960	17 000
Efficiency (%) based on NCV of fuel	25.9	32.1
Exhaust gas temp. (°C)	487	375
Exhaust gas flow (kg/s)	22	92.3

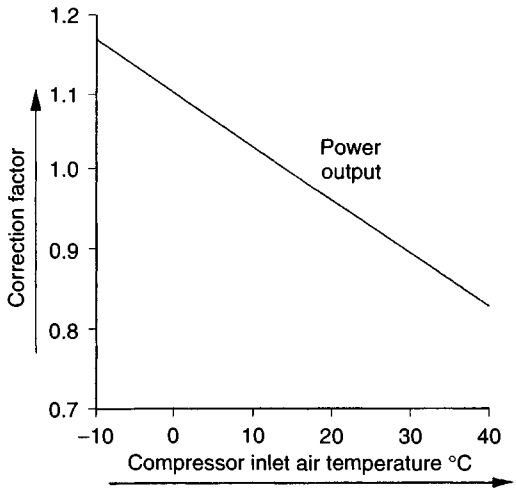


Figure 22.6 Correction to gas turbine power output for changes in ambient temperature

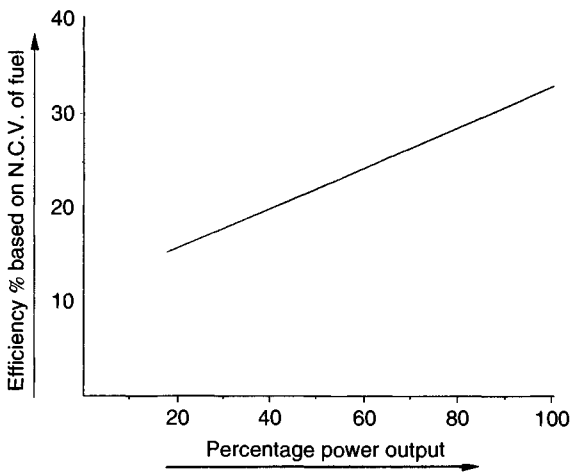


Figure 22.7 Approximate relationship showing variation of gas turbine efficiency for changes in load

significantly. Figure 22.7 shows a typical relationship for variation in gas turbine efficiency for changes of load.

22.2.2.3 Fuels

Gas turbines are capable of burning a wide variety of fuels, both gaseous and liquid. Typical liquid fuels range from kerosene and diesel to light crudes. They are also capable of running on natural gas and industrial gases such as propane. Automatic change over facilities can be incorporated.

22.2.3 Thermal power plant

Thermal power plant is more commonly associated with very large central power stations. The capital cost for thermal power plant, in terms of cost per installed kilowatt of electrical generating capacity, rises sharply for outputs of less than some 20 MW, and for this reason the thermal power plant is not usually considered for industrial applications unless it is the combined cycle or combined heat and power modes. However, for cases where the fuel is of very low cost (for example, a waste product from a process such as wood waste), then the thermal power plant, depending on output, can offer an excellent choice, as its higher initial capital cost can be offset against lower running costs. This section introduces the thermal power cycle for electrical generation only.

22.2.3.1 Condensing steam cycle

The condensing steam cycle is shown diagrammatically in Figure 22.8. The fuel is fired in a boiler which converts the heat released from combustion to steam at high pressure and temperature. This steam is then expanded through a turbine for generation of electrical power.

Exhaust steam from the turbine is condensed in a heat exchanger and then returned via the feed pumps to the boiler. The associated Rankine Cycle is illustrated in Figure 22.9.

The efficiency of the cycle, ignoring work done by the boiler feed pumps, is given by change in enthalpy as follows:

$$\text{Efficiency} = \frac{(h_1 - h_2)}{(h_1 - h_3)}$$

and h_1 to h_2 represents the ideal isentropic expansion process in the turbine. However, in practice, because of irreversibilities, this is less than unity.

This efficiency can be improved by the use of a feed heating cycle whereby bled steam can be taken from the turbine after certain stages of expansion and then used to raise the feedwater temperature via use of feed heat exchangers. By such means the feedwater temperature, before entry to the boiler, is increased, thereby increasing the efficiency as the bled system is condensed by transfer of heat to the working fluid within the cycle, so reducing condenser heat rejection.

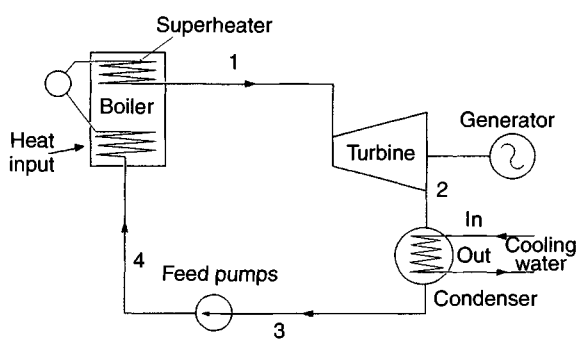


Figure 22.8 The condensing steam cycle

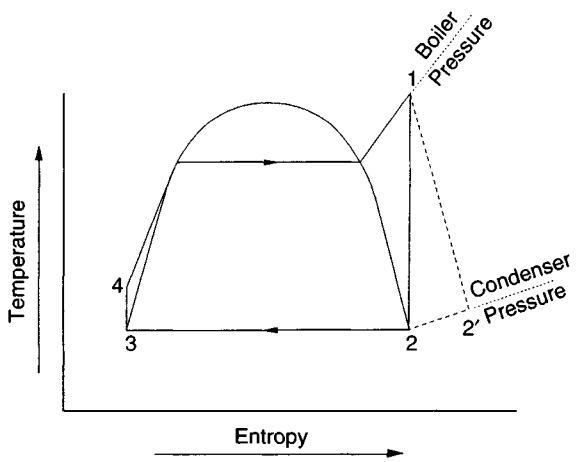


Figure 22.9 The Rankine Cycle with superheat

Large power stations use complex feed heating systems before the boiler feed pumps (LP) and after the boiler feed pumps (HP) which can give high overall thermal efficiencies of 39%. However, for the smaller machine it becomes uneconomic to consider multiple bleeds from the turbine, and the final choice is dictated by the extra cost for the additional complexity against lower running costs due to increased efficiency. As a minimum, a contact type de-aerator is often employed which would extract a small bleed of around 2–3 bar from the turbine.

22.2.3.2 Factors affecting performance

Table 22.2 gives performance data for typical industrial type schemes using thermal power plant in a condensing steam cycle. These do not operate strictly in the simple cycle mode as varying degrees of feed heating are employed. However, overall they convey the basic cycle conditions that the industrial user would encounter and give efficiencies that can be expected.

For the condensing steam cycle the heat rejected by the condenser is the total energy system loss and is significant with, in some cases, overall cycle efficiencies of only 25%. The higher the condenser vacuum, the lower is the saturation temperature of the condensing steam in the condenser. This is the temperature at which heat is rejected, so that the higher the vacuum, the lower is the temperature of heat rejection and consequently the greater is the cycle efficiency. The limit to the condensing temperature is set by the cooling water temperature and economic size of condenser. Closed-cycle cooling water systems employing cooling towers give higher temperatures than direct open-cycle cooling from river, lakes or other large water sources.

Increasing superheated steam temperature has the direct result of increased efficiency. For example, an increase in steam temperature of 55°C can give around 4% increase in efficiency. However, in practice the temperature is limited by metallurgical consideration with upper limits of around 540°C. This temperature can also be influenced by the boiler design and the fuel used.

Steam inlet pressure also has an effect on efficiency, although to a lesser extent. However, the cycle pressure is more often dictated by design limitations of the boiler for the application as well as the output.

Table 22.2 Performance of industrial steam-generating plant

Steam conditions	17 bar/260°C	30 bar/450°C	62 bar/510°C
Generator output	2000 kW	5000 kW	10 000 kW
Overall efficiency	18.1%	21.8%	26.3%

22.2.3.3 Fuels

The thermal power plant uses a fired boiler for conversion of fuel to heat. It can be said that there is a design of fired boiler to suit almost all types of fuels, including wastes and vegetable and industrial byproducts. Generally, for oils and gases these can be more readily converted to power in disels or gas turbines and would not be considered for thermal power plant, unless the station was of significant size.

22.2.4 Gas turbines in combined cycle

As discussed in Section 22.2.2, the gas turbine's main disadvantage is its low efficiency of around 25–35% in open cycle. However, this can be significantly improved by the use of a heat-recovery boiler which converts a good proportion of the otherwise waste heat in the turbine exhaust gases to high-pressure superheated steam which, in turn, drives a conventional steam turbogenerator for supplementary electrical power. This can increase the overall efficiency to 50% for no further heat input as fuel.

The combination of the Brayton (gas turbine) and Rankine (steam) cycle is known as the combined cycle. A typical gas turbine in combined cycle is shown diagrammatically in Figure 22.10.

22.2.4.1 Types of combined cycle

1. *The 'fully fired' cycle* Gas turbine exhaust contains approximately 15–16% oxygen by weight, and this can be utilized to support the combustion of additional fuel, thereby enhancing the steam-raising potential and consequently the steam turbine output. The higher gas temperatures impose no limitations on either steam pressure or temperature, commensurate with current fired boiler/steam turbine practice. The heat content of the exhaust gas can potentially be increased approximately five-fold. Consequently, the steam turbine output can be three to four times that of the gas turbine. Combustion efficiency is high due to the degree of preheat in the gas turbine exhaust, and the resultant cycle efficiency is much higher than that of conventional steam plant.

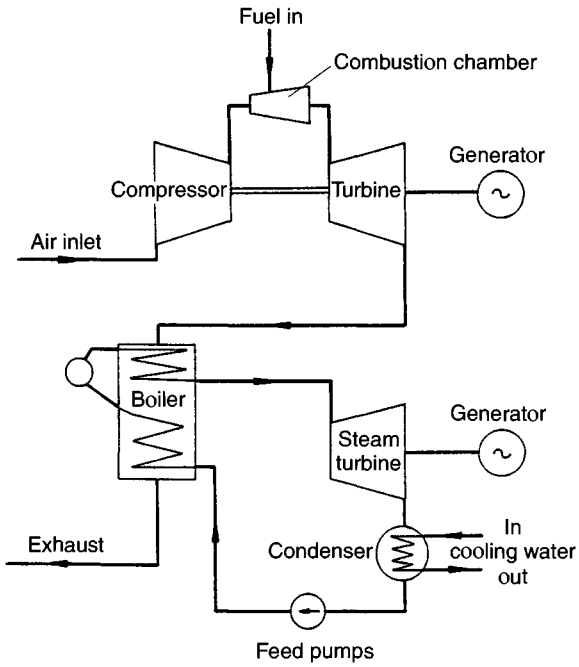


Figure 22.10 The gas turbine in combined cycle

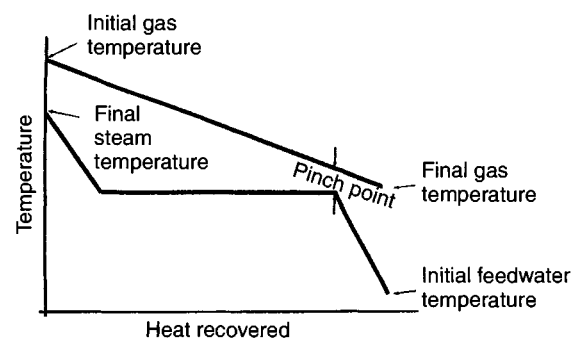


Figure 22.11 Heat-recovery diagram showing the pinch point

2. *The 'supplementary fired' cycle* The recovery of heat from gas turbine exhaust by the generation of steam has, as its basic limiting factor, the 'approach temperature' at the 'pinch point' (see Figure 22.11). The principal 'pinch point' occurs at the cold end of the evaporator and consequently the combination of the steam-generating pressure and the magnitude of the 'approach' determines the amount of steam which can actually be generated for a given gas turbine.

In single-pressure systems the only heat which can be recovered below the evaporator 'pinch point' is to the feedwater, and this, in turn, now determines the final stack temperature. If, however, a small amount of fuel is used to supplement the gas turbine exhaust heat, then while the 'pinch point' occurs at the same gas temperature level, the evaporation is increased and hence the amount of preheat required by the feedwater, resulting in a lower stack temperature. For this cycle the gas/steam power ratio is approximately 1–1.3:1.

3. *The 'unfired' cycle* This cycle is very similar to the 'supplementary fired' case except there is no added fuel heat input. The 'approach temperature' and 'pinch point' are even more critical, and tend to reduce steam pressures somewhat. Similarly, the gas turbine exhaust temperature imposes further limits on final steam temperature.

4. *General* The 'fully fired' cycle has been virtually superseded by the 'unfired' cycle, due to the former's lack of potential for increased efficiency, large cooling water requirement, larger physical size, increased capital cost and construction time. Also, because of the higher temperatures it is much less flexible in its operating capability.

The 'supplementary fired' cycle has many of the advantages of the 'unfired' cycle, and it can be argued that it is the most flexible in its operating capabilities. However, the controls are most complicated due to the afterburners and the need to maintain the steam conditions over the whole operating range. The 'unfired' cycle is the simplest in operational terms, the steam cycle simply following the gas turbine, and consequently is highly flexible in operation, having the ability to operate on sliding pressure at low loads. This cycle also has the greatest potential for increased efficiency, albeit for higher capital cost but without the need for extra fuel costs.

22.2.4.2 Single or dual pressure

There are two main pressure cycles applicable to the industrial combined cycle scheme: single or dual pressure:

1. *Single pressure* A combined cycle scheme with single pressure is shown in Figure 22.12. The waste heat recovery boiler is made up from preheater, economizer, evaporator and superheater sections giving single high-pressure steam output. The limitations imposed by the approach temperature at the pinch point, as illustrated earlier, determines the boiler heat recovery. Lowering of the boiler pressure increases the potential for heat recovery. However, the performance of the steam turbine will deteriorate at lower pressures, and therefore there is an optimum where maximum output can be achieved. The optimum pressure can be calculated, but is usually around 20–30 bara.

2. *Dual pressure* For comparison, a combined cycle scheme with dual pressure is shown in Figure 22.13. In this case the waste heat recovery boiler also incorporates a low-pressure steam generator, with evaporator and superheater. The LP steam is fed to the turbine at an intermediate stage.

As the LP steam boils at a lower temperature than the HP steam there exists two pinch points between the exhaust gas and the saturated steam temperatures. The addition of the LP circuit gives much higher combined

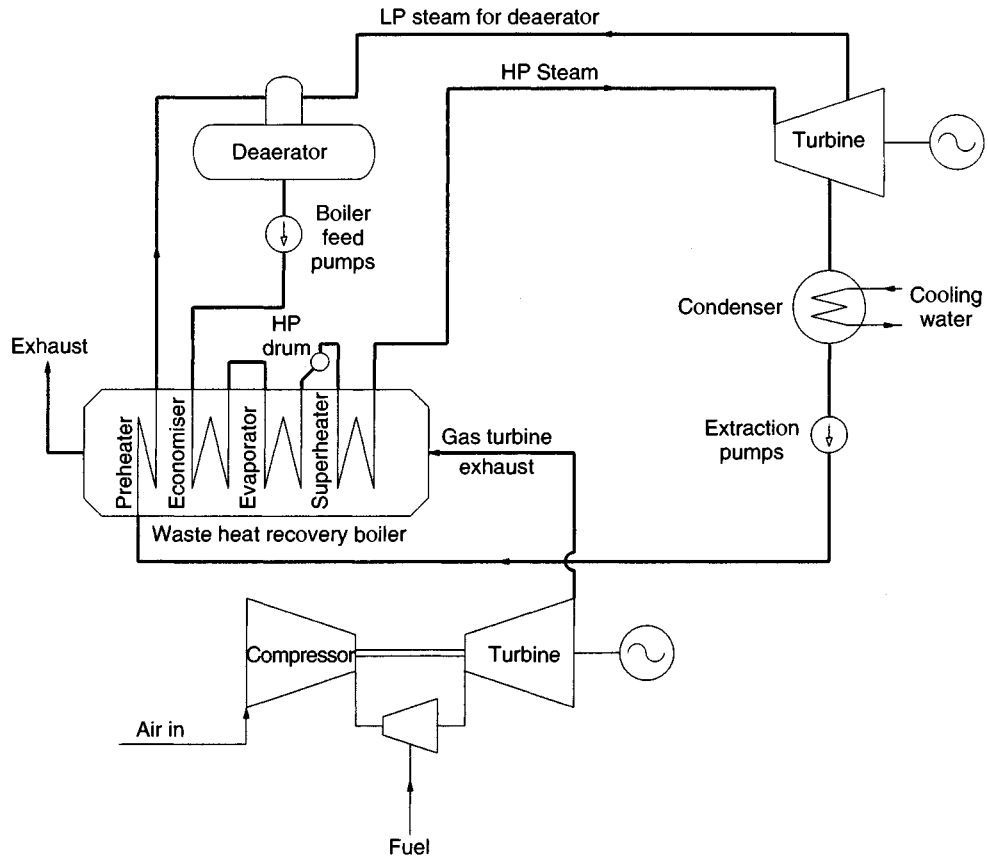


Figure 22.12 The single-pressure cycle diagram for a combined-cycle installation

cycle efficiencies with typically 20% more steam turbine output than the single pressure for the same gas turbine.

22.3 Combined heat and power (CHP)

The preceding section reviewed the application of popular prime movers for the generation of electrical power only. In the conversion of fuel energy to electricity it is shown that heat is rejected, either in the exhaust of a diesel or gas turbine or, alternatively, in the condenser of a thermal power plant. It can be seen that by applying these machines to provide both heat and electricity the total energy recovery can be much greater and efficiency thereby improved. Combined heat and power (CHP) schemes of this nature are well-established methods of producing both heat and power efficiently and economically.

22.3.1 Steam turbines for CHP

Many industrial processes require electrical power and heat. This heat is often provided from large quantities of low-pressure steam. In this section it is demonstrated that a thermal power station gives up very large quantities of heat to the cooling water in the condenser. For this purpose, the steam pressure in the condenser is usually at the lowest practical pressure (around 0.05 bara) to achieve maximum work output from the turbine.

However, if the turbine back pressure is raised to above atmospheric pressure so that the turbine exhaust steam can be transported to the process heat load then the steam will give up its latent heat usefully rather than reject this to the condenser cooling water. Although the steam turbine output is reduced, the overall efficiency is increased significantly as the generated steam is used to provide both heat and electrical power.

The alternative (but equally appropriate) logic is that a factory may use steam from low-pressure boilers. By increasing the steam pressure and then expanding this through a steam turbine to the desired process pressure additional electrical power can be provided.

An example is shown in Figure 22.14. By raising steam at high pressure (say, 60 bara and 540°C) and then expanding this through a turbine to the process steam pressure requirements of 3 bara then useful work can be done by the turbine for generation of electrical power. For this example each kg/s of steam gives 590 kW of electrical power.

There are several types of steam turbine that can be used to meet widely varying steam and power demands.

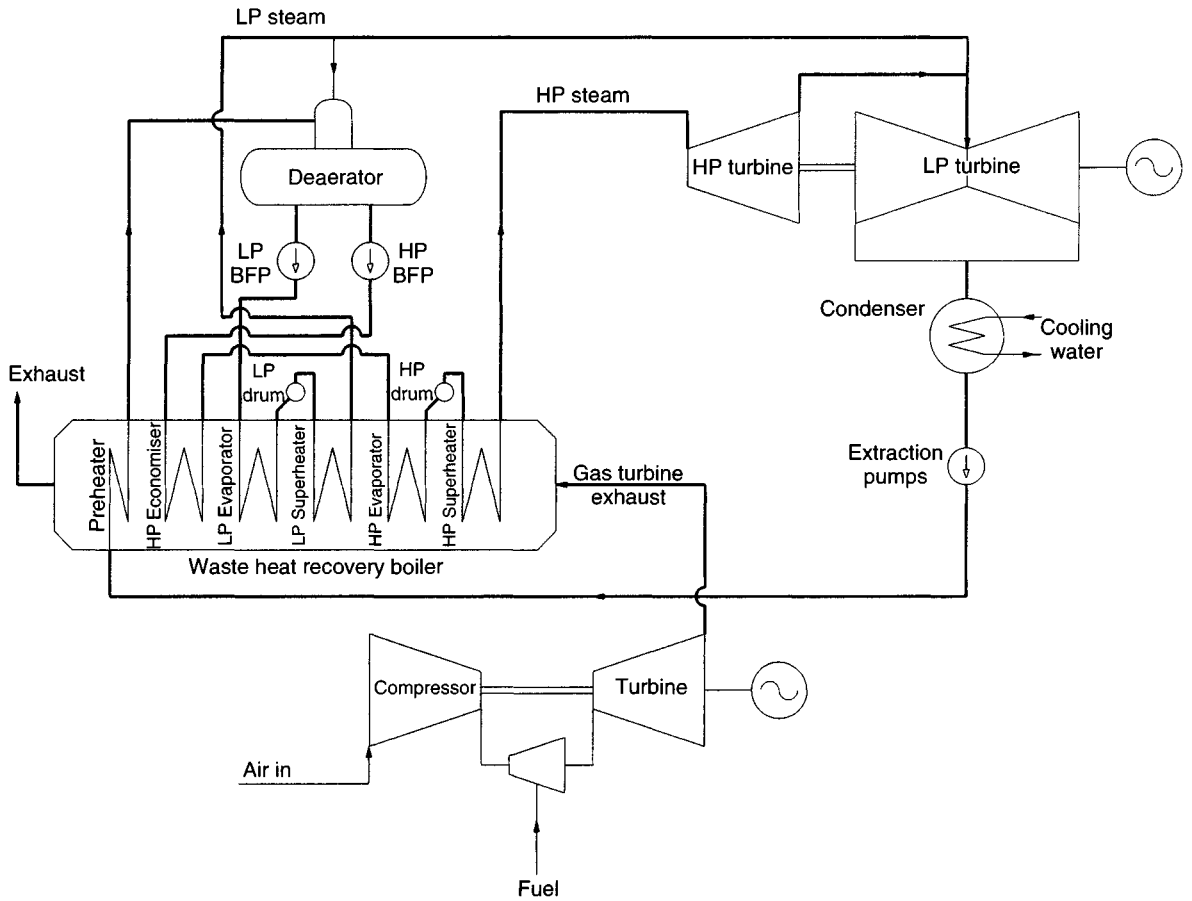


Figure 22.13 The dual-pressure cycle diagram for a combined-cycle installation

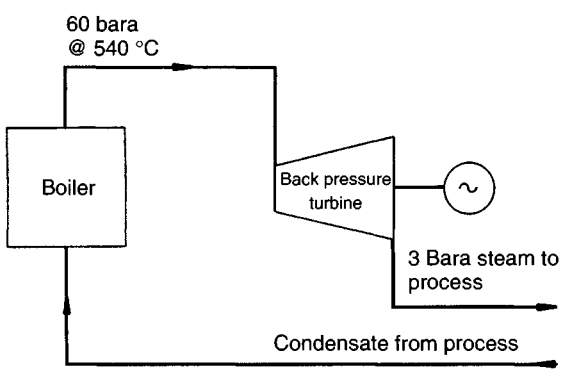


Figure 22.14 The back-pressure steam turbine in CHP application

They can be employed individually or in combination with each other.

22.3.1.1 Back-pressure turbine

The simple back-pressure turbine provides maximum economy with the simplest installation. An ideal back-pressure turbogenerator set relies on the process steam requirements to match the power demand. However, this ideal is seldom realised in practice. In most installations the power and heat demands will fluctuate widely, with a fall in electrical demand when steam flow, for instance, rises.

These operating problems must be overcome by selecting the correct system. Figure 22.15 shows an arrangement which balances the process steam and electrical demands by running the turbo-alternator in parallel with the electrical supply utility. The turbine inlet control valve maintains a constant steam pressure on the turbine exhaust, irrespective of the fluctuation in process steam demand.

This process steam flow will dictate output generated by the turbo-alternator and excess or deficiency is made up by export or import to the supply utility, as appropriate. The alternative to the system in Figure 22.15 is to use a back-pressure turbine with bypass reducing valve and dump condenser, as shown in Figure 22.16.

On this system the turbine is speed controlled and passes steam, depending on the electrical demand. The bypass reducing valve with integral desuperheater makes up any deficiency in the steam requirements and creates an exhaust steam pressure control. Alternatively, any

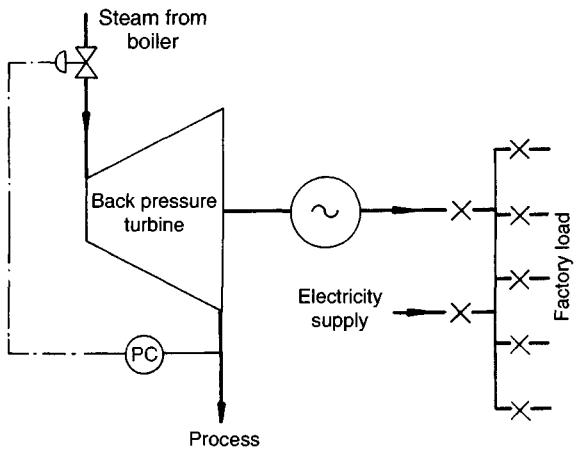


Figure 22.15 A back-pressure turbo-alternator operating in parallel with the grid supply

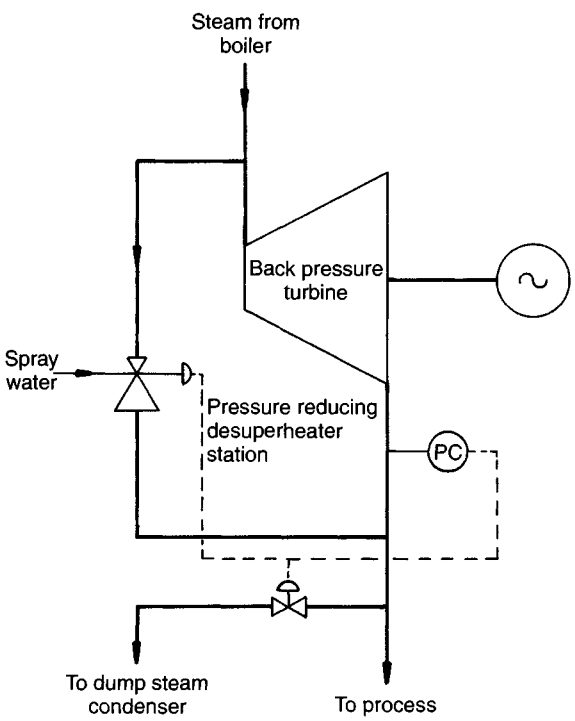


Figure 22.16 A back-pressure turbine with PRDs valve and dump condenser

surplus steam can be bypassed to a dump condenser, either water or air cooled, and returned to the boiler as clear condensate.

22.3.1.2 Pass-out condensing turbines

If the process steam demand is small when compared with the electrical demand then a pass-out condensing turbine may provide the optimum solution. Figure 22.17

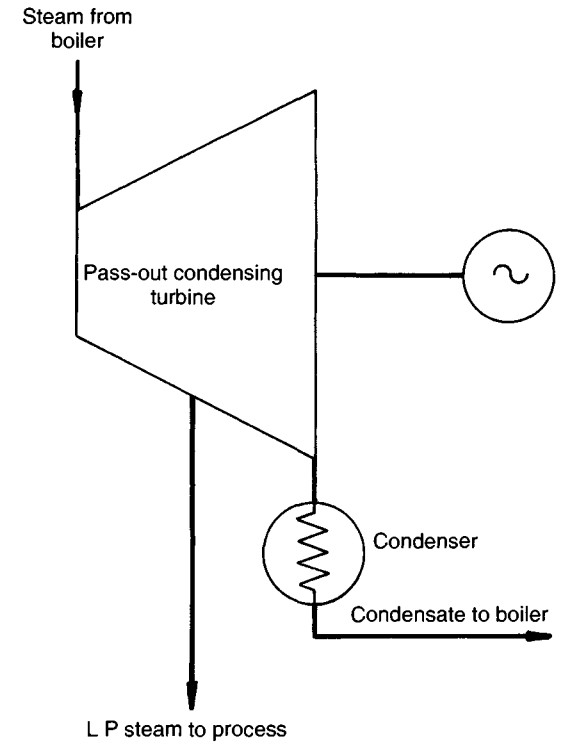


Figure 22.17 The pass-out condensing turbine

illustrates a typical scheme, which consists of a back-pressure turbine. This gives operational flexibility of the back-pressure turbine with improved power output.

22.3.1.3 Back pressure with double pass-out

Many industries require process steam at more than one pressure, and this can be done by use of a back-pressure turbine supplying two process pressures (see Figure 22.18).

22.3.2 Diesels and gas turbines in combined heat and power

In the process of conversion of fuel to electrical power both the diesel and gas turbine eject large quantities of hot exhaust gases. These gases represent a significant energy source which can be converted to useful heat by the addition of a waste heat boiler (see Figure 22.19). The boiler can be arranged to produce either steam or hot water, depending on the process needs. This heat is produced without any further fuel input and without affecting the performance of the generating machine. In addition, in the case of the diesel, additional low-grade heat can be recovered from the engine-cooling system.

The high efficiency of conversion of the diesel generator immediately restricts its potential improvement compared with gas turbines. With the simple addition of a boiler, the gas turbine can give a heat/power ratio of 2:1 compared with the diesel's 0.6:1. (The diesel heat/power

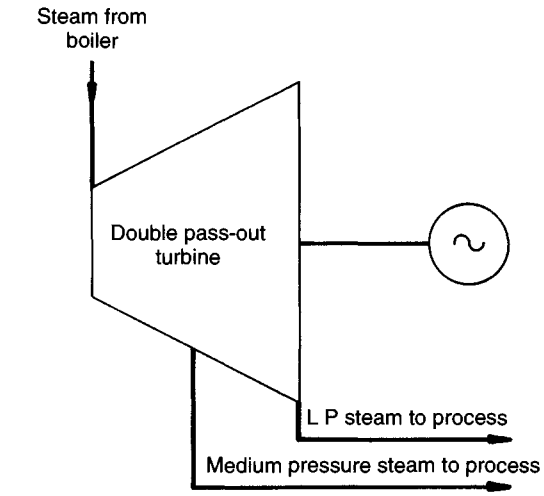


Figure 22.18 The double pass-out turbo-alternator

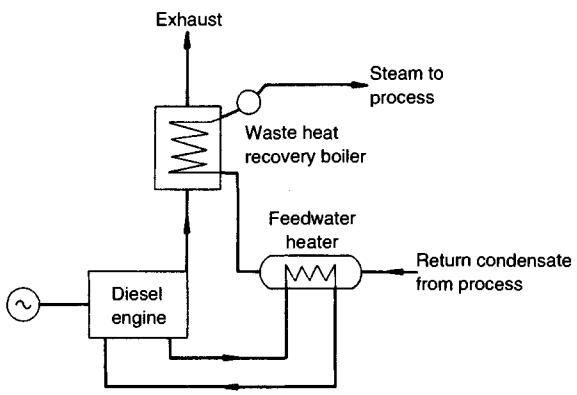


Figure 22.19 Diesel with waste heat recovery

ratio can be improved by 1:1 by use of the engine-cooling services, as shown in Figure 22.19.) However, both diesel and gas turbine exhaust gases contain excess oxygen (12–14% and 14–16%, respectively). This free oxygen can be utilized by supplementary firing the exhaust gases to produce additional steam in the heat-recovery boiler. By supplementary firing the ratio of heat to power can theoretically rise to 15:1 for a gas turbine and 5:1 for a diesel.

The chemical characteristics of the exhaust gases from diesel engines tend to make them less attractive for use in waste heat recovery, as they are likely to contain significant carbonaceous solid matter because of the range of residual oils burned. Fouling by soot build-up on heat transfer surfaces within the boiler can occur. In addition, the gas is likely to have significant pulsations, with a wide variation in mass flow with engine load, although the exhaust temperature fluctuation at low load is not as significant as for the gas turbine. However, there are many examples of successful CHP schemes using both the diesel and the gas turbine.

22.4 Factors influencing choice

The basic schemes for electrical power generation and combined heat and power have been identified in the earlier sections of this chapter. When assessing the alternatives to meet a specific project need there are many factors which will strongly influence the size, number, and type of generator as well as its specification and scope. While it is not intended to cover all of these aspects, the more important issues are discussed.

22.4.1 The available fuels

22.4.1.1 Oils

The petroleum industry is responsible for the production of a wide range of fuel oils for industrial use. These generally range from kerosene, gas oils and diesel fuel to residual fuel. (See Table 22.3 for typical fuel oil characteristics.)

Table 22.4 shows typical applications for the range of oil fuels for use with major prime movers. Medium/high-speed diesel engines generally use distillate fuel oils while medium/low-speed units generally burn residual fuels. The gas turbine, which normally operates on liquid distillate fuels, is capable of running on residual fuels, although examples of these are normally associated with crude production facilities.

In the case of residual fuel firing for gas turbines it is necessary to provide extensive fuel-preparation plant for the removal of vanadium, sodium, potassium, calcium and aluminium. Generally, oil fuels have good heating values and combustion characteristics, the main disadvantages being their higher sulphur content and the need for heating of the heavy fuel oils for storage and transport. Distillate grades of oil fuels may be stored and handled at

Table 22.3 Typical properties of fuel oils

Oil fuel	*Kerosene*	*Diesel oil*	*Residual fuel oil*
Density (kg/)	0.8	0.85	0.99
Sulphur (%)	0.05	0.5	3.5 Max
Ash (%)	Nil	0.001	0.04
Gross calorific value (MJ/kg)	46.2	45.5	42.5
Net calorific value (MJ/kg)	43.2	42.7	39.8

Table 22.4 Application of fuel oils

System	*Spark ignition*	*Compression ignition*	*Gas turbine*
Motor gasoline	√		√
Middle distillates (kerosine, gas oil, diesel fuel)		√	√
Residual fuels		√	√
Crude oil			√

Table 22.5 Typical properties of gas fuels

Gas fuel	*Town gas*	*Natural gas*	*Methane*	*Butane*	*Propane*	*Carbon monoxide*
Formulae	–	95% CH4	CH4	C4H10	C3H8	CO
Specific gravity (air = 1)	0.5	0.59	0.55	2.02	1.52	0.97
Gross CV (MJ/M3)	18.65	37.3	37.1	121.9	93.9	11.8
Stoichiometric air						
vol/vol	4.2	9.62	9.52	31.0	23.8	23.8
kg/kg	8.6	14.8	17.2	15.4	15.7	2.45
Spontaneous ignition temperature (°C)	650	660	700	480	500	570

ambient temperature. However, exposure to the cold for long periods is not advisable, and it is good practice to incorporate heaters to maintain the oil fuel at 5°C above freezing.

Heating facilities are required for all residual grades of oil fuels, and the following gives minimum storage and handling temperatures:

	Minimum storage temperature (°C)	Minimum temperature at outflow from storage and for handling (°C)
High fuel oil	10	10
Medium fuel oil	25	30
Heavy fuel oil	40	50

The tanks and pipework can be heated by use of steam, hot water, electrical heaters or a combination of these.

22.4.1.2 Gas

As a fuel, gas has many advantages in controllability and minimal effect on the environment, and it promotes reliable operation, longer life and residual maintenance compared with oil fuel. Its typical properties are shown in Table 22.5.

In many developed and developing countries there are now extensive natural gas supply networks which provide secure and reliable sources of gas fuel. The user may require some pressure reduction and metering equipment on-site, otherwise there is no requirement for storage, and the gas can be simply distributed to the generator by pipeline.

One of the alternatives to natural gas are industrial products such as propane or butane. These fuels are transported and stored in liquid form. On-site facilities are necessary for reception, off-loading and storage.

With the trends towards conservation of energy there has been significant advances in small gasification schemes. Here the solid fuel is partially combusted to give a low calorific value gas. The gas is hot and dirty, and contains tar and particulate matter, thereby requiring some cleaning before being used as a fuel. While the scope for these schemes is limited, there have been successful examples in rural areas of developing countries where the gas produced from fuels such as wood is used to run small spark-ignition engines.

22.4.1.3 Coal

In many regions of the world coal reserves represent substantial indigenous resources, and for this reason coal will always play an important role in the future of power generation. Inevitably, coal is more difficult to handle and has less appeal than other clean-burning fuels such as gas. However, substantial progress has been made in modern efficient handling techniques and combustion methods which can give clean combustion with low emissions.

For the purposes of power generation certain coal properties are significant, and a coal can be generally categorized by its rank, which embraces both volatile matter and caking properties. At the lower end of the scale are the older coals, such as anthracite with low volatile content and no caking properties. These coals are difficult to burn. As volatile content increases beyond anthracite then so does the caking quality, and prime coking coals are 12–30% volatile matter (VM). Beyond this, as VM increases further, caking properties decrease to free-burning coals of approximately 40% VM.

An example is the classification system which is common throughout the UK. The scheme divides coals into groups, generally as shown in Table 22.6. The group, grading and modes of preparation of a coal serve to indicate the usage for which the coal is suitable for application with industrial boilers. For grading of coal the nominal sizes are shown as follows:

	Through (in)	On (in)
Doubles	2	1
Singles	1	0.5
Peas	0.5	1
Grains	0.75	0.125

Smalls constitute the fraction which passes through a screen of given size and which has no lower size limit. Smalls can be washed or untreated.

The ash content of the coal is significant, not only in its mass but also with respect to the constituents of the ash, the fusion temperature, the range of fusion temperature between initial deformation and actual fusion and the amount of coal fines present.

Use of coal requires suitable storage facilities local to the power station site. The capacity of the stockpile is a decision of strategy and depends on the frequency and size of the delivery loads. In addition, the site should be

Table 22.6 Classification of coals

General description	*Volatile matter (%)*	*Specific description*
100	6–9	Anthracites
200	9–19.5	Low-volatile, steam coals
300	19.6–32	Medium-volatile coals
400		Very strongly caking
500		Strong caking
600	Over 32	Medium caking
700		Weak caking
800		Very weak caking
900		Non-caking

carefully chosen in view of access needs for reception and off-loading. Stored coal weighs about 4000 tonnes per 0.5 m depth per hectare, which gives a rough guide on areas for stockpile. Graded coals and smalls should always be stored separately. The large coal forms naturally, but smalls must be piled by layering and compacting to form a well-consolidated heap.

The object of compacting the smalls is to exclude air to ensure safe storage. If proper precautions are taken then coal can be stored safely. However, the user should be aware of the potential dangers of spontaneous combustion and the measures necessary to avoid this problem. For sites of limited area coal can be stored in large vertical bins.

There is a wide range of pneumatic, vibratory, belt or 'en-masse' type elevators and conveyors for transfer of coal from storage to boiler. The final scheme depends on site layout constraints and cost.

22.4.1.4 Other fuels

Solid fuels also encompass lignite, peat and wood. In its final form wood has a much greater commercial value as a product. However, some industrial processes (for example, the production of paper) create waste wood in offcuts, bark and shavings. Here the wood is ideal as an energy source. It has a high moisture content but nevertheless can be fired easily with full automation. Table 22.7 shows typical heating values for these fuels when compared with coal.

Additionally, there are food processes where the product is derived from a vegetation and a combustible fibrous waste is produced which can be used as fuel. A good example is the production of sugar from sugar cane with bagasse as waste. There are many others, and their by-products should not be overlooked in an assessment of suitable fuel sources.

22.4.2 The electrical load profile

In reviewing the size of a generating scheme it is necessary to consider the electrical load profile of the site demand, which must examine the electrical power needs over the daily and annual cycles. The capacity of the generator can be selected to cater for anticipated future growth or, alternatively, the station could be designed so that further generators could easily be added to match future load demands. At this stage it is worth noting that the power station itself will require electrical power for its auxiliaries (parasitic load), and this electrical load will be relatively constant, despite the output modulating to follow demand.

The load profiles can vary quite considerably, depending on the electrical users. For instance, for a factory the load will depend on the shift operation with a potential low demand at night and at weekends. The load can be influenced by seasonal changes. For instance, it may increase towards winter with greater lighting demands. However, the need for HVAC in computer installation may increase the load during summer. It is important that the power station be capable of meeting the peak capacity while also being able to operate efficiently at lower loads.

22.4.3 The heat load

Earlier, we reviewed the advantages of combined heat and power. It therefore follows that a local heat load, where practical, should be incorporated into the electrical scheme.

Heat loads are usually supplied by medium- to low-pressure steam and high- and low-temperature hot water. Steam is the main medium used by industry for the transport of large quantities of heat, and pressures generally range from 3 to 16 bar. Low- and high-temperature hot water systems are employed for heating, and they operate in 'closed' circulating systems with the high-temperature system (approximately 120°C) pressurized by an external source to prevent steam forming. Typical industrial and commercial applications are:

Table 22.7 Typical properties of some solid fuels

Fuel	*General-purpose coal*	*Wood*	*Peat*	*Lignite*
Moisture (%)	16	15	20	15
Ash (%)	8	–	4	5
Carbon (%)	61.3	42.5	43.7	56.0
Hydrogen (%)	4.0	5.1	4.2	4.0
Nitrogen (%)	1.3	0.9	1.5	1.6
Sulphur (%)	1.7			
Oxygen (%)	7.7	36.5	26.6	18.4
Gross CV (MJ/kg)	25.26	15.83	15.93	21.5
Net CV (M3/kg)	23.98	14.37	14.5	20.21

Hotels: hot water, swimming pools
Schools: hot water and steam, heating and air conditioning
Dairy: steam and hot water
Heavy manufacturing: steam, air conditioning, space heating and hot water
Hospitals: steam, hot water
Sewage plant: hot water, sludge heating
Food industries: process steam, hot water
Chemical industries: process steam, hot water

Hot water or steam can also be used in absorption-type chillers to provide chilled water with the reduction in electrical power needed for the refrigeration process.

As with the electrical load profile, it is also necessary to analyse the heat load over the daily and annual cycles. Ideally, the heat load will match the available heat from the electrical generator (however, this is rarely the case). There will be periods when supplementary output will be necessary which can be achieved by, say, supplementary firing the waste heat gases of a gas turbine, or heat output reduction is necessary by the introduction of bypass stacks. For a steam turbine installation bypass pressure-reducing valves will be necessary to supplement steam output, while a dump condenser may be needed at low-process steam demands. The nature of the electrical and heat load will obviously have significant influence in the development of the scheme and scope of equipment.

22.4.4 Power station auxiliary systems and services

A total power station project involves many aspects, covering civil works, fuel systems and storage, plant auxiliary systems and services, electrical plant and control and instrumentation. The scope will depend on the nature and size of the project envisaged. Table 22.8 gives a detailed checklist for power station auxiliary components and will provide a useful guide in developing scope. Further details of many of the components, such as ventilation systems or fuel oil handling, are given in other chapters of the book.

General information relevant to electrical system design is given in Chapter 21. Within an industrial power plant, the following key items of electrical equipment need to be addressed:

1. The power-evacuation circuit, including any generator transformer and the connection with the remaining site-supply system.
2. The supply system for the power plant auxiliaries, including the provision of supplies to any important drives and the provision of standby supply systems.
3. The protection and synchronizing schemes applicable to the generator circuit.
4. The earthing arrangements of the generator neutral.
5. The control of the excitation of the generator when operating in either isolated or parallel mode.

A typical electrical schematic for an 8 MW power station is shown in Figure 22.20.

22.4.5 Site conditions

The site conditions play an important role in the development of layout and scope. The more specific issues are as follows:

1. Naturally, the site location must be as close as practical to the electrical and heat users, thus minimizing cable and piping runs.
2. Altitude and ambient temperature, as discussed earlier, can have significant effect on the performance of the generator, and fluctuations over the annual operating cycle will similarly influence the power station output.
3. Exposure to dust or other pollutants that may exist in certain industrial processes will dictate requirements for such aspects as equipment enclosures and air filtration. For the same reasons, it may be prudent to avoid air-cooled heat transfer surfaces.
4. Adequate area will be required for water, chemical, fuel and ash storage with adequate access for reception and off-loading.
5. During the erection period access will be needed for the heavy loads, storage of equipment and for erection.
6. With the exception of the gas turbine, most generating schemes need a reliable and a good-quality water source for cooling. Alternative large air-cooled systems can be employed, but they are expensive and less efficient. Thermal power stations using steam condensers can require large cooling-water flows, although the cooling water consumption can be reduced by use of closed-cycle cooling-water systems. In these cases it is common to site the power station near a large water source such as a river or lake. The design of water-intake systems needs to recognize the changes in level and quality that can occur, depending on such aspects as time of year, rainfall and tides.
7. Boilers require very high-quality water for make-up, and for this purpose treatment facilities may be needed on-site, depending on the quality of the water source.
8. Civil engineering considerations such as ground conditions and drainage.

22.4.6 Plant availability and maintenance

It is prerequisite of most modern power stations that they achieve high availability. For normal operation it is common practice for power stations to employ standby equipment which is strategically important to overall operation. Examples are the use of 100% duty standby pumps or compressed air plant. Depending on the size of installation, $3 \times 50\%$ units can be employed with 50% standby capacity and lower initial cost. For similar reasons, security of fuel and water supplies must be addressed. Adequate fuel storage may be necessary to meet anticipated shortages in supply or, alternatively, standby fuel facilities incorporated. Water storage will be needed again to cater for periods when shortages occur.

Adequate consideration to the above will ensure that outages are minimized and maximum availability is achieved. However, at some stage the generator or generators will be closed for maintenance, and in these circumstances consideration must be given to making up the

Table 22.8 Checklist of power station auxiliary components

Fuel system

Coal:
Rail sliding
Wagon puller
Tippler
Ground hopper
Conveyor
Crusher
Screen
Sampling
Mag. separator
Stocking-out conveyor
Conveyor (reclaim)
Transfer tower
Bunker conveyor
Dust extraction
Coal feeder
Coal mills
Pneumatic transfer system

Oil:
Bulk unloading pumps
Bulk storage tanks
Tank heater
Forwarding pumps
PH and filtering sets
Oil pipework
Steam pipework
Tracing elec./steam
Daily service tank
Fuel-treatment plant
Steam/gas turbine/diesel house
Boiler house
CW pump house

Ash handling
Clinker grinder
Clinker conveyor
Econ. dust conveyor
Air heater dust conveyor
Rotary valves
Dust collector dust conveyors
Rotary valves
Ash conditioner
Ash silo
Ash sluice pump
Make-up water pump
Pneumatic conveying system
Conditioned ash conveyor
Submerged ash conveyor

Water systems
Bar screen
Travelling-band screen
Wash-water system
Penstock
Intake pump/circulating pumps
Valves
Chlorination plant
Crane/lifting equipment
Cooling tower (ID/FD/natural)
Settling pond

Boiler water treatment
Base exchange
Dealkylization
Demineralization
Demin. water tank
Demin. water pump
Bulk acid and alkali storage
Neutralizing

Chemical dosing
LP dosing set
HP dosing set
CW dosing set

Miscellaneous
Air compressor (plant)
Air compressor (inst.)
Air compressor (coal pneumatic system)
Air compressor (ash pneumatic system)
Firefighting equipment
  Detection
  Portable
  Hydrant system
  Springer system
  Panel
  Halon/CO_2
Pressure-reducing set
Press. red. and desuperheating set
Ventilation
  Turbine hall
  Boiler house
  Switchrooms
  Battery room
  Water-treatment room
  Admin.
Air conditioning
  Control room
Hydrogen-generation plant
Electroysis
Bottle storage

Piping system
Main steam
Process steam
Feedwater
Raw water
Treated water
Potable water
Aux. cooling system
Firefighting system
Clarified water
Filtered water
Water-intake system
Circulating-water system
Chemical dosing
Station drains
Fuel oil
Fuel gas
Compressed air (plant)
Compressed air (inst.)

Electrical equipment
Generator
Unit auxiliaries
Station auxiliaries
Low-voltage auxiliaries
HV and LV switchgear
Generator circuit breaker
Batteries and charger
Main power cabling
Cabling and wiring
Lightning protection
Earthing
Telephones/intercom
Protection equipment
Electrical controls, inst. meters
Lighting and small power
Temporary supplies
Elec. trace heating
Generator
AVR
Generator VTs
Busbar equipment
Synchronizing equipment

Civil
Building/annexe for:

Water treatment
Feed pumps
Fuel handling/metering
Control room
Switch house
Offices
Admin. building
Gatehouse
Site fencing
Roads
Plant drains
Storm drains
Foundations for mech. and elec.
Plant and tanks
CW culverts
Cooling tower found.
Chimney found.
Crane rails
HVAC
Plumbing and sanitary fittings
Domestic water supply
Tanks/reservoirs
Site investigations and ground
Loading tests
Demolition of existing plant and buildings
Connection to existing plant and buildings
Temporary works

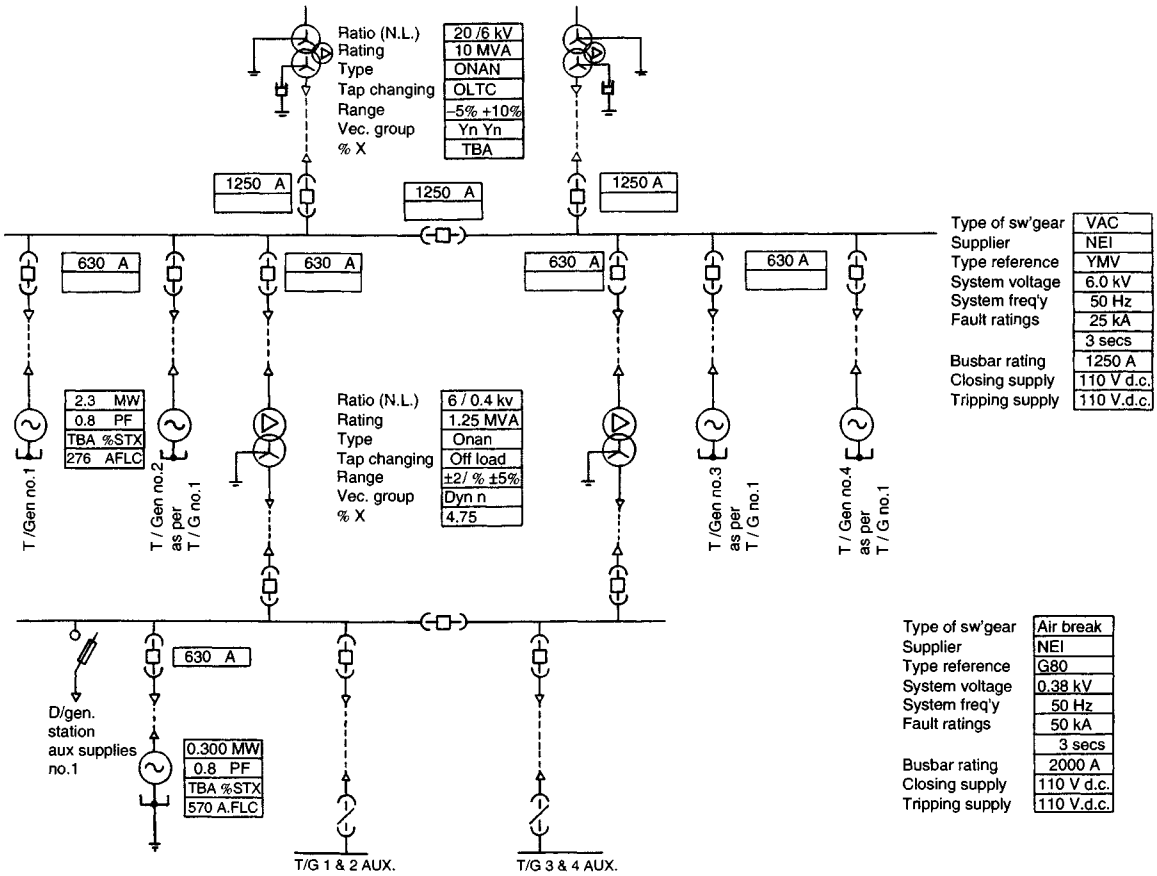


Figure 22.20 Typical electrical single-line diagram for an 8 MW power plant

electrical supply. For essential electrical loads an alternative source is needed and, at a premium, this could be supplied from the electrical supply company or from a standby generator. A standby generator will increase capital cost, but in some cases this is essential to meet the needs of total security of supply.

For locations in the Middle East subject to wide fluctuations in ambient temperature it has been common to utilize multiple gas turbines which are sized to meet the plant demands during the hot summer months and the cold winter. As the gas turbine output increases substantially there is sufficient spare capacity to allow for outage of machines without affecting the electrical power export. However, this situation is unique to the environmental conditions and type of equipment in service.

The plant components selected should be of proven design supported by strong reference installations. Modern trends are moving towards reduction in manning levels, and the use of central computer control and supervisory systems also ensures maximum efficiency of plant operation.

Specific details on maintenance of plant are given later. However, in developing the station layout adequate thought must be given to cranage, laydown areas and access for maintenance of heavy plant.

22.4.7 Environmental aspects

The effects of the power station on the local environment will be controlled by local regulations and laws. The significant considerations are:

1. Exhaust emissions of SO_x, NO_x and particulate matter.
2. Height of chimney.
3. Noise levels at the site boundary.
4. Treatment of boiler and water treatment plant effluent.
5. Architectural features and design of buildings and structures.

22.4.8 Generated voltages

The selection of generated voltage will be determined by the voltages available on-site, the amount of generation envisaged and the full load and fault current ratings of existing and proposed equipment. Following the completion of the installation, the fault levels occurring at each point within the installation (including the equipment within the supply company system) must be within the capability of the equipment, particularly the switchgear installed.

The factors affecting the generator circuit itself are related to the relative cost and availability of equipment to

be used in that circuit. Generators rated at up to 2 MVA, 2782 A at 415 V can be accommodated within standard low-voltage switchgear ratings of, typically, 3000 A full load current and 50 kA fault capacity. Generators rated larger than 2 MVA but less than 20 mVA will be usually operated at 11 kV, although at ratings of between 2 and 5 MVA, a lower-voltage 3.3 kV or 6.6 kV may be considered due to the capital cost of the generator.

22.5 The selection

It should be borne in mind that there is no single answer as to which configuration of equipment is best for any individual power generating scheme. Each alternative must be considered on its own merits, including the use of all available fuels.

22.5.1 For electrical power

For generation of electrical power only, the overriding influence in the choice of generating plant is fuel availability. In this respect the following categories can be applied:

Diesel (light and heavy fuel oils)
Gas turbine (gas and light fuel oils)
Gas turbine and combined cycle (gas and light fuel oils)
Thermal power plant (coal, lignite, wood and biomass)

For the criterion of fuel to electrical energy conversion efficiency, the diesel and gas turbine are natural choices for prime fuels such as oil and gas.

In open cycle the diesel has the higher efficiency, making it more attractive for light fuel oils. However, in combined cycle the gas turbine often has the highest overall efficiency, but there is the penalty associated with the additional cost for boiler and turbine. Nevertheless, unless the prime fuel is of low cost, the use of combined-cycle gas turbine plant will prove to be the more economic.

For industrial or commercial applications the straightforward condensing thermal power plant cannot compete with the diesel or gas turbine, as its first, or capital, cost is significantly higher and its overall efficiency is low. However, successful smaller thermal power plants have been installed where the fuel is of low cost to the user. In these cases the efficiency will be of less significance, and the much lower running costs when compared with prime fuels such as oil makes the thermal power plant an attractive alternative.

The overall efficiency of the condensing thermal cycle, as discussed, is dictated primarily by the steam conditions used. There are some small industrial stations with outputs up to 2 MW using shell-type boilers for the generation of steam. Here the steam conditions are limited to approximately 17 bara and 250°C. For larger installations these conditions will rise sharply when watertube boilers become attractive and more common steam conditions are of above 60 bara and 540°C.

Having decided the type of generator, the next questions are the capacity and unit sizes. It is usual for the total installed capacity to be capable of meeting the peak demand with spare capacity to meet outages for maintenance. However, consideration can be given to a supply from the electricity supply authority for peak demands and standby.

To meet the needs of a given output, a single generator could be provided, and this option is likely to give the lowest initial cost. However, the alternative of two or more machines, of the same total capacity, while more expensive initially gives higher availability, better flexibility of operation and improved load-following performance.

In isolated areas it may be a requirement that at least one unit is needed for standby to meet security of supply, and this can be provided by $2 \times 100\%$ or, say, $3 \times 50\%$ units. Availability is maximized as the standby unit can be brought into operation during outage of one of the normally operating machines.

This is best illustrated by the following example for a rural development project. The electrical power demand is shown in Figure 22.21 and was developed from historical data generated from similar developments in other regions. The operating statistics indicated that the maximum demand would occur at night peaking to 8 MW with a low day demand of 2 MW. Considering these power requirements, the station must be flexible and have the ability to follow the daily load pattern. In addition, because of the isolated location the power station must be sized for 'stand-alone' operation. Equally important factors are maximum availability and operating efficiency.

The use of a local indigenous coal source dictated the choice for thermal power plant. Considering the forecast power demand, it is feasible for an 8 MW turbine/boiler unit to be installed to provide the ultimate load requirement. However, the single power unit is not flexible in that it does not give the required security to cover for routine and statutory shutdowns for maintenance and is less efficient at part load (see Figure 22.22). Provision of multiple small units is the ideal solution, as it allows the station to be operated more flexibly, enabling the units to be put into or taken out of service as the power requirement demands so that the operating units run close to peak

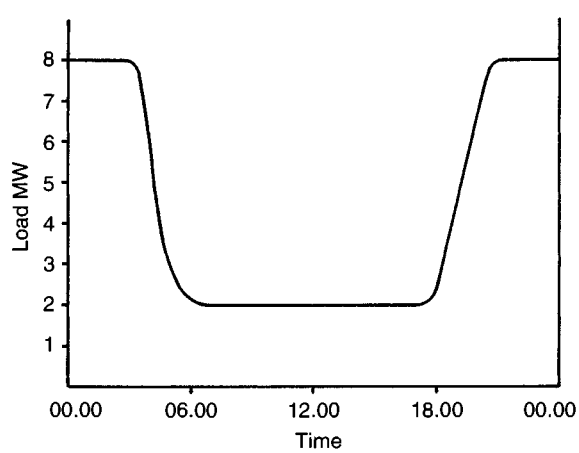


Figure 22.21 Daily load cycle for a rural development project

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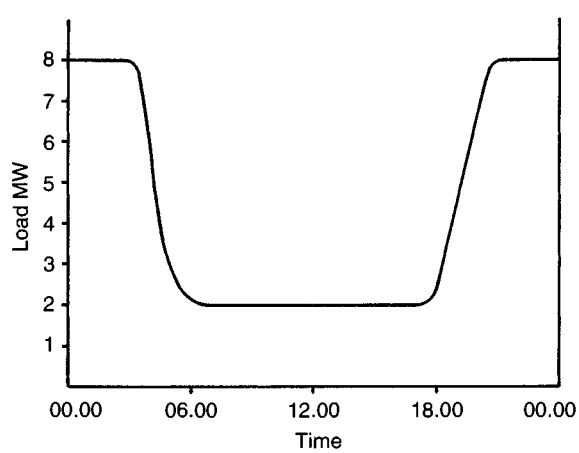


Figure 22.21 Daily load cycle for a rural development project

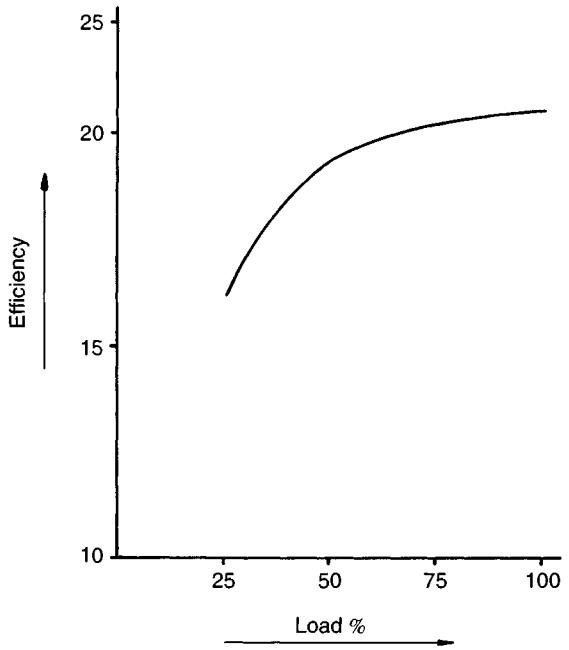


Figure 22.22 Overall efficiency of a typical coal-fired power station of 4.6 MW capacity

efficiency. From this examination the optimum scheme is 5 × 2 MW units with four units providing the normal power requirements and the fifth to cover for standby.

22.5.2 For combined heat and power

As discussed earlier (Section 22.3), steam turbines providing low-pressure steam are more established for CHP. However, for lower heat loads the diesel and gas turbine with waste heat recovery offer an attractive alternative.

22.5.2.1 Steam turbines for CHP

The first parameter to resolve is the process steam pressure or pressures. These will be dictated by the process-heating temperatures, noting that the steam will transfer its heat at constant pressure and at saturation temperature. It is in the interests of efficiency to keep the process steam pressure as low as practical. Also influencing the process steam pressure is the distribution pipeline from the turbine exhaust to process. Reductions in the pipeline pressure loss increases pipeline size and cost.

The selection is dictated by economics governing the initial plant cost versus higher turbine output. Usually, the turbine exhaust steam is designed to be slightly superheated, which is desirable, as it allows for heat loss from the steam with minimum condensate losses. At low loads from the turbine the degree of superheat can rise sharply, well in excess of the normal design conditions, and for this purpose desuperheaters are often employed to trim the steam temperature at exhaust.

The choice of boiler steam inlet conditions is usually dictated by the desire to achieve maximum output from the process steam flow. This requires high boiler steam pressure and temperature. However, there are practical considerations to observe. Above 40 bar more exacting feedwater treatment is necessary, and therefore it may be advantageous to maintain pressures below this figure. High steam and temperatures can also influence selection of boiler materials such as alloy steels. The upper limit for industrial applications is around 60 bara and 540°C.

For watertube boilers it is necessary to maintain low O_2 levels, and for this purpose a de-aerator in the feed line is required, which will also provide a degree of feed heating. The steam supply can be taken down from the low-pressure process steam main.

If a condenser is employed for a turbine with a condensing section then it is normally chosen to provide the best thermodynamic efficiency consistent with an economical capital expenditure. The condenser exhaust vacuums are usually 0.05 bara or higher.

Having ascertained the process steam flow and developed some ideas on the boiler pressure, the following step is to analyse the power available. Figure 22.23 provides a ready means of determining the approximate relationship between power available and process steam for specific steam conditions. Use of this and similar charts will allow an assessment to be made of the potential of a CHP scheme with a back-pressure turbine. The conditions can be changed to give the required balance for heat and power.

The electrical and heat analysis, as discussed in Section 22.3, will show the relationship between power and heat and how this varies over time. It may be necessary to use steam bypass stations or dump condenser, as discussed in Section 22.2. The use of dump condensers for meeting part-load requirement is inefficient and should be avoided. It is more acceptable to reduce turbine

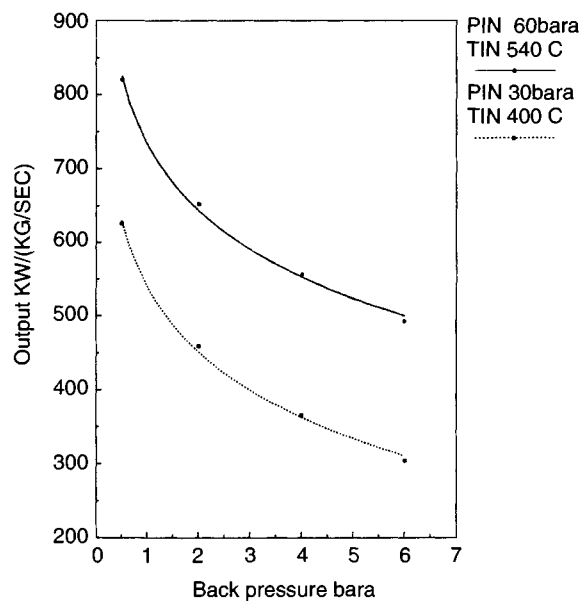


Figure 22.23 The effect of back-pressure upon steam turbine performance

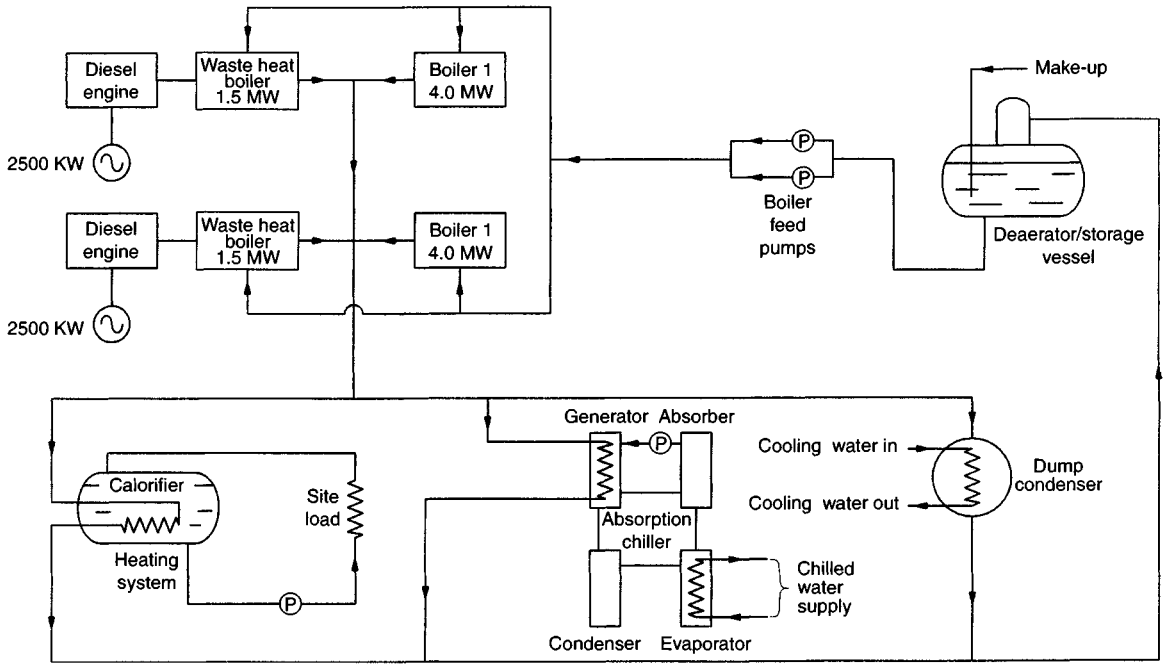


Figure 22.24 Example of a small diesel-engined combined heat and power scheme

power output accordingly and import or top-up from an alternative supply.

22.5.2.2 Diesels and gas turbines for CHP

It is generally recognized that below around 5:1 heat ratio the steam turbines in CHP become less suitable, and here the diesel and gas turbines play an important role in providing heat and power. As discussed earlier, the simple addition of waste heat boilers gives additional heat output without further input of fuel to the generator.

For flexibility supplementary firing of the oxygen rich exhaust gases can give additional heat. The following summarizes the potential of both the diesel and GT for waste heat recovery:

	Unfired	Supplementary fired
Diesel	1:1 0.6:1 (excluding the cooling-water services)	5:1
Gas turbine	2:1	15:1

This gives indicative heat/power ratios only: an actual performance will depend on the machine.

Using these guidelines it is a simple matter of matching the electrical and the heat loads. An example is a scheme which was envisaged for the supply of power and heat to a computer centre using a diesel engine with waste heat recovery. Figure 22.24 shows the proposed scheme where heat generated provides the site demand and operates with absorption-type chillers for chilled water production. The use of these chillers also reduced the electrical demand. The electrical load was a steady 2.5 MW over the year with short duration peaks of 2.9 MW. To allow for future growth, 2 x 3.6 MW diesels were selected (one operating and one standby). The electrical load calculated was 21.75×10^6 kWh/yr, and applying a useful heat recovery ratio of 0.6:1 (not including engine services), this gives 13×10^6 kWh/yr of heat energy, which is steadily available over the year. The hot water and chilled water heat loads are shown in Figures 22.25 and 22.26. As the

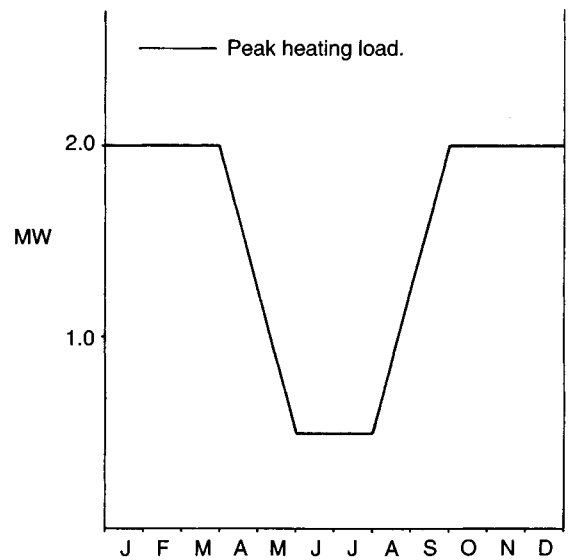


Figure 22.25 Hot water heat load. The annual heating requirement is 5.2×10^6 kWh

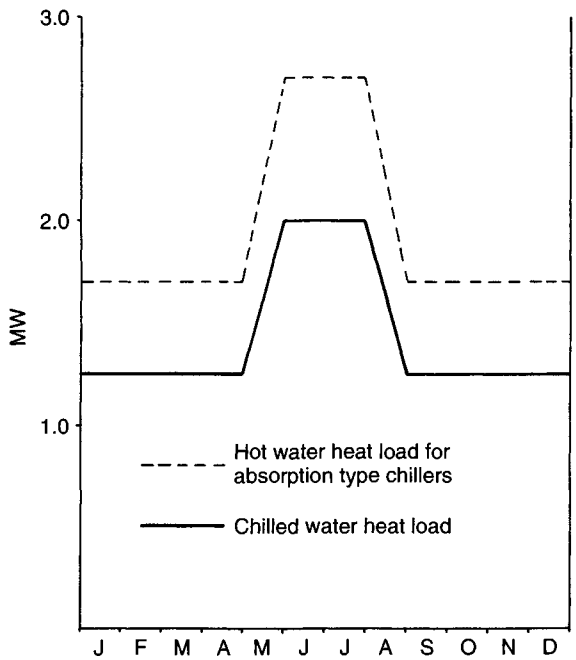


Figure 22.26 Chilled water heat load. The annual chilled water heat load is 13×10^6 kWh; the annual hot water heat load for absorption-type chillers is 17.4×10^6 kWh (a COP of 75%)

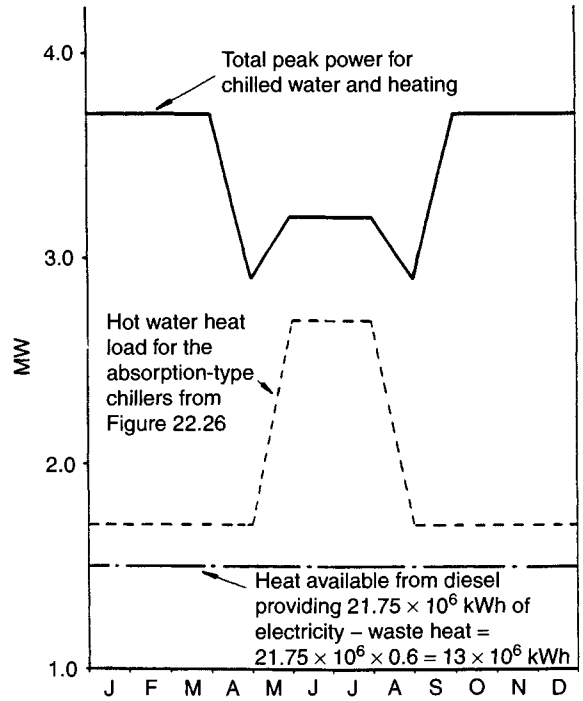


Figure 22.27 Total heat load. The heat available from the diesel waste gases of 13×10^6 kWh will provide only a proportion of the heat required for the absorption-type chiller

site heat load and chilled water load peak at different times of the year, this gave a relatively steady overall heat load, as shown in Figure 22.27. This total heat load is given as 22.6×10^6 kWh per annum. Supplementary heat is therefore necessary to provide the additional $(22.6 - 13) = 9.6 \times 10^6$ kWh per annum. For security of supply this was provided by 4 MW boilers capable of giving full independent supply.

The diesel and gas turbine with waste heat recovery are limited in terms of fuel application being suitable for gas and oils only. Also when considering oil fuel firing careful attention must be given to the effects of sulphur in the exhaust gases, as this will place limitations on the boiler performance.

22.5.3 Economic considerations

An economic evaluation will ascertain the cost for power generation when compared with purchase of electricity and (where applicable) generation of steam in low-pressure boilers. This evaluation will take the following into account:

1. *Capital cost* This cost must cover the supply and erection of all the new plant, including auxiliary systems or modifications to existing as necessary, electrical plant, control and instrumentation, civil works, new buildings and demolitions if appropriate. It will also include all payments, management and engineering fees, insurance and inspection costs – in other words, all the necessary costs for the completion of the project. This may also include the initial holding of strategic spares.

2. *Fuel costs* Capital cost and fuel costs are closely interrelated. For example, within a specific industrial range the thermal power plant can be three times more expensive than an equivalent rated diesel. However, thermal power plant can utilize lower cost fuels and, when taking into account diesel costs for consumables such as lubricating oil and maintenance spares, the thermal power plant can be attractive over the longer term. The fuel consumption must be established from an analysis of the load profile and overall efficiency of the station at various part loads. In addition, the analysis must also take into account the effects of ambient air temperature changes on air intake mass and cooling water temperatures, as these also influence efficiency. It is prudent to add a small percentage to cover for load-following and deterioration of efficiency that may occur over a prolonged operating period. The fuel consumption should also include any anticipated supplementary firing needed on CHP schemes.

3. *Chemical consumption* The chemical consumptions will be associated with boiler feed make-up water-treatment plant, dosing systems for feedwater and boiler system, treatment of cooling water circuits and effluent treatment. Typical chemical requirements for a thermal power plant are given in Table 22.9.

4. *Feedwater costs* Depending on the source of water supply, there may be charges for water consumption. This consumption will be dictated by the make-up water needs for the station.

Table 22.9 Typical chemical requirements for a 60 MW industrial steam-generating plant

Chemical	*Location*	*Quanity*
Hydrochloric acid (HCL)	Water-treatment plant (cation)	165 kg/day at 30% solution
	Effluent neutralization	14 kg/day at 30% solution
Caustic flake (NaOH)	Water treatment plant (anion)	221 kg/day at 25% solution
	Effluent neutralization	14 kg/day at 25% solution
Oxygen scavenger (e.g. hydrazine)	LP feedwater dosing	8.5 kg/day at 25% solution
pH control (e.g. ammonia)	L1 feedwater dosing	24 l/kg/day
Phosphate	Boiler dosing	Consumption depends on blowdown rate for boiler
Corrosion inhibitor Bacterial control	Cooling-water system	Consumption depends on make-up Chemicals are used to provide adequate reserve

5. *Consumables* All consumables required for normal operation should be accounted for. Typical examples here are diesel lubricating oil consumption and oil changes at service intervals.

6. *Labour costs* These will depend on the manning levels and degree of automization of the plant.

7. *Maintenance charges* Maintenance costs as an average over the plant life (based on previous experience and guidance) should be sought from the manufacturer.

8. *Purchased power costs* Depending on the schemes applicable, there may also be charges for import of electrical power. Typically this may comprise a sum based on a maximum demand charge, a unit charge and a fuel cost adjustment. Depending on circumstances, there may also be a fixed annual charge to cover rent of the supply company's equipment.

9. *Inflation* After economic analysis it may be necessary to review how inflation may influence the costs for the items purchased.

10. *Erection periods* The period of erection can be critical, as this dictates when power will be available and income earned. Depending on the size of the station and scope, this could vary between less than 6 months to over 2 years. For systems such as the combined cycle it is practical to commission the gas turbines first in advance of the steam generators, so that useful power is generated at the earliest possible date.

22.6 Plant and installation

In order to operate the prime movers described in the previous sections it is necessary to provide auxiliary equipment for the start-up, steady operation and shutdown of the basic equipment as well as for monitoring and controlling its performance. The need also arises for the maintenance of the plant which invokes the provision of cranage and lay-down areas in the engine room. The following describes these features for the various types of prime movers. The driven machines (i.e. the electrical generators) are also reviewed in detail so that the complete picture of industrial generating stations can be obtained.

22.6.1 Diesel power plants

When driving a generator the diesel engine is usually a multi-cylinder machine similar in appearance to that shown in Figure 22.28. The figure illustrates a nominal 3 MWe engine with twelve cylinders in Vee formation, such an arrangement being attractive for its compactness. The engine will be required to operate at synchronous

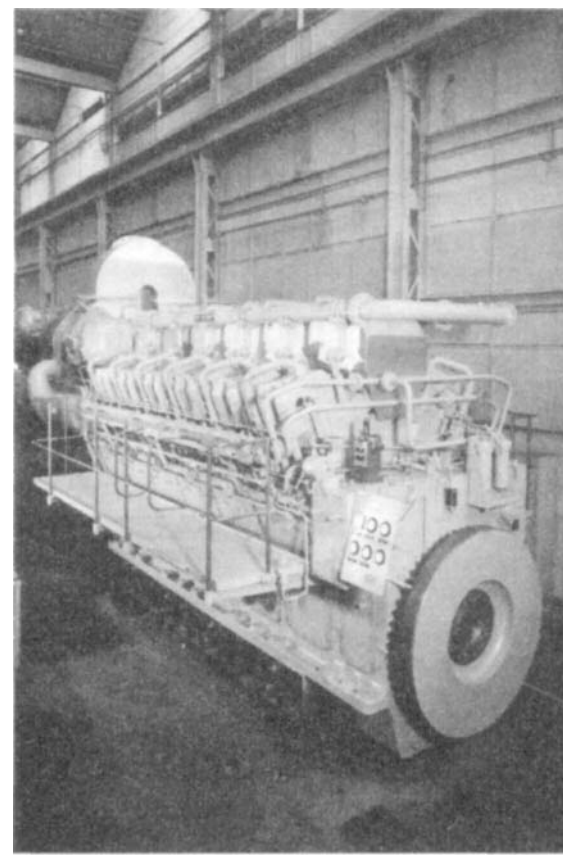


Figure 22.28 A Vee-12 diesel engine

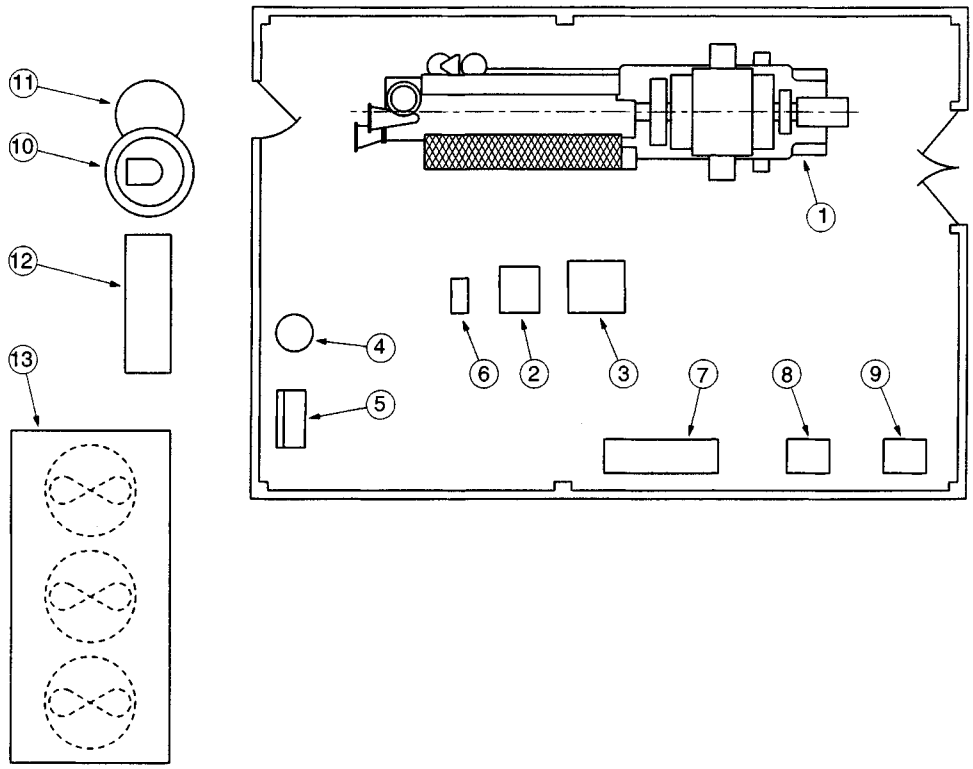


Figure 22.29 The layout of a typical diesel generator engine room. 1 Diesel generator set; 2 jacket water header tank; 3 lubricating oil service tank; 4 air receiver; 5 diesel-driven compressor; 6 batteries and charger; 7 engine control panel; 8 pneumatic control panel; 9 fuel oil control panel; 10 engine exhaust silencer; 11 charge air filter; 12 daily service fuel oil tank; 13 three-section radiator

speed which is, in turn, dependent upon the required frequency (f) and the number of generator pole-pairs (p). We have

$$\text{Operating speed, } N = \frac{60f}{p} \text{rev/min}$$

A typical block layout for a diesel engine room is given in Figure 22.29, showing the necessary auxiliaries and local control panels. Not shown but also necessary are cranes and fire-protection systems. The engine room itself must additionally provide sufficient noise attenuation as shall be deemed necessary, and there must also be adequate fuel storage, reception and handling facilities.

A key issue also concerns the foundation requirements of the generator set. Most manufacturers will provide data on their machines' requirements, but the detailed design of the block and its interface with the engine bedplate require close attention. Sometimes it is possible to provide a basement for the engine auxiliaries, while ventilation considerations (excluding combustion air requirements) should recognize that some 8% of the engine's rating will be radiated as heat, in the absence of any heat-recovery equipment.

The compression ignition engine can operate on a variety of liquid fuels and gas. Modern designs permit reliable operation on up to the heaviest residual oils, so permitting improved fuel flexibility (providing, of course, that an adequate fuel-handling capability is also present). The engine may also operate in a dual-fuel mode, using a mixture of gas and air with the option to revert to a liquid fuel in the event of any interruptions to the gas supply. Thus a more complex control and protection system must be provided in order to give modulation for both the oil and gas flows.

22.6.1.1 Air intake

The quality of the air supply directly affects the output, efficiency and life of the engine. The requirement of the induction system must therefore be to supply the engine with clean dry air close to ambient temperature conditions. Oil bath or dry (paper element) filters are adequate for low dust concentration conditions. However, as the dust burden of the air increases, centrifugal pre-cleaners become necessary. The combustion air requirements of a diesel may be taken, for estimating purposes, to be $9.5\,m^3h^{-1}$ per kW generator rating.

22.6.1.2 Cooling

For small engines below 0.5 MW output, air cooling can be considered. However, water cooling by circulation of water through cylinder jackets is the method normally used for diesel generating plants. Fan-cooled radiators (as seen in Figure 22.29) or the system shown in Figure 22.30 are typical. As an alternative to the cooling

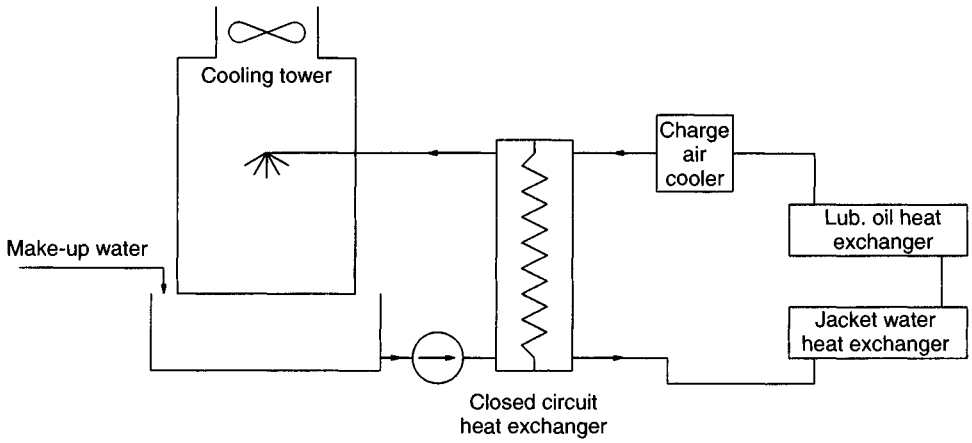


Figure 22.30 A typical closed-circuit secondary cooling system

tower, when a good source of raw water is available (such as from a river) this can be used on one side of the heat exchanger.

22.6.1.3 Engine starting

For small high-speed engines, electric start systems, incorporating lead-acid or alkaline batteries, are practical. For larger machines air-start systems are normally used. Using compressed air, starting may be effected by means of an air-driven motor engaging the flywheel or by directing air into each cylinder, in firing sequence, by means of a camshaft-driven distributor or mechanically operated valves. The air so needed can be provided from receivers charged up when the engine is running or from a small auxiliary compressor unit. The latter system is most common on the larger installations, while on critical engines an electric motor-driven compressor is backed by an IC engine-driven unit.

22.6.1.4 Control and instrumentation

Engine speed is controlled by the use of variable-speed governors which can be mechanical, mechanical-hydraulic or electronic. The last option is gaining wide acceptance for generation purposes due to its speed of response and ready integration with other control equipment used in fully automated installations (probably incorporating more than one generating unit).

Stop, start, emergency stop and speed controls are grouped adjacent to the engine, and the machine is usually equipped with instrumentation for monitoring its safe operation. Very often a centralized control room is provided, particularly when there are a number of units in operation. Typical signals monitored and recorded remotely are:

Engine and turbocharger speeds
Hours run
Lubricating oil pressures and temperatures
Starting and change air pressures
Cooling-water temperatures
Exhaust temperature
Typical alarms annunciations are:
Engine cooling water: High outlet temperature
Engine lub oil system: Low inlet pressure
Fuel system:
  Service tank: Low level
  Engine inlet: Low pressure
Overspeed protection:
  Engine speed: High
  Emergency stop: Operated

22.6.1.5 Maintenance

The diesel engine, being a reciprocating machine, is mechanically complex, and in arduous environments its wear rate can be high. Major overhauls on high-speed engines are usually stipulated at 15 000 running hours, which extends to 20 000 and 30 000 on medium- and low-speed machines, respectively.

The major class of failure concerns the fuel supply and fuel-injection equipment followed by the water-cooling system, valve systems, bearings and governors. Collectively, these five categories account for some 70% of all engine stoppages. Thus the maintenance programme must take careful cognizance of these areas together with the manufacturer's recommendations. Under arduous conditions where fuel quality is questionable, where there are high dust levels or where the machine is subject to uneven and intermittent loading, enhanced maintenance at reduced intervals must be recommended.

Lubrication clearly plays a significant role in the reliable operation of the engine. In addition to the lubricant's primary task of reducing friction and minimizing wear it also acts as a cooling medium, a partial seal between the cylinders and piston rings, and a means of flushing combustion and other impurities out of the engine.

A pressurized lubrication system using an engine-mounted pump is the choice of most manufacturers. A sump in the crankcase or an external drain tank together with filters and coolers complete the system.

The choice of oil should be consistent with the manufacturer's recommendation, and should only be varied if the engine is intended to be operated in unusual or extreme conditions.

22.6.1.6 Diesel engines with heat recovery systems

As illustrated earlier (Section 22.3.2), the utilization of heat otherwise lost in the engine exhaust (and also the cooling water) can be put to use in providing steam for process. Alternatively, this heat can be used for fuel preheating or to power a steam turbine via a steam generator. Figure 22.31 shows a two-engine arrangement with a waste heat-recovery system supplying superheated steam to a small steam turbine.

In the above example a relatively complex steam generator of the watertube type has been adopted. Where lower-quality steam for process or fuel heating is required, a simpler shell (or firetube) design may be appropriate. In some cases, supplementary firing may be provided for the boiler, so further increasing plant complexity and with it the need for enhanced control and maintenance requirements.

22.6.2 Gas turbine power plants

The combustion gas turbine is, in many respects, the most attractive means of producing power. Today the advantages of reliability, simplicity of operation and compactness outweigh the disadvantages posed by the price of the fuel required to operate it. A typical land-based machine is shown in Figure 22.32. Gas turbines are normally rated at notional sea-level (ISO) conditions when burning a specified fuel.

For land-based power-generation applications there is also a significant sub-division with the availability of aero-derived machines and specifically developed industrial designs. The smaller (up to some 42 000 hp) aero-derivatives can accept load very rapidly and will operate in remote hostile environments. Larger machines, with sizes in excess of 140 MWe, are of the industrial type taking perhaps some 30 min to reach full load. Gas turbines require a start-up drive capable of achieving a high rotational speed so that they can become self-sustaining. A typical start-up and stop schedule is shown in Figure 22.33. The power consumption of the start-up device will be between 5% and 10% of the machine rating.

As the simple (or open-cycle) gas turbine is relatively inefficient (see Table 22.1), improved efficiency can be achieved at the expense of complication and first cost by recovering some of the heat from the exhaust. One arrangement employing heat exchangers in a closed circuit system is shown in Figure 22.34. However, the most popular means of recovering a significant proportion of the gas turbine's utilized heat is by means of a combined-cycle arrangement discussed in Section 22.2.4.

22.6.2.1 Combined-cycle plant

The range of sizes, plant configurations and cycle parameters make this option extremely flexible, permitting electrical outputs of up to 100 MW to be considered by certain industries (such as aluminium smelters). It is

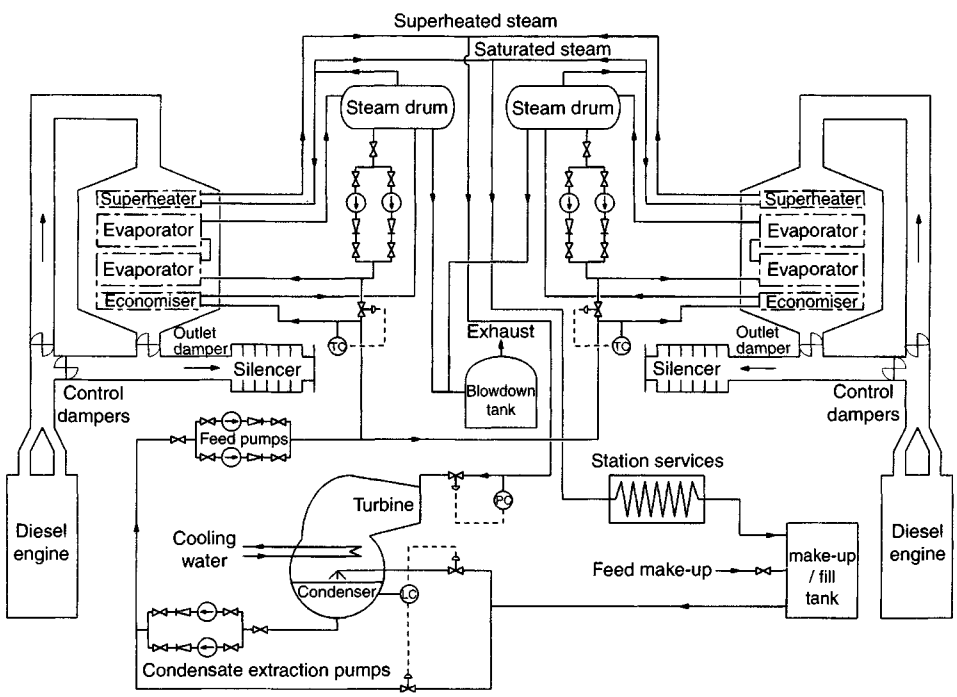


Figure 22.31 A two-engine diesel power plant with heat recovery

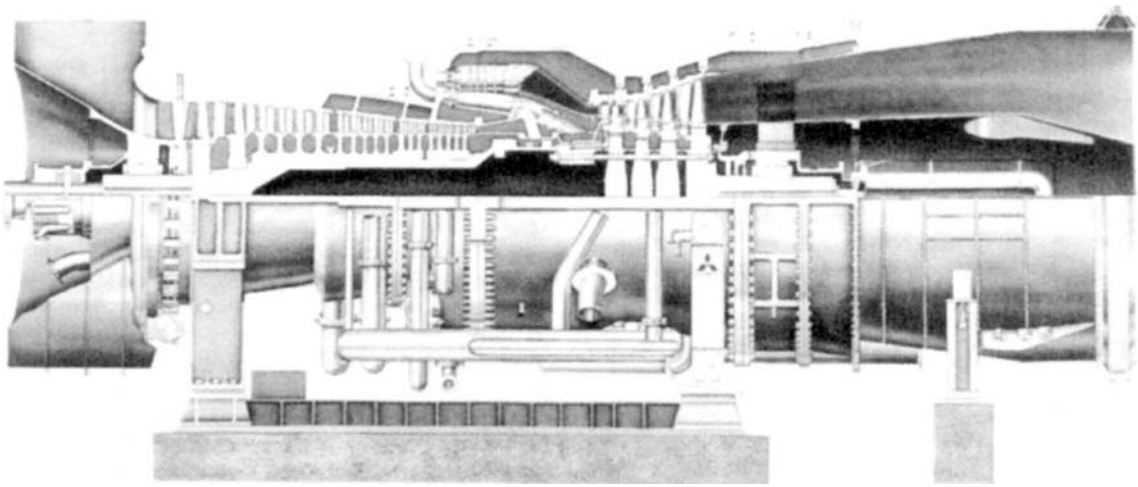


Figure 22.32 The Mitsubishi MW 701 gas turbine rated at 131 MW (ISO)

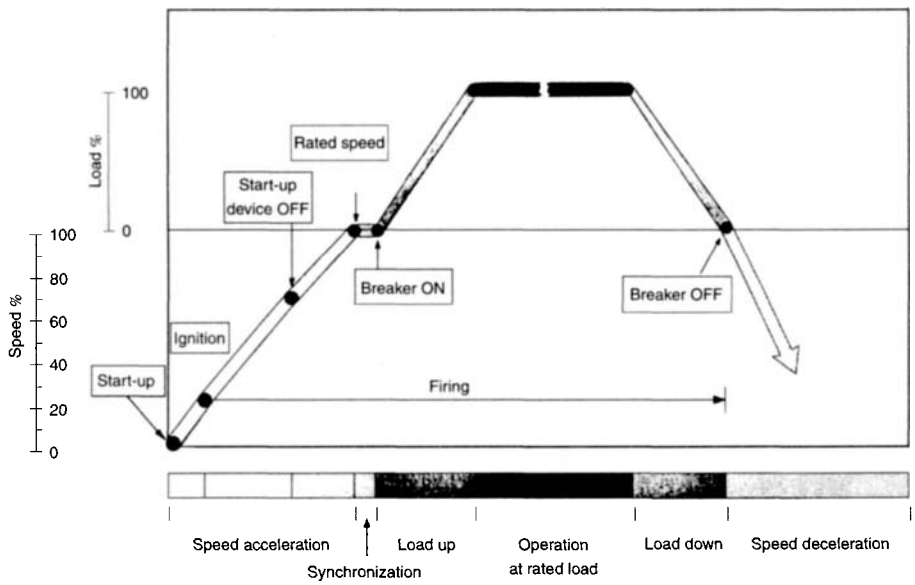


Figure 22.33 Gas turbine start-up and shut-down schedule

now becoming common practice to consider block configurations consisting of two or three gas turbines plus the associated waste heat-recovery steam generators providing steam for a single steam turbine. The 2 + 2 + 1 option has the advantage that the ratings of both the gas turbine and the steam turbine alternators are conveniently arranged to have the same rating. The 3 + 3 + 1 option provides better site economy with perhaps a 'power density' of some 7.5 MW/m^{-2} (as against 5.5 kW wm^{-2} for a 2 + 2 + 1 option) but no commonality of alternators.

A typical power train for such a generating station is shown in Figure 22.35. A further refinement, capable of improving cycle efficiency by several percentage points, is the introduction of dual steam pressures. If there is no requirement for the provision of process steam then it is unlikely that the extra cost and complexity of introducing supplementary firing into the steam generator would be worthwhile.

22.6.2.2 Control and instrumentation

Manufacturers now offer as standard microprocessor-based control systems as part of their gas turbine generator set. The set can therefore be controlled and monitored from panels adjacent to the machine or, if required, remotely from a central control room. In combined-cycle installations the system would be linked into the higher-level station control system.

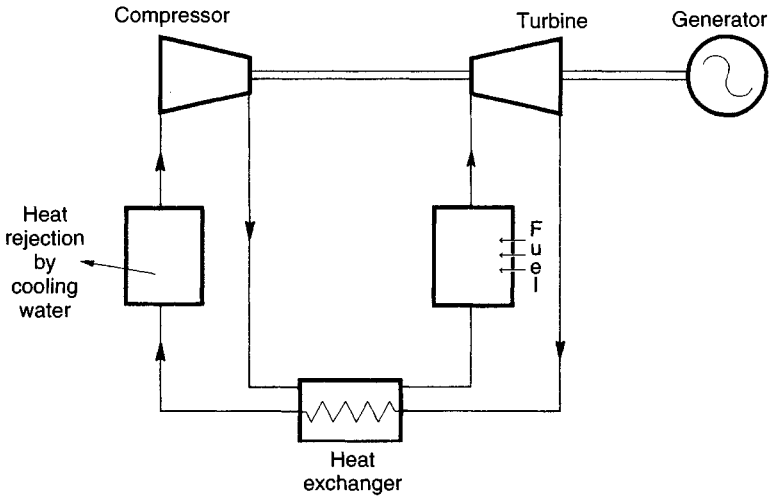


Figure 22.34 A closed-cycle gas turbine arrangement

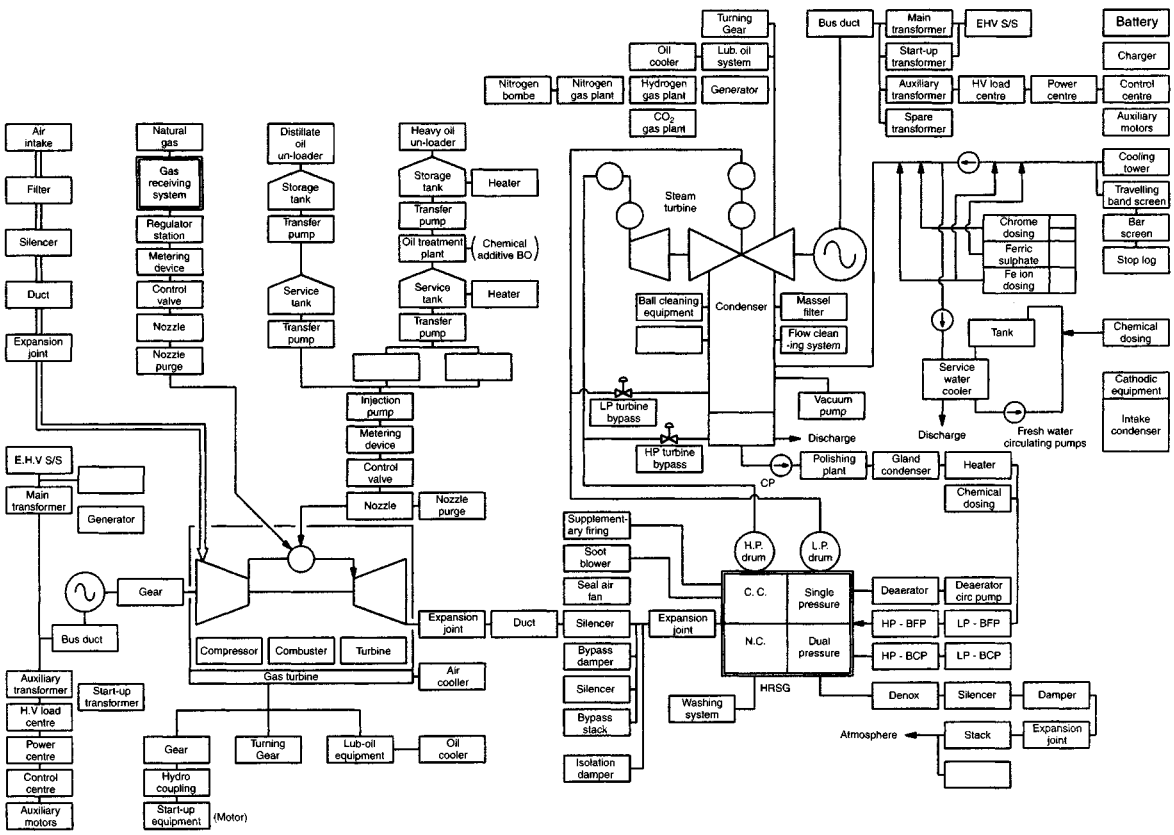


Figure 22.35 A typical combined-cycle power train

The instrumentation may typically be expected to comprise:

- Speed and load governing with electrohydraulic actuators
- Temperature control, also via electrohydraulic actuators
- Temperature, pressure and vibration monitoring systems
- Flame-detection system
- Automatic sequential control system

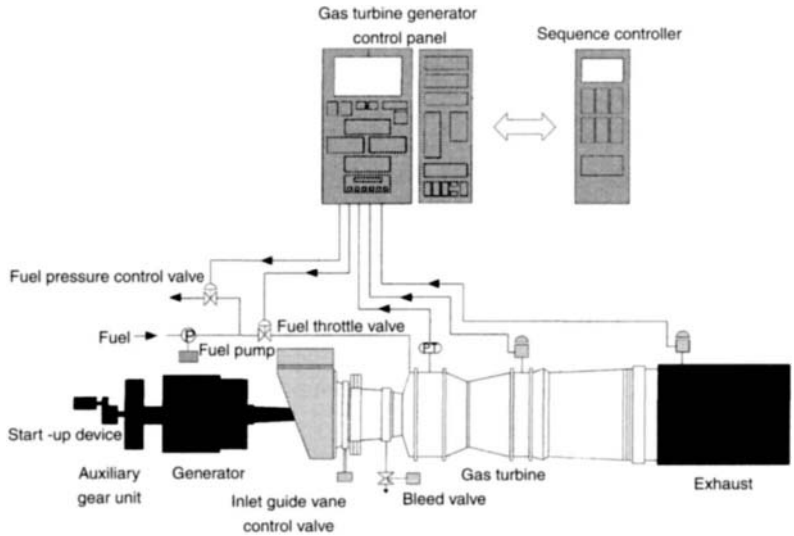


Figure 22.36 A gas turbine control system

A control system diagram for a gas turbine generator is shown diagrammatically in Figure 22.36.

22.6.2.3 Maintenance

The life and necessary maintenance of a gas turbine are heavily dependent upon both the operating regime and the fuel quality. Continuous firing on natural gas provides the optimum availability which will be progressively eroded if the plant is subject to frequent interruptions (i.e. stops and starts) from both cold and hot conditions. It may be anticipated that the combustor section will require most attention, with a maximum interval between inspections of some 8000 h. Every 16 000 h (or less) the turbine section will need inspection, while a major inspection of the entire unit will be necessary every 32 000 h. Under optimal conditions, the average operating availability of base-load and based gas turbine plant could exceed 95% (averaged over a 4-year or 32 000-h period).

22.6.2.4 Pollution control

In the past, gas turbine installations have suffered from smoke emissions. However, today, with better combustor design and combustion control, this emission has ceased to be a nuisance. Of more concern now and resulting from higher combustor (and therefore combustion) temperatures is NO_x emissions. Current legislation is tending to demand that gas turbine installations control their nitrogen emissions to levels below 25 ppm.

Such targets can be achieved in several ways, but none without some effect upon operating cost and fuel flexibility.

The NO_x constituent in the exhaust of machines firing natural gas is some 150–160 ppm, and for distillate fuels typically 260 ppm. In order to reduce these levels to the targets quoted above, catalytic filters can be used, but the systems currently available are expensive. As an alternative, low-NO_x burners are available by certain manufacturers but these limit the user to natural gas firing.

The third option incorporates the injection of water or steam into the combustion chamber(s) of the machine. Whenever possible, steam should be selected, as it has less effect upon machine efficiency than water injection. By way of example, reducing NO_x emissions when firing natural gas to within a 75 ppm limit would require steam or water injection at a rate of 60% of the fuel flow rate.

Finally, noise is also becoming of increasing concern, particularly on sites adjacent to urban areas. Acoustic enclosures, supplied by the manufacturer, will normally reduce noise levels to 85 dB, but if further reduction is required attention must be paid to the material used to construct the buildings and enclosures; low noise levels can be achieved only at a cost.

22.6.3 Steam turbogenerators

One of the most widely used means of generating power both in industry and in public utilities utilizes the steam turbine. For industrial power generation the advantages of high availability and good machine efficiency have to be balanced against relatively high first costs and the need for the provision of both expensive steam-generating plant and heat-rejection equipment. However, in many instances the recovery of waste process heat by means of a steam cycle is economically attractive.

Alternatively, the option that a steam plant offers of the provision of process steam coupled with power generation may be the key element in the selection of generating plant. The turbogenerators and their auxiliaries for use in such applications tend therefore to be relatively unsophisticated, with no feed heating, except for

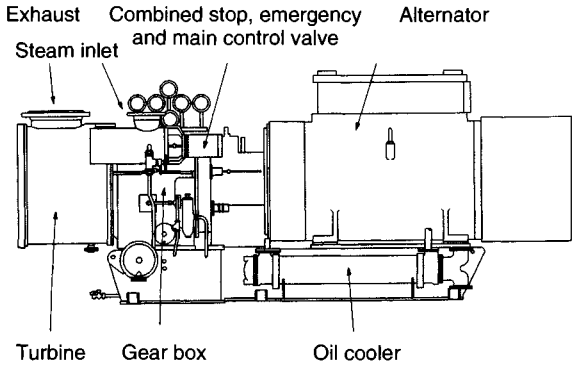


Figure 22.37 A single-stage steam turbine driving an alternator

probably the provision of a deaerator. Again, in the turbine itself, machine efficiency tends to be sacrificed for robustness and the ability to accommodate varying load conditions.

22.6.3.1 Options

The single-stage, single-valve turbine is the simplest option. Such a machine is suitable for applications requiring powers up to 300 kW, steam conditions up to a nominal 120 bar, 530°C and rotational speeds below 5000 rev/min. A typical machine is shown in Figure 22.37, characterized by an overhung rotor mounted on a stiff shaft capable of being accelerated from cold to operating speed within 10 s. The efficiency is low, but so is the cost of the installation.

For higher powers and for a wider range of steam conditions incorporating all combinations of backpressure, condensing and pass-out systems, the multistage axial flow machine is the natural choice. However, it is possible to design a turbine in which the steam flow is radially outward (or inward), passing through groups of blades set in concentric rings. Such an arrangement is known as the Ljungström turbine (Figure 22.38). Steam leakage and attendant machine efficiency deterioration have tended to discourage operators from the selection of these machines.

In the more favoured multi-stage axial flow design the blading is of the impulse type (known as a Rateau or Curtis type stage) or of the reaction type. It is popular among manufacturers to design multi-stage machines with a combination of these two types, and the most common combinations are:

1. Velocity-compounded impulse wheels followed by several single-row impulse wheels. This is a combination of the Curtis and Rateau types.
2. Velocity-compounded impulse wheels followed by impulse reaction stages (Curtis–Parsons type).
3. One or more impulse stages followed by several stages of impulse reaction blading (Rateau–Parsons type).

A typical axial flow condensing turbine for industrial application is shown in Figure 22.39.

The major considerations affecting turbine selection may be listed as follows:

1. Required power output;
2. Steam conditions available (pressure and temperature);
3. Steam cost (in order to assess the value of machine and cycle efficiencies);

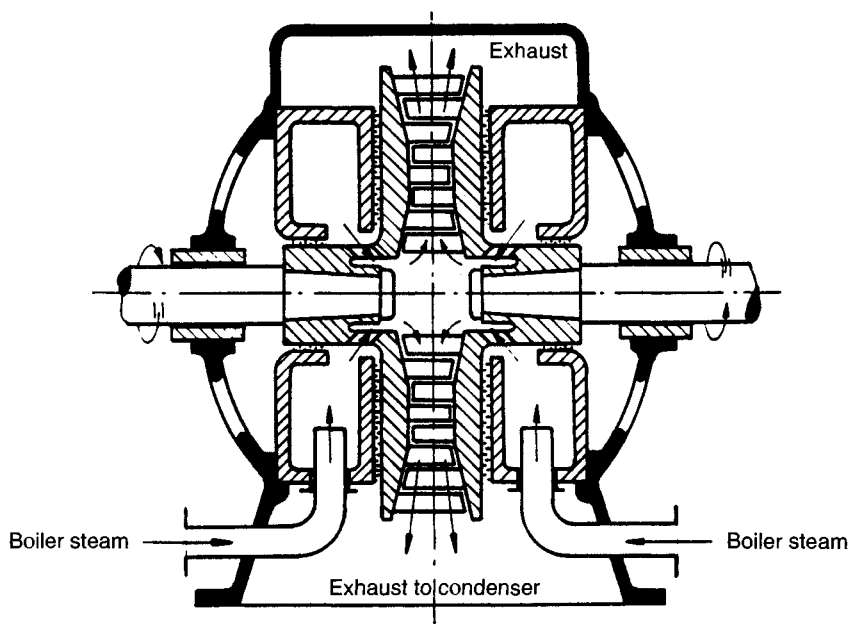


Figure 22.38 The radial-flow double-motion reaction turbine (Ljungström)

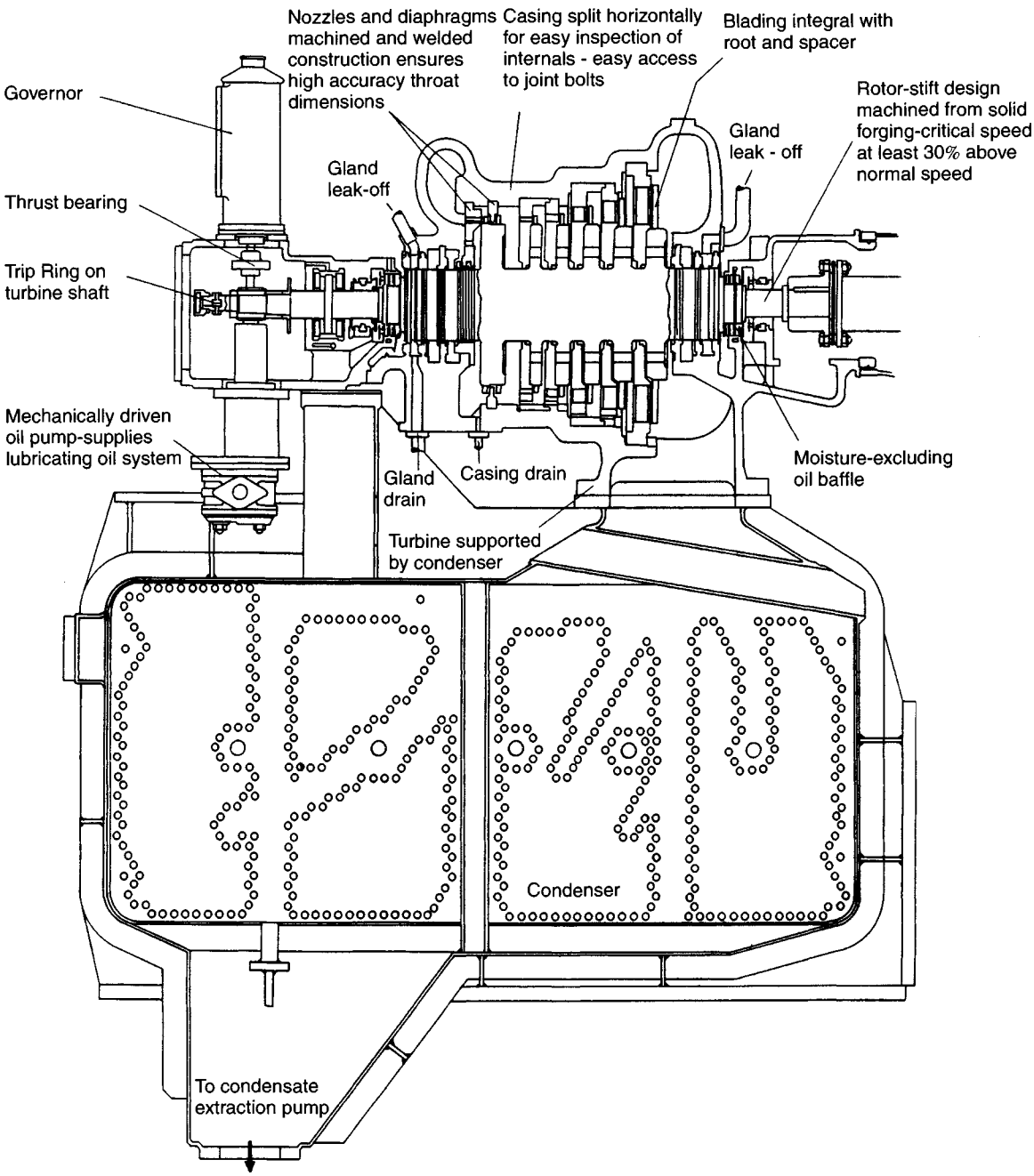


Figure 22.39 Longitudinal section of a small condensing turbine

4. Process steam requirements (to assess the relative merits of pass-out and back-pressure arrangements);
5. Cooling-water (or other cooling medium) costs and availability;
6. Control systems (ideally compatible with other process plant instrumentation) and automation;
7. Safety features (e.g. operation in explosive environments, alarm and condition-monitoring systems).

22.6.3.2 Installation

The foundations of any turbogenerator installation play a significant part in the safe operation of the machine.

Industrial turbines will normally operate at above synchronous speed and will drive an alternator via a reduction gearbox. Any vibration or out of balance occurring under both normal or abnormal operation must

be accommodated by the foundations, and their design should therefore best be undertaken by a specialist organization. The layout of the steam and water pipework, of the machine auxiliaries and, when required, of the condenser all tend to add to the complexity of the turbine island.

Where an underslung condenser has been specified, the provision of a basement to the engine room offers the attraction of compactness at the expense of enhanced civil works, while alternatively, the specification of pannier condensers can obviate the need for a basement and will simplify the foundation design, but will considerably increase the floor area requirements. The condensing plant itself consists essentially of banks of tubes through which cooling water flows and around which exhausted steam from the turbine is condensed to form a vacuum. Such tubes have traditionally been made of brass, but where severe corrosion conditions exist, cupro-nickel is sometimes used.

22.6.3.3 Control and lubrication

The turbogenerator speed must be maintained within narrow limits if it is to generate power acceptably and the control system must also be capable of preventing overspeed upon sudden loss of load. For this latter requirement fast-acting valves are necessary with full modulation within 0.5 s. The security of the turbine is also dependent upon the lubrication of its bearings, and it will be found that the control systems are closely linked with the various lubricating systems (turbine, gearbox and alternator).

A typical high-pressure, quick-response governor and lubricating system for a speed-governed turbine is shown in Figure 22.40. Basically, a speed governor controls the oil pressure supplied to the servo-operated control valves, which are arranged so that they open in sequence to ensure maximum steam economy. Other types of control systems can be incorporated with the basic speed-governed system to provide back-pressure, inlet-pressure and pass-out pressure governing. A typical fully interlinked control system for a pass-out system is shown in Figure 22.41.

Oil is supplied to these systems by a pump normally driven from the turbine rotor, with an auxiliary pump for use when starting the turbine. The main lubricating oil pump draws oil through a suction strainer and discharges to the emergency valve and hence through a cooler and

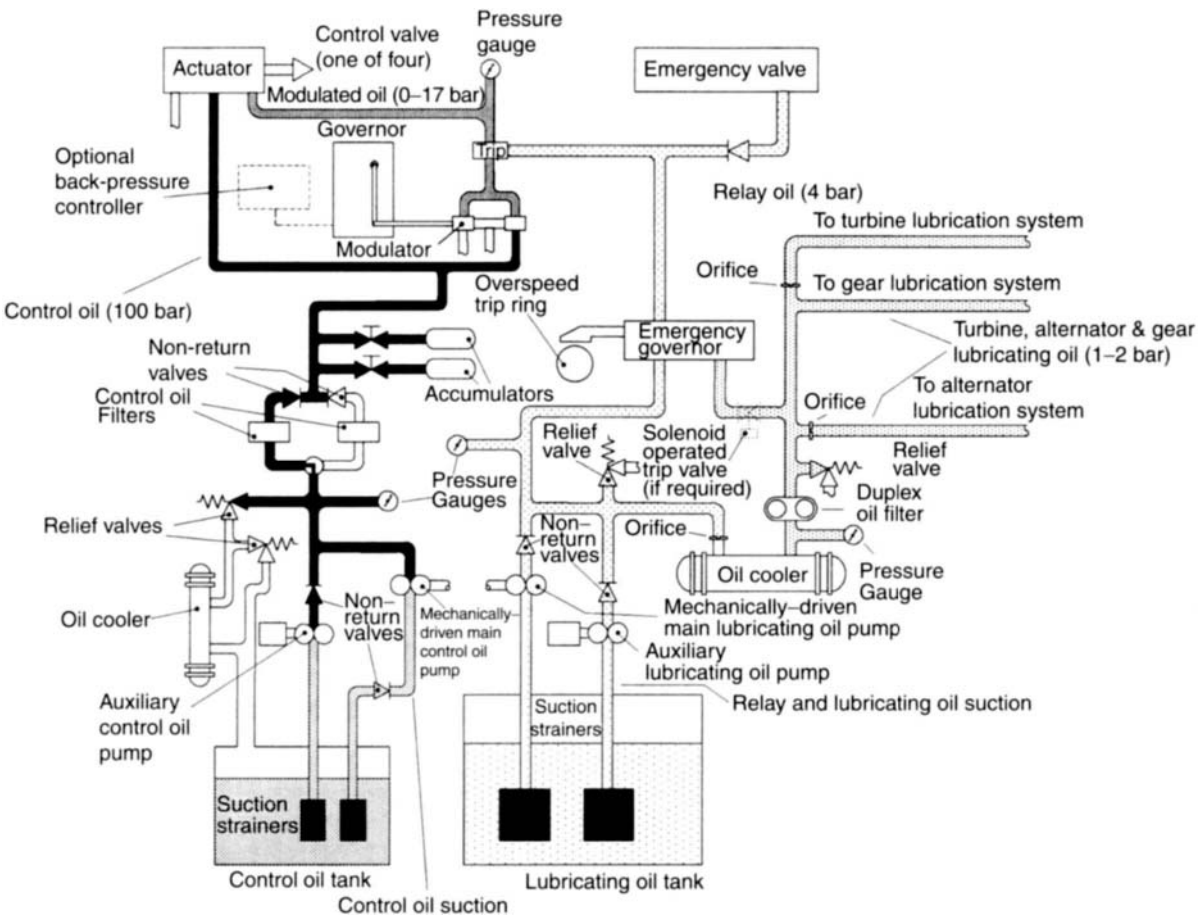


Figure 22.40 A control system for a speed-governed steam turbine

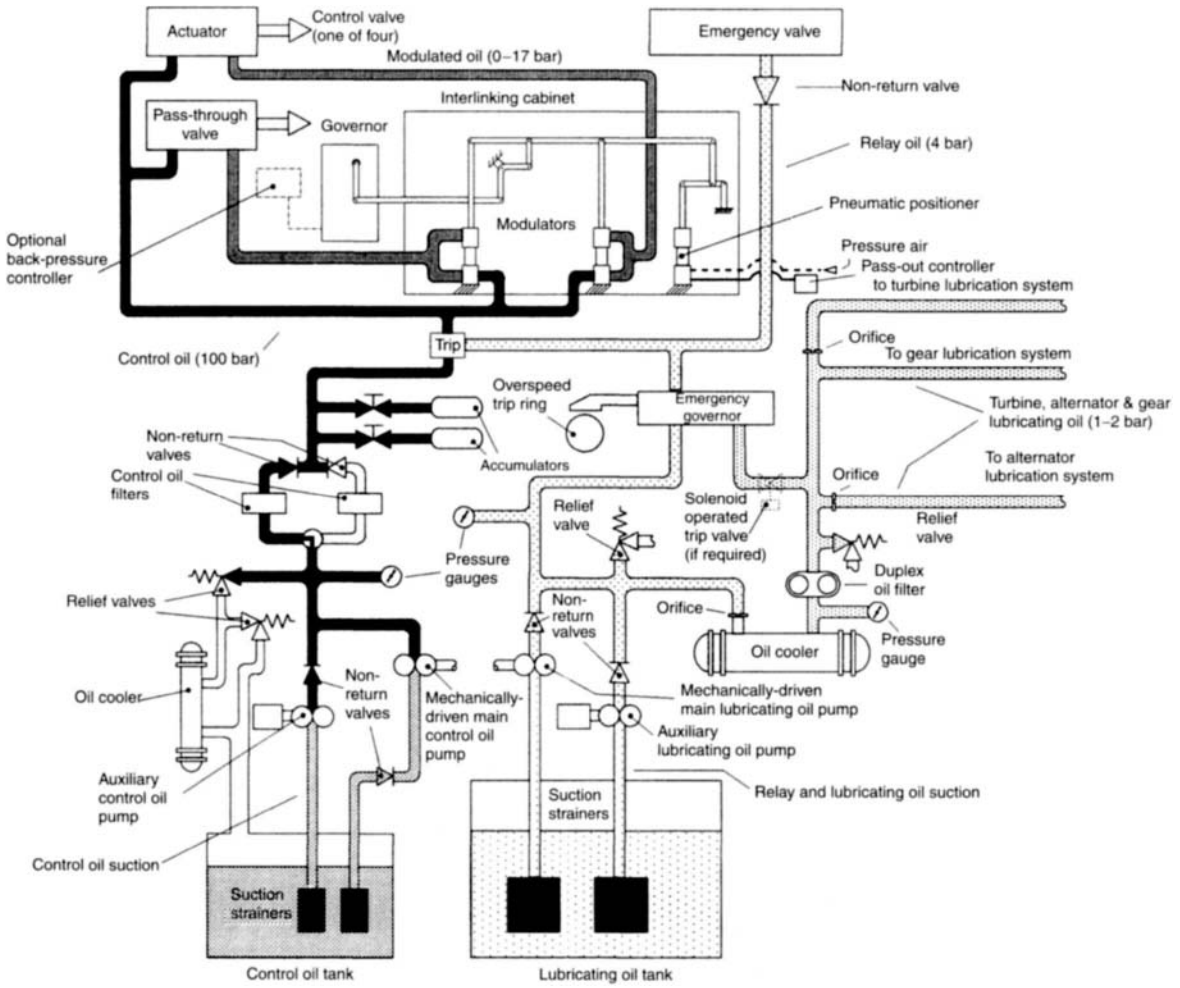


Figure 22.41 A control system for a pass-out steam turbine

filter to the lubrication system. A separate auxiliary lub-oil pump is fitted for supplying oil to the bearings when stopping and starting and to lift the emergency valve at start-up.

These systems must be inherently reliable and safe, particularly from the point of view of fire protection, and fire-resistant fluids can be used for control systems in order to reduce this risk. Fire-detection and fire-fighting systems should always be provided for any turbogenerator installation.

22.6.4 Generators

Generators for use with the prime movers previously described will almost invariably operate in conjunction with an alternating current electrical system. Such a.c. generators will operate either in parallel with other sources of supply (i.e. a grid system or other generators) or in isolation providing the whole electrical supply to an installation. A.C. generators can be one of the two main types:

1. *Asynchronous generators* These types are, in effect, induction machines operated at supersynchronous speed. An asynchronous generator can be either compensated type, in which excitation supplies are provided via a commutator, or uncompensated type, in which excitation supplies are provided by the supply system to which the generator is connected. Clearly, uncompensated generators are only suitable for use in parallel with other sources of supply capable of providing the excitation-magnetizing current necessary. While asynchronous generators offer a low-cost option for generation, the disadvantages of lack of control capability and the need usually for alternative sources of supply means that they are only occasionally utilized and rarely at ratings exceeding 5 MW.

2. *Synchronous generators* This type are in use for all generating appications up to the highest ratings (660 MW and above). The machine is operated at synchronous speed and the terminal voltage and power factor of operation are controlled by the excitation. Principal features of synchronous generators relate to:

(a) The method of excitation;
(b) The method of cooling;
(c) Temperature rise classifications;
(d) Insulation systems.

Since synchronous machines represent the most common type of generator used in power installations, the remainder of this section is principally concerned with this type.

22.6.4.1 Excitation

The excitation system provides the magnetizing current necessary for the generator to operate at the desired voltage and, when in parallel with other generators, supplies the required amount of reactive current. In modern practice the excitation system can be either brushless or static.

In a brushless system an a.c. exciter with a rotating armature and stationary field system is provided. The voltage applied to the stationary field system is varied, thus changing the output of the rotating armature. This output is rectified via shaft-mounted diodes to produce a d.c. supply which is connected to the main generator field.

The excitation system is generally designed such that failure of a single diode within the rectifying bridge does not affect the capability of the generator to provide full load. Diode failure can be monitored by measuring the amount of a.c. ripple induced within the a.c. exciter field winding and an alarm or trip provided. In operation, however, diode failure rates are extremely low.

In static systems d.c. is supplied to the generator field winding via slip rings, the d.c. being produced from diode cubicles supplied from rectifier transformers fed from the generator output. In general, static systems are capable of producing a faster response time than brushless systems and are typically used on larger (above 70 MW) sets.

22.6.4.2 Cooling

Cooling of generators is classified according to the nature of the coolant, the arrangement of the cooling circuit and the method of supplying power to circulate the coolant.

For air-cooled machines a simplified coding designation is widely used to describe the cooling system. In this system the first characteristic numeral signifies the cooling circuit arrangement (e.g. inlet duct ventilated or integral heat exchanger) while the second signifies the method of supplying power to circulate the coolant (e.g. self-circulation or from an integral mounted independently powered fan). For machines with more than one cooling system (e.g. a primary and a secondary cooling circuit) a complete coding system is used. This includes the nature of the coolant within each cooling system and the means of circulating the coolant and of removing heat from the machine.

22.6.4.3 Insulation type and temperature rise

The winding insulation must remain intact with respect to both electrical insulating properties and mechanical strength for the life of the machine. Operation of insulation at temperatures higher than the design will affect the life of the insulation.

Temperature-rise limitations above an assumed ambient temperature (dependent upon location) are used to specify the requirements of the insulation. Classifications utilized for generators are typically:

Class A	105°C
Class B	130°C
Class F	155°C
Class H	180°C

Typically, insulation limited to Class B and Class F temperature rises will employ inorganic materials (e.g. mica or glass fibre) bonded with a thermosetting synthetic resin. Class H type insulation may also include silicone elastomers.

22.6.4.4 Connections

The connection of the generator to associated switchgear may be from a cable box located on the side of the generator or exposed terminals usually placed below the machine. When the terminals are the exposed type a cable connection can still be made by utilizing cable sealing ends or by phase-insulated or phase-segregated busbars. Typically, cable boxes will be provided for machines rated up to 10 MVA while for generators rated above 30 MVA, phase-isolated busbars are generally used.

23 Electrical distribution and installation

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23.1 Introduction

This chapter introduces the basic items of design and specification for the principal systems and components of an electrical industrial installation. Electrical supply systems are discussed with regard to interface with the supply authorities and the characteristics. Salient features of switchgear, transformers, protection systems, power factor correction, motor control equipment and standby supplies are identified and discussed together with reference to the relevant Codes of Practice and standards. The equipment and systems described are appropriate to industrial plant installations operating at typically 11 kV with supply capacities of around 20 MVA.

23.2 Bulk supply

The majority of industrial installations will receive all or part of their electrical energy from an area electricity board supply authority. The factors which will affect the way in which this energy is imported to the site and subsequently controlled are:

1. The voltage and frequency
2. The load requirements
3. The fault level
4. The tariff
5. Access to equipment

The key parameters for each of these factors are discussed below.

23.2.1 Voltage and frequency

The voltage of the supply will depend upon the load requirements of the site and the relative capability of the local supply system. Voltages typically available are 33 kV, 11 kV, 6.6 kV, 4.16 kV, 415 V and 380 V. For some larger installations 132 kV (or higher) voltage supplies may be provided.

Statutory regulations imposed upon the supply authorities will normally limit variations in supply voltage to ±6% and in frequency to ±1%. In order to maintain supply systems within these limits supply authorities may, in certain cases, impose restrictions upon the starting of large motors in terms of either current drawn at start-up or of frequency of start-up. Alternatively, the supply may be arranged so that the point of common coupling with other consumers is at a higher voltage system where source impedance will be lower.

The increasing usage of semiconductor equipment, particularly for variable-speed drives, has caused more attention to be given to the problem of distorting loads and the harmonics, currents and voltages they create within the supply system. The presence of harmonic voltages and currents within a supply system will affect induction and synchronous motors, transformers, power factor correction capacitors, energy metering and devices relying upon a pure sine wave for operation.

The supply authority will be concerned about the levels of each harmonic and the total percentage distortion. Within the UK, Electricity Council Engineering Recommendation G5 gives limits for harmonic voltages and currents acceptable at the point of common coupling with other consumers.

23.2.2 Load requirements

The load imposed upon the supply system will need to be analysed for load profile, i.e.:

1. Is the load constant?
2. Does the load vary significantly on a regular hourly, daily or annual cycle?
3. Is the load likely to increase as the installation expands?
4. Will the characteristics of the load affect the system supplying it?

The factors which then need to be considered are potential unbalanced loading, transient occurrences and harmonic distortion. Unbalanced loading will cause an unequal displacement of the voltages, producing a negative phase sequence component in the supply voltage. Such negative phase-sequence voltages will cause overheating, particularly in rotating plant. The starting of large motors or the operation of electric arc furnaces are two examples of loading which draw large amounts of reactive current from the supply system. These currents, flowing through the largely reactive supply system, will result in fluctuations in the supply voltage, and these fluctuations will affect other consumers (e.g. causing lighting to flicker).

23.3.3 Fault level

The fault level at the point of supply to the installation requires consideration. The minimum fault level which can occur will affect the operation of the installation, particularly with regard to voltage regulation when starting motors, while the maximum fault level will determine the ratings of equipment installed. All supply systems develop with time, and the switchgear and other equipment installed at an installation must be chosen to be suitable if the external supply system expands.

The contribution of the installation itself to fault level at the point of common coupling is another important consideration. Rotating plant, either generators or motors, will contribute to both *make* and *break* fault levels. The contribution of synchronous machines to fault current can be calculated from sub-transient and transient reactance values, and although similar calculations can be carried out for induction motors, accurate data are not generally readily available for groups of small motors operating together, as in a typical industrial installation. Generally, induction motor contribution to *make* fault levels is taken as being equivalent to motor starting current and to *break* levels as twice motor full-load currents.

23.2.4 Industrial maximum demand tariffs

The exact details of industrial maximum demand tariffs vary between energy suppliers. However, the salient features of most tariffs are as follows:

1. *Fixed charge*: This is typically a fixed cost per month plus a charge for each kVA of agreed capacity. It is important to realize that any change in the operation of a particular site may affect the supply capacity required. The supply capacity charge, although related to, is not dependent on the rating of the equipment installed at the site.
2. *Maximum demand*: These charges are related either to kVA or to kW of maximum demand. If they are of the kW type then a separate power factor charge will be made.

   The charges depend upon whether the supply is provided at high or low voltage and the time of year. They are higher if the supply is provided at low voltage since the supply authority will seek to recover the cost of the equipment and losses incurred in providing a low-voltage supply. Within the Northern Hemisphere, demand charges are highest for the months of January and December and generally reduced for February and November. They may also apply for March but are not normally incurred during the remainder of the year.
3. *Unit charge*: This is related to actual energy consumption, and two options are generally available; a rate applicable for 24 h or a split day and night rate, with, typically, a 7-hour night period duration. In per-unit terms these costs will be:

   24 h = 1 per unit
   Day/night = 17-h day, 1.04 per unit
   7-h night, 0.51 per unit

   Some suppliers offer reduced rates as energy usage increases.
4. *Power factor adjustment*: Although related to the average power factor of the load, the method of calculation may be based directly on measured power factor or on the measurement of reactive kVA over the period.

   Values at which power factor charges are incurred vary from 0.8 to 0.95 lag.

23.2.5 Access

The switchgear provided at the installation for the provision of the supply by the supply authority will be the property of that authority. That provided for the distribution of the electricity around the installation will be the property of the consumer, while metering for tariff purposes will be located on or supplied from the supply authority switchgear.

It is normal for the supply authority switchgear to be separate from the consumers' switchgear and frequently located in a separate room within the same building. The supply authority may insist that access to this equipment or room is limited to their own personnel.

23.3 Distribution systems

The object of any electrical power distribution scheme is to provide a power supply system which will convey power economically and reliably from the supply point to the many loads throughout the installation. The standard method of supplying reliable electrical supplies to a load centre is to provide duplicated 100% rated supplies. However, there are a number of ways in which these supplies can be provided.

The standard approach for a secure supply system is to provide duplicated transformer supplies to a switchboard with each transformer rated to carry the total switchboard load. Both transformers are operated in parallel, and the loss of single incoming supply will not therefore affect the supply to the load feeders. With this configuration the supply switchboard must be able to accept the fault current produced when both transformers are in parallel. The system must, however, be designed for the voltage regulation to remain within acceptable limits when a single transformer supplies the load.

If the two incoming supplies are interlocked to prevent parallel operation, the power flow, fault current flow and voltage regulation are governed by a single transformer supply infeed. Although the configuration has the disadvantage that the loss of a single infeed will cause a temporary loss of supply to one set of load until re-switching occurs, the advantage is that each incoming transformer can be rated higher than the first, and thus a higher concentration of loads can be supplied.

A third alternative is to rate the transformer infeeds for single supplies but to arrange for automatic switching of the bus section and two incomers in the event of loss of supply to one section. A rapid transfer switching to the remaining supply in the event of loss of single supply can prevent the total loss of motor loads. In such a situation the effect of the current taken by motors to which the supply has been restored must be taken into account.

Since a group of motors re-accelerating together will draw an increased current from the supply, this current will affect voltage regulation and must be recognized when selecting protection relay settings. Figure 23.1 illustrates these arrangements of transformer operation. The effect of these combinations upon the loads which can be supplied is summarized in Table 23.1 for two typical supply voltages and fault levels, circuit breaker capabilities and transformer reactances.

In the case of parallel operation the maximum transformer rating is limited by the fault rating of the switchgear, while for a single transformer infeed the limitation is by the full-load current rating of the switchgear.

Table 23.1 takes into account only the fault contribution from the supply system. The contribution from rotating plant within an installation must also be considered when specifying switchgear and transformer ratings.

If a fully duplicated supply system is thought to be necessary, the transformer reactances can be increased in order to limit the fault level when operating in parallel mode. However, this will increase the initial capital cost, and voltage regulation with a single transformer in circuit will still need to be maintained within acceptable limits.

23.4 Switchgear

Switchgear is a general term covering circuit-interruption devices, the assemblies which enclose them and associated

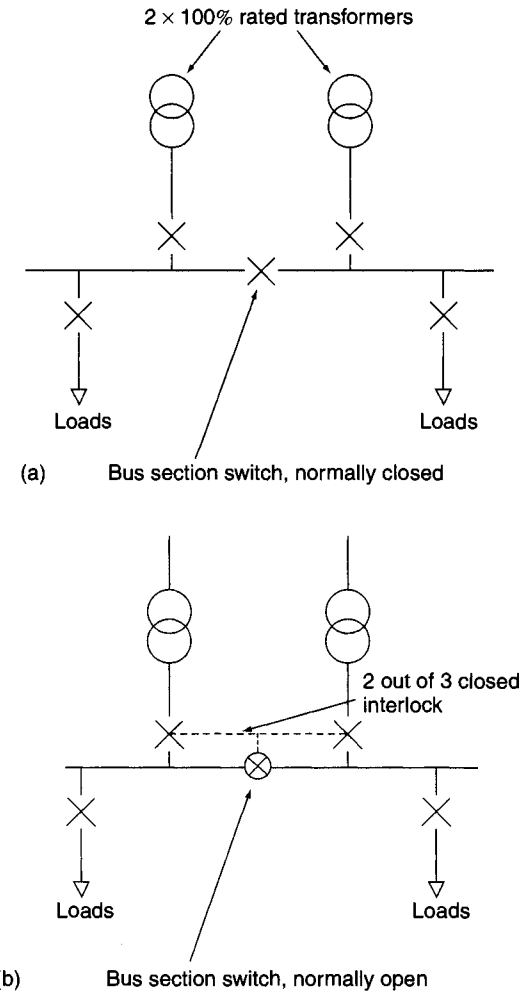


Figure 23.1 Transformer arrangement. (a) Parallel operation; (b) 2 out of 3 interlock

equipment such as current transformers, voltage transformers, disconnect switches, earthing switches and operating mechanisms. The circuit breaker is the interrupting device within the switchgear capable of closing onto, carrying and breaking those currents which can flow under healthy or fault conditions.

Table 23.2 British/European standards applicable to switchgear

BS EN 60044	Instrument transformers
BS 5311	High voltage alternating current circuit breakers
BS EN 60947	Low voltage switchgear and control gear
BS EN 60298	AC Metal – Enclosed switchgear and control gear for rated voltages above 1 kv and up to and including 52 kv.

Switchgear is frequently described by the medium used in the interrupting device and method of mounting. The principal types of medium presently in operation are bulk oil, minimum oil, air, sulphur hexafluoride gas (SF_6) and vacuum. The most common mounts for indoor industrial switchgear are cubicle and metal clad. The main features of and the perceived advantages and disadvantages of the different types of medium are reviewed below, while international standards applicable to switchgear are listed in Table 23.2.

23.4.1 Bulk oil

The fact that oil was effective for the extinction of the arc formed between the opening contacts of a circuit breaker was discovered towards the end of the nineteenth century. In a bulk oil circuit breaker the oil is used both as the medium for arc extinction and as the insulating material of the contacts. The contacts are contained within a small chamber within the oil-filled breaker tank. When the circuit breaker contacts open an arc is formed which decomposes the oil, creating gases. These form a bubble which forces oil across the arc path, causing rapid extinction of the arc. Bulk oil circuit breakers have been used for many years, and it is probable that about 70% of the high-voltage circuit breakers installed in the UK are of this type.

Advances in design of circuit breakers using other mediums for arc extinction, means virtually no bulk oil switchgear is now manufactured.

23.4.2 Minimum oil

In a minimum oil circuit breaker only the arc control device is enclosed within an oil-filled housing. This housing is supported and insulated separately to provide the necessary phase clearances between phase connections and earth.

Table 23.1 Load supply capabilities and single and parallel transformer combinations

Source	*Load*		*Load circuit breaker*				*Max. supply transformer rating (MVA)*			
Voltage kV	*Fault level MVA*	*Voltage* kV	*Full load, rating A*			*Fault rating*	*Reactance (%)*			
			630	*2000*	*3000*	*kA (MVA)*	*6*	*10*	*6*	*10*
			MVA				*Parallel*		*Single*	
33	1428	11	12	38.1	–	25(476)	21	35.7	38.1	38.1
11	476	3.3	3.6	11.4	–	25(143)	6.1	10.2	11.4	11.4
11	476	0.415	–	1.4	2.2	50(35.9)	12	1.9	2.2	2.2

23.4.3 Air

Air circuit breakers can be either *air break* types (which utilize atmospheric air) or *air blast* (which use compressed air). Air-break type breakers extinguish the arc by high-resistance interruption, the arc being controlled within an arc chute. As the arc resistance increases, the current is reduced until at current zero arc extinction occurs.

Air-blast circuit breakers operate on the low-resistance principle; the arc length is minimized and a blast of air is directed across the arc to cool and remove ionized gas. Air break circuit breakers are now used extensively at medium voltages while air blast circuit breakers have been employed up to the highest voltages.

For use at normal industrial distribution voltages the principal advantages are

1. Suitability for all types of switching
2. Good fault ratings
3. No fire risk
4. Low maintenance costs

while the main disadvantages are

1. Capital cost
2. Physical size

23.4.4 Sulphur hexafluoride gas (SF_6)

Sulphur hexafluoride gas (SF_6) has a high thermal conductivity and a high electronegative attraction for ions. It has insulating properties similar to oil and arc-interruption properties comparable to compressed air at 4826 kN/m^2. Recent switchgear design utilizes SF_6 at a relatively low pressure for insulation, with compression occurring via a piston activated by the opening mechanism of the contacts.

Principal advantages of SF_6 circuit breakers are

1. Good arc-extinction properties
2. Low maintenance
3. Size

and few disadvantages are perceived.

23.4.5 Vacuum

As a replacement for bulk oil circuit breakers for distribution purposes, vacuum is a rival to SF_6. The contact interruption chamber is a sealed unit with a small contact-separation distance (typically, 16 mm for 24 kV). Choice of contact material is critical since the material affects:

1. The electrical and mechanical conductivity;
2. The production of metal vapour upon arc interruption necessary to control current chopping and permit voltage recovery; and
3. The provision of consistent contact wear and separation.

Principal advantages of vacuum circuit breakers are

1. Minimum maintenance
2. Less operating energy required
3. Size

Table 23.3 Capability of distribution voltage switchgear

Medium	*Full-load current (A)*		*Fault current (kA)*	
	Typical	*Max.*	*Typical*	*Max.*
Bulk oil	1200	2000	26.4	43.72
Minimum oil	1600	4000	26.4	50
Air	2500	5000	26.4	52
SF_6	2000	3150	25	50
Vacuum	2000	2000	25	40

while disadvantages are

1. Possible restriction on fault capability
2. Possible switching overvoltages

23.4.6 Range

Distribution voltage switchgear available within the UK is designed for the range of full-load current and fault-current capabilities shown in Table 23.3.

23.4.7 Construction

A.C. metal enclosed switch gear and control gear between the voltages of 1 and 72.5 kV can be manufactured to three basic designs: metal enclosed, metal clad and cubicle.

In *metal-enclosed* assemblies the equipment is contained within an earthed metal enclosure. In *metal-clad* types separate compartments are provided for the circuit interrupter, the components connected to one side of the interrupter (e.g. the cable box) and those connected to the other side of the interrupter (e.g. the busbar chamber and the control equipment).

Cubicle-type switchgear may have non-metallic components for separation between compartments, no segregation between compartments housing different components or they may be of a more open type of construction. Frequently access to cubicle-type switchgear is via doors interlocked to prevent access to energized parts. The other feature of construction of switchgear concerns the circuit breaker itself, which can be either fixed type or removable. In a fixed construction the switchgear will be fitted with isolating and earthing switches so that access to the circuit breaker is only possible when the circuit breaker is safely isolated from the supply.

In a removable design the circuit breaker is mounted on either a truck or a swing-out frame. The circuit breaker is arranged so that isolation from the busbars is only possible when the circuit breaker is open. Connections between the removable circuit breaker and the fixed assembly is either by a plug and socket arrangement or by secondary isolating contacts. Figure 23.2 illustrates a truck-mounted, vertically isolated, metal-clad, SF_6 circuit breaker design as marketed by a UK manufacturer.

23.4.8 Mechanisms

Operating mechanisms for switchgear can be either *stored-energy* or *dependent-energy closing*. Stored-energy closing is frequently achieved by means of a spring which



Figure 23.2 NEI Reyrolle SF_6 switchgear

is either manually charged (type QM) or charged by an electrical motor. Dependent-energy closing is by use of a solenoid.

The selection of operating mechanism will depend upon the control regime required for the circuit breaker. If the circuit breaker is to be operated locally (i.e. at the switchgear itself) then the manually charged spring option will be acceptable. If it is to be operated from a remote location then either motor-wound spring or solenoid operation will be required.

This choice will depend upon circuit breaker availability required, since a motor-wound spring has a finite spring-wind time. A solenoid operation will impose a significant load upon the d.c. supplies while a motor-wound spring will require a supply to the spring-wind motor.

23.5 Transformers

Transformers are classified by their method of cooling, winding connection arrangement and temperature-rise classifications. Each of these parameters is applicable, irrespective of the voltage ratio and rating required. In the UK core-type transformers are used for almost all power systems applications. In core-type transformers the primary and secondary windings are arranged concentrically around the core leg of substantially circular cross section. International standards applicable to transformers are listed in Table 23.4.

23.5.1 Cooling

Mineral oil provides a greater insulation strength than air for any given clearance. When used in a power transformer mineral oil also augments the removal of heat from the windings.

In power transformer manufacture the case of paper insulation and oil used in combination is well established. Both materials can be operated safely at the same maximum temperature (105°C) and this combination of use seems unlikely to be phased out in the near future.

Table 23.4 British standards applicable to transformers and their components

BS 171, Power transformers:
Part 1, General
Part 2, Temperature rise
Part 3, Insulation levels and preelectric tests
Part 4, Tappings and connections
Part 5, Ability to withstand short circuit
BS 158, Insulating oil for transformers and switchgear
BS 2757, Thermal classification of electrical insulation
BS 223, Bushings for alternating voltages above 1000 V
BS 5622, Insulation co-ordination
BS 2562, Cable sealing boxes for oil-immersed transformers

For transformer windings immersed in oil, hydrocarbon oil is the most widely used, whereas in areas where fire risk is a problem, then air-cooled transformers (AN) or synthetic silicon-based liquid cooling (SN) can be specified. Silicon-based liquids do not have any of the disadvantages identified with the chlorinated biphenyls. Air-cooled transformers can be provided with Class C insulation or be cast resin insulated. The relative costs per unit of each type are:

Mineral oil	1
Silicon filled	1.25–1.5
Class C	1.8
Cast resin	2.0

23.5.2 Types

23.5.2.1 ONAN

Oil-immersed air-cooled transformers cover the majority of units installed of up to 5 MVA rating. Cooling of the oil is provided by fins or corrugations of the tank or by tube banks. For ONAN transformers of above 5 MVA rating radiator banks of elliptical tubes or banks of corrugated radiators are often provided.

23.5.2.2 ONAF

In oil-immersed air-forced transformers a direct blast of air from banks of fans is provided to the radiators which increases the rate of heat dissipation. This arrangement has no effect upon the size of the transformer itself but less space for external coolers is required.

23.5.2.3 OFAN

Oil-immersed air natural circulation is an uncommon arrangement, and is useful only if the coolers are situated away from the transformer.

23.5.2.4 OFAF

Most larger-rated transformers are oil-forced air-forced cooled. Oil-forced circulation improves the heat dissipation around the windings, thus reducing the size of the transformer itself and air blast cooling of the radiators decreases the size of the cooling surfaces. Thermostatic

control of both oil forcing and air blast is usually provided so that each is brought into service at a different oil temperature. The ONAN rating of an OFAF transformer is typically 50% of the OFAF rating, although any value can be designed when required.

23.5.2.5 AN

These are solidly insulated transformers using typically cast resin insulation. They are particularly useful when an indoor installation is necessary, since they represent a very low fire risk and oil leakage and drainage does not need to be considered. AN transformer maximum ratings are typically of the order of 1500 kVA. Forced cooling (AF) can be added in the same way as oil-immersed transformers, permitting increased output from the same size of unit.

23.5.3 Temperature rise

Temperature classes for transformers A, E, B, F, H and C are generally recognized. All classes are applicable to both oil-immersed and air-cooled transformers. Classes A, B, H and C are most commonly used but the use of Class F is increasing.

For windings immersed in either hydrocarbon oil or synthetic liquids the coil insulation is usually a Class A material. For oil-immersed transformers BS 171 specifies two maximum oil temperatures: 60°C for sealed-type transformers for those fitted with conservators and 55°C for transformers without either. In the case of air-insulated, air-cooled transformers the maximum permitted temperature rise is limited by the class of insulation used, i.e.:

Class A	60°C
Class B	90°C
Class C	150°C

These temperature rises apply above a maximum ambient temperature of 40°C and a daily average temperature of 30°C is assumed.

23.5.4 Tests

BS 171 defines both routine and type tests for transformers. Routine tests comprise the following:

1. Ratio measurement, polarity check and phase relationship;
2. Measurement of winding resistance;
3. Measurement of insulation resistance;
4. Measurement of load loss and impedance voltage;
5. Measurement of core loss and magnetizing current;
6. High-voltage withstand tests. The rated withstand voltages applicable to transformers of up to 36 kV are shown in Table 23.5.

The measurement of impedance voltage is defined as the voltage required to circulate full-load current in one winding with the other windings short circuited. It is common practice to express the leakage impedance, Z, of a transformer as a percentage (or per unit) value. The per unit value is:

$$\frac{IZ}{V}$$

where I and V refer to full-load current and rated voltage and IZ is the voltage measured at rated current during a short-circuit test transformer. In the case of a transformer with tappings the impedance is conventionally expressed in terms of the rated voltage for the tapping concerned.

Table 23.5 Rated withstand voltage transformers

High voltage (kV)	*Rated short-duration power frequency withstand voltage (kV)*	*Rated lighting impulse withstand voltage*[a]	
		(kV)	*(Peak)*
3.6	10	20	40
7.2	20	40	60
12	28	60	75
24	50	95	125
36	70	145	170

[a] Choice of rated lighting impulse withstand voltage depends on exact site conditions and duties.

23.5.5 Fittings

In selecting the fittings to be provided, the specifier of a transformer has a wide choice. The most common types and their purpose are as follows.

23.5.5.1 Oil-level indicator

This is usually mounted on the transformer tank, providing a visual indication of the transformer oil level.

23.5.5.2 Thermometer pockets

These measure oil temperature from a separate temperature indicator.

23.5.5.3 Tap changing

The range and duty (i.e. off-load/on-load) can be specified to suit each particular installation. For standard distribution transformers of up to 3.15 MVA rating for use purely as load supplies, off-load tap changing for a ±5% voltage range is normal.

23.5.5.4 Breather/conservator/gas and oil relay

This is specified where the transformer is of the breathing type. The gas- and oil-actuated relay will be fitted with contacts for remote alarm or tripping.

23.5.5.5 Pressure-relief device

This is essential on a sealed transformer and optional on a breathing unit. It can be fitted with contacts for remote alarm/tripping.

23.5.5.6 Disconnecting chambers

These are fitted between the cable boxes and the transformer windings and are accessible through a secured cover. Disconnecting chambers can be employed as a method of isolation, but their most common usage is to facilitate phase-to-phase testing of the connected cables.

23.5.5.7 Connection

Figure 23.3 illustrates the most commonly used transformer, grouping and winding arrangements and phase displacements.

23.6 Protection systems

The analysis and understanding of the operation of protection systems and the application of protective devices to power systems is wide ranging and complex. This section considers only the objectives of protection systems, discrimination and its importance to protection, and describes the most common types of relay used in industrial power systems. Many publications covering the subject of protection systems are available (e.g. *Power System Protection*, edited by the Electricity Council).

23.6.1 Objectives

All electrical systems must be provided with protection equipment, the purpose of which is to isolate faulty electrical equipment from the electrical supply system as rapidly as possible. This can be achieved by use of devices which respond directly to the current flowing (e.g. fuses) or by protective relays which respond to fault current flow and are used to initiate the tripping of other devices (e.g. circuit breakers).

So that only the faulty equipment is isolated from the supply, the protective devices provided throughout a power system must discriminate between faulty and healthy equipment. This discrimination of protective equipment is a key element in the design of electrical systems and the selection of protection devices for use within them. Each electrical system must be provided with an adequate number of suitably rated disconnecting devices located correctly throughout the power system. These must be so arranged that only appropriate devices operate to remove the faulty equipment from the supply.

23.6.2 Discrimination

The methods of achieving discrimination most commonly found in industrial power systems are as follows:

1. *By time*: Protective relays are provided with timedelay features such that the device closest to the fault will operate first.
2. *By magnitude*: In different parts of a power system fault currents of different magnitude can flow.
3. *By time/direction*: Protective devices responsive to the direction of current flow. These are necessary for parallel feeders or closed ring-main supplies.
4. *By comparison*: The currents flowing into and out of a circuit are compared. In a healthy circuit, or in a circuit in which 'through fault' current is flowing, the two currents should be equal and the protective device does not operate. (Compensation for any transformation is necessary.)

   If the two currents differ the protective device operates.

In selecting discriminating time margins between protective devices connected in series the following should be taken into account. Full discrimination is achieved between fuses of different rating when the fault is cleared by the lower rated or minor fuse without affecting the higher rated or major fuse. In order to achieve this, the total let-through energy of the minor fuse must be less than the let-through energy necessary to cause pre-arching of the major fuse.

23.6.3 Testing

Tests carried out on protection systems comprise factory tests, on-site commissioning tests and maintenance checks. Those made on individual relays at the place of manufacture will demonstrate the compliance of the equipment with specification and the verification of its operation under simulated conditions, while tests carried out on-site prior to the equipment being put into service ensure that the full protection scheme and associated equipment operate correctly. These on-site tests must be comprehensive and should include:

1. Performance tests on current and voltage transformers to verify ratio and polarity. These may include the injection of current into the primary load circuit (primary injection).
2. Sensitivity and stability checks on each protective device. These tests may be carried out either by primary injection or by the injection of voltage into the CT secondary circuit (secondary injection).
3. Wiring checks, including insulation resistance and any pilot cables.
4. Operational checks on all tripping and alarm circuits.
5. Calibration checks on all relevant relays.

On-site commissioning tests of protection equipment must be carried out in a planned logical manner, and arranged so that the disturbance of tested equipment is minimized.

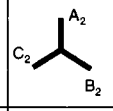
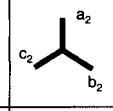
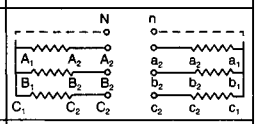
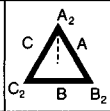
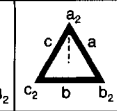
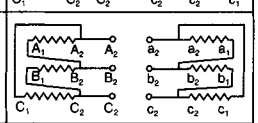
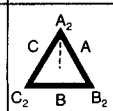
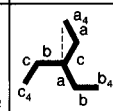
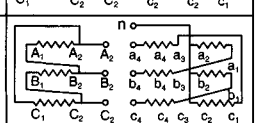
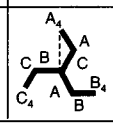
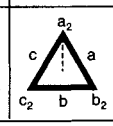
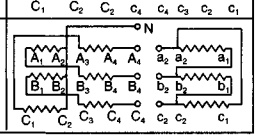
23.6.4 Relay types

The main relay types found within an industrial power system can be:

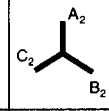
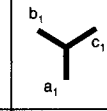
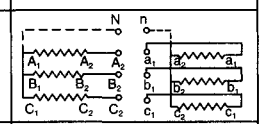
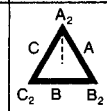
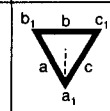
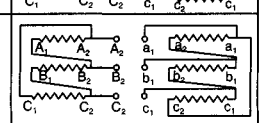
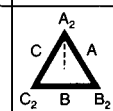
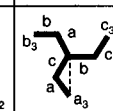
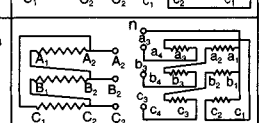
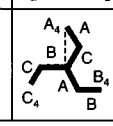
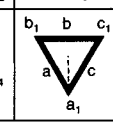
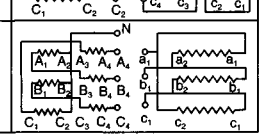
1. Instantaneous in operation;
2. Definite time; or
3. Inverse, in which the time of operation is dependent upon the magnitude of the current,

and such relays can be arranged to protect equipment in one of the following ways:

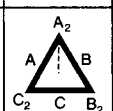
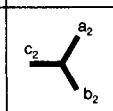
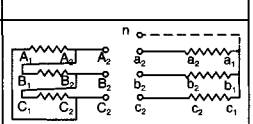
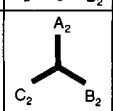
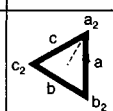
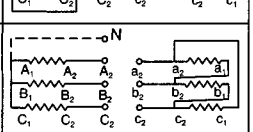
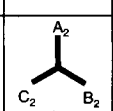
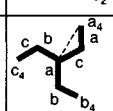
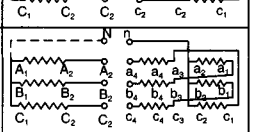
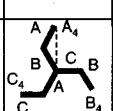
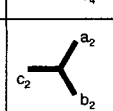
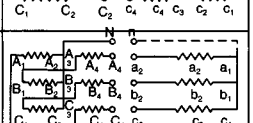
GROUP No. 1 : PHASE DISPLACEMENT = 0°

Vector symbols	Line terminal markings and vector diagram of induced voltages		Winding connections
	HV Winding	LV Winding	
Yy0			
Dd0			
Dz0			
Zd0			

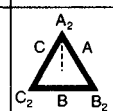
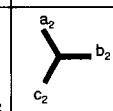
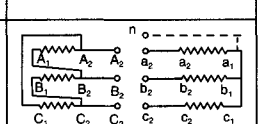
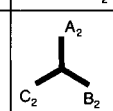
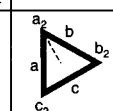
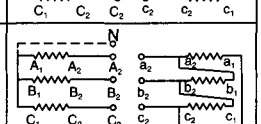
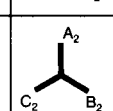
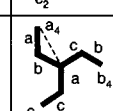
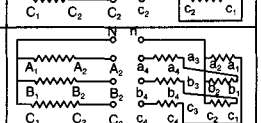
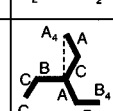
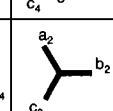
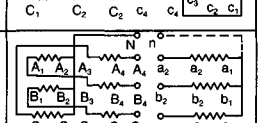
GROUP No. 2 : PHASE DISPLACEMENT = 180°

Vector symbols	Line terminal markings and vector diagram of induced voltages		Winding connections
	HV Winding	LV Winding	
Yy6			
Dd6			
Dz6			
Zd6			

GROUP No. 3 : PHASE DISPLACEMENT = MINUS 30°

Vector symbols	Line terminal markings and vector diagram of induced voltages		Winding connections
	HV Winding	LV Winding	
Dy 1			
Yd 1			
Yz 1			
Zy 1			

GROUP No. 4 : PHASE DISPLACEMENT = PLUS 30°

Vector symbols	Line terminal markings and vector diagram of induced voltages		Winding connections
	HV Winding	LV Winding	
Dy11			
Yd11			
Yz11			
Zy11			

ALL TRANSFORMERS FROM ANY ONE GROUP MAY BE OPERATED IN PARALLEL WITH OTHER TRANSFORMERS FROM THE SAME GROUP.

PHASE DISPLACEMENT APPLIES FOR COUNTER CLOCKWISE PHASE ROTATION.

Figure 23.3 Typical transformer vector groupings and connection arrangements

1. *Unrestricted*: The protection device will operate in response to any fault current flowing through the circuit.
2. *Restricted*: The protection device will operate in response to any fault current flowing within a zone restricted by the location of the current transformers. Such protection is normally applied to a single winding of a power transformer.
3. *Differential*: The protection device will operate in response to a fault current flowing within a zone bounded by current transformers located at each end of the protected circuit.

   Such protection can be used on a power transformer, a motor or generator, or a single feeder.

In addition, other types of relay are used for particular applications (e.g. transformer Buchholz gas, neutral voltage displacement and overvoltage).

23.6.5 Applications

Figures 23.4 and 23.5 show typical protection schemes for two circuits of a 60 MW generator, a generator transformer with tripping logic and a 2 MVA transformer. The figures illustrate the protection devices provided, the current and voltage transformers supplying them and the tripping scheme associated with each.

23.7 Power factor correction

23.7.1 Background

Power factor in an alternating current circuit is defined as the ratio of actual circuit power in watts (W) to the apparent power in voltage amperes (VA). The need for correction arises from fact that the majority of a.c. electrical loads take from the supply a lagging quadrature current (voltage amperes reactive, var) and thus operate at a lagging power factor due to the reactive (rather than capacitive) nature of their construction.

Most industrial installations comprise a combination of one or more of the following electrical loads:

1. A.C. motors (induction)
2. Furnaces (electric arc, induction)
3. Fluorescent or discharge lighting
4. Power transformers
5. Thyristor drive equipment (for either a.c. or d.c. drives)
6. Welding machines

All these types of load fall into the above category and operate at a lagging power factor.

Since the electrical supply system carries the full apparent power (VA) a current higher than is theoretically necessary to supply the power demand needs to be supplied. Equipment must therefore be rated to carry the full apparent power plus the losses of the supply system, which are proportional to the square of the current.

A supply system operating at a low power factor will be inefficient due to the overrating of the supply components and to the losses incurred, and supply authorities will seek to recover the costs of this inefficient operation by introducing cost penalties for consumers operating at a low power factor. In practice, these penalties are incurred on the basis of either the maximum demand of the apparent power in kVA of the load or of charges initiated if the power factor falls below a set trigger point (typically, 0.95 lag). The latter charges are monitored by measuring either the power factory directly or by the relative current drawn by the load and comparing it with the actual power drawn.

Within any particular installation, in instances where no financial penalties are incurred from the supply authority the power factor of individual circuits will influence both the losses within the installation and the system's voltage regulation. Therefore power factor correction is considered necessary in order to achieve one or more of the following objectives:

1. A direct reduction in the charges made by the supply authority;
2. A reduction in the losses within a system with consequent savings in charges;
3. An improvement in the voltage regulation of a system.

Figure 23.6 illustrates the phasor diagram applicable to power factor correction.

23.7.2 Methods of achieving correction

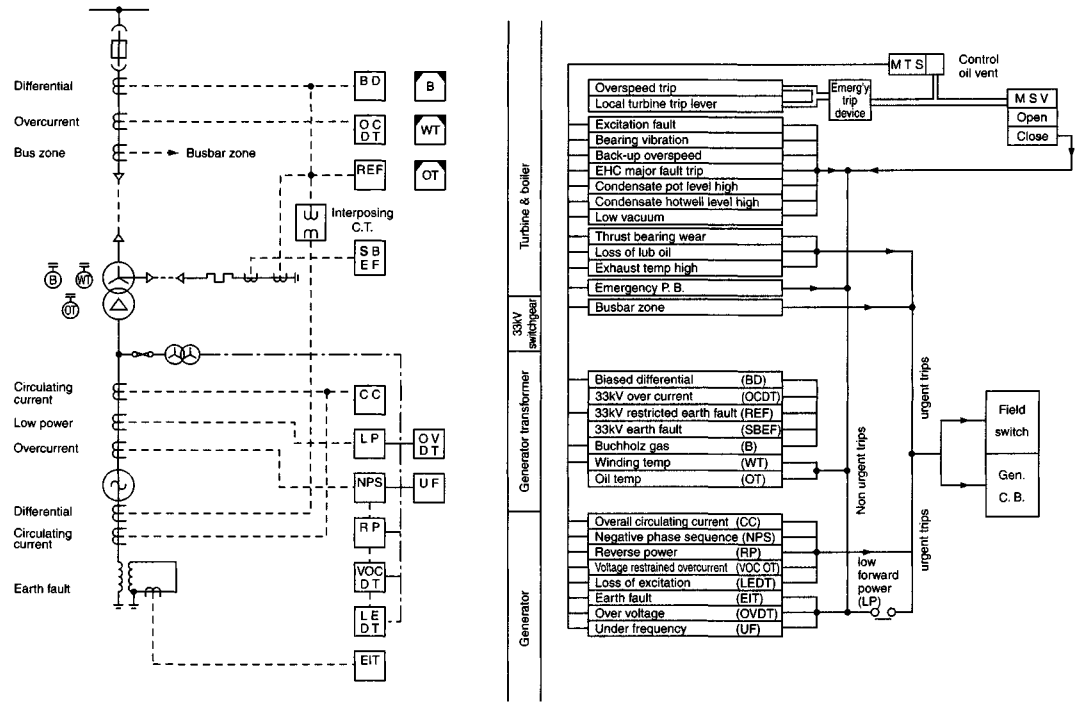
The power factor of an installation can be improved by the use of either a.c. synchronous machines or of static capacitor banks. An a.c. synchronous machine will either draw current from the supply or contribute current to the supply, depending on whether the machine is operating:

1. As a generator, driven by a prime mover, contributing active power;
2. As a motor-driving load, drawing active power;
3. Over-excited, contributing reactive var; or
4. Under-excited, drawing reactive var.

Figure 23.7 illustrates these four modes of operation.

When an a.c. synchronous machine operating as a motor in parallel with other loads and an external supply system is over-excited the machine will contribute reactive kvar to the supply. The net effect of this will be to reduce the amount of reactive current drawn from the supply, and this will improve the overall system power factor. When an a.c. synchronous machine operating as a generator in parallel with other loads and external supply system is over-excited the net effect will still be to reduce the amount of reactive current drawn from the supply.

However, the power factor of the current drawn from the supply will only improve if the power factor of the generated current is less than that of the parallel loads, since the active power drawn from the supply will also be reduced by the amount of actual power generated. In each case the reactive current produced by the synchronous machine can be increased within the capabilities of the machine by increasing the excitation so that the power factor of the current drawn from the supply can improve to unity or become leading. In this case the installation becomes a net exporter of lagging reactive current to the supply. Figure 23.8 illustrates these two cases.



TYPICAL ARRANGEMENT PROTECTION AND TRIPPING LOGIC 60MW. STEAM TURBINE GENERATOR

Figure 23.4 Protection and tripping logic for a 60 MW steam turbine generator

The second method of improving the power factor of an installation is to provide static capacitor banks. These can be installed as a single block at the point of supply busbar, as a set of switchable banks or as individual units connected to specific loads. For an installation where no synchronous machines are installed for other purposes (i.e. as prime movers or generators) then static capacitor banks are almost invariably the most cost-effective way of improving the power factor.

The amount of power factor correction capacitors necessary in order to correct from an initial power factor $\cos\phi$ to a target power factor $\cos\phi_1$ is given by:

Initial reactive requirement $\phi = P\tan\phi$
Final reactive requirement $\phi_1 = P\tan\phi_1$
Correction required $= P(\tan\phi - \tan\phi_1)$
where $\phi = \cos^{-1}$ (PF). The correction required is
$P[\tan\cos^{-1}(\text{initial PF})] - [\tan\cos^{-1}(\text{final PF})]$

Figure 23.9 illustrates the amount of power factor correction required per 100 kW of load to correct from one power factor to another.

The degree of correction necessary for any particular installation will depend upon the circumstances. In economic terms the costs and prospective benefits can be simply set out as:

Capital	*Running*	*Savings*
Capital cost of equipment	Maintenance	Reduction in demand charges
Installation costs	Depreciation	Reduction in losses

23.7.3 Types of control

Capacitors as bulk units can be connected to the supply busbar via a fuse switch, moulded-case circuit breaker of air circuit breaker. In this type of installation control is purely manual, and in cases of a reasonably constant load and where the amount of power factor correction is limited such a manually controlled system is perfectly adequate. The supply authority may, however, require to be informed that a capacitor bank is permanently connected to the supply. Capacitors are more generally connected either in banks controlled from a VAR sensitive relay or across individual loads (e.g. motors).

When connected as switchable banks the rating of each step of the capacitor bank must be selected with care. It is important that the control relay settings are matched to the ratings of each capacitance step in order to prevent hunting (i.e. continuously switching in and out at a particular load point). When capacitors are connected to one particular load (usually a motor) the capacitor bank can be located at the motor, adjacent to but separate from the control switchgear or within the control switchgear itself.

When located at the motor the capacitor bank will be normally cabled from the motor terminal box, so that the size of the motor cable can then be selected on the basis of the reduced-power factor corrected current drawn by the motor/capacitor combination. However, whenever a capacitor is connected across an individual motor circuit, by

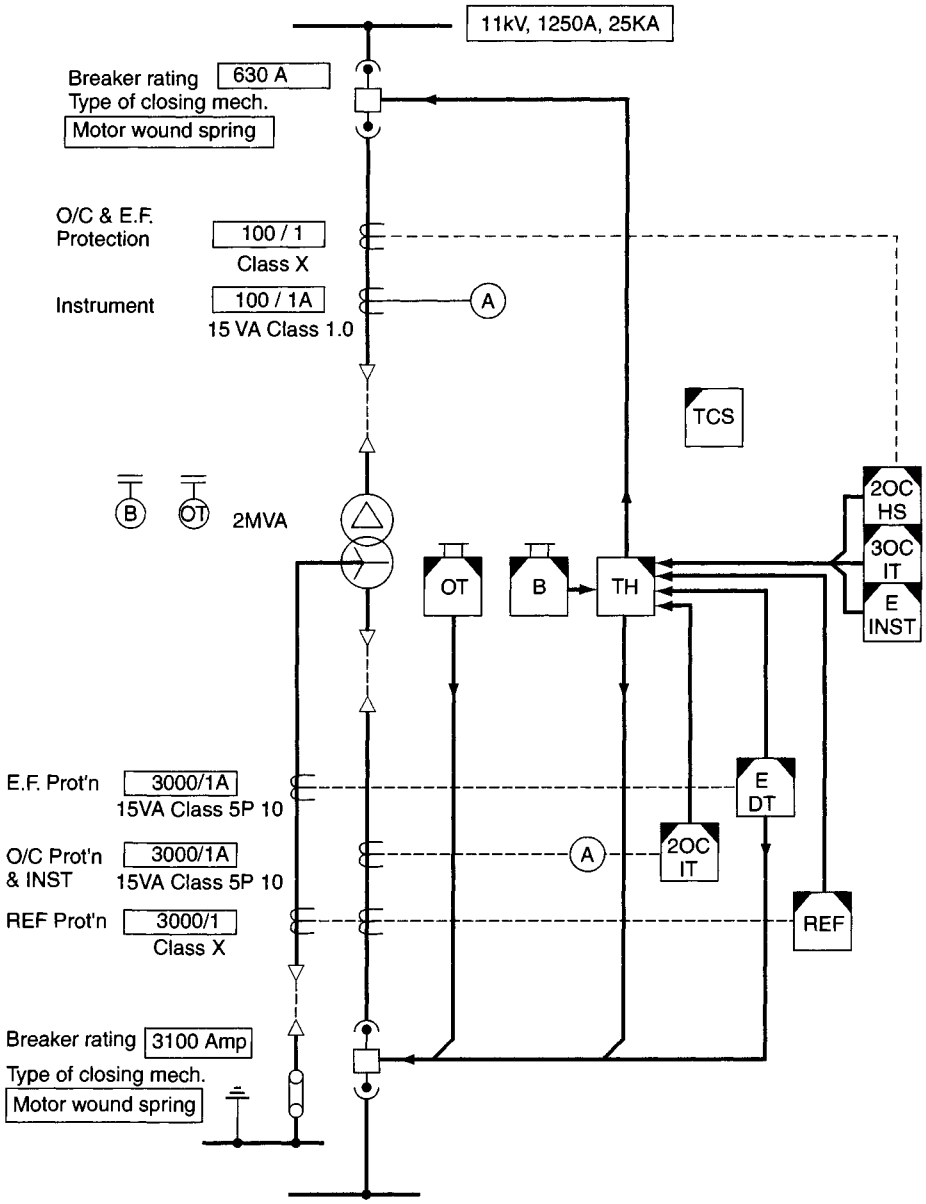


Figure 23.5 Protection and tripping logic for a 2 MVA transformer

whatever means, the setting of the motor overload device must be chosen to take account of the corrected current rather than the uncorrected motor full-load current.

23.7.4 Potential problems

23.7.4.1 Control devices

Capacitors, circuit breakers and HRC fuses must be selected with care for use with capacitor circuits, with contactors chosen on the basis that the capacitor current can rise by 25% above nominal line current. Equally, HRC fuses for capacitor applications should be de-rated by a factor of 1.5.

When choosing high-voltage circuit breakers for capacitor control it is necessary to select the full-load current of the breaker, taking into account variations in supply voltage, tolerance on rating manufacture and harmonic currents. Again, a de-rating factor of 1.5 is usually considered to be adequate. The capacitor manufacturers will insist that the control device is re-strike free and that the control device has been tested to IEC 56, Part 4. When the control device is a high-voltage circuit breaker, capacitor manufacturers frequently recommend a maximum between initial current make and final contact closure (typically, 10 m/s).

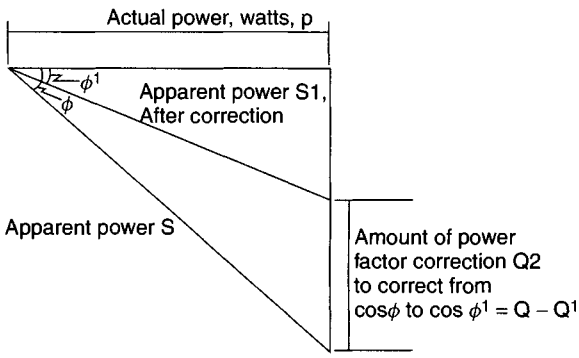


Figure 23.6 Power factor correction

23.7.4.2 Motor circuits

In instances where a capacitor is connected directly across the terminal of the motor, the capacitor can act as a source of excitation current after the control device is opened. In order to prevent this the capacitor rating should not exceed 90% of the motor no-load magnetizing current.

23.7.4.3 Harmonics

A capacitor bank will represent a reducing impedance to currents of increasing frequency. Such a reducing impedance, if matched with a similarly increasing inductance impedance of a transformer or a supply system, can cause a resonant condition. In plants where equipment produces harmonic current a full survey of the installation is recommended prior to installation of the capacitors.

23.8 Motors and motor control

23.8.1 Functions

The principal functions which have to be met by any type of motor control gear are:

1. Provision of a means of starting the motor, taking into account the requirements of torque, acceleration, load, frequency of operation and safety;
2. When required, to limit the current drawn from the supply and starting;
3. When necessary, to provide means of speed control, reversing, braking, etc.;
4. Provision of protection for the motor itself in the case of faults and for the equipment controlling it (e.g. the contactor).

Motors used in industrial operations are predominantly of the induction type. The voltage at which they will be supplied will depend on the rating of the motor, the voltages available on-site and the capital cost of equipment. In general, the following voltage/load ranges apply:

Up to 185 kW	415 V
185 kW to 2 MW	3.3 kV
1–15 MW	11 kV

23.8.1.1 Squirrel-cage induction motor

The principal advantages of the squirrel-cage induction motor are its simplicity of design and robust construction. Its torque/speed and current/speed characteristics are such that, on starting, a torque of typically *twice* full-load torque is produced but a large current (typically, six to eight times full-load current) is drawn from the supply. It is this latter aspect of the current drawn upon starting which is important in deciding upon the type of starting equipment needed for a squirrel-cage motor because

1. The drawing of a large current from the supply will cause a corresponding voltage drop at the point of common coupling with other consumers. This will affect other drives within the installation or consumers fed from the same supply authority.
2. If the motor drives plant of high inertia (e.g. fans) the time during which the large current is drawn may be extended. Such a current flowing for an extended period may cause the unwanted operation of overload or overcurrent protection relays within the supply system.

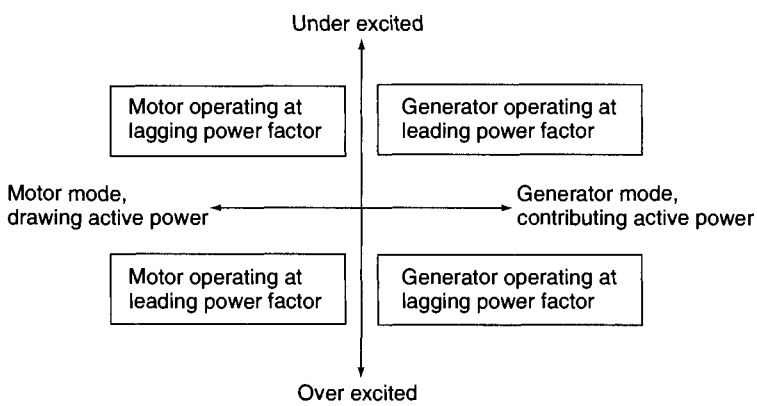


Figure 23.7 Synchronous machine operating modes

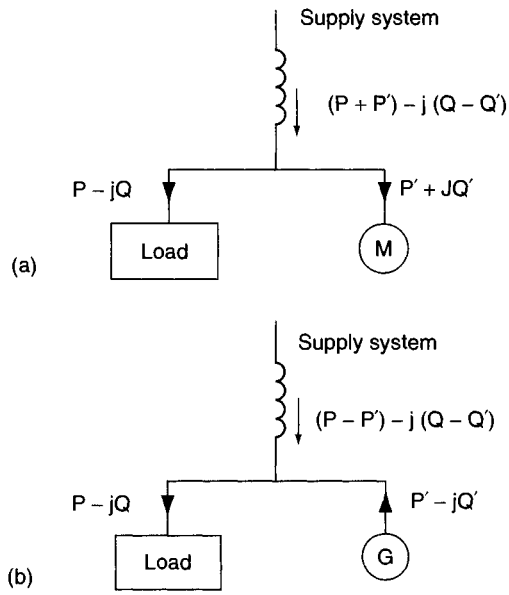


Figure 23.8 Synchronous machine operation. (a) Synchronous machine acting as a motor (over-excited); (b) synchronous machine acting as a generator (over-excited)

In order to overcome (1) it is often necessary to introduce a form of assisted starting, which can also help in overcoming problem (2). However, modification of the overload protection device characteristics may also be necessary.

23.8.2 Types of starter

For starting an induction motor the following types of starter are available:

1. *Direct-on-line*: Full voltage is applied to the motor;
2. *Start/delta, auto transformer, primary resistance*: Reduced voltage is applied to the motor;
3. *Electronic softstart*: The voltage and frequency applied to the motor is controlled;
4. *Stator/rotor*: Full voltage is applied with external rotor resistance.

The principal features of each type are as follows.

23.8.2.1 Direct-on-line

The equipment and connections are simple and the starter is robust. The basic equipment will comprise an isolator, high rupturing capacity fuses, a contactor, overload devices and control switches.

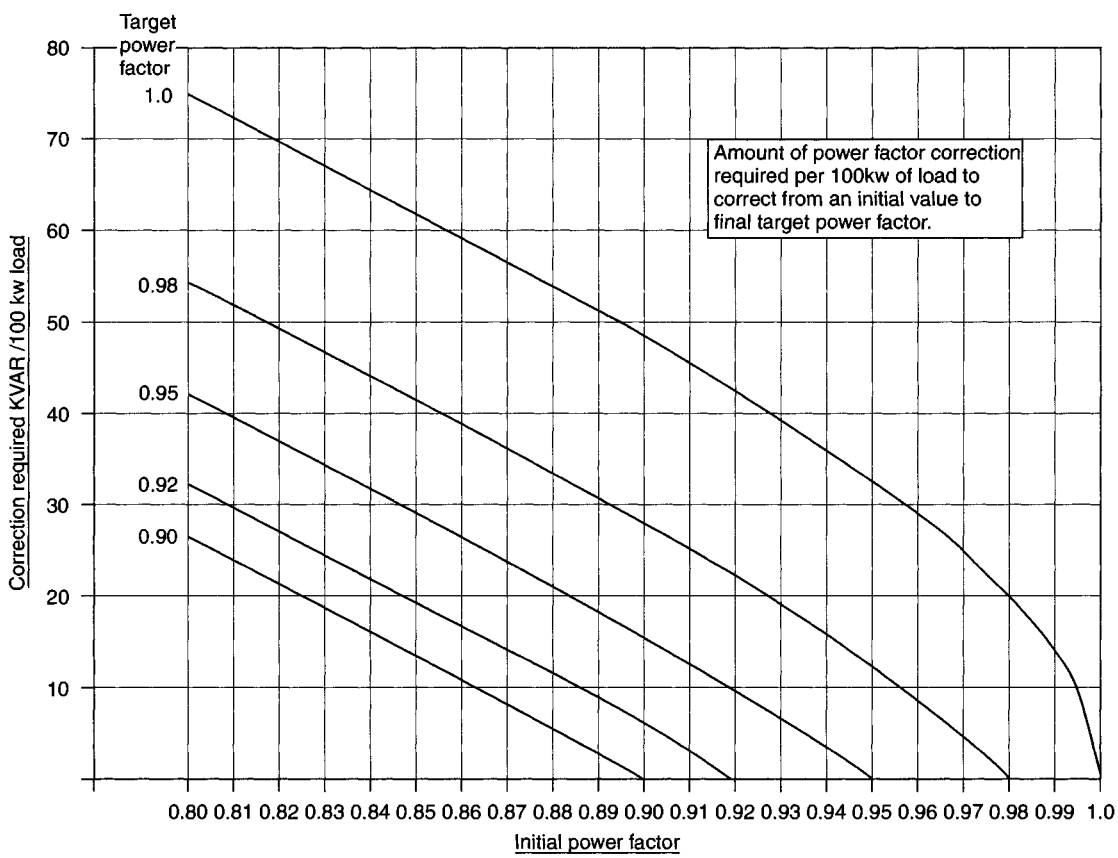


Figure 23.9 Amount of power factor correction required

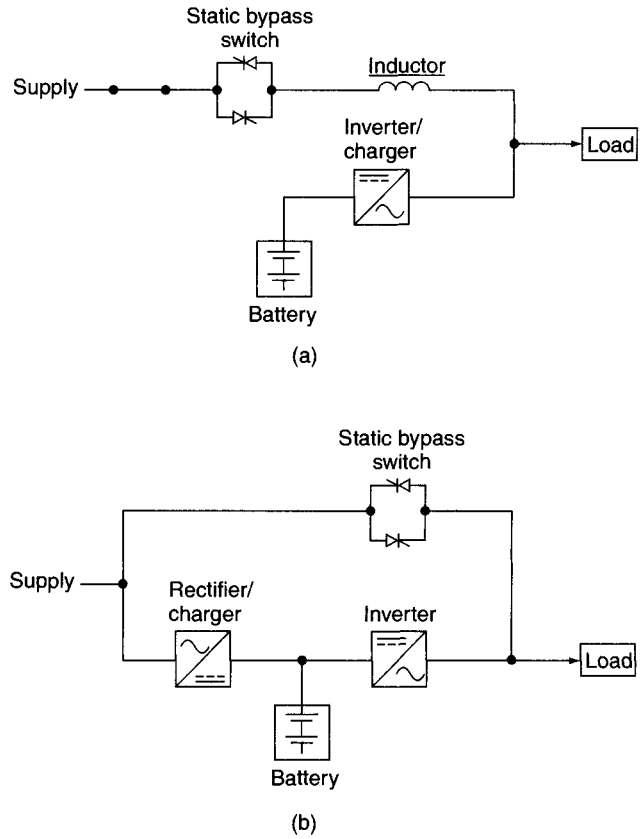


Figure 23.10 (a) Passive on-line UPS (b) On-line UPS

23.8.2.2 Star/delta starting

This is the most common form of reduced-voltage starting used in the UK. Both ends of the motor winding are cabled back to the starter. On starting, the windings are connected in star configuration, and thus the voltage applied to each winding is 57.7% of normal and the current taken from the supply is one third of that taken when started direct-on-line.

Change-over from star- to delta-connection takes place automatically by means of a timer. At change-over the motor is momentarily disconnected from the supply and the delta contactor is then closed. The closure of the delta contactor can cause a further surge of current to occur. The magnitude of the surge will depend on the speed of the motor at change-over, but it can be comparable to that taken when started direct-on-line.

Auto-transformer An auto transformer is used to provide a reduced voltage to the motor on start-up. The exact voltage applied to the motor can then be chosen, taking into account any limitation on starting current and motor torque. In an induction motor both starting current and motor torque are approximately proportional to the square of the applied voltage. Therefore for a motor which produces twice full-load torque and draws eight times full-load current on start-up, if the voltage is reduced to 75% by use of an auto transformer the starting torque $= 0.75^2 \times 2 = 1.125$ times full-load torque and starting current $= 0.75^2 \times 8 = 4.5$ times full-load current.

Primary resistance A resistance is inserted into the supply to the motor. This reduces the voltage available at the motor terminals on starting, and this voltage increases gradually as the motor current falls when the motor speeds up. Once the motor has reacted at a predetermined speed the resistance banks are shortcircuited.

Depending on the value of the resistor, the motor will, in general, draw a heavier current then when started using star-delta or auto-transformer methods. The resistors must be rated to carry the limited motor starting current for the time they are in circuit.

23.8.2.3 Electronic soft-start

An increasing used form of motor starter is known as "soft start". Soft starters utilise sold state technology, typically thyristors, to supply the motor.

In a "soft starter" voltage and frequency of supply to the motor is varied in a controlled way in order to provide the required torque as the speed increases up to full load.

Soft starts can be arranged to provide up to 200% full load torque at starting, whilst limiting the current

drawn from the supply to perhaps 350% rather than the 600% typically experienced from direct on line. Other parameters and facilities including kick start ability, ramp time to full speed and low load energy saving are available depending upon supplier.

Soft starters are available for the largest 400/600 volt motors. By specifying soft starters the specification of the associated supply system can be relaxed since large starting currents and resultant voltage drops will not occur.

Some users are specifying speed control inverters for motor starting even when full speed control facilities are not needed. So used inverters provide a soft starter capability, have good motor control, protection and diagnostic facilities as well as providing an energy saving function, if needed.

23.8.2.4 Stator/rotor

With this technique the motor has a wound rotor brought out to slip rings and an external resistance is connected into the rotor circuit. This resistance usually consists of a series of resistor banks which are switched out progressively in a number of steps as the motor accelerates. The number and rating of each step is chosen so that starting current and motor torque are within requirements.

23.8.3 Motor-starting equipment

Each component within a motor starting circuit must be selected to be suitable for the operation of the motor as it is required and for use on the electrical system from which the motor is to be operated. It must also be compatible with the other elements within the circuit. The principal components comprise:

Isolator
HRC fuses
Contactor
Overload device
Cable

The main parameters to be considered for each component are as follows.

23.8.3.1 Isolator

This must be:

1. Rated to close onto a fault at the rated fault level of the switchboard;
2. Able to carry starter rated full-load current continuously;
3. Capable of breaking a stalled motor current.

23.8.3.2 Fuses

Fuse manufacturers' catalogues give suggested fuse sizes for all 415 V motors. However, the following parameters all affect the fuse rating:

1. The starting current drawn by the motor, including all tolerances;
2. The starting time of the drive under worst-case conditions;
3. Full-load current, including efficiency and power factor;
4. Number of consecutive starts;
5. Short-time capability of contactor, overload, cable and isolator.

23.8.3.3 Contactor

A contactor must have full-load rating and be coordinated to proven capability with a selected fuse.

23.8.3.4 Overload device

Overload devices in current use are typically thermal overload relays to BS 4941, motor starters for voltages up to and including 1000 V a.c. and 1200 V d.c. or BS 142 electrical protection relays. Relays to BS 4941 generally provide overload and single-phasing protection. Those complying with BS 142 are also frequently fitted with instantaneous earth fault and overcurrent trips.

While applications vary from one industry to another, relays complying with BS 142 are typically specified for all motors larger than 45 kW.

23.8.3.5 Cable

The cable must be selected on the basis of full-load current rating, voltage drop on both running and start-up, and short-time current rating.

23.9 Standby supplies

23.9.1 Definitions

Standby supply systems within an electrical installation provide supplies to critical loads on loss of normal power supplies. In an installation one or more of the following types of standby supply systems are likely to be found:

1. Battery systems (either d.c. or inverted);
2. Uninterruptible a.c. power systems;
3. Standby diesel generating sets.

Each system type is utilized to satisfy different needs, and these and the salient points relevant to each type are as follows.

23.9.2 Battery systems

D.C. systems

These provide supplies to equipment which requires a d.c. supply both during normal operating conditions and when a.c. supplies have been lost. The loads can comprise:

1. Essential instruments
2. Control schemes
3. Switchgear closing and tripping
4. Telecommunications
5. Protection schemes
6. Interlocking

7. Alarms
8. Emergency lighting
9. Emergency drives (e.g. rundown lube oil pumps)
10. Standby diesel starting systems

Voltages in use range from 24 to 250 V. A d.c. installation will comprise a charger (capable of both float and boost charging), the battery itself and a distribution outlet.

The charger is normally arranged so that boost charging is carried out off-load, and should be designed so as to recharge the battery, after an emergency discharge has occurred, within a quarter to a half of the normal charting time. When the charger is operating in *float charge* mode it must be rated to supply the d.c. load requirements as well as float charging the battery.

Chargers can be fitted with an integral voltage-sensing device measuring circuit voltage at the charger output terminals. In the event that the terminal voltage rises significantly above the normal float voltage of the battery, the circuit will be arranged to trip the charger and provide an alarm. A separate alarm will be provided during boost charging. Alarms normally fitted comprise:

Charger fail
Rectifier fail
Battery earth fault
Battery boost charge
Battery low volts

Battery types are either lead–acid or nickel–cadmium cells. Lead–acid types have been used for a long time and, when correctly maintained, have a working life of 25 years. Nickel–cadmium batteries offer the same working life as lead–acid but are smaller in weight and volume, generally with a higher initial capital cost.

Loads applied to d.c. systems can be categorized into three types:

1. *Standing levels*: Loads which impose a consistent and continued load upon the battery (e.g. alarm facias).
2. *Emergency loads*: Loads which are only applied on loss of normal supplies. These are usually supplied only for a fixed period of time (e.g. turbine emergency rundown lube oil pump).
3. *Switching loads*: Loads imposed by the operation of both opening and closing of switchgear.

These loads, the expected duration of emergency loads and the required switching regime, and number of operations must be specified at the time of order placement.

23.9.3 UPS-a.c. systems

A.C. uninterruptible supply systems are used for the provision of supplies to those loads which:

1. Are required for post-incident monitoring and recording following a loss of normal supplies;
2. Require a high-quality supply in terms of voltage, frequency waveform and availability. These comprise loads which would not give an adequate standard of reliability if operated directly from the normal a.c. supply system;
3. Are necessary to monitor plant, particularly generating plant, during a shutdown operation or loads necessary to assist in a rapid restart.

In specifying an UPS three principal options are available:

- Off-line.
- Passive on-line.
- Active on-line.

1 Off-line UPS – the load is supplied directly by the mains. In the event of mains failure, the load is supplied by a battery and inverter after a short delay, typically less than 5 ms.
Off-line UPS are low cost units designed to provide a limited load, say up to 5 kva, for a relatively short period of time, up to 10 minutes.

2 Passive on-line – in this relatively recent development size and cost savings are achieved by the omission of a charger rectifier. The inverter used to supply the load when the supply fails is also used as a rectifier to charge the batteries.
Unlike the off-line UPS in a passive on-line UPS the inverter is connected to the load all of the time. With the inverter in circuit at all times, an UPS failure is more likely to become apparent to the user without a supply interruption occurring.

3 On-line UPS – this is the most commonly used form of UPS. The loan is supplied via the rectifier/charger and inverter at all times. In this way the power supply is not only supported by the batteries but is also conditioned.
On-line UPS frequently also incorporate a static by-pass switch, which will automatically supply the load if the rectifier/inverter fails.
On-line UPS continue to be used for loads where high quality waveform and security of supply are of paramount performance.
In addition to UPS relying on solid state technology, rotary UPS comprising a motor/generator with flywheel or rectifier/battery/DC motor/AC generator continue to be used for very large loads (1 MVA).

The main problem in specifying UPS equipment is that of inadequately identifying the characteristics of the loads which the UPS is to supply, and the following must be specified:

Steady-state voltage regulation
Acceptable transient voltage variation
Non-linearity characteristics of load current
Percentage distortion in voltage
Frequency tolerance
Power factor of load
Inrush upon switch-on

23.9.4 Standby diesel generators

The selection of a diesel generator is governed basically by the electrical load and the standard engine frame sizes

available. In specifying a diesel generator for use as a standby supply the electrical load must be analysed in terms of final running load, load profile, starting characteristics of individual motor loads and required operating time. Chapter 20 gives a full description of the types of diesel-driven time movers available. Electrical characteristics to be considered include:

1. Type of generator;
2. Type of excitation (brushless or static);
3. Transient performance (the capability of the generator to maintain the output voltage when a load is applied). It must be remembered that the impedance of the generator will be greater than that of the supply system which it has replaced;
4. Method of alternator cooling (the heat gain to the building housing the diesel generator must be taken into account);
5. Method of neutral earthing;
6. Method of testing. If the diesel is to be tested it may be necessary for it to operate in parallel with the supply system in order to apply load. Synchronizing facilities will be needed and the fault levels during parallel operation must be assessed.
7. Electrical protection schemes. The installation should be carried out in accordance with Electricity Council Engineering Recommendation G26, *The installation and operational aspects of private generating plant.*

23.10 Earthing

23.10.1 General

Electrical supply systems and equipment are earthed in order to maintain the voltage at any part of the system at a known potential relative to true earth and to provide a path for current flow under earth fault conditions so that protective devices operate correctly. The connection to earth should be such that the flow of fault current to earth does not cause voltages or voltage gradients to be of sufficient magnitude or duration likely to cause danger.

An electrical earth system comprises the provision on the supply system of an earth connection to facilitate earth fault current flow, the connecting of all exposed metalwork within the installation to a common earthing terminal and the connection of this terminal to earth. For a complete installation the principal factors which need to be considered are:

The earth electrode
Neutral earthing
Substation earthing
Supply system earthing
Bonding

23.10.2 Earth electrode

The connection to earth can be made utilizing earth rods, earth plates, earth lattices or grids, or buried strip conductors. Selection depends on the locality and type of ground conditions at the site, and since the effectiveness of the earth connection is, in turn, dependent on the resistivity of the soil at the site, the type of soil and climatic conditions have a direct effect upon the resistance of the connection made. Typical values of resistivity (Ω-m) for different types of soil are:

Garden loam	4–150
Chalk	30–200
Clay	5–100
Sand	50–800
Rock	Above 1000

The resistivity of the soil in any particular location will be a function of moisture content, soil temperature and presence of dissolved salts. At a site where climatic conditions vary considerably throughout the year, earth electrodes should be buried at a depth where such changes will not affect the resistivity. Earth rods are generally made of copper bonded onto a steel core. The copper provides a good connection to earth and offers a high corrosion resistance, while the steel core gives the mechanical strength necessary to allow the rods to be driven to the required depth.

Earth plates or lattices made of pure copper, while displaying good current-carrying capacities, do not provide a particularly low resistance due to the depth at which they are able to be buried. The third alternative is to bury lengths of copper tape around the installation. The use of reinforced concrete foundations for earthing electrodes has also recently been considered.

Formulae for calculation of the resistance to earth of each type are as follows:

$$\text{Single rod } R = \frac{P}{2\pi L}\left[\ln\left(\frac{8L}{\delta}\right) - 1\right]$$

$$\text{Plate } R = \frac{e}{8r}\left(\frac{r}{2.5h + r} + 1\right)$$

$$\text{Grid } R = P\left(\frac{1}{4r} + \frac{1}{L}\right)$$

where

R = resistance,
e = resistivity,
L = rod or conductor length,
δ = rod diameter,
r = radius of plate; for a rectangular plate or grid

$$r = \frac{\sqrt{a}}{\pi}$$

h = depth of plate,
P = soil resistivity.

The earth electrode system must be designed to be capable of carrying without damage to the full earth fault current of the supply system.

23.10.3 Neutral earthing

An earth can be established on an electrical supply system by the connection to earth of the neutral point of

the supply transformers, or generators or the use of interconnected star-wound earthing transformers. The earthing must be arranged to ensure that an earth is provided on the supply system at all times and that the resistance of the connection to earth must be such that earth fault protection operates correctly. In instances where generators are to be run in parallel with each other or in parallel with a grid supply the neutral earthing arrangements will require special consideration.

23.10.4 Earthing in substations

The earth systems associated with high-voltage substations must satisfy the following conditions:

1. The resistance of the system to earth must be low enough to ensure that earth fault protection equipment operates correctly.
2. In the event of an earth fault the difference in potential between a person's feet (step potential) should not reach dangerous levels.
3. In the event of an earth fault the difference in potential between any point which may be touched and the ground (touch potential) should not reach dangerous levels.
4. The substation and its environment should not be connected to metal objects such that the voltages arising within the substation under fault conditions can be transferred to a point remote from the substation.
5. The earthing conductors must be capable of carrying maximum earth fault current without overheating or causing mechanical damage.

23.10.5 Types of system earthing

The IEE Regulations for Electrical Installations recognize the following designations of earthing systems using a two-, three- or four-letter code as follows:

First letter (denoting the earthing arrangement at the source)
T – Direct connection of one or more points to earth;
I – All live parts isolated from earth or one point connected to earth through an impedance.
Second letter (denoting the relationship of the exposed conductive parts of the installation to earth)
T – Direct connection of the exposed conductive parts to earth, independently of the earthing of any point of the source of energy;
N – Direct electrical connection of the exposed conductive parts to the earthed point of the source of energy (usually the neutral).

The designation TN is subdivided, depending on the arrangement of neutral and protective conductors. S indicates that neutral and protective functions are provided by separate conductors and C that neutral and protective functions are provided by a single conductor.

Examples of these designations and their usage are as follows:

1. *TN-C system*: Neutral and protective functions combined in a single conductor throughout the system.
2. *TN-S system*: Separate neutral and protective conductors throughout the system;
3. *TN-C-S system*: Neutral and protective functions combined in a single conductor in a part of the system;
4. *TT system*: All exposed conductive parts of an installation are connected to an earth electrode which is electrically independent of the source earth.

The following publications contain further information on and expansion of the factors relating to earthing.

Electricity Council Engineering Recommendation G26, *The installation and operational aspects of private generating plant*
BS Code of Practice CP1013, Earthing
IEE Regulations for Electrical Installations

23.11 Cables

Electrical power distribution within an industrial installation is most often at a voltage up to and including 33 kV. This section describes the types of cable suitable for power circuits for use up to 33 kV and considers the factors which will influence the current-carrying capacity of such cables.

The principal components of a power distribution cable are the conductors and the insulators. The cable is completed by the provision of armouring, overloads and other features designed to protect the cable within its installed environment.

23.11.1 Conductors

Material used for conductors comprise copper or aluminium in either stranded or solid form. Copper is the most common type of conductor due to its good conductivity and ease of working. Despite having a conductivity of only 61% of that copper, aluminium can be used as the conductor material. The lower density of aluminium results in the weight of an aluminium cable offsetting, to a certain extent, that of the additional material necessary to achieve the required current-carrying capacity.

Although aluminium cable has a proven record of satisfactory operation, the problems of terminating such cables must be recognized at the time of specifying. Since an aluminium cable will be larger than an equivalent copper cable of the same current-carrying terminal, enclosures and cable support systems must be designed to suit. Table 23.6 illustrates current-carrying capacity, overall diameter and weight for a typical range of 3.3 kV cables.

23.11.2 Insulation

Insulation materials used at voltages up to 33 kV comprise paper, PVC and polythene (XLPE). Paper-insulated cables have been used for the complete voltage range up to 33 kV throughout this century, although today they

Table 23.6 Comparison of parameters for 1900/3300 V XLPE insulated, armored, three-core cable

	Copper			*Aluminium*		
Nominal area of conductor (mm^2)	*Current-carrying capacity (A)*	*Weight (kg/1000 m)*	*Overall diameter (mm)*	*Current-carrying capacity (A)*	*Weight (kg/1000 m)*	*Overall diameter (mm)*
50	210	2850	34.7	160	2075	33.0
70	265	3625	38.0	200	2450	36.0
95	325	4500	41.4	245	2875	39.1
185	495	8075	51.9	370	4650	48.7
240	580	10375	56.9	440	5625	53.2

Table 23.7 Comparison of full-load capabilities for paper, PVC and XLPE insulated copper cable

Cable size (mm^2)	*Paper*[a]	*PVC*[b]	*XLPE*[c]
	Current-carrying capacity in air (A)		
16	91	87	105
35	150	142	170
50	180	172	205
95	280	268	320
185	430	407	490
240	510	480	580

[a] 600/1000 V: Three-core, belted, paper-insulated, lead-sheathed, stranded-copper conductor.
[b] 600/1000 V: Three-core, PVC-insulated, SWA, PVC, stranded-copper conductor.
[c] 600/1000 V: Three-core, XLPE-insulated, PVC-sheathed, SWA-stranded copper conductor.

are limited in general to 6.6 kV and above. Paper cable is usually designed to operate at a conductor temperature not exceeding 80°C and PVC cable has largely replaced paper cables at voltages up to 3.3 kV. The relative imperviousness of PVC to moisture has contributed greatly to the design of the cables, making them easier to handle and install. The excellent dielectrics of properties of cross-linked polythene, together with the fact that XLPE does not soften at elevated temperatures, means that XLPE cables can operate with high continuous operating temperatures and short-circuit temperatures. The maximum operating temperature of XLPE is 90°C, with a maximum under short-circuit conditions of 250°C. Table 23.7 gives a comparison of the full-load capabilities of a range of cable sizes.

23.11.3 Selection

In selecting a cable for a particular installation the following factors need to be considered:

1. The steady-state voltage drop of the circuit;
2. The voltage drop in starting if the cable is for a motor circuit;
3. The current-carrying capacity under full-load conditions;
4. The maximum fault current which can flow and its duration.

For (3) and, to a certain extent, (4) the exact details of the cable installation will have a direct bearing on the cable chosen.

The cable rating will be affected by the ambient temperature of the installation, and account should be taken of any local high temperatures caused by proximity of process plant, the presence of and location of other cables and any thermal insulation which may prevent or inhibit heat dissipation. Cable ratings applicable to a variety of cable-installation techniques, together with the correction factors applicable, are given in a number of sources, including manufacturers' catalogues, the IEE Wiring Regulations and reports published by ERA Technology and IEC.

24 Electrical instrumentation

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24.1 Introduction

The plant engineer needs to know the circumstances under which the plant for which he is responsible is operating. Hence he needs to be able to measure the inputs to the plant and the power inputs to the individual sectors. It will also be necessary to measure the plant outputs. In most cases the instrumentation uses electrical or electronic techniques, i.e. it measures either electrical quantities *per se* or quantities such as temperature or pressure which have been converted to electrical signals by means of transducers. The degree of accuracy to which these measurements are required will vary, depending on their purpose. In the case where the measurement is used as a direct basis for charging for energy then the accuracy must be very high. This is also the case where precise process control is involved. In other instances it is sufficient for the plant engineer to have a less accurate measurement of what is going on. As well as being technically suitable for the purpose, the instrument chosen will reflect these considerations. In the case of process control the instrumentation must be reliable and it must yield information, often over very long periods of time, which represents the state of the plant or the process and its past history. It is on the basis of this information that the plant engineer will make decisions, many of which will affect the economic viability of the process and some of which will have a direct impact on the safe operation of the plant.

Most plants will be supplied either directly or through the factory distribution system from the electricity supply authority. In the UK this supply is usually a.c. at a frequency of 50 Hz and at a voltage depending on circumstances, but which, in the case of large power demands, can be 11 000 V or even higher. Thus meters are required to measure these and related quantities. A variety of transducers are available for the measurement of physical quantities. These either give a direct readout to the operator or initiate some form of control action. In addition, there is a requirement for test and diagnostic equipment to determine if the measurement and control equipment is operating correctly and, if failures occur, to aid in tracing the source of the problem.

The plant engineer will need to familiarize himself with what is available in all these categories so that he may make the most appropriate equipment selection. He will also need to be familiar with what to expect from his instrumentation both in terms of accuracy and in order to know how to interpret the information correctly.

24.2 The role of computers in plant engineering

The continued reduction in cost and size of computers coupled with increases in operating speed and reliability has led to the extensive use of computers and embedded microprocessors in the process industries. The computing power now available in a personal computer (PC) is greater than that available in a mainframe computer of a generation ago. This increase in power and availability of computers has transformed the way in which plant engineers operate.

Embedded micro-controllers are used to control individual pieces of equipment such as packaging machines, they are also used to facilitate communications throughout a plant via ethernet connections. Personal computers can be used to monitor and control every aspect of a production operation, or can be used to monitor the operation of an entire plant.

While communications links have moved the control room from the shop floor to an office environment, the internet will make it possible to monitor and control multiple process plants across the globe from a single location.

24.3 Data logging

In the operation of complex plant there is a need to record and analyse large amounts of data relating to the performance of the plant. Traditionally strip-chart recordings were taken of the process parameters during a production run. Analysis of the interaction of process parameters was then carried out 'off-line' to determine the operational settings of future production runs.

Data loggers utilise modern transducers, communication systems, display techniques and data storage media to facilitate automatic real-time collection and storage of plant data. The data logger will also be able to perform calculations on the data to reduce it to an appropriate form for evaluation by technical staff.

Many data logging systems are now implemented by use of a personal computers (PC). In this context a data-acquisition card is installed into the PC. The data acquisition card converts the incoming analogue signal into digital form and organizes it in such a way that the PC software can access the data to carry out calculations and to display the data in an appropriate form. Often the display of data is done graphically.

24.4 Supervisory control

The operational requirements of a process plant often demand automatic control to be implemented. If this is the case then data logging systems can be extended to provide the control function. As the system measures and records the process variables and carries out calculations based upon these measurements it can also determine the most appropriate set-points for the process loops. So as various loads in a process change, it is possible to alter set-points in certain loops to increase efficiency or to maintain the operation within the defined limits of the process.

There are two main types of controller used in the process industries.

24.4.1 The PID controller

This type of controller has been in use for many years in pneumatic form, in the form of an analogue electronic circuit, as a digital circuit, and more recently it is implemented in software using a microprocessor. These controllers are predominantly used to maintain the constant

value of a process variable under conditions of changing load.

Modern PID controllers tend to be of the 'self-tuning' type, this means that they will adjust their own parameters to give the optimal control of the process loop to which they are connected. They tend to be interfaced by a serial communications link to a supervisory control system.

24.4.2 The programmable logic controller (PLC)

This type of controller is used with ON/OFF systems and can be programmed using ladder logic to perform complex operations based on decisions taken on the basis of the plant status. A typical example may be:

IF sensor A reads HIGH
THEN switch output B OFF
IF sensor A reads LOW
THEN switch output C ON

These controllers may incorporate counters and timers making them ideal for batch processes.

PLC's are often used as stand alone systems, however, they may be connected via a serial communications link to a supervisory control computer to enable the operator to monitor the current state of the plant.

24.5 Distributed systems

In situations where a large, complex plant has to be monitored and controlled there may be many hundreds of signals to be recorded and displayed by the supervisory control computer. If each signal is connected directly to the supervisory control computer by a unique cable there will be many hundreds of signal cables to run throughout the plant, plus a large area must be allocated to allow marshalling and termination of the cables prior to connection to the computer. This approach is often unacceptable for a large plant. An alternative is to divide the plant into small areas or zones. The signals required in each zone are then marshalled in a cable box or cable room in that zone. The signals are multiplexed by a microprocessor which then transmits all of the signals to the central supervisory control computer by a single serial communications link. Thus the central computer is connected to a small number of outstation computers which collect all of the data for each allocated zone.

In industries where the data is safety critical there are often two serial communications links for the same data. These links can be physically separate and can be routed differently to ensure that if one link is broken the other remains in tact. This type of redundancy is common in the nuclear industry.

24.6 Display of data

One of the important features of a supervisory control system is that it allows the plant to be controlled and monitored from a single point. The central control room may, in fact, be some distance from the plant itself and is often remote from hazardous environments.

Visual display units (VDU's) are the main vehicle for the display of data to operators. The graphics software used is sophisticated and often the screen will show diagrammatic representations of the individual parts of the plant, these are often known as 'mimics'. The operator may interrogate the mimic to see the actual value of the process variable, the set-point value of a process loop or the value of the controller output as a percentage of its maximum.

Some VDU's used in control rooms are touch sensitive or light pen sensitive so that the operator merely has to touch the part of the display which is of interest and further information relating to that part of the plant will be displayed.

24.6.1 Alarms

One of the most important items to be displayed in a control room are the alarms. These are pre-specified and typically may be of the type:

Flow rate Z1123	Low
Temperature Z2345	High
Level Z5678	High

The supervisory control system will continuously monitor all measured variables to check their alarm status. If an alarm occurs then an audible warning may be given, a visual warning may be given or both may occur. In a typical system the operator will be requested to acknowledge that the alarm has been recognized, this is usually achieved by the operator pressing an acknowledge button. In many plants a printed record is taken of all alarms that have occurred, the time at which they occurred, the time at which they were acknowledged by the operator and the time at which the alarm was cleared. This data may be used as part of an audit trail to check on safety or quality control procedures.

24.6.2 Archiving of data

In many industries the day to day operational data is not required for more than a few hours. However, in some industries there is a requirement to keep operational records for a considerable period of time. These records may be used for quality control or for safety audits. Much of the data required to be archived can be stored on magnetic media such as floppy disks, hard disks or magnetic tape back-ups. However, if the data is critical for legal requirements then it should be printed and stored securely as hard copy.

24.7 Transducers

Many of the quantities required to be measured in process plant operation are not, in themselves, electrical, and if electrical or electronic instrumentation is to be used then these need to be converted to electrical signals using a transducer. The transducer is a physical object and its

presence will have an effect on the quantity being sensed. Whether or not this effect is significant will depend on the particular application, but in all cases it is advisable to consider carefully the balance between the requirement that the transducer should, on the one hand, cause the minimum interference with the quantity being measured and, on the other, that it should be intimately associated with the effect being measured.

Temperature measurement is a case in point. A large transducer in close contact with the body whose temperature is being measured will act as a heat sink and consequently produce a localized reduction at the point where the temperature is being measured. On the other hand, if an air gap exists between the transducer and the hot surface then the air (rather than the surface) temperature will be measured.

The important characteristics of a transducer used in conjunction with an electronic measurement system are accuracy, susceptibility, frequency, impedance and, if appropriate, the method of excitation. The transducer is likely to be the least accurate component in the system, and it should be calibrated (and recalibrated) at frequent intervals. It is likely to be subject to a range of different physical conditions, some of which it is there to detect and others by which it should remain unaffected (for example, a pressure transducer should be unaffected by any changes in temperature which it might be called upon to experience). Some types of transducer are not suitable for use under d.c. conditions and all will have an upper limit of frequency at which accuracy is acceptable. Many types of transducer are also affected by stray electromagnetic fields.

The impedance of the transducer is important if it provides an output signal to an electronic device (an amplifier, for example) and the impedance of the two must be matched for accurate measurement. Some transducers (thermocouples, for example) generate their output by internal mechanisms (i.e. they are self-excited). Others such as resistance thermometers need an external source and an appropriate type must be available. Transducers used in the measurement of the more common physical quantities are discussed below.

24.7.1 Temperature

There are several instruments for measuring temperature as follows.

24.7.1.1 Resistance thermometers

These utilize the fact that the resistance of most materials changes with temperature. In order to be useful for this purpose this change must be linear over the range required and the thermal capacity must be low. Although the above implies a high resistivity and temperature coefficient, linearity and stability are the paramount considerations, and suitable materials are platinum, nickel and tungsten.

The sensor usually consists of a coil of wire made from the material which is wound on a former and the whole sealed to prevent oxidization, although a film of the metal deposited on a ceramic substrate can also be used. The resistor is connected in a Wheatstone bridge network (Figure 24.1), using fixed resistors in the other three arms. The instrument connected across the bridge is calibrated directly in terms of temperature. The range is limited by the linearity of the device and the upper temperature, which can be measured, must be well below the melting point of the material.

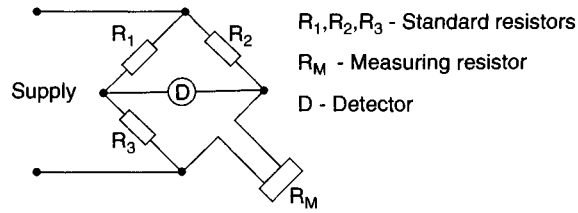


Figure 24.1 Resistance temperature measurement

24.7.1.2 Thermocouples

These are active transducers in the sense that they act as a generator of emf whose magnitude is a function of the temperature of the junction of two dissimilar metals. Rare-metal combinations are used for high accuracy and at high temperatures, but for most engineering applications one of the following is suitable, depending on the temperature:

Copper/constantan	(up to 670 K)
Iron/constantan	(up to 1030 K)
Chromel/constantan	(up to 1270 K)
Chromel/alumel	(up to 1640 K)

If the instrument is to be direct reading the second (or 'cold') junction must be kept at a constant reference temperature. If high temperatures are to be measured then the terminals of the detector can be used as the cold junction without an unacceptable loss of accuracy.

The voltage output of the more common types of thermocouple is of the order of 50 microvolts and the output is either read on a sensitive moving-coil meter or on a digital voltmeter. The reading is converted to temperature using a calibration chart supplied with the thermocouple. Some commercial units are available in which the thermocouple and instrument is supplied as an integral unit with the scale directly calibrated in temperature. If a separate instrument is to be used then it should be noted that the thermocouple resistance is only of the order of 10 Ω and for maximum sensitivity the meter resistance should be matched to this.

The commercial units have a very low thermal capacity and very high response speeds. Some are available with several independent channels and a common 'cold' junction. Each channel is scanned in turn by the instrument, and the readings either displayed or stored for future recovery. Accuracies of better than 0.2 per cent are possible. Thermocouples are available to cover a very wide range of temperatures, their cost is low and they have a small mass, so minimizing the intrusive effect on the surface at the point where the temperature is being measured. The output characteristics (output voltage versus temperature) are reasonably linear but the measurement accuracy is not particularly high.

24.7.1.3 Thermistors

These are semiconductor devices which have a high resistivity and a much larger temperature/resistance coefficient than the materials available for resistance thermometers. However, there is a temperature limitation of around 550 K and the characteristics are excessively non-linear, although it is possible to obtain matched pairs to measure differential temperatures. Thus, for example, they can be used to measure air flow in ducts. The change in resistance is again detected using a Wheatstone bridge network. The materials used are manufactured from sintered compounds of copper, manganese, nickel and cobalt. Conventional semiconductor diodes in the form of $p-n$ junctions can also be used in this way.

Although thermistors with a positive temperature characteristic are available, the negative characteristic type are more common. Devices which are physically small have low power-handling capabilities and some form of output amplification is usually needed. They do, however, have a fast response. Larger units are available in which amplification can be dispensed with but the response is much slower. These are used for indication (rather than control) purposes.

24.7.1.4 Pyrometers

These are non-contact instruments for measuring temperature, and as such their thermal mass is relatively unimportant. They can be used for very high temperatures. Radiation pyrometers focus the infrared radiation emitted by the body onto a thermocouple contained within the instrument. The voltage produced by the thermocouple is then read on a dial calibrated directly in terms of temperature. If required, this voltage can be amplified and used as a control signal. The actual temperature measured is that integrated over the whole of the surface 'seen' by the pyrometer and the reading may be affected by infrared absorption in the medium between the hot surface and the instrument. This also applies to optical pyrometers, which are usually of the disappearing-filament type. The instrument contains a lamp the filament of which is viewed against the background of the hot body. The current through the lamp is adjusted, so varying the brightness of the filament until it merges into the background. The current required to achieve this is measured and converted into a temperature reading on the dial.

24.7.2 Flow

Sensing and measurement of liquid flow is a vital part of plant control especially where the manufacturing process is continuous rather than batch. The measurement of liquid flow may be achieved in three ways. Firstly by sensing the speed of the liquid flow, secondly by measuring the volume of liquid passing a point per second, and thirdly by measuring the mass of liquid flowing past a point per second. Volume flow rate is usually the method used.

24.7.2.1 Orifice plate

The simplest method of measuring flow rate is to use an orifice plate, this is a plate fitted into a pipe which reduces the diameter along a short section of pipe. For a liquid whose flow rate is slow enough to be laminar the pressure difference across the orifice plate is linearly proportional to the rate of flow. For flows which are not laminar but are turbulent the pressure difference across the orifice plate is proportional to the square of the flow rate.

24.7.2.2 Turbine

The turbine method uses a rotating turbine in the path of the flowing liquid, the movement of the liquid turns the turbine the speed of rotation of the turbine is approximately linearly proportional to the flow rate of the liquid.

24.7.3 Level

Measurement of liquid level in a storage tank leads directly to volume of liquid stored in the tank. Expansion due to temperature changes and mechanical deformation of then tank may add complications to accurate calculations, but in most situations measurement of level produces adequate results.

24.7.3.1 Float arm

This is a very basic measurement method which uses a float attached to a lever which rotates a potentiometer to produce a change in resistance for a change in liquid level. An improvement of this method is to attach the float to a chain which rotates as the float mover up and down. The chain in turn rotates an encoder which then senses the amount of movement of the float.

24.7.3.2 Capacitative method

This method uses the permittivity of the liquid to form a capacitor between two plates. As the liquid level changes the value of capacitance changes so providing a measure of level.

24.7.4 Pressure

24.7.4.1 Piezoelectric crystals

These use crystalline materials in which the electrical properties of the material are changed when it undergoes slight deformation by, for example, the application of mechanical pressure. The principal effect is to cause a change in the frequency at which the material resonates. This change in resonant frequency can be detected and measured, so giving an indication of the change in pressure.

Quartz is a natural crystalline material which exhibits this form of behaviour, although its relevant properties are highly temperature dependent and synthetic materials have been developed which, although fundamentally less accurate, are more stable under varying temperature conditions.

One application is the accelerometer, in which the acceleration force of a mass is made to increase (or decrease) the pressure produced on the crystal by a spring. This, in turn, produces the required electrical change, the effect of which is amplified. It is important to select units appropriate for the expected changes, which should be within the frequency range from almost zero to the natural frequency of the crystal.

24.7.4.2 Strain gauges

These units are rigidly attached to a surface. Any small deformation in that surface due to the application of an external force changes the dimension of the strain gauge, and this change is then detected to give a value of the applied force or the strain in the material. Resistance strain gauges consist of a grid resistance wire cemented between two films. This resistance element is connected in one arm of a measurement bridge with a similar, compensating, gauge in a second arm. The bridge is rebalanced when the strain is applied, and the changes required to do this are measured and converted, using the calibration information, to the quantities required.

Modern techniques use thin-film resistors deposited directly on the area and semiconductor units are available which are considerably more sensitive than the resistive type. Dynamic measurements can also be made. The change in resistance unbalances the bridge, causing a voltage to appear across the detector terminals. This voltage is then amplified and applied to a CRO or the information can be stored digitally for future retrieval.

Strain gauges can also be used to measure pressure by bonding the gauge to a diaphragm in the wall of a liquid or gas container, acceleration, by sensing the relative change along one or more sensing axes, and torque (by sensing angular strain).

Temperature-sensing devices may also be used for the measurement of flow in pipes or ducts and for an indication of the level of liquid in a tank. The device is indirectly heated, using a separate heating filament, and the flow of liquid cools the sensor at a rate which is a function of the velocity of the flow. Thus by incorporating the device into a bridge circuit it is possible, after appropriate calibration, to obtain a direct measurement of the flow velocity. Similarly, several such devices can be placed, one above the other, in a tank, containing liquid. The liquid acts as a heat-transfer medium, those devices below the surface are cooled as the liquid level falls and the temperature and therefore the resistance of the devices increase. This can be detected, and the whole chain is thus used as a level detector.

24.7.4.3 Impedance transducers

Strictly, the strain gauges referred to above come into this category, since in such cases the change in the measured quantity causes a corresponding change in the resistance of the element. However, the principle has a much wider application, using changes in either the inductive or capacitive reactance of electrical circuit elements.

The inductance of an iron-cored inductor varies with any air gap included in the iron core. Thus physical movement can be detected by allowing this movement to displace part of the core, so changing the width of the gap. The detection of very small movements is possible in this way, and instruments based on the principle are used to measure acceleration, pressure, strain, thickness and a variety of other changes.

The effects usually need to be amplified, and in some cases signal processing is necessary in order to obtain the derived information. Two electrical conductors at different potentials exhibit the property of capacitance (i.e. energy storage) between them. The value of this capacitance changes when the relative position of the plates alters or when the medium between them is changed. Such changes can be detected by employing the capacitor in an oscillatory circuit. The resonant frequency of this circuit is proportional to the capacitance which it contains and therefore the detection of such a frequency change allows the original quantity to be determined.

This technique can be used to measure displacement where, in effect, the two electrodes are connected to the two bodies. It has also other applications (for example, in moisture meters where the presence of water vapour between the electrodes causes the capacitance change).

24.8 Electricity supply metering

24.8.1 Metering requirements

The electricity supply to the factory is usually obtained from the public supply authority, who will need to install metering in order to be able to assess the charges due in accordance with the agreed tariff. This metering will be the responsibility of the energy supplier but, in order to ensure that the rights of the customer are protected, the design of this instrumentation, and the accuracy limits within which it must operate, are controlled by statute.

The customer will usually either have visual access to this instrumentation in order to confirm the readings or will install his own, duplicate, instrumentation as a check.

In any event, in most plants the plant engineer will have a need to monitor the electricity consumed by the various sectors on the site and he will need similar instrumentation to do this. The normal method of charging for electrical energy is based on two components, since the true cost is a function of (1) the total amount of primary (e.g. coal, nuclear) energy and the costs of converting it to electricity (these are the 'unit costs') and (2) the cost of providing the necessary plant to carry out the conversion and to transport the electrical energy to the customer (the 'maximum demand charge'). The first of these is primarily a function of the energy (kWh) supplied while the second is a function of the maximum value of the electric current drawn at any time from the supply and the voltage at which it is supplied. Thus two forms of instrumentation are needed, an energy (kWh) meter and a maximum demand (kVA) meter.

24.8.2 Energy meters

Energy is usually measured using an induction integrating meter (BS 37). In the case of a single-phase load the

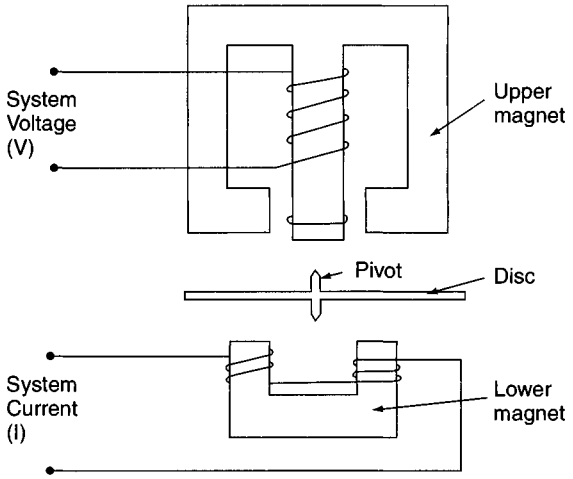


Figure 24.2 Schematic diagram of an induction meter

arrangement is as shown in Figure 24.2 this consists essentially of two electromagnets, mounted one above the other, with a light-weight aluminium disc free to rotate between them, as shown in the figure. The upper electromagnetic is energized by the system voltage (V), or a voltage proportional to it, and a current proportional to the system current (I) flows through the coil on the lower magnet. The electromagnetic flux created by the two magnets interact in the disc in which a torque is produced proportional to the product of the two multiplied by the cosine of the phase angle between them. Thus this torque is proportional to ($VI\cos$), the electrical power supplied to the system, and the speed of rotation of the disc is proportional to the torque. Hence the number of revolutions made by the disc in an hour is a measure of the energy used, i.e. the watt-hours (Wh) or, more usually, the kilowatt-hours (kWh).

The number of rotations of the disc is registered and can be recorded on a dial. As noted above, the voltages and currents energizing the coils are the normal system voltages unless these are too large for convenience, in which case voltage and current transformers are used as appropriate.

A high degree of accuracy is required over a very wide range of input currents. At very low loads (i.e. very low input currents) this accuracy can be affected by pivot friction, but this can be allowed for in the instrument design. The disc rotation is converted to a dial reading using a gear train (the 'register') and this reading is then used as a basis for charging under the tariff arrangements in use. In some cases two-part tariffs are involved, the simplest form being that in which kWh (units) above a certain number are charged at a different rate. This adjustment can be made after the reading is taken. In other cases units used during specific periods of the day are charged at a rate different from that in force during the remainder of the time. This can be catered for by incorporating a time switch into a meter with two sets of registers. At the appropriate time the switch operates and an electromagnet changes the drive to the second register. Alternatively, an entirely separate instrument can be used, with the changeover again being controlled by the time switch.

24.8.3 Error limits

The permissible error limits are defined in BS 37. In general, the error must not exceed ±2 per cent over the working range, although in practice the accuracy is usually much higher than this. Temperature changes are compensated for in the design and the instrument is likely to be unaffected by variations in voltage and frequency provided that these are within the limits laid down in the Electricity Supply Acts (±4 per cent in voltage and ±0.2 per cent for frequency). Very low voltages and reduced supply frequencies will both cause the instrument to read high if the load has a high power factor. If the power factor is low and the load is predominantly inductive then the frequency effect is reversed.

24.8.4 Three-phase metering

For large loads supplied with three phases then a three-phase meter is necessary. In these cases three single-phase units with their rotor torques combined mechanically are used, the whole being contained in one case. If the load current is above 150 A per phase then it is common to use instruments which combine the measuring elements, each with their own current transformer (see below) so that the combination can be calibrated as one unit (Figure 24.3).

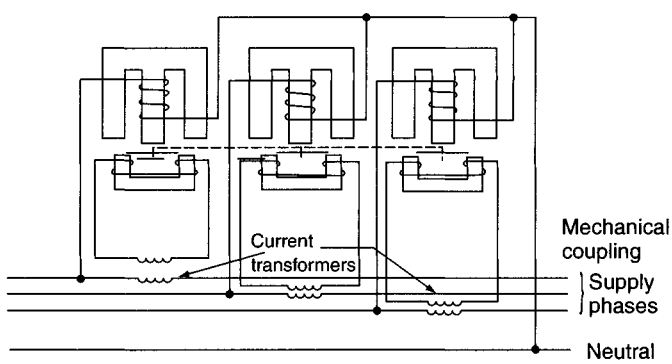


Figure 24.3

24.8.5 Maximum-demand metering

As noted above, the tariff may also contain a component based on the maximum demand taken from the supply in a given period. In this case a separate maximum-demand meter is required. This is a modified energy meter which has a special register such that after a given period (usually half an hour) the dials are disconnected. During the next half-hour the register mechanism still operates but the clutch driving the dials is only energized if the total exceeds that already on the meter. This continues for the whole of the recording period, and thus, at the end, the reading on the meter is the maximum obtained during any one of the half-hour periods. This value is then doubled to yield the maximum kW taken in any half-hour.

It should be noted that this is not necessarily the actual instantaneous maximum demand. The quantity measured on this meter is, of course, the maximum kW demand, but some forms of tariff are based on the maximum kVA demand in order to encourage power factor improvement (see below).

24.8.6 Summation metering

In some instances it is required to measure the sum of the energy supplied along several feeders. This is the case, for example, when a factory site is fed by more than one cable and the tariff is based on the overall energy and maximum demand used. The usual method of doing this is to summate the currents in the individual feeders by installing separate current transformers in each and connecting their secondaries in parallel (Figure 24.4).

The current transformers must have identical ratios. The assumption is that all the feeders have voltages which are equal in magnitude and phase. If the feeders are physically close together it may be possible to use one current transformer as a summation unit. The current transformer has a number of primary windings, each carrying the current of one feeder. The magnetic fluxes due to the individual currents are summed in the transformer core and the output is obtained from a single secondary winding. An alternative is to use impulsing techniques whereby each meter incorporates a device which generates pulses at a rate depending on the energy being used. The pulses are transmitted to a single instrument in which they are recorded to give the total energy used over the whole group.

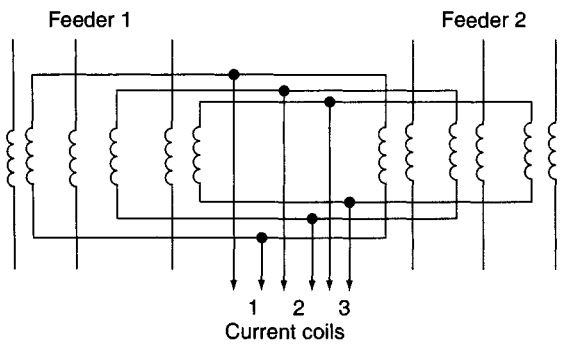


Figure 24.4 Summation current transformers

The pulses can be generated mechanically by a cam driven from an auxiliary spindle by using phototransistors illuminated when a slot on a disc mounted on the main spindle passes a small lamp or by employing inductive techniques in which a shield on the disc passes a pick-up coil each time it rotates. This action modifies the e.m.f. output from the coil, so generating a pulse.

Electronic techniques can generate a larger number of pulses in a specified time and are therefore more accurate than mechanical devices. At the receiving end the pulses are used to determine the state of a series of bistable networks. These are scanned and reset sequentially and the total number of pulses recorded.

24.9 Power factor correction

Electricity is normally charged for on the basis of power (kilowatts) and the supply authority must install plant whose rating (and therefore cost) is a function of the voltage of the system and the current which the consumer takes (i.e. kilo-volt-amps). The relationship between the two is:

$$\text{kW} = \text{kVA} \times \cos\phi$$

where $\cos\phi$ is the power factor and is less than 1.0. In the case of loads which have a low power factor the supply authority is involved in costs for the provision of plant which are not necessarily reflected in the kWh used. A penalty tariff may then be imposed which makes it economically worthwhile for the consumer to take steps to improve his power factor. Low power factors occur when the load is predominantly either inductive or capacitive in nature (as opposed to resistive). In most industrial circumstances where the load includes a preponderance of motors the load is inductive (and the power factor is therefore 'lagging'). Consequently if the power factor is to be brought nearer to unity the most obvious method is to add a significant capacitive component to the load.

It is important to ensure that, as far as possible, this additional equipment is purely capacitive, i.e. that it has no resisitive component, otherwise the customer will face an increase in his energy bill. The situation is illustrated by the circuit and phasor diagrams of Figure 24.5. In the figure V represents the system voltage, I is the current drawn from the supply before the addition of power factor correction equipment and $\cos\phi$ is the associated power factor. If a capacitance, C, is connected in parallel with the load then this will introduce an additional current component I_c, the resultant total current drawn from the supply is I' and it will be seen from the figure that the new power factor is $cos\phi'$, where $cos\phi' > \cos\phi$.

Even if the power factor correction capacitance consumes no energy it will need capital investment, and therefore the consumer must balance the capital charges of this equipment against the savings which it produces in the energy bill. It is not normally economic to correct the power factor to its theoretically maximum value of unity, and a value of 0.9–0.95 is more usual.

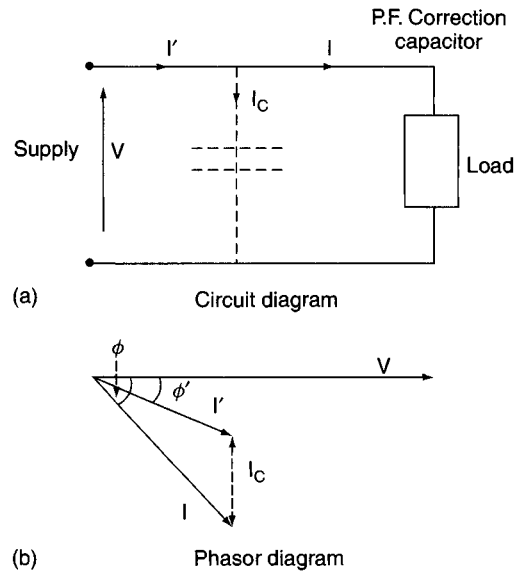


Figure 24.5 Power factor correction

24.9.1 Equipment

For relatively small loads the power factor correction equipment usually takes the form of static capacitors. In larger installations it may be more economic to install an a.c. synchronous motor which, if its excitation is adjusted correctly, can be made to draw a 'leading' current from the supply. In most industrial plants the load is variable, and to gain the maximum benefit from the power factor correction plant this must also be varied to suit the load conditions.

If static capacitors are employed this can be achieved by using several capacitors arranged in units (banks) which can be switched in or out as required. This variation can only be carried out in discrete steps. In the case of the a.c. machine (the synchronous condenser) it is possible to obtain a continuous variation. The switching of the equipment can be carried out by an operator or automatically in response to the output from a power factor sensing instrument.

24.9.2 Thyristor switched capacitors

The latest generation of power factor correction equipment uses thyristors to control the current to the capacitor during the charging period, the thyristor is controlled by a microprocessor which is integral to the power factor correction unit. The use of thyristors reduces the system interference as they take the place of inductors used to limit the transient current surge. Thyristor units also reduce the harmonic content of the supply. As standard contactor controlled capacitors are slow to switch they may not react quickly enough to sudden fluctuations in demand, whereas thyristors have a fast switching time and can handle the fluctuations caused by non-linear loads in low voltage networks.

24.9.3 Power factor measurement

Instruments are available to measure power factor. One form is an electrodynamic instrument employing the same basic principle referred to above but with two coils mounted at right angles to each other on the same shaft (Figure 24.5). These coils are situated in a field produced by a third coil carrying the line current. One of the coils on the moving element carries a current derived from the supply voltage and is connected in series with a pure resistance. The second carries a similar current, but in this case a pure inductance is connected in series. The torque produced by each coil is a function of the current which it carries and therefore depends on the impedance of the particular coil circuit. There is also a third torque component due to the mutual inductive effects between the fixed and moving coils. The nett result is that the moving element is displaced by an amount which is a function of the phase angle between the system current and the system voltage. This form of instrument is suitable for low frequencies only, and electronic measuring techniques are used for higher frequencies. See Figure 24.6 for schematic diagram of power factor meter.

24.10 Voltage and current transformers

The instruments discussed above (and many of the others which follow) act in response to the system voltage and/or current. In most cases the values of these two parameters are very high, which presents problems in the design of the insulation and current-carrying capabilities of the instrument. In these instances the instrument is supplied with a known fraction of the measured quantity using a voltage transformer or a current transformer, as appropriate.

The important factor in the design of these transformers is that the ratio between the actual quantity and that at the output of the transformer must be maintained accurately over the complete range of values which the unit is required to measure. In general terms, the degree of accuracy required when the instrument is used for metering purposes is higher than when a straightforward indication of the quantity is needed. In both cases the accuracy must conform to the relevant British Standard.

24.10.1 Voltage transformers

There are fundamental differences between the behaviour of the two types of transformer. The voltage transformer is shown diagrammatically in Figure 24.7. The system voltage V_p is applied across the primary winding which has N_p turns. The secondary voltage V_s is:

$$V_s = V_p(N_s/N_p)$$

neglecting errors. These errors are small and constant provided that the transformer is used over a small voltage range as specified by the manufacturer and the loading imposed by the measuring instrument connected to the secondary winding is between 10 and 200 VA.

Voltage transformers are classified into types AL, A, B, C and D, in descending order of accuracy. The ratio

errors for small voltage changes (within ±10 per cent of the rating) vary between 0.25 per cent and 5 per cent and the phase errors between ±10 min and ±60 min.

For all but the highest voltages the construction of the voltage transformer is very similar to that of a normal power transformer at voltages of magnitudes normally met with in plant engineering. However, at primary voltages of 100 kV and above it may be necessary to use alternative

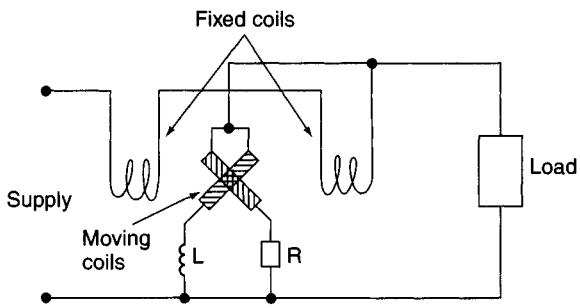


Figure 24.6 Schematic diagram of power factor meter

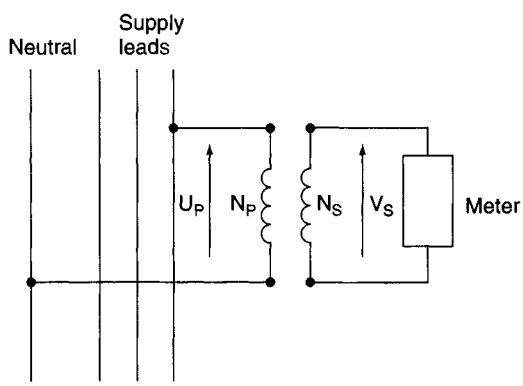


Figure 24.7 Voltage transformer

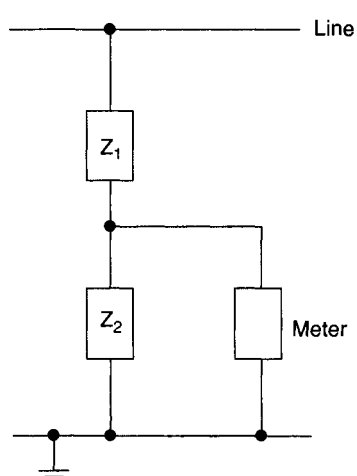


Figure 24.8 Voltage divider

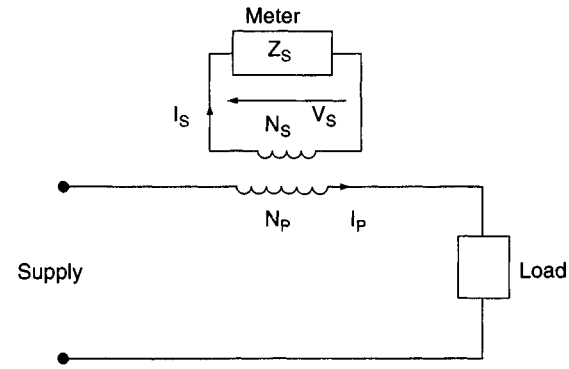


Figure 24.9 Current transformer

means. The type of voltage transformer described above is suitable for relatively low alternating frequency supplies. It cannot be used at d.c. and there is a possibility of large errors occurring at high frequencies. In these instances some form of voltage divider is necessary. The arrangement is as shown in Figure 24.7. The two impedances, Z_1 and Z_2, are connected across the supply with the indicating instrument connected across Z_2. Then (referring to the Figure 24.8):

$$V_s = V_p[Z_2/(Z_1 + Z_2)]$$

The load (or instrument) impedance is connected in parallel with Z_2 and should be very much larger than Z_2 if accuracy is to be maintained. If d.c. voltages are involved then the impedances can be purely resistive and, in the steady state, any leakage inductance or capacitance has no effect. At high a.c. frequencies, however, it is important that they are non-reactive and that stray inductances and capacitances to earth, etc. are taken into account.

24.10.2 Current transformers

The current transformer is arranged with its primary winding in series with the supply (Figure 24.9). It thus carries the load current. The measuring instrument is connected across the secondary as shown. The ideal theoretical relationship between the currents and the number of turns on the primary and secondary is:

$$I_s = I_p(N_p/N_s)$$

The voltage appearing across the secondary terminals is:

$$V_s = I_s Z_s$$

where Z_s is the impedance of the measuring instrument connected to the secondary terminals (the 'burden').

If this impedance is high then so also is this voltage. The primary of the device should therefore never be energized when the secondary is open circuit, since in that case Z_s, and therefore V_s, is infinite. Standard secondary current ratings are 1 A and 5 A, and the preferred range of values for the burden is between 1.5 VA and 30 VA.

Ratio and phase angle errors also occur due to the need for a portion of the primary current to magnetize the core and the requirement for a finite voltage to drive the current through the burden. These errors must be small and current transformers are classified (in descending order of accuracy) into types AL, AM, BM, C and D. Ratio errors in class AL must be within the limits of ± 0.1 per cent for AL and ± 5 per cent for D, while the phase error limit on class A1 is ± 5 min to ± 2 min in types CM and C.

Again, there are problems both at d.c. and at high frequencies. In the former case a current sample is obtained by connecting a very low resistance, R_s, in series with the load and using a voltmeter to measure the voltage across it. This voltage is equal to $I_s R_s$ and, provided R_s is known, then I_s is specified.

At very high frequencies the current is measured by assessing one of the effects which it produces. Several techniques are possible, e.g. (1) measuring the temperature rise when the current flows through a known resistance or (2) using a Hall-effect probe to measure the electromagnetic field created by the current.

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25 Lighting

Hugh King
Thorn Lighting

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25.1 Lighting theory

25.1.1 The nature of light

Light is a form of electromagnetic radiation similar in nature and behaviour to radio waves at one end of the frequency spectrum and X-rays at the other. The range to which the human eye is sensitive covers a waveband of approximately 380–760 nanometers (nm), a nanometer being a wavelength of one millionth (10^{-6}) of a millimetre. Within these limits there are differences in colour, white light being that in which an approximately equal amount of power occurs at all frequencies within the waveband.

25.1.2 Frequency and colour

The human eye is more sensitive to frequencies in the middle of the spectrum (green and yellow light) than those at the ends (red and violet). Consequently, more power must be expended to obtain the same effect on the eye from red or violet light than from green or yellow.

The regions of radiation just outside the visible spectrum are known as the ultraviolet (UV) and infrared (IR). Both are present in natural daylight and they are emitted in varying amounts by artificial light sources. IR gives the effect of heat, while UV radiation is used to excite fluorescence in the powders in fluorescent lamps. Short-wave UV causes skin tanning and can damage the eyes, but the long-wave UV, used for theatrical or display purposes and in discotheques, is virtually harmless.

25.1.3 Basic lighting units and terms

The average illumination on a surface will diminish as the square of its distance from the source. This is known as the *inverse square law* and is common to all forms of radiation.

Light is *reflected* from a polished (specular) surface at the same angle as it strikes it. A matt surface will reflect it in a number of directions and a semi-matt surface will behave in a manner between the two.

Refraction occurs when light passes through a surface between two media (e.g. air and water, air and glass). The 'ray' of light is bent and this property is used in the manufacture of lenses and prisms.

Diffusion is the scattering of light when it passes through an obscured medium (such as opal glass or plastic). The medium contains a number of particles of matter which reflect and scatter the light passing through it. A uniform diffuser scatters the light equally in all directions, and partial diffusers allow some directional flow of light. All these properties are used to control the direction and distribution of light from artificial light sources.

Excessively bright areas in the visual field can, separately or simultaneously, impair visual performance (disability glare) or cause visual discomfort (discomfort glare). Lighting systems in most working interiors are unlikely to cause significant direct disability glare but a degree of discomfort glare is probable.

The unit of luminous intensity is the *candela*. This is the illuminating power of a light source in a given direction. The candela is the standard international (SI) unit.

The unit of light flux is the *lumen*. This is the amount of light contained in one steradian from a source with an intensity of one candela in all directions. Alternatively, it is the amount of light falling on a unit area of the surface of a sphere of unit diameter from a unit source.

The unit of illuminance is the *lux*. This is the illumination produced by one lumen over an area of one square metre. The non-metric equivalent, the lumen per square foot (lm/ft^2), is still used in the UK and is called a 'foot-candle' in the USA. It is approximately equal to 10 lux.

The units of measured brightness (luminance) are the *candela per square metre* and the *apostilb* (lumens emitted per square metre). The imperial units are the *candela per square foot* and the *foot-lambert* (one lumen emitted per square foot of surface). Note that *luminance* should not be confused with *illuminance*. Illuminance is the measure of light falling on a surface and luminance that of the light reflected from it (or, in some case, emitted by it).

Two other terms which can easily be confused are *luminance* and *luminosity*. Luminance is used to describe the measured brightness of a surface and luminosity is apparent brightness.

Efficacy (or luminous efficiency) of lamps is measured in lumens per watt (lm/W).

25.1.4 Colour appearance and colour rendering

We see objects by the light reflected from them. If they have the property of absorbing some wavelengths of light and reflecting others they will appear to be coloured. Some colours are 'pure', that is, they consist of only one waveband of light. Others are obtained by mixing frequencies (for example, mixing red and green light gives the effect of yellow).

Obviously, only those colours which fall on a surface can be reflected from it. Consequently if it is lit by light of one colour only (e.g. yellow light from a sodium lamp) it will appear to be that colour. If the light falling upon it is deficient in some colours (e.g. red and blue light) those colours will appear weak or may not be seen at all. The eye is unable to distinguish between pure colours and those obtained from mixing, so that the *colour appearance* of a light source (the apparent colour of the light emitted from it) does not necessarily indicate its *colour rendering* (the colour of objects seen in its light).

One way of defining colour appearance is by *colour temperature*, measured in degrees Kelvin (K). Colour rendering can be quantified by a general colour rendering index (RA), of which 100 is the best number to achieve.

25.2 Electric lamps

25.2.1 Light production

Light can be produced from electricity in four main ways:

1. *Incandescence* or thermoluminescence is the production of light from heat. Light from a filament lamp is

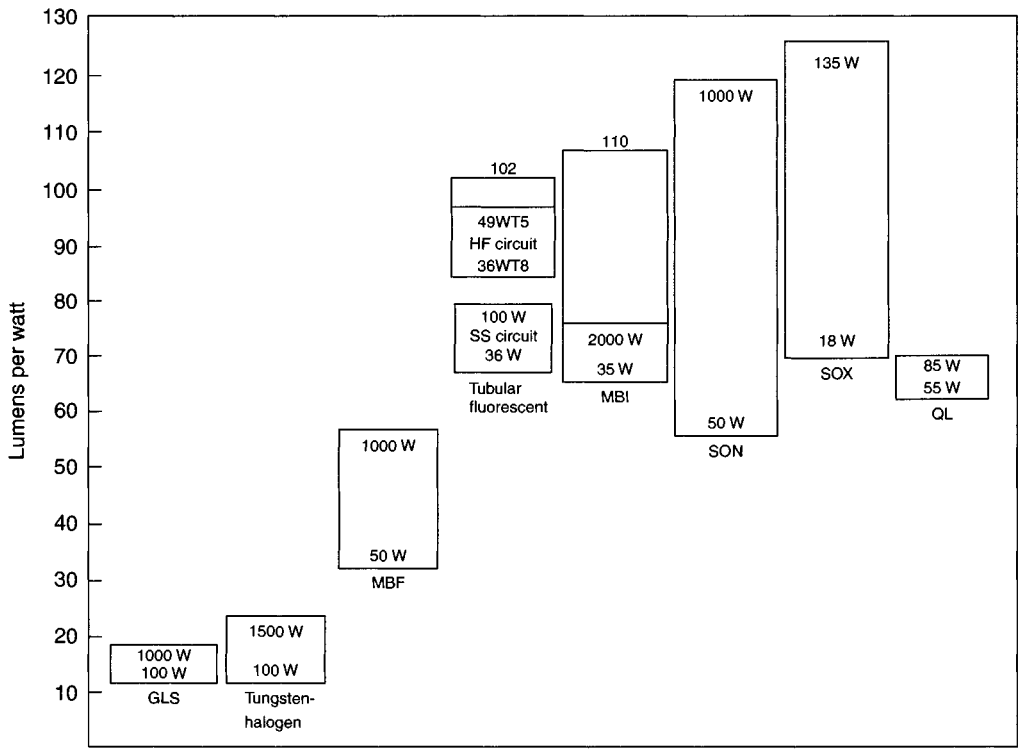


Figure 25.1 Luminous efficacy comparison based on initial lumens and total circuit watts

produced in this way. Electricity is used to raise the temperature of the filament until it is incandescent.

2. *Electrical discharge* is the production of light from the passage of electricity through a gas or vapour. In lamps using this principle the atoms of the gas are agitated or excited by the passage of the electric current and this atomic excitation produces light and sometimes UV and IR energy.
3. *Phosphorescence* and *fluorescence* are the processes of converting invisible UV energy emitted normally from an electrical discharge into visible light. Material called phosphors cause UV energy to make this transition into visible light.
4. Induction principle

25.2.2 Incandescent lamps

The following abbreviations are used in the UK to define these lamps:

GLS General lighting service.
TH Tungsten-halogen.
PAR Followed by lamp nominal diameter in eighths of an inch. (Pressed glass filament lamps with an internal reflector coating.)
R Followed by lamp nominal diameter in millimetres (previously in eighths of an inch). (Blownglass filament lamps.)

Comparisons of luminous efficiency and light output are given in Figures 25.1 and 25.2.

25.2.2.1 GLS lamp

A tungsten-coiled filament is held by molybdenum filament supports and connected to lead wires. An electric current passing through the filament raises the temperature of the filament so it becomes incandescent, emitting light and heat. The outer glass bulb is usually filled with amounts of argon and nitrogen to inhibit the evaporation of tungsten and arcing across the filament. The bulb can be clear or internally etched to give a pearl finish, resulting in diffused light. The lamp has a suitable lamp cap for its size and wattage (see Figure 25.3).

25.2.2.2 Application

Domestic, commercial and industrial uses. It is the most familiar type of light source, with many advantages (for example, low initial cost, immediate light when switched on, good colour rendering, no control gear, easily dimmed). For these reasons there are numerous applications. The very low efficacy is often the factor that precludes the selection of GLS lamps.

25.2.2.3 Average life

1000 h.

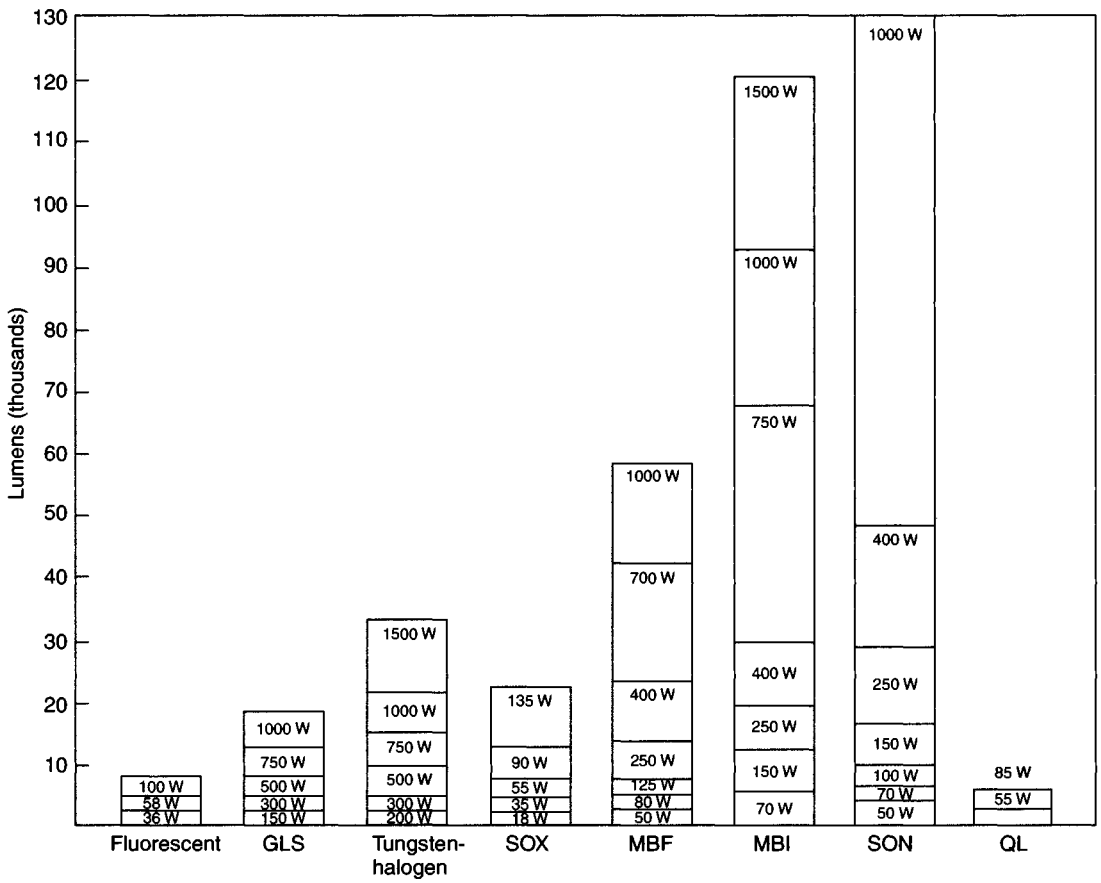


Figure 25.2 Light output comparison

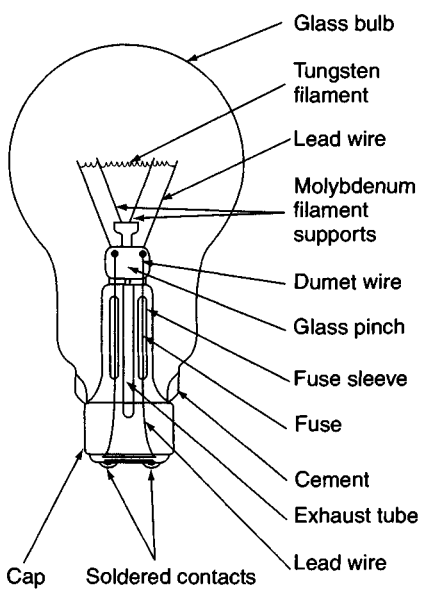


Figure 25.3 Typical construction of a GLS lamp

25.2.3 Fluorescent lamp MCF

Abbreviations used are:

MCF	Tubular fluorescent lamps.
MCFA	Tubular fluorescent lamp with earth strip cemented to outside of tube. Restricted range, mainly for cold environments.
T12	38 mm ($1\frac{1}{2}$ in) nominal diameter.
T8	26 mm (1 in) nominal diameter.
T5	15 mm ($\frac{5}{8}$ in) nominal diameter.
T2	7 mm ($\frac{1}{4}$ in) nominal diameters.

25.2.3.1 Description

A low-pressure mercury discharge operates in a thin-walled glass tube that is internally coated along its entire length by a phosphor coating. This emits light from the UV energy generated by the discharge that strikes it. A wide range of shapes and sizes have power ratings from 4 W to 125 W. The phosphor determines the colour of light produced and the colour rendering properties of the lamp (Figure 25.4).

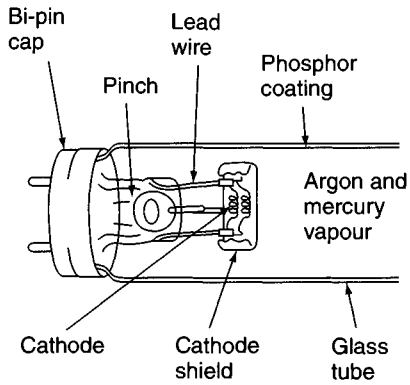


Figure 25.4 Typical construction of a fluorescent tube

Recently a new range of lamps (T5's – in ratings from 14 W–35 W) has been developed with lengths that will fit modern metric luminaires. These operate only from special electronic control gear and are slimmer than standard tubes (16 mm). Lamp efficiacy is better than existing lamps. Phosphors are pre-coated tri-phosphors so the lamps have excellent lumen maintenance.

25.2.3.2 Application

Worldwide, about 80% of electric lighting is provided by fluorescent lamps. The applications are particularly diverse, operating in interior and exterior luminaires. The majority of office lighting is provided by fluorescent lamps and in industry they can still be the best choice for new installations despite the range of high-pressure discharge lamps. High-frequency electronic ballasts increase their efficacy and give a more comfortable light by the absence of flicker. Triphosphors that combine high light output with good colour rendering are recommended. Many other 'white' lamps are made as well as coloured ones for special applications.

25.2.3.3 Operating circuit

The basic circuit usually has power factor correction. Various types are used – high-frequency electronic ballast, electronic starting circuits (Vivatronic) and switch-start circuits. Existing luminaires may have quick-start and semi-resonant start (SRS) circuits.

25.2.4 Compact fluorescent

25.2.4.1 Description

Compact fluorescent lamps save a lot of energy and give a much longer life than conventional filament lamps. Power consumption is about 25% of an equivalent GLS lamp and average lamp life is five to ten times longer, lowering the cost of maintenance. The lamp runs cooler and gives light that has good colour rendering properties by using triphosphors. They are also a compact alternative to conventional fluorescent tubes.

25.2.4.2 Application

A wide range of interior and exterior luminaires are made for commercial, leisure, civic, domestic and other uses. In terms of light output the GE 2D 16 W is comparable to a 75 W GLS lamp. As the lamps are cool running small luminaires can be designed in a great variety of materials.

25.2.4.3 Average life

10 000 h

More powerful linear compact fluorescents are now marketed by the major lighting companies. They are particularly suitable for 600 mm × 600 mm ceiling modules.

25.2.5 Low-pressure sodium lamps

Abbreviations used are:

SOX Single-ended, U-shaped arc tube.
SLI Double-ended. Linear arc tube (now obsolete).

25.2.5.1 Description

SOX A low-pressure sodium discharge operates in a U-shaped are tube enclosed in a tubular outer bulb which has an internal IR reflecting coating to provide thermal insulation. The discharge has a characteristic yellow colour, and achieves a high efficacy around 160 lm/W for the highest wattage. Due to the monochromatic nature of the light output, correlated colour temperature and colour rendering index figures are not applicable.

SOX-E The construction of SOX-E lamps is similar to standard SOX except that, by improving the thermal insulation, higher efficacies can be achieved. By operating lamps at lower wattages significant power savings can be obtained with only a small reduction in light. output. (The 'E' suffix denotes economy.) Care should be taken in the disposal of SOX lamps.

25.2.5.2 Application

SOX and SOX-E The high efficacy results in low power costs, particularly useful where long operating hours are involved. The main use is for roadways, security lighting, subways and footpaths where the poor colour rendering is not so important. The time it takes the lamp to reach full brightness from switch-on (the run-up time) is around 10 min. In some applications SON lamps may be considered as an alternative.

25.2.5.3 Operating circuit

Ballast circuit using leakage reactance transformer or electronic ignitor and ballast. Power factor correction capacitor is included in both cases.

Average life 16 000 h

25.2.6 High-pressure sodium lamps

Abbreviations used are:

SON	(often replaced by HPS)
SON-E	Diffused ellipsoidal outer bulb, single ended.
SON-T	Clear tubular outer bulb, single ended.
SON-TD	Clear tubular outer bulb, double ended.
SON-R	SON with internal reflector.
SON E DL	SON with improved colour rendering.
SON T DL	SON-T with improved colour rendering.
Ⓔ	For use with external starting device.
Ⓘ	Contains internal starting device.

25.2.6.1 Description

SON-T A high-pressure sodium discharge operates in a sintered alumina arc tube contained in a clear tubular-shaped bulb. This is a high-efficiency light source that gives a long life while maintaining the lumen output well. The warm coloured light allows some colour discrimination but not accurate colour rendering. As the arc tube is small, precise optical control can be achieved by suitable luminaire design.

SON-E This is similar but has an elliptical outer bulb with a diffuse internal coating.

SON-TD A high-pressure sodium discharge operates in a sintered alumina arc tube contained in a clear quartz sleeve with lamp caps at each end.

SON-R A 70 W high-pressure sodium arc tube is mounted axially inside a 96 mm diameter soft glass reflector bulb which has a diffuse front to remove striations from the beam.

25.2.6.2 Application

SON-T/SON-E Suitable for many interior and exterior industrial applications, floodlighting, street and precinct lighting. It is now the most common form of street-lighting for city centres. The warm colour of SON frequently improves the appearance of stone and brickwork. The long life combined with good lumen maintenance throughout its life makes the lamp suitable where access is difficult or expensive, as may be the case in lofty industrial interiors such as steelworks, power stations and aircraft hangars. A wide range of lamp wattages is available from 50 W to 1000 W. Energy savings and reduced maintenance can often result in the refurbishment of industrial installations. Another aspect of SON is the ability to operate at low temperatures (−40°C).

SONDL-T This is a high-pressure sodium lamp with a discharge arc that operates at a higher pressure and temperature than is the case with the standard SON-T lamps, resulting in a great improvement in the colour-rendering properties. It is mainly used in commercial interiors, leisure centres and institutional and social areas. Swimming pools and sports halls are common applications, which are often the same scale as the industrial interiors for which these lamps are also used. Another frequent application is with uplighters in offices.

SON-TD The lamp is specifically for use in floodlights where precise optical control can be attained. Floodlights can be compared because the lamp is slim and if the control gear is mounted remotely the floodlight can be relatively low weight and easy to handle.

SON-R Typical applications include lobbies, foyers, pubs and clubs where the warm colour can create a warm and informal atmosphere with a reduced heat load when compared against conventional downlights.

25.2.6.3 SON lamps

Operating circuit
Ballast circuit with power factor correction capacitor and electronic ignitor.
Lamp uses an external ignitor.
Average life 12 000–28 500 h

25.2.7 Linear tungsten-halogen lamps

25.2.7.1 Description

A tungsten filament is supported between molybdenum foils connected to contacts in ceramic caps at each end of a slim quartz-enclosed tube. The gas filling inside the tube includes halogen, which regenerates the loss of tungsten from the filament. It operates at a higher temperature and in a gas at a higher pressure than GLS lamps. The lamp provides a whiter light and improved efficacy. K-type lamps have double the average life of a standard GLS lamp.

25.2.7.2 Application

Display, exhibition, commercial, photographic and car lighting, and security and floodlighting. It is suitable where the requirement is for immediate light or good colour rendering with a warm colour appearance. The initial capital cost is low, but efficacy is high.

25.2.7.3 Average life

4000 h for 100–3000 W (K type);
2000 h for 500–2000 W (K type).

25.2.8 Low-voltage tungsten-halogen lamps

25.2.8.1 Description

A compact tungsten-halogen lamp operating at low voltage (12 V) is combined with a precision-faceted glass reflector. Due to its dichroic coatings, the reflector allows about 50% of the heat to be transmitted backwards while reflecting light forwards in a controlled beam. A choice of beam

angles is available. The lamp provides a white light, improved efficacy and beam control, and longer average life than conventional display lamps. Cooler interiors, reduced maintenance and running costs can result when compared against conventional PAR 38 display spots. Clip-on colour filters extend the scope for display purposes.

25.2.8.2 Application

These lamps are suitable for display, exhibition, museum, commercial and domestic lighting. Their compactness has enabled diverse spotlight designs, some incorporating the necessary transformer to step down the voltage to 12 V.

25.2.8.3 Average life

3500–4000 h

25.2.8.4 Operating circuit

Wirewound transformer or electronic transformer for connection to 240 V supply.

25.2.9 High-pressure mercury lamps (Figure 25.5)

Abbreviations used are:

MBF High-pressure mercury with phosphor coating.
MBFR MBF with internal reflector.
MBTF Combination of MBF lamp and filament lamp.

25.2.9.1 Description

MBF A high-pressure mercury vapour discharge operates in a quartz arc tube. The internal surface of the outer elliptical bulb is coated with a phosphor which converts UV radiation from the discharge into light.

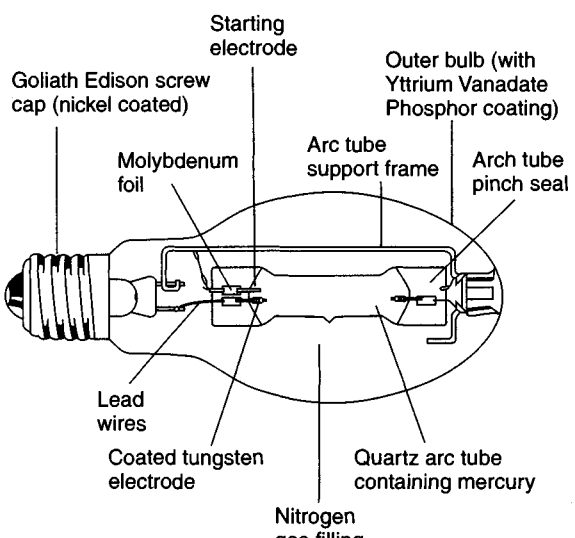


Figure 25.5 Typical construction of a mercury lamp

MBFR This is an identical lamp except the outer bulb is shaped to form a reflector. Titanium dioxide is deposited inside the conical portion of the outer bulb and this deposit is coated with a phosphor. About 90% of the light is emitted through the front face of the lamp in a directional manner.

25.2.9.2 Application

MBF Used in industry for low initial cost where colour rendering is not a major factor. Also employed in street-lighting, mainly for replacement or matching existing installations.

MBFR Suitable for industrial applications where minimum maintenance is important (for example, in a foundry or processing plant with a dusty atmosphere). The internal reflector is not affected by dirt or a corrosive atmosphere. The outer bulb, which is made of hard glass, allows exterior use.

Both types of high-pressure mercury lamp have a life-survival characteristic similar to SON lamps but MBF lumen maintenance reduces more throughout its life.

25.2.9.3 Operating circuit

Ballast circuit with power factor correction capacitor. No ignitor is needed.

MBFD A high-pressure mercury de-luxe lamp that is identical to the MBF lamp except that it has a different phosphor coating to create more red light. The colour rendering is improved and the colour temperature reduced.

MBTF This is similar to the MBF high-pressure mercury lamp but with a coiled tungsten filament connected to the arc tube that acts as a ballast within the outer glass bulb. Therefore no external control gear is needed.

25.2.9.4 Application

MBFD Suitable for commercial interiors such as shops, supermarkets, public concourses and reception foyers. It is capable of blending well with 'white' fluorescent tubes in adjoining areas.

MBTF A direct replacement for tungsten filament lamps giving a higher light output and longer life with a cooler colour appearance. The tungsten filament emits light immediately when switched on. The efficacy is higher than an equivalent tungsten filament GLS lamp.

25.2.9.5 Operating circuit

MBFD Ballast circuit with power factor correction capacitor. No ignitor is needed.

MBTF No control gear is needed.

25.2.10 Metal halide lamps

Abbreviations used are:

MBI High-pressure discharge with metallic halides.
MBIL Double-ended linear arc tube.

MBIF MBI with phosphor coating.
CSI Compact source discharge with metal iodides.

25.2.10.1 Description

MBIF A high-pressure discharge in mercury vapour with metallic additives operates in a quartz tube. The metallic additives are introduced as halide compounds which control the dosing and ensure that the metallic elements mix well with the mercury vapour. An elliptical outer bulb is internally coated with phosphor.

MBI This lamp is similar but has a clear outer bulb.

25.2.10.2 Application

Commercial and industrial interiors and exterior applications where good colour quality white light is required. The efficacy is better than the same wattage of MBF lamps. These lamps are suitable for televising events when the appropriate illuminances are provided. Uplighting is a typical commercial use when the white quality of light is important.

25.2.10.3 Operating circuit

Ballast circuit with power factor correction capacitor and ignitor. The lamp uses an external ignitor.

25.2.10.4 Lamp orientation

BUH Base up to horizontal. Operates in any position between cap up and cap 15° below horizontal.

H horizontal Primarily designed with cap ±15° of horizontal, but can be used up to ±60° of horizontal BU Base up. Cap up ±30°.

25.2.10.5 Description

MBI-T A high-pressure mercury vapour discharge with metal halides operates in a quartz bulb. These halides are chosen to give high efficiency and good colour-rendering properties. The electrode spacing is only 6 mm, so the arc is extremely compact, making it suitable for precise optical control in small luminaires. An outer quartz bulb gives thermal stability and protection. This bulb is mounted in a ceramic bi-pin cap.

25.2.10.6 Application

Suitable for display lighting, uplighting and floodlighting. A choice of colour temperatures (3000 K and 4000 K) can blend in with tungsten-halogen and selected fluorescent lamps. Efficacy is around four times higher and the average life three times longer (at 6000 h) than comparable tungsten-halogen lamps. This makes it an attractive alternative to some former tungsten-halogen applications.

25.2.10.7 Operating circuit

Ballast circuit with power factor correction capacitor and electronic ignitor.

25.2.10.8 Lamp orientation

BDH Base down or horizontal.

25.2.11 Induction principle

An induction lamp is like a fluorescent tubular lamp. It contains a low pressure of mercury which when excited radiates UV, which in turn is absorbed by a phosphor coating and re-radiated as visable light. However, unlike a fluorescent the induction lamp has no electrodes and the discharge is created by a magnetic field generated externally to the bulb. The bulb has a hollow central stem and the antenna, like a small radio transmitting aerial, is thus in the centre of the lamp. Because there are no electrodes the lamp life is not dependent upon the initial ion emission from the cathode coating. They operate at high frequency so there is little flicker.

25.2.11.1 Application

The Philips QL lamp operates from separate dedicated electronic control gear. The phospor coating is sealed into the bulb surface so does not degrade due to mercury contamination.

Average life 60 000 h

25.2.12 Lamp selection

1. First decide what minimum standard of colour rendering is needed. Except in the case of specialist applications, the CIBSE/CIE colour-rendering classes (Table 25.1) are ideal for this purpose.
2. Do not select lamps from the appropriate class in the colour-rendering guide shown in Table 25.2. Lamps in a better class may be more efficient or preferable for some other reason. Instead, make a note to reject any lamps which are in inferior classes.
3. Now decide which colour appearance groups will be unacceptable, e.g.:

Table 25.1 CIBSE/CIE colour-rendering classes

Minimum class needed	*Description*
1A	Excellent colour quality. Where accurate colour matching is required (e.g. colour printing inspection)
1B	Very good colour quality. Where accurate colour judgement or good colour rendering is required for reasons of appearance (e.g. merchandizing)
2	Good colour quality. Where moderate colour rendering is required, good enough for merchandizing
3	Poor colour quality. Where colour rendering is of little importance. Colour can be distorted but marked distortion is not acceptable
4	Very poor colour quality. Colour rendering is of no importance and severe distortion of colours is acceptable

Table 25.2 Colour-rendering guide

Class	*Type*	*GE description*
1A	MCF	Northlight
		Artificial daylight
		De-luxe natural
	TH	Tungsten-halogen
	GLS	General lighting service
1B	MCF	Kolorite
		Polylux XL840
		Polylux XL835
		Polylux XL830
		Polylux XL827
	CSI	Compact source iodide
	MBI-T	CMH
2	MCF	Natural
		De-luxe warm white
	MBI/MBIF	Metal halide
	MBIL	Linear metal halide
	SONDL	Lucalox Classique
3	MCF	Cool white
		White
		Warm white
	MBFD	High-pressure mercury – de-luxe
	MBF/MBFR	High-pressure mercury
4	SON	High-pressure sodium Lucalox T
	SON-R	SON Lucalox RFL
	SON-TD	Reflector/double ended Lucalox TD
None	SOX	Low-pressure sodium

Table 25.3 Colour-appearance guide

Colour temperature (K)	*Type*	*GE Description*
		Cold
6500	MCF	Northlight
		Artificial daylight
		Intermediate-cool
5200	MBIL	Linear metal halide
4000	MCF	Kolorite
		Natural
		Polylux XL840
	MBI/MBIF	Metal halide
	MBI-T	CMH 4000
	CSI	Compact source iodide
		Intermediate
3800	MBF/MBFR	High-pressure mercury
3500	MCF	Polylux XL835
		White
		Warm
3300	MBFD	High-pressure mercury de-luxe
3300	MCF	Polylux XL830
		De-luxe warm white
		Warm white
2900	TH	Tungsten halogen
	MBI-T	CMH 3000
2700	MCF	Polylux XL827
	GLS	General lighting service
2200	SONDL	Lucalox Classique
2200	SON	High-pressure sodium Lucalox T
None	SOX	Low-pressure sodium

4. Note that some applications which call for precise colour judgement must use lamps with a specific colour appearance (often cool or cold). Make a note of what lamp appearances to reject from the colour-appearance guide in Table 25.3.
5. Decide how the lighting will be controlled and how rapidly light will be required. This can be compared to the run-up and re-strike times of different lamps to determine which are unacceptable (auxiliary lamps can be used for rapid illumination). Make a note of the lamps that are unacceptable from the run-up and re-strike times shown in Table 25.4.
6. By deleting lamps which have unsuitable colour appearance and colour-rendering properties, and those with unacceptable run-up and re-strike characteristics, a list of suitable lamps can be compiled. It is possible to rank this list in terms of efficacy, life and other factors which the designer considers to be important so that a decision can be made.
7. One of the other factors which may be a limitation to the use of certain lamp types is the ambient temperature.

Table 25.4 Run-up and re-strike times

Type	*Rating (W)*	*Run-up time (min)*	*Re-strike time (min)*
TH	All	Instant	Instant
GLS	All	Instant	Instant
MCF	All HF	Instant[a]	Instant[a]
	All others less than 1[a]		Less than 1[a]
CSI	1000	1	10
MBI-T	150	1	4
MBI	250	2	7
	400	2	7
	1000	2	7
MBIL	750	2	8–12[b]
	1500	2	15–20[b]
SON, SON-R	50	3	Less than 1
and SON-TD	70	3	Less than 1
	100	4	Less than 1
	150	6	Less than 1
	250	6	Less than 1
	1000	6	3
MBIF, MBFSD	50	5	4
and MBFR	80	3	4
	125	3	4
	250	4	4
	400	4	4
	700	3	6
	1000	2	7
SONDL	150	8	Less than 1
	250	8	Less than 1
	400	7	Less than 1
SOX and SOX-E	18	12	Instant
	35	9	Instant
	55	9	Instant
	90	9	10
	135	8	10

[a]Striking time.
[b]In floodlight.
HF: High-frequency circuit.

25.3 Luminaires

25.3.1 Basic design requirements

The majority of light sources emit light in all directions, but for most purposes this is both wasteful and visually uncomfortable. The function of most luminaires is therefore:

1. To redirect the light of a bare electric lamp in a preferred direction with the minimum of loss;
2. To reduce glare from the light source;
3. To be acceptable in appearance and, in some cases, make a contribution to the decor of the surroundings.

In addition to optical design there are other aspects which must be considered:

1. *Lamp protection*: Apart from requiring electrical connections, the electric map must be mechanically supported and protected. The extent of this protection will depend on the application for which the luminaire is intended.
2. *Electrical safety*: The lampholder and associated wiring must be supported and protected, as well as the control gear if used to operate the lamp.
3. *Heat dissipation*: The heat generated by lamps and control gear must be conducted away from heat-sensitive parts and surfaces adjacent to the luminaire.
4. *Finishing*: Any exposed metalwork must be painted or plated to protect it against corrosion. The degree of protection necessary will depend on the luminaire's application. Some *proof luminaires* designed for use in particularly hostile, corrosive atmospheres may be made in plastic materials rather than metals.

In addition to the functional aspects of mechanical, electrical thermal and chemical protection, the designer will also select materials and processes to achieve the desired external form and appearance of the design, bearing in mind production costs for either small or large batch quantities. Consideration must also be given to 'built-in' design features aimed at making the installation and maintenance of the luminaires easier (Figure 25.6).

25.3.2 Luminaires and lighting terms

There is an abundance of lighting terms in common use and the following list attempts to cover the main ones.

Accent lighting See *display*.

Air terminal devices The means by which air is supplied or extracted from a room. This term applies to all such equipment whether called air diffusers or grilles.

Airfield lighting This is covered by a range of specialized luminaires intended primarily as an aid to navigation and include approach lighting (line and bar, VASI and PAPI), runway and taxiway lighting.

Amenity lighting This is most commonly applied to outdoor public areas and is primarily intended to provide safe movement. It can incorporate decorative elements, both in terms of the appearance of the equipment and the lighting effect produced. In its most utilitarian form it is also applied to exterior private industrial areas intended mainly for pedestrian use.

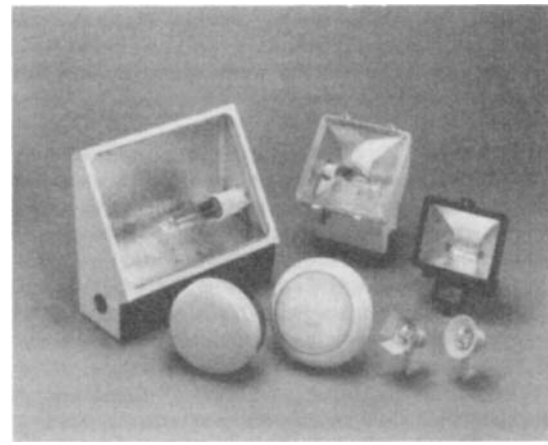


Figure 25.6 A selection of modern luminaires. Included are two SON floodlights; a linear tungsten-halogen floodlight; two compact fluorescent bulkheads and two low-voltage spotlights

Barndoors Four independently highed matt-black flaps mounted on a rotate frame solely intended for reducing spill light or shaping the soft-edged beam of a spotlight.

Batten This refers to a fluorescent luminaire with no attachments; just the control gear in a channel and a bare tube. It is often designed to take various attachments as the basis of a complete range.

Bulkhead fittings These luminaires are often compact, designed for horizontal or vertical mounting outdoors or indoors. A wide selection of lamps are used, including miniature fluorescent tubes and high-pressure sodium lamps. The front is sometimes prismatic of either plastic or glass and the fittings are usually intended for exterior use over doors and stairways.

Ceiling systems A grid and panel system providing a false ceiling to incorporate lighting and other building services.

Columns Poles for mounting roadlighting lanterns or floodlights usually from 3 to 12 m constructed in steel, aluminium or concrete.

Commercial These luminaires are designed to have a clean shape and efficient design but are devoid of decorative treatment. The term is applied to interior fluorescent diffuser luminaires as well as tungsten and discharge units for similar applications. There is frequently a grey area between this term and decorative or display luminaires.

Controller A clear plastic or glass with prism shapes in the surface. The overall shape may be flat or formed. This is distinct from opal plastic or glass diffusers.

Dark light See *Downlighters.*

Decorative (1) Decorative 'fittings' designed primarily to have a pleasing appearance, efficiency not always being of major importance. (2) Decorative 'lighting', however, refers to the effect produced and may require optically efficient fittings which may or may not have an external decorative appearance.

Diffuser An attachment intended to reduce the lamp brightness by spreading the brightness over the surface of the diffuser. Many types of fluorescent, tungsten and discharge lamp luminaires use diffusers.

Display Lighting intended to attract attention and show objects to good effect.

Downlighters This term is frequently misused to refer to any luminaire which produces no upward light, whereas the object of a downlighter is to provide illumination without any apparent source of light. They are therefore extremely 'low-bright' luminaires, referring particularly to small (usually circular) recessed, semirecessed or surfaced 'can' luminaires with mains or low-voltage tungsten reflector lamps. Some high-pressure discharge versions are also available.

Egg-crate See *Louvres.*

Emergency lighting Lighting provided for use when the mains lighting fails for whatever reason. There are two types: (1) Escape lighting; (2) Standby lighting.

Emphasis lighting See *Display*

Escape lighting See *Emergency lighting.*

Eyeball fitting A recessed adjustable display spotlight.

Fibre optics Fibre optic technology is based on the transmission of light from a single source along a group of fibres with the light emitted in a concentrated beam at the far end of each fibre. With fibre optics it is the light which is transmitted and not the power or heat as the light source is remote, hence its benefit in industrial/hazardous area applications. A typical system comprises three distinct elements: a light box housing the light source and associated optical reflector; a light conductor, better known as a harness with numerous cables or 'tails'; and an optical terminal or lens at the end of each tail. Each tail comprises of thousands of minute, individual strands of coated glass or plastic all bunched together. Each strand has a core that provides the light path and enclosed cladding to give total internal reflection.

Flameproof An enclosure capable of withstanding the pressure of an internal explosion and preventing transmission of the explosion to gases and vapours outside the luminaire.

Floodlight A very general term usually applied to exterior fittings housing all types of lamps and producing beams from very narrow to very wide. They usually employ a specular parabolic reflectors, and their size and shape is determined by the type of lamp employed and the distribution of light required.

Fresnel lantern A soft-edge spotlight with a stepped front lens which gives a wide range of beam-angle adjustments by moving the lamp and reflector relative to the front lens.

General lighting An interior installation designed to provide a reasonably uniform value of horizontal illumination over a complete area.

High bay As the name implies, these are for use when mounting heights of around 8–10 m or above are encountered. They have a controlled light distribution to ensure that as much light as possible reaches the working plate. Cut-off angle is 60–65° . Although primarily intended for industrial areas, they also find application in lofty shopping areas and exhibition halls.

High mast lighting This was originally developed as a system for lighting exterior parking areas and complex road intersections using high-pressure discharge lamps in luminaires very similar to industrial high bay reflectors at heights of 20–50 m. Since then, many installations using directional floodlights have been installed and the same term is used for this.

Hood A baffle projecting forward from the top of the floodlight or display spotlight to improve the cut-off of spill light above the horizontal to reduce glare and light pollution.

Indirect lighting System of illumination where the light from lamps and luminaires is first reflected from a ceiling or wall. Traditionally, tungsten or fluorescent lamps were mounted in a cove and cornice to light a ceiling or behind a pelmet or in 'wall washer' units to light walls. For modern high-efficiency applications of this technique, see *Uplighting.*

Industrial These luminaires are designed for high optical efficiency and durability. They range from simple fluorescent reflector luminaires to complex proof luminaires housing all modern light sources for both interior and exterior use.

Inverter Electronic device for operating discharge lamps (usually fluorescent) on a d.c. supply obtained from either batteries or generators.

Lantern Apart from reproduction period lighting units, this is an alternative terms for 'luminaire' or 'fitting', usually restricted to roadlighting and stage lighting equipment.

Local lighting Provides illumination only over the small area occupied by the task and its immediate surroundings.

Localized lighting An arrangement of luminaires designed to provide the required service illuminance over the working area together with a lower illuminance over surrounding areas. This is an alternative system to installing 'general' lighting. See also *Uplighting.*

Louvres Vertical or angled fins of metal, plastic or wood arranged at right angles to linear lamps or in two directions. The object is to increase the cut-off of the luminaire and so reduce glare from critical angles. Louvres can also form ceiling panels with lighting equipment placed in the void above.

Low bay Luminaires housing high-pressure discharge lamps (usually mounted horizontally) to provide a wide distribution with good cut-off at mounting heights around 4–8 m. Apart from industrial applications, these are used in many sports halls and public concourses. They are often fitted with louvres or clear visors.

Low brightness This term is usually applied to commercial fluorescent luminaires where, by use of specular reflectors or low-reflectance louvres, the brightness of the luminaire is strictly limited above 50° from the vertical. They are particularly appropriate for offices with VDUs or if it is wished to make the luminaires in an interior particularly unobstrusive (see *Downlighters*).

Maintained emergency lighting An emergency lighting circuit which remains energized at all times both when the main supply is available and when it has failed for any reason.

Mast Mounting columns higher than 12–15 m are generally referred to as masts and are used to support floodlighting for lighting large areas. For heights above 30 m access ladders are usually mounted inside the shaft and the base compartment is large enough to house control gear.

Optic The reflector and/or refractor system providing the light control for the luminaire.

Perimeter lighting See *Wall washer* and *Security lighting.*

Post top lantern Road or amenity lighting luminaire which mounts directly onto the top of a column without a bracket or out-reach arm. These are available for all lamp types with systematical and asymmetric distributions for mounting heights from 3 m to 20 m. The external design can vary from purely decorative to highly functional.

Precinct lighting See *Amenity*. This is generally associated with public rather than private areas.

Presence detector A device activated either by sound or heat energy to detect the occupation of an area or an intruder and thereby control the lighting approximately.

Projector A term often applied to any type of floodlight. More correctly it is an alternative to 'profile spotlight'.

Proof Applied to all types of luminaires which have a higher degree of protection from the ingress of solids and liquids than standard interior lighting luminaires.

Rack lighting Warehouse lighting where goods are stored on racking systems. The lighting must provide adequate vertical illumination on the faces of the racking which form narrow gangways.

Recessed The luminaire mounting arrangement where the whole or part (semi-recessed) of the luminaire body is set into a ceiling or wall or floor surface. With modular ceilings the luminaire fills the space provided by the removal of one or more tiles, but the term applies equally to where any type of luminaire is set into a false ceiling, wall or floor or solid structural slab.

Refractor Clear glass or plastic, panel or bowl where an array of prisms is designed to redirect the light of the lamp into the required distributions.

Residential lighting An installation for subsidiary roads and areas with little or no vehicular traffic except that generated by the residents themselves. Requirements are covered by BS 5489: Part 3 (see *Amenity*).

Road lighting An installation intended primarily to serve the needs of drivers. Although this is usually associated with public motorways, trunk and feeder roads and tunnels, the same principles apply to private, industrial and commercial roadways with vehicular traffic. It is covered by BS 5489: Parts 1–9.

Safety/security lighting An installation designed to protect property, plant and people from criminal activity and to assist guards in detecting the presence of intruders. In the case of prisons the objective is reversed, in that the aim is to prevent escape. In many cases, other detection devices, such as closed-circuit television and vibration detection, are used in conjunction with the lighting. All security lighting tends to be concentrated around the perimeter of the site and it is therefore sometimes referred to as 'perimeter' or 'perimeter fence' lighting. In certain high-security areas invisible IR systems are used and linked with closed-circuit television facilities.

Semi-recessed See *Recessed.*

Spine See *Batten.*

Spotlight An adjustable interior luminaire with controlled beam using a reflector lamp or optical system (see *Display, Floodlight, Fresnel, Profile*).

Stage lighting An installation designed to enable an audience to view a 'performance', ranging from legitimate theatre in all its forms to a lecture.

Standby lighting See *Roadlighting.*

Studio lighting Lighting for film and television has similar requirements for *Stage lighting* but involves a live audience less often. The higher lighting levels dictate the use of 5–10 kW lamps.

Tower Lattice, steel or concrete structure from 15 m to 50 m to support area floodlighting equipment (see also *Mast*).

Track system A linear busbar system providing one to three main circuits or a low-voltage supply to which display lighting can be connected and disconnected at will along the length of the system. The luminaires must be fitted with an adaptor to suit the particular track system in use.

Troffer Fluorescent or discharge luminaire designed to recess into suspended ceilings and fit the module size of the ceiling (see *Recessed*).

Trunking Apart from standard wireway systems in ceilings and floor, trunking, associated specifically with lighting, usually provides mechanical fixings for the luminaires as well as electric connection. These are usually favoured where (1) there is a lack of fixing points for separates luminaires and the trunking can span between trusses (to carry the wiring and support the luminaires); (2) a simple means must be provided for repositioning lighting equipment with changes in use in the area and where track systems would not be appropriate; (3) additional support for suspended ceilings is required.

Uplighting Indirect lighting system where task illuminance is provided by lighting reflected from the ceiling. When used as a functional rather than a decorative system it usually employs high-pressure discharge lamps and high-efficiency reflector systems. The luminaires can be floor standing, wall mounted or suspended, and can be arranged to provide either general or localized lighting. They are particularly suitable for areas with VDUs although they have many other applications.

VDU lighting See *Low brightness* and *Uplighting*.

Vizor Clear or diffused glass or plastic, bowl or flat panel closing the mouth of a luminaire. It is fitted either to protect the lamp or to prevent falling debris from the luminaire. In the case of diffusing vizors the object is to reduce lamp brightness and, to a certain extent, reduce glare.

Wall washer Interior floodlight or spotlight with asymmetric distribution intended to provide uniform lighting of walls from a close offset distance. Units may be recessed or surface mounted and house tungsten or sometimes high-pressure discharge lamps, mounted in a pelmet unit. This is commonly used to light shelf units in supermarkets and other large stores.

Wellglass These consist of a lamp surrounded by an enclosure of transparent or translucent glass or plastic. They are usually proof luminaires and often used outdoors fixed to a bracket.

Zones 0, 1 and 2 Classification of various hazardous areas.

25.3.3 The International Protection (IP) code

This code is now widely used and classifies luminaires under two headings:

1. Protection against electric shock and the ingress of solid foreign bodies, including fingers or tools at one end of the spectrum and fine dust at other;
2. Protection against the ingress of liquids. The system is referred to in BS 4533: Part 1, section 2.3, and is fully explained in BS 775: Part 1, Appendix B.

An IP number consists of two numerals, the first in the left-hand column and the second in the right-hand column of Table 25.5. For example, a dust-proof luminaire which can be hosed down would carry the number 55 and the symbols shown in Figure 25.7. A rainproof fitting with protection from finger contact within the enclosure would bear the number 23 and only the symbol in the right of the figure. The higher the numerals of the first and second characteristic, the greater the degree of protection the enclosure offers. For example, Jetproof IP55 meets all the less onerous degrees such as IP22, IP23, IP34 and IP54.

25.3.4 Explosion hazards

If a luminaire is to be used in an explosive atmosphere protection over and above that described in the IP code is needed. Explosive atmospheres are a potential problem in various industries where flammable materials are manufactured, processed or stored.

Electrical regulations over the years and, more recently, the Health and Safety at Work, etc. Act 1974, stipulate that any possible danger to safety be recognized and the necessary action taken to ensure adequate protection of the workforce. This places considerable responsibility on the user and installer, and it is most important that the correct type of luminaire be selected and that the installation is in accordance with the recognized safety standard.

Unlike the IP code, the equipment is classified according to the nature of the area in which it is to be known as the *zonal classification*. The latest UK Code of Practice (BS 5345) covers the selection, installation and maintenance of electrical apparatus for use in potentially explosive atmospheres (other than mining applications or explosives processing and manufacture). Therefore the user or engineer handling plant design should refer to this before equipment is specified.

25.3.5 Assurance of safety

Under the Consumer Protection Act 1987, it is unlawful to make, or hold in stock, or to offer for sale any electrical appliance that is unsafe. In order to give assurance that lighting products are safe, manufacturers have two options:

1. To mark with the symbol of a third party approval authority. This is a mark of guarantee endorsed by an independent testing authority e.g. the BSI Kitemark. For luminaires and lighting components, European harmonization of the various European Test House approval marks has been achieved with the introduction

Table 25.5 Defining IP numbers for luminaires (from BS 775)

Protection of persons against contact with live or moving parts inside the enclosure and protection of equipment against ingress of solid foreign bodies. Protection against contact with moving parts inside the enclosure is limited to contact with moving parts inside the enclosure that might cause danger to persons		Protection of equipment against ingress of liquid	
First characteristic numeral	*Degree of protection*	*Second characteristic numeral*	*Degree of protection*
0	No protection of persons against contact with live or moving parts inside the enclosure No protection of equipment against ingress of solid foreign bodies.	0	No protection.
		1	Protection against drops of condensed water. Drops of condensed water falling on the enclosure shall have no harmful effect.
1	Protection against accidental or inadvertent contact with live or moving parts inside the enclosure by a large surface of the human body, e.g. a hand, but not protection against deliberate access to such parts. Protection against ingress of large solid foreign bodies.	2	Protection against drops of liquid. Drops of falling liquid shall have no harmful effect when the enclosure is tilted at any angle up to 15° from the vertical.
		3	Protection against rain. Water falling in rain at an angle equal to or smaller than 60° with respect to the vertical shall have no harmful effect.
2	Protection against contact with live or moving parts inside the enclosure by fingers. Protection against ingress of medium-size solid foreign bodies.	4	Protection against splashing. Liquid splashed from any direction shall have no harmful effect.
3	Protection against contact with live or moving parts inside enclosure by tools, wires or such objects of thickness greater than 2.5 mm. Protection against ingress of small solid foreign bodies.	5	Protection against water jets. Water projected by a nozzle from any direction under stated conditions shall have no harmful effect.
		6	Protection against conditions on ship's decks (deck watertight equipment). Water from heavy seas shall not enter the enclosure under prescribed conditions.
4	Protection against contact with live or moving parts inside the enclosure by tools, wires or such objects of thickness greater than 1 mm. Protection against ingress of small solid foreign bodies.	7	Protection against immersion in water. It shall not be possible for water to enter the enclosure under stated conditions of pressure and time.
5	Complete protection against contact with liver or moving parts inside the enclosure. Protection against harmful deposits of dust. The ingress of dust is not totally prevented, but dust cannot enter in an amount sufficient to interfere with satisfactory operation of the equipment enclosed.	8	Protection against indefinite immersion in water under specified pressure. It shall not be possible for water to enter the enclosure.
6	Complete protection against contact with live or moving parts inside the enclosure. Protection against ingress of dust.		

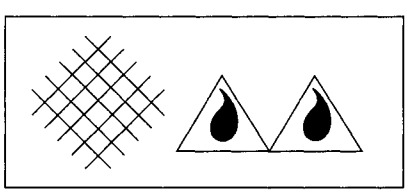


Figure 25.7 IPSS symbols

of the ENEC mark. This may be awarded by any of the recognized European approval authorities, such as BSI, VDE or SEMKO, in the same way as a national approval mark. It shows that the product is approved to the Harmonized European luminaire standard EN60598 (BS4533). It also indicates that the luminaire conforms to the most onerous national deviations set out in the standard.

2. Self certification. The manufacturer claims that the product is safe and fit for purpose. The value of such a claim is directly related to the standing of the firm making it. Customers should look for firms that are quality assured to BS5750/ISO9000.

25.4 Control gear

25.4.1 General

The electrical characteristics of many lamp types dictate that they cannot be operated directly from the normal

a.c. mains supply. Most discharge lamps need a current-limiting device in the circuit to control lamp power. To provide the necessary control, electrical components, collectively known as control gear, are needed. There may also be components in the circuit which have no direct effect on lamp operation. They are, strictly speaking, control gear, although they are not always thought of as such. Power factor correction capacitors and fuses are examples.

25.4.2 Ballast

This is the general term for control gear inserted between the mains supply and one or more discharge lamps, or fluorescent lamps, which, by means of inductance, capacitance or resistance, singly or in combination, serves mainly to limit the current of the lamp(s) to the required value. A ballast may also incorporate means of:

Transforming the supply voltage
Providing a starting voltage
Providing a preheating current
Improving cold starting
Reducing stroboscopic effects
Correcting power factor
Suppressing radio interference

Other components are as follows.

25.4.2.1 Choke

A simple low power factor inductive ballast.

25.4.2.2 LPF switchchart ballast

A one-piece unit with a choke and a starter switch socket.

25.4.2.3 HPF switchstart ballast

A one-piece unit containing choke, starter switch socket and power factor correction capacitor.

25.4.2.4 Leakage reactance autotransformer

A one-piece unit with a special magnetic circuit which provides a high starting voltage and subsequent ballast control.

25.4.2.5 Transformer

A wire-wound unit which steps up or steps down its supply voltage.

25.4.2.6 Lagging (inductive) circuit

A circuit in which the current waveform leads the voltage waveform.

25.4.2.7 Lead/lag circuit

A twin-lamp circuit comprising one leading circuit and one lagging circuit. Such an arrangement overcomes stroboscopic problems and also results in a circuit with near-unity power factor.

25.4.2.8 Ignitor

A starting device, intended to generate voltage pulses to start discharge lamps, which does not provide for the preheating of electrodes.

25.4.2.9 Electronic starter

A starting device, usually for fluorescent tubes, which provides the necessary preheating of the electrodes and, in combination with the series impedance of the ballast, causes a surge in the voltage applied to the lamp.

25.4.2.10 Glow-starter switch

A starter, which depends for its operation on a glow discharge in a gaseous atmosphere, closes or opens the preheating circuit of a fluorescent tube and, in combination with the series impedance of the ballast, causes a surge in the voltage applied to the lamp.

25.4.2.11 An energy limiter

An energy limiter is a device which may be incorporated into the electrical distribution board in a building to reduce the supply voltage and hence the power consumed by fluorescent lighting installations. Such voltage reductions also cause a drop in light output and changes to other lamp operation characteristics, depending on lamp type, ballast circuit and luminaire.

25.4.2.12 Temperature

Rated maximum ambient temperature (t_a) – the temperature assigned to a luminaire to indicate the highest sustained temperature in which the luminaire may be operated under normal conditions.

Rated maximum operation temperature (t_c) – the highest permissible temperature which may occur at any place on the outer surface of a device under normal operation conditions.

Rated maximum operating temperature of a winding (t_w) – the operating temperature of a ballast winding which gives an expectancy of 10 years' continuous service at that temperature.

Rated temperature rise of a ballast winding (Δt) – the temperature rise of the winding under the conditions specified in the relevant BS or IEC publication.

25.4.2.13 Electronic ballast

All electronic single piece ballasts provide an improved method of starting and running fluorescent lamps and offer many advantages over the conventional wire wound ballasts, particularly high quality lighting and reduced running costs.

25.4.3 Power factor correction

Inductive devices are the major source of current control in discharge lamp circuits but the inductance causes the supply current to lag the supply voltage – they become out of phase. This effect is quantified by the power factor (PF) of a circuit which is the relationship between the power and volt/amps:

$$\text{PF} = \frac{P}{V \times I}$$

where

P is the circuit power input (W), V is the circuit supply voltage (V), I is the total circuit current (A).

The circuit power factor can be no greater than one. When there is no phase difference $P = V \times I$ and the power factor is unity.

With a low power factor the circuit's apparent power ($V \times I$) and current are large compared with its power demand. Unnecessarily high currents require large cables and this is wasteful. As a result, the supply authority may impose extra tariffs where the overall power factor is low. There are therefore good reasons for operating at a high power factor.

In an inductive circuit the current lags the voltage; in a capacitive circuit the reverse is true. A combination of inductance and capacitance can be arranged so that these effects at least partially cancel each other out to produce a small phase difference and consequently a high power factor. This is a form of power factor correction.

More commonly, a capacitor is included connected across the circuit supply between 'live' and 'neutral' in what was a low power factor inductive circuit to reduce the supply current and bring the power factor closer to unity. The capacitor is referred to as a power factor correction (PFC) capacitor. Capacitors are usually included in discharge lamps circuits for power factor correction.

25.4.3.1 Large installations

Where the lighting installations will be a high proportion of the load on a distribution transformer, liaison with the transformer manufacturer at the design stage is advisable to ensure that natural resonance between transformer leakage reactant and the total ballast parallel PFC capacitor load does not occur at the lower harmonic frequencies of the main supply. Increased line current will be avoided if natural resonance occurs at frequencies above 400 Hz, where the voltage level of the harmonics is normally very low.

25.5 Emergency lighting

25.5.1 General

In the UK the Fire Precautions Act 1971 and the Health and Safety at Work, etc. Act 1974 make it obligatory to provide adequate means of escape in all places of work and public resort. Emergency lighting is an essential part of this requirement. BS 5266 (EN1838:1999) lays down minimum standards for design, implementation and certification of such installations.

The UK has a long history of fire and safety legislation (a legacy of the Great Fire of London in 1666). In other countries the legislation ranges from none to different regulations with similar weight and intent. The nature of the legislation and the variation from one country to another make it impossible to deal with this topic in a general way. The reader must refer to the regulations which apply to the locality and comply with them.

The comments in this section refer to UK practice, but even within the UK there is considerable local variations in the regulations (by means of bye-laws) and approval should be obtained from the appropriate authority.

23.5.1.1 Escape lighting

This type of emergency lighting is provided to ensure the safe and effective evacuation of the building. It must:

1. Indicate the escape routes clearly and unambiguously.
2. Illuminate the escape routes to allow safe movement towards and out of the exits.
3. Ensure that fire-alarm call points and fire equipment provided along the escape route can be readily located.

23.5.1.2 Standby lighting

Some building areas cannot be evacuated immediately in the event of an emergency or power failure because life would be put at risk (for example, a hospital's operating theatre or chemical plants where shutdown procedures must be used). In these circumstances the activities must be allowed to continue and standby lighting is required. The level of standby lighting will depend on the nature of the activities, their duration and the associated risk, but the provision of 5–25% of the standard service illuminance is common.

Standby lighting can be regarded as a special form of conventional lighting and can be dealt with accordingly, but escape lighting requires different treatment, and is the major concern of BS 5266. Like most British Standards, this is not a legal document, but it can acquire legal status by being adopted as part of the local bye-laws. Although most local authorities quote BS 5266, many modify the conditions (for example, by insisting on higher illuminances). It is left to the enforcing authority to decide for what duration emergency lighting shall be required to operate. This is normally longer than the time needed for an orderly evacuation, for the sake of rescue services (typically, 1, 2 or 3 hours).

25.5.2 Escape lighting

25.5.2.1 Marking the escape route

All exits and emergency exits must have exit or emergency exit signs. These to be kept in order and illuminated for as long as it takes to evacuate the building. Standards for signing are following the pictogram route but without wording – that is a man running towards a solid door with a pointing arrow in-between. These are gradually replacing the interim format (detailed in BS5499) of the mixture of a running man inside a box, arrow and text. The old BS5260 'Exit' word sign on its own is now obsolete. Note: it is not permitted to mix signs of different formats in an installation.

25.5.2.2 Illuminating the route

The emergency lighting must reach its required level 5 seconds after failure of the main lighting system. If the occupants are familiar with the building this time can be increased to 15 seconds at the discretion of the local authority. The minimum illuminance at floor level

along the centreline of an escape route, without hazard, must be 0.2 lux and preferably 1 lux. In an open area such as a hall or open-plan office, this applies to all areas where people may walk on their way to the exits. For open areas greater than $60\,m^2$ a minimum level of 0.5 lux applies, excluding the last 0.5 m to the wall.

25.5.2.3 Glare

Luminaires should not cause disability glare and should therefore be mounted at least 2 m above floor level. They should not be too high or they may become obscured by smoke.

25.5.2.4 High risk task areas

These areas need to be lit to a minimum 10% of the normal lighting level, or 15 lux, whichever is greater. Light must be provided within 0.5 seconds, placing emphasis on maintained luminaires or those with tungsten lamps.

25.5.2.5 Exits and changes of direction

Luminaires should be located near each exit and emergency exit door, and at points where it is necessary to emphasize the position of potential hazards, such as changes of direction and floor level, and staircases. Points of emphasis require a minimum of 1 lux.

25.5.2.6 Fire equipment

Firefighting equipment and fire-alarm call points along the escape route must be adequately illuminated at all reasonable times.

25.5.2.7 Lifts and escalators

Although these may not be used in the event of a fire, they should be illuminated. Emergency lighting is required in each lift car in which people can travel. Escalators must be illuminated to the same standard as the escape route to prevent accidents.

25.5.2.8 Toilets and control rooms

In toilets of over $8\,m^2$ gross area, emergency lighting should be installed to provide a minimum of 0.2 lux. Emergency lighting luminaires are required in all control rooms and plant rooms.

25.5.3 Types of systems

There are two main types of supply for emergency lighting: generators and batteries. Few generators will run up to provide the required illuminance within 5 or 15 seconds, in which case they must either be running continuously or be backed up with an auxiliary battery system. Generators require considerable capital investment and are difficult to justify except for standby use.

A battery system can one of two types; either a central system, where the batteries are in banks at one or more locations, or a self-contained system, where each individual luminaire has its own battery.

25.5.3.1 Central systems

These have battery rooms or cubicles in which the charger, batteries and switching devices are located. Modern systems tend to have several cubicles to improve system integrity in the event of fire damage to one cubicle.

25.5.3.2 Self-contained luminaires

These are self-powered and operate independently in an emergency. Thus although an individual luminaire may be destroyed in a fire, the other luminaires will be unaffected. The fact that each luminaire is an independent unit means that maintenance must be thorough. For most applications self-contained luminaires must operate for a period of 1–3 hours. Most designers base their designs on the safer 3-hour standard, irrespective of the requirements of the enforcing authority.

25.5.3.3 Maintained

In this mode the lamp is on all the time. Under normal conditions it is powered directly or indirectly by the mains. Under emergency conditions it uses its own battery supply.

25.5.3.4 Non-maintained

Here the lamp is off when mains power is available to charge the batteries. Upon failure the lamp is energized from the battery pack.

25.5.3.5 Sustained

This is a hybrid of the previous two modes. A lamp is provided which operates from the mains supply under normal conditions. Under emergency conditions a second lamp, powered from the battery pack, takes over. Sustained luminaires are often used for exit signs. Although self-contained luminaires are the easiest and most flexible to install, maintenance and testing must be thorough if operation in the event of an emergency is to be guaranteed. Maintained systems continuously demonstrate the integrity of the lamp, but the lamp is continually ageing and an operating lamp gives no indication of the state of the battery or charger circuits. In non-maintained and sustained systems the lamps do not age, but only regular testing will reveal faults.

A variation of the self-contained luminaire is the standard luminaire with an inverter unit and battery pack. These luminaires are normally conventional types used for general lighting (e.g. batten fittings, recessed reflector fittings, etc.) but have a change-over device, inverter and battery pack which will run one of the fluorescent lamps at reduced output if the mains fails.

25.5.4 Planning

When planning an emergency lighting system the following sequence is recommended:

1. Define the exits and emergency exists.
2. Mark the escape routes.
3. Identify any problem areas (for example, areas that will contain people unfamiliar with the building, toilets over 8 m^2, plant rooms, escalators, etc.).
4. Mark location of exit signs. These can be self-illuminated or illuminated by emergency lighting units nearby. Indicate these on the plan.
5. Where direction signs are required, mark these and provide necessary lighting.
6. Identify the area of the escape route which is already illuminated by the lighting needed for the signs.
7. Add extra luminaires to complete the lighting of the escape route, paying particular attention to stairs and other hazards. Remember to allow for shadows caused by obstructions or bends in the route.
8. Add extra luminaires to satisfy the problem areas identified in (3) above. Make sure that the lighting outside the building is also adequate for safe evacuation.
9. Check that all fire-alarm points and fire equipment have been adequately dealt with.

25.5.4.1 Testing

The local inspector will normally require a written guarantee that the installation conforms to the appropriate standards. Drawings of the system must be provided and retained on the premises (this also applies to modifications).

All self-contained luminaires and internally illuminated signs must be tested for a brief period once a month. The battery system must be used twice a year in a simulated mains failure for a period of at least one hour. The charging system must also be checked. The system must be operated to its full duration (normally 3 hours) at least once every three years.

25.6 Lighting design

25.6.1 General

Lighting is an art as well as a science. This implies that there are no hard-and-fast rules of design nor will there be one ideal or optimum solution to a particular lighting problem. More often than not, the lighting designer is presented with a list of conflicting requirements to which priorities have to be allocated before a satisfactory compromise can be found. Here we can therefore do little more than give general guidance.

This section should be read in conjunction with the current CIBSE Code, which includes appropriate illuminances and glare indices for various activities, together with useful notes and flow charts for easy planning (see Figure 25.8).

25.6.2 Choice of lighting system

One should not confuse choosing a lighting system with selecting lamps, luminaires or other equipment. This is a strategic decision which determines the relationship between daylight and artificial light and the degree to which the lighting system is tailored to match the local needs within the space. One basic system decision is to choose between general, localized or local lighting.

25.6.2.1 Uniform or general lighting

Lighting systems which provide an approximately uniform illuminance on the horizontal working plane over the entire area are called general or uniform lighting systems. The luminaires are arranged in a regular layout, giving a tidy appearance to the installation. General lighting is simple to plan and install, and requires no coordination with task locations which may not be known or which may change.

The greatest advantage of such a system is that it permits complete flexibility of task location. Its major disadvantage is that energy is wasted in illuminating the whole area to the level needed only for the most critical tasks.

25.6.2.2 Localized lighting

Localized lighting systems employ an arrangement of luminaires related to the position of tasks and workstations. They provide the required service illuminance on work areas together with a lower level of general illumination for the space. By careful luminaire positioning, good light utilization is achieved with few problems from shadows, veiling reflections and discomfort glare. Localized systems normally consume less energy than do general systems, unless a high proportion of the area is occupied by workstations.

25.6.2.3 Local lighting

Local lighting provides illumination only over the small area occupied by the task and its immediate surroundings. A general lighting system is installed to provide sufficient ambient illumination for circulating and non-critical tasks. Therefore the local lighting system simply supplements the general lighting to achieve the necessary service illuminance on tasks. The system is sometimes referred to as 'task-ambient lighting'. It is very efficient, particularly when high standards of task illuminance are required.

Local lighting is commonly provided by luminaires mounted on the workstation, providing a very flexible room layout. Such local units must be positioned carefully to minimize shadows, veiling reflections, and glare. There is therefore much to be said against making the units adjustable by their lay uses. They offer some personal control of lighting, which is often a popular feature in a large open office.

25.6.3 Choice of lamp

The choice of lamp affects the range of luminaires available, and vice versa, so one cannot be considered without reference to the other. (Section 25.2 will help to differentiate the performance of the main lamp types.)

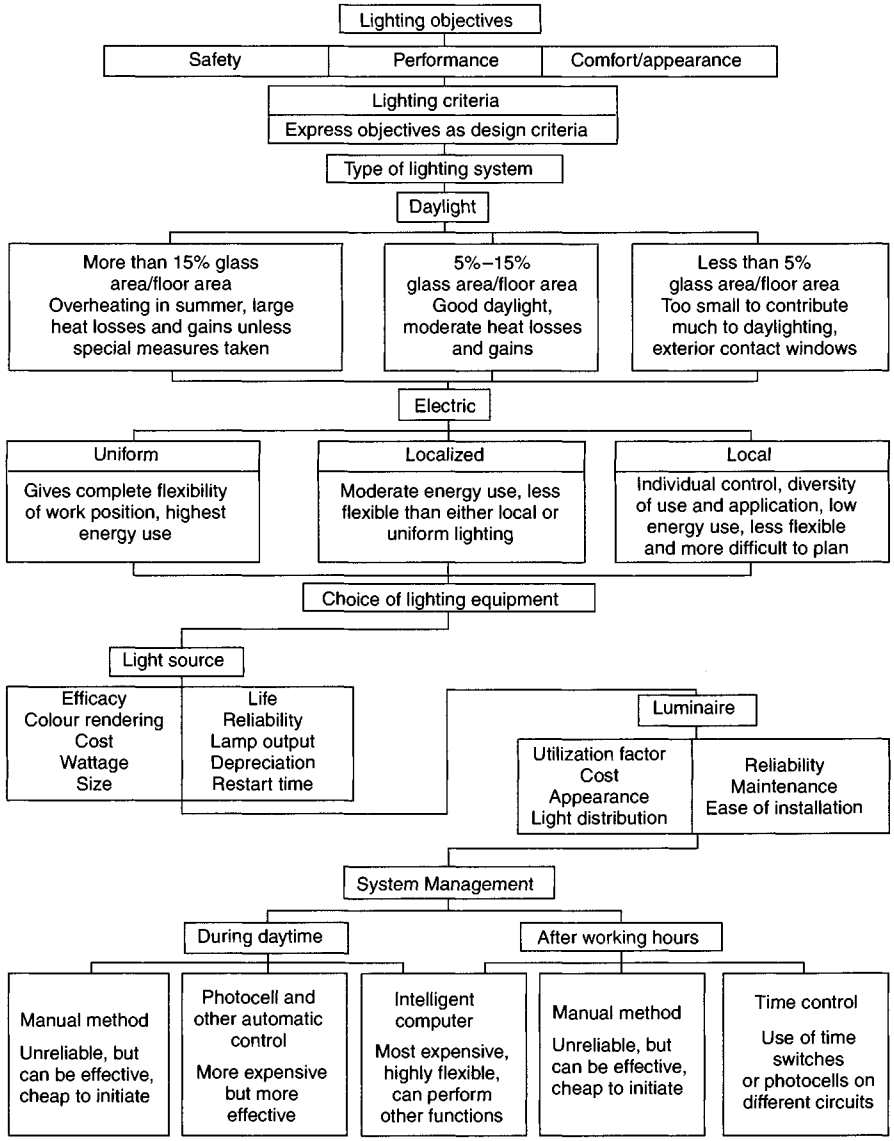


Figure 25.8 An interior lighting design flowchart

The designer should compile a list of suitable lamps by rejecting those which do not satisfy the design objectives. The availability of suitable luminaires can then be checked and the economics of the combinations assessed.

Lamps must have satisfactory colour-rendering properties. Visual tasks requiring accurate perception of colour are less common than is generally believed, but there are many merchandizing situations where good colour rendering is desirable. The suitability of a lamp for a particular application is best decided by experimental tests.

Lamps must also provide the right colour appearance. A warm colour tends to be preferred for informal situations, at lower illuminances, and in cold environments, while a cool appearance tends to be preferred for formal situations, at higher illuminances, and in hot environments. It is normally undesirable to illuminate visibly adjacent areas with sources of significantly different colour appearance.

Lamp life and lumen maintenance must be considered in conjunction with the maintenance policy for sensible economic calculations, and it needs to be remembered that standardization of lamp types and sizes within a particular site can simplify maintenance.

This selection process deals with most simple situations and is usually more reliable than trying to find a lamp which matches the needs of the design, which normally

calls for a very difficult compromise decision. However, it must only be regarded as a guide. Size, output, the availability of suitable luminaires and many other aspects will influence the choice.

25.6.4 Choice of luminaire

Luminaires have to withstand a variety of physical conditions (e.g. vibration, moisture, dust, high or low ambient temperatures, or vandalism). IR charts identify several acceptable luminaires and the final decision on which luminaire to use can be based on cost, efficiency, glare control, etc., and may have to be left to a later stage in the design process.

25.6.5 System management

A lighting system should not only be well designed but also be managed and operated effectively and efficiently. Good system management implies:

1. Maintaining the system in good order; and
2. Controlling its use to conserve money and energy.

Both these components of management must be considered in the design. The maintenance policy will affect the number of luminaires needed to achieve the service illuminance and the degree of control required will determine the circuits in which the luminaires will operate. They must also be electrically safe.

Further reading

A. M. Marsden and M. A. Cayless, *Lamps and Lighting*, 3rd edn, Edward Arnold, London
Chartered Institution of Building Services Publications and Codes, Delta House, 222 Balham High Road, London SW12 9BS
Lighting Industry Federation Factfinders, Swan House, 207 Balham High Road, London SW17 7BQ
ICEL: Emergency Lighting Design Guides
Tel: 0181-675 5432
email: info@icel.co.uk

Classification of dangerous areas

Unlike the IP Code, hazardous equipment is classified according to the nature of the area in which it is to be used, known as the Zonal Classification. Areas are defined as hazardous where a danger of explosion exists owing to the presence, or possible presence, of a potentially explosive atmosphere or dust resulting from the processes or activity undertaken in the immediate or surrounding area. Area classification is as follows:

Zone 0 where an explosive atmosphere is either continuously present or present for long periods
Zone 1 where an explosive atmosphere is likely to occur during normal operation
Zone 2 where an explosive atmosphere is not likely to occur during normal operation, and, if it does occur, will only be present for a short period

The risk decreases as the Zone number ascends, therefore, equipment which is designed for use in Zone 0 or Zone 1 areas will also be suitable for Zone 2 areas, but, equipment designed only for Zone 2 areas will not be acceptable for Zone 1 or Zone 0 areas. As only very specialized EEx i equipment can be used in Zone 0 areas, it is more usual to light them by locating luminaires in an adjacent area which has lower risk, thus permitting the use of Zone 1 or Zone 2 products.

For combustible dusts:

Zone 10 where explosive dusts are continuously present or present for long periods
Zone 11 where explosive dusts are occasionally present

The choice of electrical equipment

Prior to the selection of electrical equipment it is necessary to define the nature of the gas or vapour and the probability of its presence. In any plant a decision on the zone has to be made by the engineering and process teams. The type of protection would need to be of the appropriate class for use with the particular gas or vapour that might be present. The main points taken into account in making a decision are:

- Probability of presence of gas
- Quantity of gas or vapour
- Degree of ventilation available
- Nature of the gas (whether heavier than air)
- Consequences of an explosion

Gases are 'grouped' according to the amount of energy produced by an explosion of the gas and air mixture

Gas group	*Representative gas*	*Typical application*
1	Methane	Underground mining
11A	Propane	Surface
11B	Ethylene	Surface
11C	Hydrogen	Surface

Equipment which is certificated as Gas Group 11 is suitable for use with Gas Groups 11A 11B 11C

Ignition temperature classification

The ignition temperature of a gas is that at which it will ignite and sustain combustion if in contact with a hot surface and, as one would expect varies from one explosive mixture to another. Town gas for example requires a temperature of 600°C (T1 Class) before it will ignite, a mixture of petrol and air about 250°C (T3 Class) while carbon disulphide has an ignition temperature of only 100°C (T6 Class). A system of 'T ratings' has been established to help determine, for areas in which gases in Group II could be present, the relationship between

temperature class and the maximum surface temperature of the equipment. Naturally, the surface temperature of any equipment installed within a hazardous area must not exceed the ignition temperature of the gas/air mixture which is, or maybe, present.

Temp. Class or T Rating	*Max. permitted surface temp.*	*Ignition temp. of gas/air mixture*
T1	450°C	>450°C
T2	300°C	>300°C
T3	200°C	>200°C
T4	135°C	>135°C
T5	100°C	>100°C
T6	85°C	>85°C

The design of electrical equipment for use in hazardous areas is based on a number of established engineering concepts which are intended to protect against the possibility of explosion. These most popular types of protection are:

Zone 0

EEx i Intrinsic safety

The luminaire is incapable of causing ignition of a surrounding gas/air mixture.

Zone 1

EEx d Flameproof enclosure

The enclosure is designed to withstand and contain an internal explosion of the relevant gas/air mixture without igniting an explosive atmosphere surrounding the enclosure

EEx e Increased safety

The luminaire and internal components do not produce arcs or sparks or reach a temperature which could ignite the gas/air mixture. Such fittings rely on the safety built into the internal components and not the enclosure

EEx q Powder filled

The luminaire or component is within an inert powder to prevent arcs, sparks or dangerous temperatures

Zone 2

Ex N Non sparking

The luminaire does not produce arcs, sparks or dangerous temperature during normal operation. There are two types allowing for 'restricted' and 'unrestricted' breathing. The former implies that the enclosure may be hermetically sealed to prevent the ingress of gases or it may be gasketed to hinder their entry. The latter is applied to a simple enclosed luminaire.

Misc

Ex s Special

This symbol is used to denote protection which is not included in the established concepts. It enables the use of new techniques prior to their inclusion in standard specifications

The use of Ex or EEx within the symbol denotes if the protection concept is contained within a National standard – Ex or within a harmonized European standard – Eex. If the design of a luminaire uses more than one of these concepts to acquire the required protection all symbols are shown – for example 'EEx de' indicates a luminaire which utilizes a flameproof enclosure but also incorporates increased safety concepts.

Approval authorities

There are two approval authorities in the UK for luminaires for use in hazardous areas: The Electrical Equipment Certification Service (EECS) operated by the Health and Safety Executive which also encompasses the British Approvals Service for Electrical Equipment in Hazardous Atmospheres (BASEEFA) and SIRA Certification Services (SCS)

Product selection

As a conclusion, here is a handy checklist for the plant engineer.

1 **What ZONE is applicable?**
for Zone 2 all protection concepts can be used
for Zone 1 all protection concepts except Ex N can be used

2 **What GAS GROUP is applicable**
Identify the gas which will or maybe present from the given schedule and select a luminaire approved for this gas group

3 **What T Rating is required**
Use the same table to identify the required temperature class or T rating and select a luminaire with that or higher T rating

4 **What IP rating is required**
Assess the protection against ingress of solids or liquids to find the minimum acceptable IP rating. Select a fitting with an IP rating with both digits not less than the required number

Schedule of common gas groups and T ratings

Gas Group	*Temperature Class*				
	T1	*T2*	*T3*	*T4*	*T6*
IIA	Acetone	Ethyl Alcohol	Petrol	Acet Aldehyde	
	Ethane	I-Amyl Acetate	Diesel	Ethyl Ether	
	Ethyl Acetate	N Hexane	Aviation Fuel		
	Ammonia	N Butane	Heating Oil		
	Benzol	N-Butyl Alcohol			
	Acetic Acid				
	Carbon Monoxide				
	Methanol				
	Propane				
	Toluene				
IIB	Town Gas	Ethylene			
IIC	Hydrogen				Carbon Disulphide

Where combustible dusts are, or maybe, present detailed guidance should be taken from BS 7535:1992. Luminaires classified EE xd (flameproof) or EE xe (increased safety) with T rating T4 or above and IP rating IP6 (x) will usually be acceptable.

26 Compressed air systems

British Compressed Air Society

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26.1 Assessment of a plant's air consumption

The main consideration in the selection of a compressor plant is the production of an adequate supply of compressed air at the lowest cost consistent with reliable service. The installation of a compressed air system, as with all forms of power transmission, calls for capital investment with consequent operating and maintenance costs. The information on which the selection of plant is based should be as accurate as possible. Important factors to be considered are the following.

26.1.1 Operating pressure

Most compressed air equipment operates at about 6 bar (gauge) and it is usual for the compressor to deliver air into the mains at 7 bar (gauge) in order to allow for transmission losses (see Tables 26.1–26.4). If some of the air is to be used at a lower pressure (for example, for instrument control) the pressure is reduced by means of a pressure regulator to the required line pressure.

All equipment connected to the system shall either have a design pressure greater than the maximum output pressure of the compressor or special precautions shall be taken to ensure that, if its design pressure is lower than the output pressure of the compressor, it cannot be subject to excessive pressure (see Section 26.3.1). If there is a requirement for a large volume of air at a higher or lower pressure it may be more economical to install a separate compressor to deal solely with that.

26.1.2 Maximum and average load

Ideally, the total capacity would be based on exact knowledge of the equipment or process requirements. If this is underestimated the compressor plant will be too small, and will be unable to maintain the required pressure in the system. Conversely, if the total air consumption is greatly overestimated, there may be excessive capital investment. Furthermore, any arrangement which results in significant off-load running wastes energy. However, it is safer to err on the high side with a slight overestimates, as in most installations the use of compressed air will increase and soon take up any surplus capacity.

Table 26.1 Maximum recommended flow through main lines[a]

Nominal bore (mm)	*Actual bore (mm)*	*Rate of free air flow at 7 bar (l/s)*
6	6	1
8	9	3
10	12	5
15	16	10
20	22	17
25	27	25
32	36	50
40	42	65
50	53	100
65	69	180
80	81	240
100	100	410
125	130	610
150	155	900

Velocity of air flow must be restricted to less than 6 m/s as shown if carry over of moisture past drain legs is to be avoided.
[a]Medium-weight steel tube to BS 1387, table 2, or ISO 65.

26.1.3 Use factor

Before deciding the capacity of the compressor required it is necessary to calculate the air consumption expected. It is recommended that reference is made to Table 26.5 and Figure 26.1, which show typical 'use factors' for various types of pneumatic equipment. In some cases, where there is experience of a similar installation, a fairly accurate

Table 26.2 Maximum recommended flow through branch lines of steel pipe[a]

Applied gauge pressure[b] *bar*	*Nominal standard pipe size (nominal bore) (mm)*										
	6	*8*	*10*	*15*	*20*	*25*	*32*	*40*	*50*	*65*	*80*
0.4	0.3	0.6	1.4	2.6	4	7	15	25	45	69	120
0.63	0.4	0.9	1.9	3.5	5	10	20	30	60	90	160
1.0	0.5	1.2	2.8	4.9	7	14	28	45	80	130	230
1.6	0.8	1.7	3.8	7.1	11	20	40	60	120	185	330
2.5	1.1	2.5	5.5	10.2	15	28	57	85	170	265	470
4.0	1.7	3.7	8.3	15.4	23	44	89	135	260	410	725
6.3	2.5	5.7	12.6	23.4	35	65	133	200	390	620	1085
8.0	3.1	7.1	15.8	29.3	44	83	168	255	490	780	1375
10.0	3.9	8.8	19.5	36.2	54	102	208	315	605	965	1695
12.5	4.8	10.9	24.1	44.8	67	127	258	390	755	1195	2110
16.0	6.1	13.8	30.6	56.8	85	160	327	495	955	1515	2665
20.0	7.6	17.1	38.0	70.6	105	199	406	615	1185	1880	3315

[a]Maximum recommended air flow (l/s free air) through medium series steel pipe for branch mains not exceeding 15 m length (see BS 1387). The flow values are based on maximum recommended peak flows. Normal steady state air consumption should not exceed 80% of these figures in pipe sizes 6–15 mm nominal bore and 60% of these figures in pipe sizes 20 mm nominal bore and above.
[b]Applied pressures selected from ISO 2944: Fluid Power Systems – nominal pressures.

Table 26.3 Pressure loss through steel fittings – equivalent pipe lengths

Item	*Equivalent pipe length (m)*									
	Inner pipe diameter (mm)									
	15	*20*	*25*	*40*	*50*	*80*	*100*	*125*	*150*	*200*
Gate valve fully open	01.	0.2	0.3	0.5	0.6	1.0	1.3	1.6	1.9	2.6
half closed		3.2	5	8	10	16	20	25	30	40
Diaphragm valve fully open	0.6	1.0	1.5	2.5	3.0	4.5	6	8	10	
Angle valve fully open	1.5	2.6	4	6	7	12	13	18	22	30
Globe valve fully open	2.7	4.8	7.5	12	15	24	30	38	45	60
Ball valve (full bore) fully open	0.5	0.2	0.2	0.4	0.3	0.4	0.3	0.5	0.6	0.6
Ball valve (reduced bore) fully open	3.4	4.9	2.4	2.2	5.0	2.6	4.1	3.3	12.1	22.3
Swing check valve fully open		1.3	2.0	3.2	4.0	6.4	8.0	10	12	16
Bend R = 2*d*	0.1	0.2	0.3	0.5	0.6	1.0	1.2	1.5	1.8	2.4
Bend R = *d*	0.2	0.3	0.4	0.6	0.8	1.3	1.6	2.0	2.4	3.2
Mitre bend 90°	0.6	1.0	1.5	2.4	3.0	4.8	6.0	7.5	9	12
Run of tree	0.2	0.3	0.5	0.8	1.0	1.6	2.0	2.5	3	4
Side outlet tee	0.6	1.0	1.5	2.4	3.0	4.8	6.0	7.5	9	12
Reducer		0.3	0.5	0.7	1.0	2.0	2.5	3.1	3.6	4.8

The table shows the length of pipe with equivalent pressure loss in a given size and type of fitting.

Table 26.4 Pressure loss through ABS fitting – equivalent pipe lengths

Pipe outside diameter	*Equivalent pipe length (m)*							
	16	*25*	*32*	*50*	*63*	*75*	*90*	*110*
90° elbow	0.34	0.5	0.65	1.0	1.26	1.5	1.88	2.58
45° elbow	0.16	0.24	0.32	0.52	0.63	0.75	0.95	1.33
90° bend	0.1	0.16	0.22	0.34	0.44	0.56	0.75	1.00
180° bend	0.28	0.41	–	–	–	–	–	–
Adaptor union	0.14	0.21	0.25	0.4	0.5	–	–	–
Tee in line flow	0.123	0.19	0.23	0.36	0.45	0.56	0.69	0.95
Tee in line to branch flow	0.77	1.17	1.47	2.21	2.98	3.68	4.57	6.00
Reducer	0.22	0.31	0.37	0.51	0.80	1.11	1.34	1.58

The table shows the length of pipe with equivalent pressure loss in a given size and type of fitting. For example, a 50 mm 90° elbow has a pressure loss equal to 1.0 m of 50 mm ABS pipe.

analysis can be made by plotting data obtained from past activity.

26.1.4 Future expansion

Future expansion should always be taken into account when installing new plant. Increasing compressor capacity presents no problem provided that the rest of the plant installation has been planned accordingly.

26.1.5 Allowance for air leakage

Experience has shown that the initial estimate of the total compressor capacity should include an allowance for leakage. Leakage in the piping can be overcome by proper installation practice. A large proportion of the total leakage occurs at hoses, couplings and valves.

For installations with regular inspection and maintenance a factor of 5% minimum should be adequate. The importance of this is obvious when one remembers that while a tool or appliance may use a considerable amount of air, it is only working intermittently, whereas any leakage, even from a small hole, is both continuous and significant.

26.2 Compressor installation

26.2.1 Type of installation

When planning a compressor installation one of the first matters to be decided is whether there should be a central compressor plant or a number of separate compressors near the main points of use. The following comments can be no more than general. In order to select the type and size of installation which will be adequate for both immediate and future requirements it is advisable to consult the supplier. Points to be considered are as follows.

26.2.1.1 Centralized installation

1. Lower total installed compressor capacity and, perhaps, lower initial cost;

Table 26.5 Air consumption of pneumatic equipment

Example of calculation The following calculation is typical of a medium-sized engineering workshop including a foundry, where a high degree of mechanization is to be carried out by means of compressed air-driven machines and tools. Listed in the table are the tools and other pneumatic devices which are expected to be included in the installation at full production capacity. The use factor of the different tools is calculated in connection with production planning and thus it is possible to establish the average total air consumption.

Machine or tool	*Air consumption per unit (l/s)*	*Quantity*	*Maximum air consumption (l/s)*	*Use factor*	*Average air consumption (l/s)*
Foundry					
Core-shop (I)					
Core blowers	11	3	33	0.50	16.5
Bench rammers	4	2	10	0.20	2.0
			43		18.5
Machine moulding (II)					
Moulding machines	12	5	60	0.30	18.0
Blow guns	8	5	40	0.10	4.0
Air hoist – 500 kg	33	2	66	0.10	6.6
			166		28.6
Hand moulding (III)					
Rammers					
– medium	6	1	6	0.20	1.2
– heavy	9	2	18	0.20	3.6
Blow guns	8	3	24	0.10	2.4
Air hoist – 500 kg	33	1	33	0.10	3.3
			81		10.5
Cleaning shop (IV)					
Chipping hammers					
– light	6	2	12	0.35	4.2
– medium	8	3	24	0.35	8.4
– heavy	13	2	26	0.20	5.2
Grinders					
– 75 mm	9	2	18	0.30	5.4
– 150 mm	25	3	75	0.45	33.8
– 200 mm	40	1	40	0.20	8.0
– medium	23	2	46	0.10	4.6
– heavy	42	2	84	0.10	8.4
Sandblast units					
– light	32	1	32	0.50	16.0
– heavy	53	1	53	0.50	26.5
			410		120.5
Total for foundry			700		178.0
Workshop					
Machine shop (V)					
Blow guns	8	10	80	0.05	4.0
Operating cylinders for jibs, fixtures and chucks			12	0.10	1.2
			92		5.2
Sheet metal shop (VI)					
Drills					
– light	6	1	6		1.2
– medium	8	1	8		1.6
– 12 mm	15	2	30		9.0
– angle	8	1	8		1.6
– screwfeed	52	1	52		2.6
Tapper	8	1	8	0.20	1.6
Screwdrivers	8	2	16	0.10	1.6
Impact wrench					
– 20 mm	15	1	15	0.20	3.0
– 22 mm	23	1	23	0.10	2.3
Grinders					
– 150 mm	25	2	50	0.30	15.0
– 200 mm	40	1	40	0.20	8.0
– medium	23	2	46	0.30	13.8
– heavy	42	1	42	0.20	8.4

(continued overleaf)

Table 26.5 *(continued)*

Machine or tool	*Air consumption per unit (l/s)*	*Quantity*	*Maximum air consumption (l/s)*	*Use factor*	*Average air consumption (l/s)*
Riveting hammers					
– medium	18	1	18	0.10	1.8
– heavy	22	1	22	0.05	1.1
Chipping hammers					
– light	6	2	12	0.20	2.4
– medium	8	2	16	0.20	3.2
– heavy	13	1	13	0.10	1.3
Air hoist – 5 tonne	97	1	97	0.05	16.2
Blow guns	8	1	16	0.10	1.6
			538		97.3
Assembly shop (VII)					
Drills					
– light	6	3	18	0.20	3.6
– medium	8	5	40	0.30	12.0
– 12 mm	15	6	90	0.35	31.5
– angle	8	2	16	0.10	1.6
– heavy	22	1	22	0.10	2.2
– heavy	33	1	33	0.10	3.3
Tappers	8	2	16	0.10	1.6
Screwdrivers	8	2	16	0.20	3.2
Impact wrenches					
– light	6	1	6	0.20	1.2
– 20 mm	15	2	30	0.20	6.0
– 22 mm	23	1	23	0.10	2.3
Grinders					
– 75 mm	9	2	18	0.20	3.6
– 150 mm	25	1	25	0.10	2.5
– medium	23	2	46	0.20	9.2
Air hoists					
– 500 kg	33	1	33	0.10	3.3
– 1 tonne	33	1	33	0.10	3.3
Blowguns	8	5	40	0.05	2.0
			505		92.4
Painting shop (VIII)					
Grinders and polishers					
– angle	8	1	8	0.20	1.6
– medium	23	1	23	0.30	6.9
Sandblast unit	38	1	38	0.50	19.0
Blow guns	8	1	8	0.10	0.8
Air hoist – 5 tonne	97	1	97	0.05	4.9
Spray painting guns	5	2	10	0.50	5.0
			184		38.2
Total for the workshop			1319		233.1

2. Possibly a higher efficiency, and thus lower power cost, due to larger units;
3. Lower supervision cost.

26.2.1.2 Decentralized installation

1. Output and/or pressure can be varied to suit each particular plant section.
2. Pipe sizes can be reduced, thus minimizing leakage and cost.
3. Compressors and/or associated equipment can be shut down during periods of low demand or for preventative maintenance with only a localized effect.

26.2.2 Compressor siting

The requirements for a compressor site will be affected by location and climate as well as by the equipment to be installed. The following aspects should be considered.

26.2.2.1 Foundations

The compressor plant should be located in a place with good ground conditions. In some cases the compressor foundation may have to be isolated from that of the main building so that vibration is not transmitted from compressor to the building structure, and from heavy plant to the compressor. Where the vibrations are slight, resilient pads

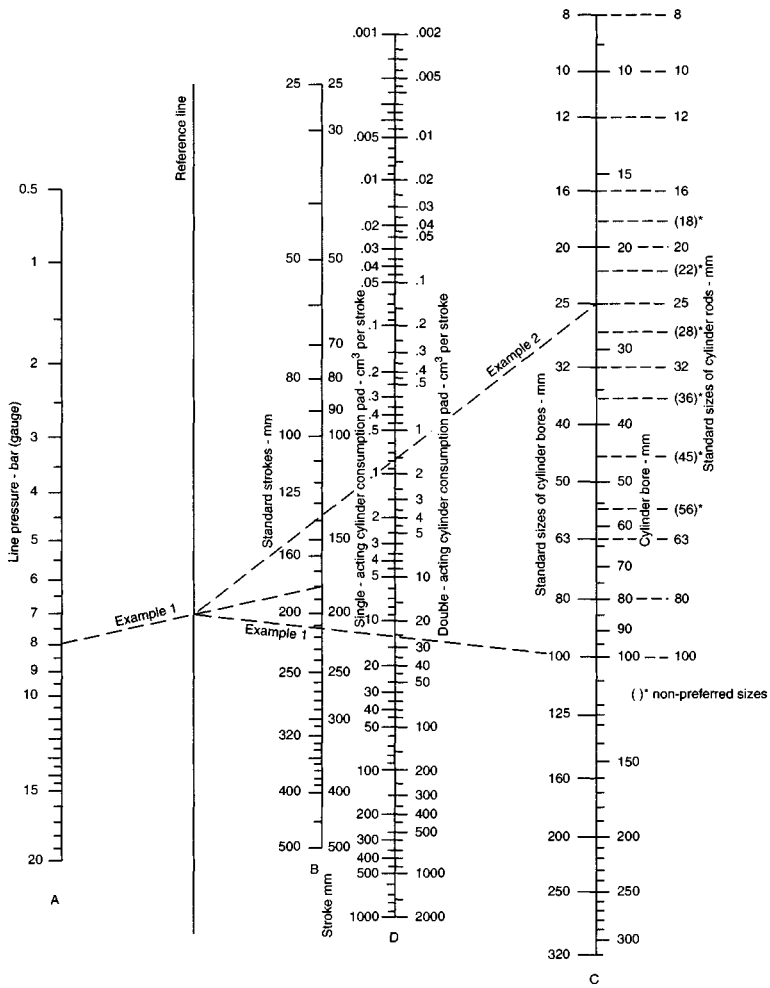


Figure 26.1 Air consumption of cylinders (metric)

How to use the nomogram
First connect line pressure (A) to stroke (B); then from the point where this cuts the reference line, connect across to cylinder bore size (C). Read off consumption where this line cuts the consumption scale (D). Figures on the left of this scale are for single-acting cylinders. Figures on the right are for double-acting cylinders, neglecting the effect of the rod. This is accurate enough for most purposes. However, if the correct (theoretical) consumption is required for double-acting cylinders, go back to the point on the reference line and connect across to the rod *diameter* size, entered on the 'cylinder bore' scale. This figure should then be deduced from the consumption arrived at with the first solution.

Example 1: Find the (nominal) consumption of a double-acting 100 mm bore cylinder with a stroke of 180 mm operating at 8 bar line pressure.

Answer: 25.4 l per stroke.

Example 2: The cylinder above has a 25 mm diameter rod. Find the true (theoretical) consumption.
Connection from the same point on the reference scale to the rod diameter size on the bore scale gives a single-acting cylinder consumption figure of 0.8 l per stroke. Deduce this from the solution found in Example 1 to give the true consumption figure, i.e. 25.4 – 0.8 = 24.6 l per stroke

may be used to advantage. Receiver-mounted units should always be either free-standing or mounted on resilient pads. If in doubt, the suppliers should be consulted.

26.2.2.2 Servicing facilities

For small and medium compressors lifting gear is necessary only for installation or re-siting, no special hoisting equipment being normally needed when overhauling the units provided individual components do not exceed 16 kg in weight. On larger units, lifting equipment is essential; the manufacturer or supplier must state the maximum hoisting load. Sufficient access and headroom must be provided around the compressor for servicing.

26.2.2.3 Weather protection

Adequate protection from the weather must be provided.

26.2.2.4 Ventilation

Heat generated by the compressor and prime mover must be dispersed. For air-cooled units sited in enclosed rooms

this heat must be removed in order to limit the temperature rise. It is sometimes possible to recover this heat for use elsewhere. Intake openings should be located so that dust and other foreign matter does not enter with the air.

26.2.2.5 Noise

Noise from a compressor plant arises at different sources, and each source has its own pattern of sound pressure levels. Noise levels can be divided into two groups, the low-frequency pulsating air intake sound and the higher-frequency machine noise from compressor, prime mover and fans. Local statutory regulations on noise levels should be determined, and action taken by the supplier to ensure that the noise levels do not exceed those stipulated.

26.2.3 Compressor intake

26.2.3.1 General

The compressor intake air must be clean and free from solid and gaseous impurities; abrasive dust and corrosive gases are particularly harmful. Exhaust fumes present a hazard if compressed air is required for breathing purposes. The possibility of contamination of the intake by discharge from pressure-relief devices of other plant must be taken into consideration and changes of wind direction must not be overlooked.

For maximum efficiency the intake air should be as cold as possible. A temperature decrease of 3°C will increase the volume of the delivered air by 1%. The air intake system should be sized to give a minimum pressure drop. Each compressor should have its own intake filter.

26.2.3.2 Intake silencing

The reciprocating compressor inspires air in a series of pulsations which causes an equivalent variation in pressure in the intake system. Dependent on the length of the intake pipe, resonance may occur; this can decrease the compressor output and produce disturbing noise levels and stresses sufficient to cause damage. By fitting a pulsation dampener or changing the length of the intake pipe, its natural resonant frequency can be changed, and any related vibration, noise and interference (with the air flow) will be diminished. The inherent pulsation noise can be removed by the use of a suitably designed silencer.

26.2.3.3 Intake filter

An air intake for a compressor should have a high capacity to remove abrasive materials, including those of small particle size, and good accumulating ability, that is, to collect large quantities of impurities without any significant decrease in filtering efficiency and air flow.

Normally the filter should be placed as close as possible to the compressor. When an intake silencer is fitted, it should be fitted between the intake filter and the compressor.

The filter should also be placed in such a way that it is easily accessible for inspection and cleaning or replacement. The most common types of filter in use are:

1. Paper
2. Oil-wetted labyrinth
3. (Woven and non-woven) cloth
4. Oil-bath (not suitable for reciprocating compressor)

Any of these may be incorporated into or be used in combination with suitable silencers.

For installations in areas of heavy contamination, such as quarries or cement works, additional filtration or automatic self-cleaning is required, otherwise the air filter will clog up rapidly. Filter condition indicators are available and are recommended.

26.2.3.4 Intake ducts

The air intake of a compressor should be sited so that, as far as possible, cool, clean, dry air is inspired. When located outdoors the air intake should be protected against the weather. The air intake should be designed and sited so that noise is reduced to the necessary level.

If large compressor plant requires clear headroom for cranes, air intakes may have to run through underfloor piping or ducting. Intake ducts must be of a cross-sectional area sufficiently large to avoid excessive pressure drop, and the number of bends should be kept to a minimum. The ducts should be of non-corrosive material and care should be taken that extraneous material cannot enter the duct. The duct should be cleaned thoroughly before connection to the compressor.

Intake pipes may be subject to pulsations and should not be too rigidly attached to walls or ceilings, since vibration may be transmitted to the building structure.

26.2.3.5 Corrosive intake gases

In certain plants, especially in the chemical industry or in the neighbourhood of such plants, the air is often polluted with acidic and corrosive gases which can cause corrosion in the compressor and the compressed air system. Special filtration methods and/or materials may have to be used and the supplier should be consulted.

26.2.4 Compressor discharge

26.2.4.1 Discharge pipe specification and siting

The diameter of the compressor discharge pipe should not normally be smaller than the compressor outlet connection and should be arranged with flanged fittings or unions to permit easy access to the compressor and components at any time. The possibility of vibration should be taken into account. The compressor discharge pipe will attain a high temperature and precautions must be taken to prevent this being a source of danger.

The interior of the pipelines through which the discharge air passes to the aftercooler or air receiver should be cleaned regularly so that a build-up of combustible oily carbon deposits is avoided. All the piping should slope downwards in the direction of air flow to a suitable drain point at the lowest point of the pipeline.

Discharge pipes can be located in trenches covered by floor plants, and there is no technical reason against laying

the pipes directly on the, but provision must be made for drainage.

Any pocket unavoidably formed after the compressor discharge shall be provided with a drain valve or trap at the lowest point so that any oil and condensate can be removed. Direct discharge to ground or sewer is not permitted.

Under certain conditions of installation and operation, pulsations may be set up in the compressor discharge lines. It is essential to consult the suppliers for their recommendations.

Thermoplastics shall not be used for a compressor discharge pipe and inflammable materials shall be kept away from it.

26.2.4.2 Isolating valve

Where an isolating valve is installed in the discharge pipework the piping on the compressor side of the valve shall be protected by a suitable safety valve. This safety valve must be of sufficient size to pass the full output of the compressor without the pressure rising more than 10% above the maximum allowable working pressure (BS 6244, Section 21).

26.2.4.3 Multiple compressors

Where two or more compressors feed into a single air line, the discharge line from each compressor shall be fitted with a non-return valve and isolation valve at the furthest point from the compressor or outlet, just prior to where the discharge pipe enters the common manifold feed pipe. A safety valve is fitted on the compressor side of the isolation valve, upstream of the aftercooler.

26.2.4.4 Non-return valves

Non-return valves used in compressor delivery lines must be designed to withstand the pressure, temperature and pulsations of compressed air.

26.2.5 Cooling-water system

26.2.5.1 General

Where water is used as a cooling medium for compressor and ancillary equipment it should be within the temperature and pressure levels prescribed by the compressor supplier and should be free from harmful impurities. The cooling water should have a low inlet temperature in order to assist in achieving a high volumetric efficiency in the compressor and to cool the air passing through the aftercooler to a temperature adequate for effective condensation of water vapour.

26.2.5.2 Overcooling

The compressor should not be overcooled so as to cause condensation in and on the compressor.

26.2.5.3 Water quality

Good-quality cooling water is essential.

26.2.5.4 Re-cooling the cooling water

In order to achieve economy in the use of water it will have to be re-cooled. This is achieved by transferring heat to the ambient air by means of cooling ponds, towers, tanks or mechanical coolers. Temperature regulators may assist control and conserve energy.

26.2.5.5 Mechanical coolers

The cost of cooling water is an important factor and mechanical coolers are in most cases more economical than allowing the water to run to waste. A forced-draught type of cooler consists of a casing with a water header at the top and a sump at the bottom. A series of cooling elements is provided which offers a large area for the transfer of heat between the water to be cooled and the cooling air. The hot water enters the top header and runs through the elements to a sump from which it is pumped through the compressor plant. A fan forces the colder ambient air through the elements to absorb the heat from the water as it passes through the elements.

Where this type of cooler is installed inside a building it is essential to duct away the warm air discharged by the fan. Consideration must be given to protection against frost.

26.2.5.6 Cooling towers

These operate by setting the cooling air in motion over a surface of water. This can be done by either natural convection or a fan. In order to provide a good transfer between water and air, towers usually have internal arrangements for spreading the water as a thin film. With cooling towers a final water temperature of about 5°C above the ambient air temperature can be expected. In general, good cooling can be obtained even at relatively high ambient temperatures, since the relative humidity is, in such a case, usually low. However, extreme tropical climates are an exception. The amount of water which is lost as vapour during re-cooling must be replaced by the addition of 'make-up' water. This quantity is considerably smaller than that consumed in open-flow cooling. Cooling towers should not be used in heavily contaminated atmospheres.

26.2.5.7 Cooling ponds

A cooling-water pond is the simplest form of cooling arrangement. The pond should be located so that an unrestricted air circulation is obtained. Vaporizing ability is improved if the hot water is returned to the pond by some kind of sprinkler device. Most of the cooling effect is caused by vaporization and the water thus lost must be replaced. Cooling ponds should not be used in heavily contaminated atmospheres.

26.2.5.8 Cooling tanks

A cooling tank is, in effect, a small cooling pond. However, because of the difficulty in keeping the water clean, this method is not recommended.

26.2.5.9 Keeping the cooling system clean

Cooling water should be free from solid impurities which could damage pumps and cause blockages and filtered, with filters cleaned regularly. The whole cooling system should be inspected and cleaned regularly. Sand, sludge, rust, etc. can be removed by flushing against the normal direction of flow. Lime deposits are more difficult to remove. Such deposits can usually be avoided by keeping the water outlet temperature at a low level. If excessive deposits do occur, a specialist should be called in to clean the system by chemical methods.

26.2.6 Ventilation

In compressor operation, part of the heat given off by the compressor and motor is transmitted to the surrounding air. For plants located in closed rooms this heat must be removed to limit the rise in temperature of the ambient air. Some of the heat dissipates through walls, windows, floor and roof, but this heat removal is seldom sufficient. The compressor room should be ventilated and the heat removed with the ventilating air. Sometimes the heat can be recovered and used for heating purposes. In an entirely water-cooled compressor installation the heat to be removed by ventilation is relatively small, since the major part is taken away by the cooling water.

Insufficient ventilation shortens the life of the electric motor. In installations where the intake air is drawn from the compressor room poor ventilation may also damage the compressor, as the temperature of the discharge air increases in proportion to that of the intake air. The compressor room should always be placed so that ventilation air is available without the need for long ducts. The intake should be sited low down on the coldest wall, whereas the ventilation air outlet should be situated high up on the opposite wall in order to avoid temperature stratification.

Modern completely air-cooled compressor plants have aftercoolers with fans. The aftercooler should be arranged so that it assists in the ventilation of the room. For the major part of the year the aftercooler fan will handle room ventilation. Extra fans may be needed only during hot months in the summer.

26.3 Overpressure protection

1. If any equipment having a design pressure lower than the maximum output pressure of the compressor is used, or if an increase of pressure above normal operating pressure will cause a malfunction, it shall be protected against overpressure by suitable means.
2. Any relief valve or safety valve shall have a design flow capacity such that when subjected to the maximum output pressure and flow of the compressor, and taking into account the flow restriction caused by the upstream piping and fittings, it will prevent the pressure in that part of the system exceeding the design pressure of the equipment. This requirement may, in certain circumstances and depending upon compressor pressure and design pressure of the equipment, imply the need for a relief valve having a port size at least twice the nominal diameter of the pipework and pressure regulator feeding the equipment.
3. An alternative method of protection is the use of a smaller relief valve in conjunction with an automatic isolating valve which shuts off the air supply to the equipment if the pressure rises more than 20% above the blow-off pressure of the relief valve. If this method is used it is essential to ensure that sudden cessation of air supply to the equipment cannot cause a hazard.

26.4 Selection of compressor plant

26.4.1 Air compressors

The principal types of compressors and their basic characteristics are outlined below (see also Figure 26.2).

26.4.1.1 Positive displacement compressors

Positive displacement units are those in which successive volumes of air are confined within a closed space and elevated to a higher pressure. The capacity of a positive displacement compressor varies marginally with the working pressure.

Reciprocating compressors The compressing and displacing element (piston or diaphragm) has a reciprocating motion. The piston compressor is available in lubricated and non-lubricated construction.

Helical and spiral-lobe compressors (screw) Rotary, positive displacement machines in which two intermeshing rotors, each in helical configuration displace and compress the air; available in lubricated and non-lubricated construction; the discharge air is normally free from pulsation; high rotation speed.

Sliding-vane compressors Rotary, positive displacement machines in which axial vanes slide radially in a rotor mounted eccentrically within a cylindrical casing. Available in lubricated and non-lubricated construction; the discharge air is normally free from pulsation.

Two impeller straight-lobe compressors and blowers Rotary, positive displacement machines in which two straight, mating but non-touching lobed impellers trap the air and carry it from intake to discharge. Non-lubricated; the discharge is normally free from pulsation; low pressure; high rotation speed.

26.4.1.6 Dynamic compressors

Dynamic compressors are rotary continuous-flow machines in which the rapidly rotating element accelerates the air as it passes through the element, converting the velocity head into pressure, partially in the rotating element and partially in stationary diffusers or blades. The capacity of a dynamic compressor varies considerably with the working pressure.

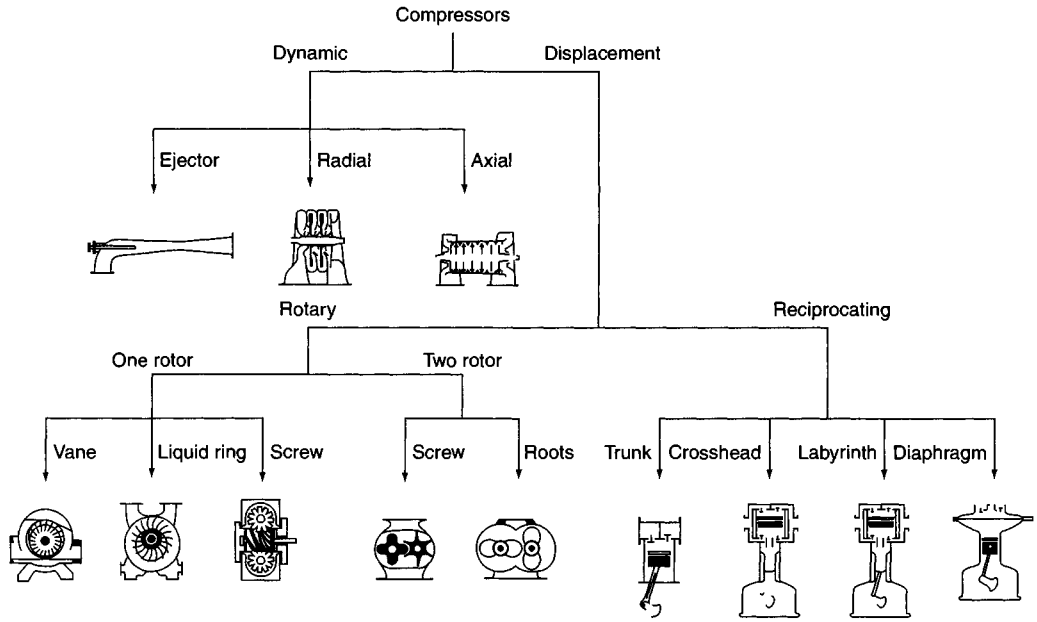


Figure 26.2 Basic compressor types

Centrifugal compressors Acceleration of the air is obtained through the action of one or more rotating impellers; non-lubricated; the discharge air is free from pulsation; very high rotation speed.

Axial compressors Acceleration of the air is obtained through the action of a bladed rotor, shrouded at the blade ends; non-lubricated; very high rotation speed; high-volume output.

26.4.1.9 Specific power consumption

This varies with the size and type of compressor; consultation with the supplier is advised.

26.4.2 Capacity and pressure limitations

Figure 26.3 shows the approximate capacity and pressure limitations of each type of compressor. There are areas where more than one type of compressor will provide the required capacity and pressure. In such cases other characteristics such as those given above and the type and pattern of use will govern the selection. Consultation with the supplier is advised.

26.4.2.1 Compressor standby capacity

On many installations it is normal to plan the number of compressor units and their output so that there is a standby capacity to permit one unit to be shut down for servicing. Where a constant supply of air is essential to operations, standby compressors are a necessity.

26.4.2.2 Load splitting

In all installations consideration should be given to having at least two compressors to allow for conditions of light load and for maintenance.

26.4.2.3 Closed-loop systems

The same general considerations listed above apply to two level closed-loop systems but the required input power to the compressor will be considerably reduced or a smaller compressor can be used.

26.4.3 Output control

A wide range of controls is available to match compressor output to demand. Consultation with the equipment supplier is essential. The output of a compressor can be controlled by several methods as outlined below. The following functions can be performed by pneumatic, hydro-pneumatic and electronic devices:

1. *Reciprocating compressors*:
   (a) Intermittent operation using automatic stop/start mechanism;
   (b) Constant speed running with inlet valve blocking or intake throttling or external bypass or inlet valve unloading or clearance pocket;
   (c) Variable speed;
   (d) Combinations of (a) – (c) above.
2. *Rotary sliding-vane compressors*:
   (a) Intermittent operation using automatic stop/start mechanism;
   (b) Constant-speed running with inlet valve blocking or intake throttling or external bypass;
   (c) Variable speed; minimum rotational speed must be high enough to ensure that the blades remain in full contact with the stator.

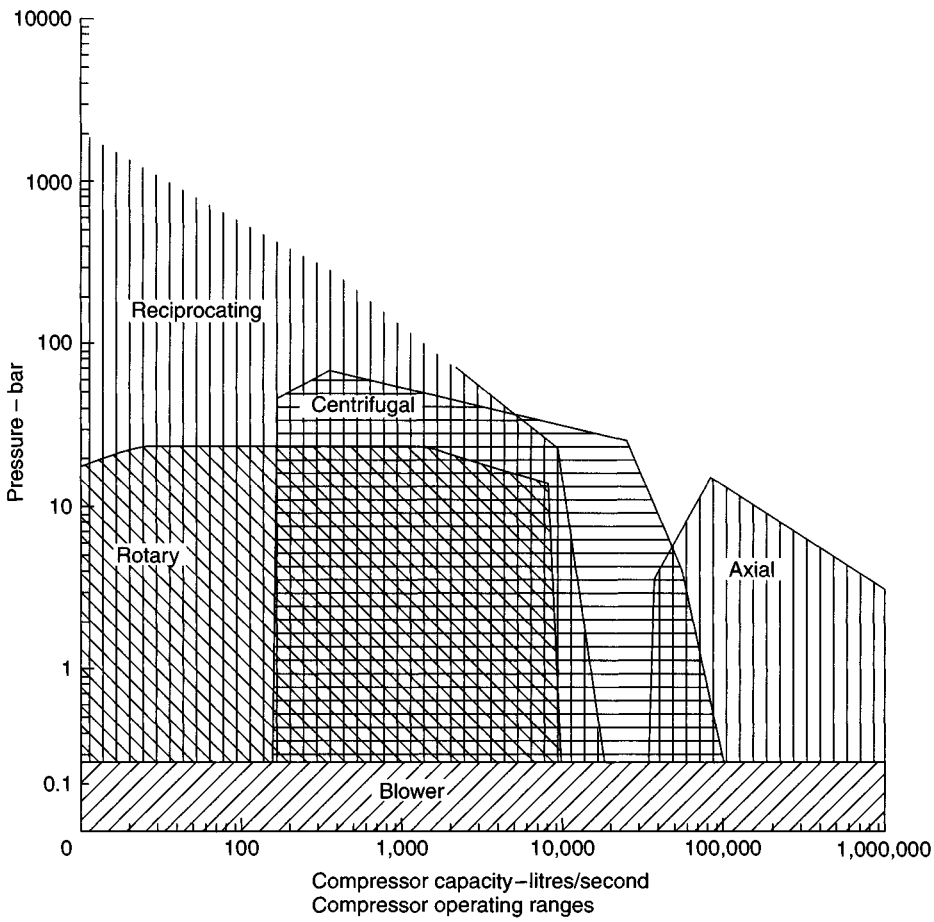


Figure 26.3 Compressor types – approximate capacity and pressure limitations

3. *Rotary screw compressors*:
   (a) Constant speed running with external bypass or intake throttling coupled with blow-off to atmosphere;
   (b) Variable speed.
4. *Dynamics*:
   (a) Constant-speed running with intake throttling coupled with blow-off to atmosphere;
   (b) Variable speed.

Advise should be sought from the supplier as to the best type of control to suit a particular application.

26.4.4 Selection of compressor prime movers

An important factor in obtaining an economical plant is the selection of an appropriate compressor drive. The most common power units are:

Electric motor
Engine (diesel, petrol, gas, etc.)
Turbine (gas, steam, etc.)

Among the advantages of electric motor drive are compactness and ease of control. The internal combustion engine is preferred for mobile units, emergency standby units, or where electric power is not available.

A turbine drive is preferred where it helps balance the energy system of a plant or where the steam or gas can be further used. This type of drive permits easy speed control and conserves energy.

Regardless of the type of prime mover, professional advise should be taken in matching prime mover to compressor.

26.4.4.1 Application requirements

To avoid delays in the preparation of estimates and unnecessary expense for both buyer and supplier it is important that all necessary data should be available and recorded. The parameters which must be established are outlined below.

26.4.4.2 Compressor output conditions

1. Volume of free air required (l/s); including an allowance for future expansion;

2. Minimum discharge pressure required to maintain an acceptable working pressure at the point of use;
3. Quality of air; degree of cleanliness required (see ISO 8573);
4. The purpose for which the air is to be used;
5. The pattern of demand for air; continuous or intermittent consumption;
6. Estimated operating hours per day/week;
7. Type of control;
8. The need for an air receiver;
9. Any special conditions which the compressor must satisfy;
10. Requirement for ancillary equipment (for example, water pumps, valves, piping, anti-vibration mountings, aftercoolers, dryers, intake filters and silencers, etc.).
11. The protective devices the compressor manufacturer is required to supply.

27 Noise and vibration

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27.1 Introduction to basic acoustics

Sound can be defined as the sensation caused by pressure variations in the air. For a pressure variation to be known as sound it must occur much more rapidly than those of barometric pressure and the degree of variation is much less than atmospheric pressure.

Audible sound has a frequency range of approximately 20 Hz to 20 kHz and the pressure ranges from 20×10^{-6} N/M to 200 N/M. A pure tone produces the simplest type of wave form, that of a sine wave (Figure 27.1). The average pressure fluctuation is zero, and measurements are thus made in terms of the root mean square (rms) of the pressure variation. For the sine wave the rms is 0.707 times the peak value.

Since rms pressure variations have to be measured in the range 20×10^{-6} N/M to 200 N/M (a range of 10^7) it can be seen that an inconveniently large scale would have to be used if linear measurements were adopted. Additionally, it has been found that the ear responds to the intensity of a sound (αP^2) in a logarithmic way. The unit that has been adopted takes these factors into account and relates the measured sound to a reference level. For convenience, this is taken as the minimum audible sound (i.e. 20×10^{-6} N/M) at 1 K.

The logarithm (to the base 10) of the ratio of the perceived pressure (squared) to the reference pressure (squared) is known as the bel, i.e.

$$B = \log \frac{P^2}{P_{\text{ref}}^2}$$

Since this would give an inconveniently small scale (it would range from approximately 0 to 14 for a human response) the bel is divided numerically by 10 to give the decibel. The equation therefore becomes:

$$\text{dB} = 10 \log \frac{P^2}{P_{\text{ref}}^2}$$

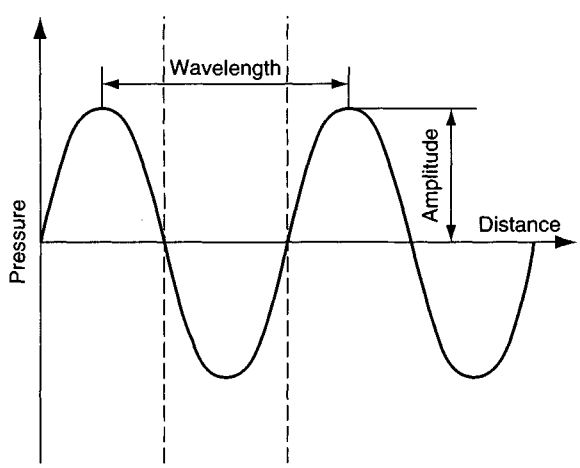


Figure 27.1 Sine wave

27.1.1 Sound intensity

Sound intensity is a measure of energy, and its units are watts per metre. Intensity is proportional to the square of pressure:

$$\frac{I}{I_0} = \left(\frac{P}{P}\right)^2$$

Sound intensity level is defined in a similar manner to sound pressure level. In this case the equation is

$$\text{(dB) (Sound intensity level)} = 10 \log \frac{I}{I_{\text{ref}}}$$

I_{ref}, the reference level, is taken as 10^{-12} W/M^2.

27.1.2 Sound power

The power of a source (measured in watts) can be similarly expressed in terms of decibels (in this case, called the sound power level):

$$\text{(dB) (Sound power level)} = 10 \log \frac{W}{W_{\text{ref}}}$$

where W_{ref} is taken as 10^{-12} W.

It can thus be seen that it is important not only to express the unit but also to state sound pressure level, sound intensity level or sound power level.

27.1.3 Addition and subtraction of decibels

For coherent sound waves addition of values is possible. It will be apparent that as the scale is logarithmic, values cannot merely be added to one another. Intensities can, however, be added and thus the equation becomes:

$$\text{SIL (total)} = 10 \log \frac{I_1 + I_2}{I_{\text{ref}}}$$

i.e. 70 dB + 73 dB

$$70 = 10 \log \frac{I_1}{I_{\text{ref}}}$$

$$I = \frac{\text{Antilog } 7}{I_{\text{ref}}}$$

$$73 = 10 \log \frac{I_2}{I_{\text{ref}}}$$

$$I = \frac{\text{Antilog } 7.3}{I_{\text{ref}}}$$

$$\text{SIL (total)} = 10 \log (\text{Antilog } 7 + \text{Antilog } 7.3)$$

$$= 10 \log (10^7 + 1.99526 \times 10^7)$$

$$10 \log (2.99526 \times 10^7)$$

$$= 74.76 \text{ dB}$$

The square of individual pressures must be added, and thus the equation in this case must utilize:

$$P(\text{total}) = \sqrt{(P_1^2 + P_2^2)}$$

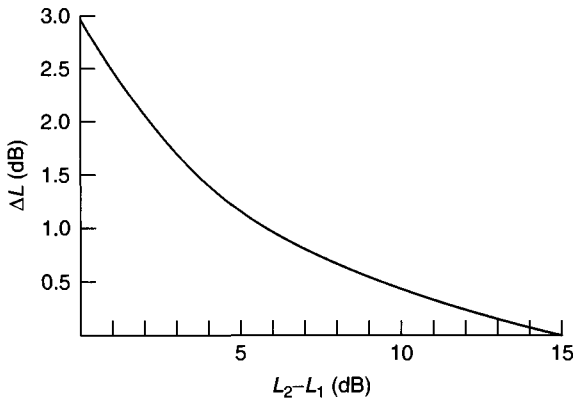


Figure 27.2 Noise-level addition graph

27.1.4 Addition of decibels: graph method

It is possible to use a graph to calculate the addition of decibels, even in the case of multiple additions (Figure 27.2). The graph is used in the following way:

1. *In the case of addition of two levels.* The difference between the higher and the lower levels is plotted on the lower scale of the graph. The correction is then read from the vertical scale by projecting a horizontal line across to this scale from the point on the graph. The correction is added to the highest original level to give the total level.
2. *In the case of the subtraction of levels.* The difference between the total sound level and the one to be subtracted is plotted onto the graph and the correction obtained as above. In this case the correction is subtracted from the total level to give the remaining sound level.
3. *In the case of multiple additions.* If there are more levels to be added, the first two levels are added using the graph and then the third is added to the resultant using the same method.

27.1.5 The relationship between SPL, SIL and SWL

The total acoustic power of a source can be related to the sound pressure level at distance r by the following equation (assuming spherical propagation):

$$W = P^2/\rho_c \cdot 4\pi r^2$$

where ρ = density of the medium and C = velocity of sound in the medium. By substituting this back into the SPL equation we obtain:

$$\text{SPL} = \text{SWL} - 20\log r - 11 \text{ (spherical propagation)}$$

It is also possible to derive equations for the other common situations, i.e.

Point source on a hard reflecting plane
Line source radiating into space
Line source on a hard reflecting plane

These equations are:

$$\text{SPL} = \text{SWL} - 20\log r - 8 \text{ (hemispherical propagation)}$$

$$\text{SPL} = \text{SWL} - 10\log r - 8 \text{ (line source in space)}$$

$$\text{SPL} = \text{SWL} - 10\log r - 5 \text{ (line source radiating on a plane)}$$

The above equations are useful for calculating distance-attenuation effects.

If the sound pressure level at a distance r_0 is known it is possible to calculate the sound pressure level at positions r_1 quite easily:

$$\text{SPL}_0 - \text{SPL}_1 = 20\log r_1 - 20\log r_0$$

$$\text{SPL}_0 - \text{SPL}_1 = 20\log \frac{r_1}{r_0} \text{ dB}$$

If r_1 is double r_0 it will be seen that $\text{SPL}_0 - \text{SPL}_1$ will be approximately equal to 6 dB ($20\log 2$). This gives us the principle of a decrease in level of 6 dB per doubling of distance (inverse square law). For the line source the same calculation produces a difference of only 3 dB per doubling of distance.

27.1.6 Frequency weighting and human response to sound

In practice, noises are not composed of one single pure tone but are usually very complex in nature. It is essential that more than the overall noise level (in dB) is known in order to appreciate the 'loudness' of a noise, as the ear does not respond uniformly to all frequencies.

As previously stated, the ear can respond from 20 Hz to 200 kHz, and this response can be demonstrated by equal-loudness contours (Figure 27.3). It can be seen from the figure that there is a loss in sensitivity (compared to 2 kHz) of approximately 60 dB at the low-frequency end of the chart. It will also be noted that all the curves are

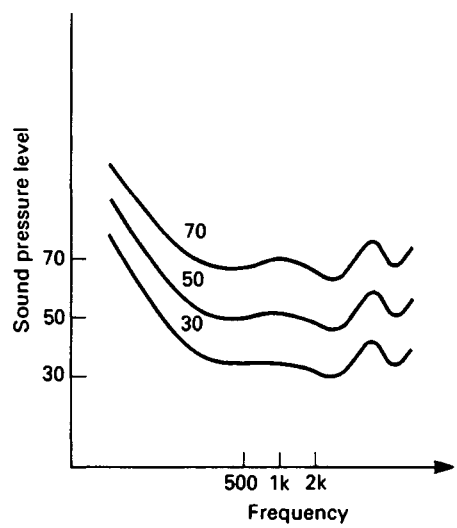


Figure 27.3 Equal-loudness contours

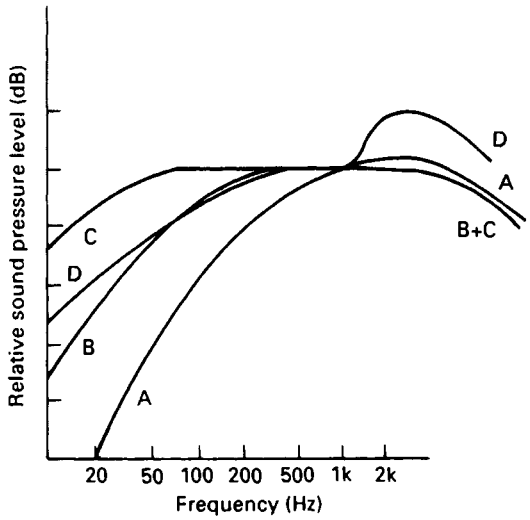


Figure 27.4 Weighting networks

approximately parallel, but there is a tendency towards linearity at the higher noise levels. In order to produce meaningful readings it is therefore important to state the sound pressure level in decibels and the frequency of the noise.

A weighting can be imposed on noise readings which corresponds to the inverse of the equal-loudness contours. If this weighting is used, all readings which are numerically equal will sound equally loud, regardless of frequency.

Originally, three networks were proposed (A, B, and C) and it was suggested that these be used for low, medium and high noise levels, respectively. It was shown in practice that this introduced numerous difficulties, particularly with a rapidly changing noise when a change of filter network was necessary. It was also found that at all noise levels the A weighting network corresponded well to annoyance levels. It was therefore decided that the A weighting would be used as the norm for noise readings concerning human response. Another weighting network (the D network) is used for aircraft noise measurement (Figure 27.4).

If it is necessary for engineering purposes to know the tonal make-up of a noise, several approaches are possible. The noise can be processed by a bandpass filter. The most common filters are octave band filters, and the agreed centre frequencies are as follows:

31 63 125 250 500 1 K 2 K 4 K 8 K 16 K (Hz)

If further resolution is necessary one-third octave filters can be used but the number of measurements required to be taken is most unwieldy. It may be necessary to record the noise onto tape loops for the repeated re-analysis that is necessary. One-third octave filters are commonly used for building acoustics, and narrow-band real-time analysis can be employed. This is the fastest of the methods and is the most suitable for transient noises. Narrow-band analysis uses a VDU to show the graphical results of the fast Fourier transform and can also display octave or one-third octave bar graphs.

27.1.7 Noise indices

All the previous discussions have concerned steady-state noise. It will, however, be apparent that most noises change in level with time. It may therefore be necessary to derive indices which describe how this happens. The most common of these are percentiles and equivalent continuous noise levels.

Percentiles are expressed as the percentage of time (for the stated period) during which the stated noise level was exceeded, i.e. 5 min L_{90} of 80 dB(A) means that for the 5-min period of measurement for 90% of the time the noise exceeded 80 dB(A). Therefore L_0 is the maximum noise level during any period and L_{100} is the minimum. Leq (the equivalent continuous noise level) is the level which, if it were constant for the stated period, would have the same amount of acoustic energy as the actual varying noise level.

27.1.8 Noise-rating curves

These are a set of graphs that are used as a specification for machinery noise. They are similar to noise criteria curves (used in the USA to specify noise from ventilation systems). The rating of a noise under investigation is the value of the highest noise-rating curve intersected by the readings when plotted on the graphs (Figure 27.5).

27.2 Measurement of noise

The simplest sound level meter consists of a microphone, an amplifier and a meter of some type. Sound level meters are graded according to British and international Standards, and the most common type used for accurate measurement purposes it known as the Precision Grade or Type 1 meter. In practice, a basic sound level meter will incorporate weighting networks with either in-built octave filters or provision for connecting an external filter set (Figure 27.6).

The meter will also have a control for the time constant for the display (i.e. the 'speed' of the meter response), and the two common time constants are 'Fast' and 'Slow'. Others may have an impulse and peak hold facility. More complex meters incorporate Leq-measuring devices, and these are also available as hand-held Type 1 meters with filters as in the basic meter.

Outputs are available in either analogue (d.c. or a.c.) or digital form. Digital output may connect the meter to computers (either portable or office based) for more complex calculations or to produce larger graphical displays.

Portable sound level meters are also available which can measure percentiles. These either hold the results in a memory which can be separately interrogated or may be connected to a computer for a printout. Larger machines (known as environmental noise analysers) are available which can record percentiles and Leq readings and produce a printout. These are resistant to weather and can be left on-site for up to a week.

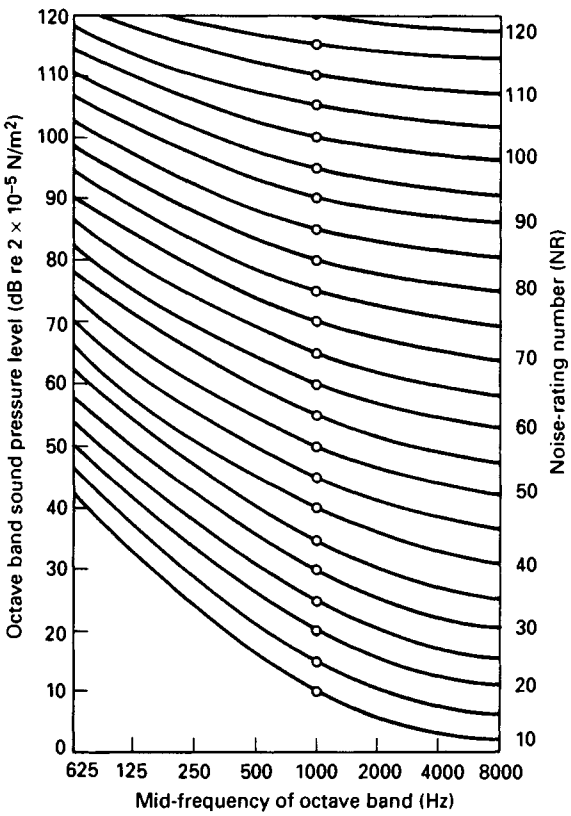


Figure 27.5 Noise-rating curves

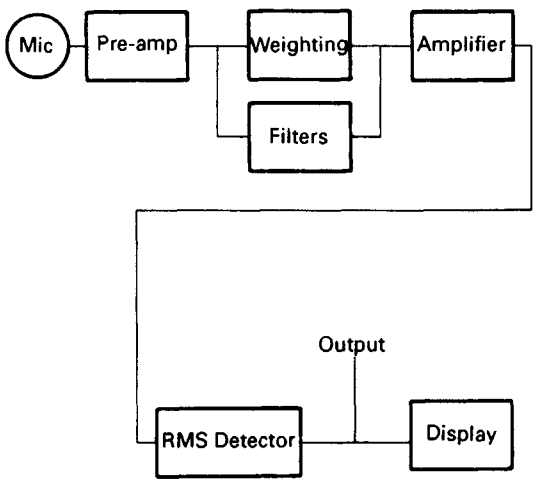


Figure 27.6 Schematic diagram of a sound level meter

Computers may be used for noise analysis when connected to dedicated hardware devices. One machine incorporates a narrow-band analyser, octave and one-third octaves with all the features of an environmental noise analyser. These devices cost much less than purchasing all the dedicated instruments separately. They may be obtained in portable form but are rarely weatherproofed to be used out of doors.

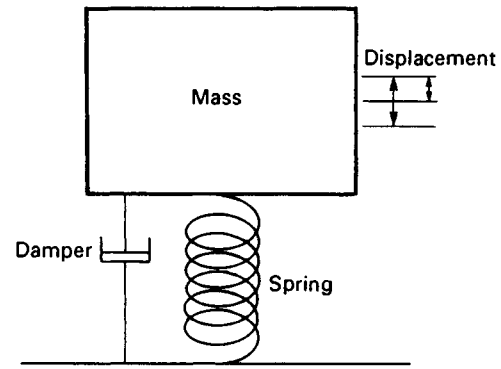


Figure 27.7 Mass/spring diagram

27.3 Vibration

This may be defined as the oscillatory movement of a mechanical system, and it may be sinusoidal or non-sinusoidal (also known as complex). Vibration can occur in many modes, and the simplest is the single freedom-of-movement system. The vibration of a system can be explained by a mass/spring diagram (Figure 27.7).

The displacement of the object from its rest position can be derived from

$$X = X_{\text{peak}} \text{ sine}(\omega t)$$

where $X =$ displacement at time t, $X_{\text{peak}} =$ peak displacement and $\omega =$ angular velocity $(2\pi f)$. The velocity of the object is proportional to displacement and frequency and its acceleration is proportional to the displacement and the square of frequency. There is a phase angle of 90° between displacement and velocity and a further 90° between velocity and acceleration. The units of measurement may be made directly, i.e.

Displacement in metres
Velocity in metres per second
Acceleration in square metres per second

Vibration may also be expressed in decibels, and the standard reference levels used are:

$10\ \text{m}^{-8}/\text{s}$ for velocity
$10\ \text{m}^{-5}/\text{s}^2$ for acceleration

In practice, measurements are made with the use of an accelerometer. This device is connected to a sound level meter and may make measurements of acceleration in terms of decibels (or by changing scales or use of a device similar to a slide rule, in direct terms). An integrater can be connected between the accelerometer and the meter to express the results in terms of velocity or displacement.

27.3.1 Effects of vibration on people

If a body is vibrating at a frequency within the audible range, sound will be radiated. Vibration may be transmitted considerable distances through buildings, ground structures or rock strata, and then reradiated as noise at the receiver position. For example, low-frequency noise nuisance has been caused at a residence on the banks of the River Thames, caused by vibration from a pump on the opposite bank. In this case the vibration passed under the river along a curved layer of harder rock.

Vibration can be perceived from a frequency of approximately 3 Hz. The lower frequencies appear to cause the most discomfort. At high levels (above 120 dB) vibration can be physically damaging to people, and resonances of the human body occur at the following frequencies:

3.6 Hz:	Thorax, abdomen
20–30 Hz:	Head, neck
60–90 Hz:	Skull

High vibration levels at these frequencies can therefore be the most disturbing.

Various sources publish data of permissible vibration levels for employees (usually as a graph of acceleration against frequency). These are designed to avoid injury and cannot be used as a guide to the degree of disturbance caused by vibration. Vibration caused by neighbouring industrial premises when received at a residence as vibration (i.e. no noise implications) has been considered a nuisance when it is just perceptible.

27.4 Avoiding physical injury to workers

Noise levels between 85 and 120 dB(A) affect the hearing of exposed workers on a dose-related basis. The Leq of the noise is calculated and compared to the criterion currently employed. Under Section 2 of the Health and Safety at Work, etc. Act 1974 an employer has to take all steps, as far as is reasonably practicable, to ensure the health, safety and welfare of his workers. Permissible noise levels are defined by codes of practice, and the figure permitted for employee exposure is 90 dB(A) 8-hour Leq.

Low-frequency noise (in the range 3–50 Hz) may have other injurious effects on the body. Research has also indicated that a type of fatigue caused by low-frequency noise has a similar effect to that caused by alcohol. Infrasound (low-frequency sound) also has a synergistic effect with alcohol. Low-frequency noise is particularly important in the case of workers operating machinery (e.g. vehicles, cranes, etc.). It must also be remembered that very high power levels may be generated at low frequency and may not be readily detected by the ear. Attenuation of low-frequency noise is very difficult (see Section 27.7).

27.5 Avoidance of damage to plant/machinery/building structures

Plant and machinery may be directly affected by excessive vibration but may also be damaged due to operator fatigue (caused by working in high noise-level areas) or to operators not being able to hear unusual noises from machines before it is too late. Vibration may be caused either by direct transmission or by excitation. Damage to machines may occur in many ways, including the accidental impact of surfaces on one another and the fatigue of shafts, etc. caused by bending moments.

In extreme cases building structures can be damaged by vibration. Damage can be caused either directly to the structure or by settlement of foundations due to vibration. It is possible to calculate the effects of the former (graphs are obtainable from various sources) but not the settlement effect. However, this will occur only on certain strata and in extreme cases.

27.6 Noise control engineering

Before attempting noise control it is important to consider the nature of the problem:

Source of sound energy ⟶ Transmission pathway ⟶ Receiver

There are many proprietary systems available for controlling noise and it is easy to become blinkered in one's approach to noise control.

The first consideration is the source of the noise itself. In the case of a new project the first option must be to select the quietest machine available that will perform the required task. With an existing problem this may still be the cheapest option, particularly in the case of a machine which is coming to the end of its useful life. Spin-offs may include more efficient operation (less fuel costs), greater reliability or quieter operating conditions.

If the decision is made to retain the original machine the design of the noise-control devices to be employed should be considered. These may affect:

Access to machine	(may hinder cleaning, tool changing, etc.)
Heat build-up	
Safety, etc.	

In nearly all cases noise control at source is the best option. Typical examples are:

1. *Presses*: Is the degree of impact necessary? Can it be adjusted? Can the press operate by pressure alone?
2. *Air discharge – use of air tools and nozzles*: The turbulence in the boundary layer of air between the rapidly moving airstream and the atmosphere is heard as noise. Can the air stream be diffused (silencers fitted to the exhaust)? Nozzles used for cleaning can have devices fitted which give a gradual transition from the rapidly moving air to atmosphere by the use of an annular ring of small nozzles round the central nozzle. These silence with very little loss in efficiency.
3. *Reciprocating compressors*: These cause very high noise levels at low frequency (typically, below 250 Hz). The low-frequency noises are very difficult to attenuate, and the most popular solution is to use rotary (vane type) compressors. These are inherently quieter and have the further advantage that the noise

they generate is at high frequency (typically, above 1 kHz) and is therefore easy to attenuate.
4. *Cutting machines*: Modifications can be made to the method of restraining material being cut to reduce 'ringing' (i.e. reducing free lengths of material).

27.6.1 Noise-reduction principles

There are many noise-control devices. All, however, rely on one or more of the three basic noise-control principles: insulation, absorption and isolation.

27.6.2 Insulation

The simplest insulator is a sheet of material placed in the sound-transmission pathways. Sound energy reaches the surface in the form of a pressure wave. Some energy passes into the partition and the rest is reflected.

Energy that passes into a partition may be partially absorbed and transformed into heat. This is likely to be very small in a plain partition. The remainder of the energy will then pass through the partition by displacement of molecules and pass as sound in the same way that sound travels in air. This can then pass to the edge of the partition and be reradiated as sound from other elements of the structure. This is known as flanking transmission. In a thin partition by far the greatest amount of energy will pass through the partition by actually causing the partition to vibrate in sympathy with the incident sound and hence reradiating the sound onto the opposite side. The amount of sound transmission through a partition is represented by the ratio of the incident energy to the transmitted energy. This factor, when expressed as decibels, is known as the sound-reduction index (SRI):

$$\text{SRI} = 10 \log \frac{1}{\text{Transmission coefficient}} \text{dB}$$

The moment of the panel (and hence its resistance to the passage of sound) is controlled by a number of factors:

1. The surface mass affects the inertia of panel. Greater mass causes a corresponding greater inertia and hence more resistance to movement. At high frequencies this becomes even more significant. The mass law can be expressed as

   $$\text{SRI} = 20 \log mf - 43\text{dB}$$

   where m is the superficial weight (kg/m^2) and f the frequency (Hz).
2. At very low frequencies the movement of the panel will be controlled by the stiffness, as inertia is a dynamic force and cannot come into effect until the panel has measurable velocity. Stiffness controls the performance of the panel at low frequencies until resonance occurs. As the driving frequency increases, the resonance zone is passed and we enter the mass-controlled area. The increase in the sound-reduction index with frequency is approximately linear at this point, and can be represented by Figure 27.8.

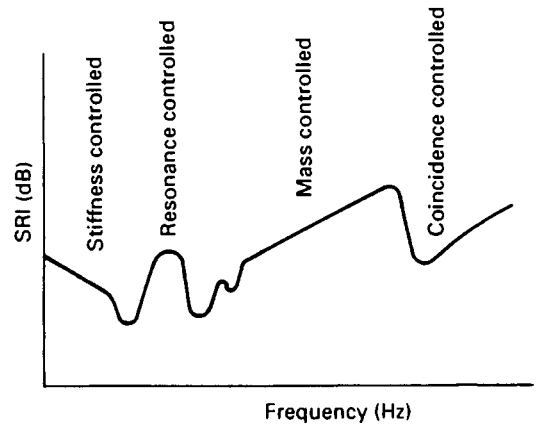


Figure 27.8 Typical insulation characteristics of a partition

3. A panel will have a bending mode when a wave travels along the length of the sheet of material. The frequency of this bending mode is known as the critical frequency. This mode of bending will be introduced by sound incident at angles greater than 0°. At the critical frequency coincidence will only occur for a sound wave with a grazing incidence (90°). At greater frequencies the partition will still be driven, but in this case by progressively lower angles of incidence. The coincidence dip is therefore not a single dip but will result in a loss of SRI at progressively higher frequencies. The desirable insulation panel will therefore be very large but not stiff.

27.6.3 Absorbers

27.6.3.1 Porous

As sound passes through a porous material, energy is lost by friction within the material. The material is usually attached to various surfaces in a room. The absorber will have the highest efficiency when positioned where the air molecules are moving the fastest (and hence more energy is absorbed). At the wall surface the molecules are stationary. If we plot a single-frequency graph we find that the maximum particulate velocity occurs at $\lambda/4$ (one quarter wavelength) from the surface. In practice, incident sound is rarely of single frequency, but the principle can be observed that the absorber must be one quarter of the wavelength away from the wall (for the frequency of the sound to be absorbed). This can be arranged either by having a thickness greater than $\lambda/4$ for the lowest frequency to be absorbed or by mounting the absorber on a frame some distance away from the wall so that the centre of the absorber is at $\lambda/4$ for the frequency to be absorbed.

27.6.3.2 Resonant

The simplest resonant absorber is known as the Helmholtz resonator. This consists of a chamber connected to the duct (or whatever area is to be controlled) by a narrow

neck. The volume of air in the chamber will resonate at a frequency determined by the volume of the chamber, the length of the neck and the cross-sectional area of the neck:

$$F_{res} = 55\sqrt{\frac{S}{IV}}\ (\text{Hz})$$

where S = cross-sectional area (m), I = length of neck (m) and V = volume of enclosure (m). As the chamber resonates, air is forced through the narrow neck and hence energy is absorbed in overcoming the resistance.

The degree of attenuation at the critical frequency can be very large, but this type of silencer has a very narrow bandwidth. This device may be suitable when the machine being dealt with emits sound predominantly of a single wavelength. The absorber bandwidth of a Helmholtz resonator can be expanded by lining the chamber with absorbers, but this has the effect of reducing the efficiency. The perforated absorber which forms the basis of many acoustic enclosures and silencers is a development of the resonator principle.

As stated previously, the bandwidth may be broadened by packing the chamber with an absorber, but this lowers efficiency. It may be overcome by using multiple absorbers in the sound path, and this can be done by placing a perforated sheet some distance away from the rigid outer wall of the enclosure and filling the cavity with absorber. It is not necessary to use cross walls between the 'chambers' so formed. In this case the equation becomes:

$$F_{res} = 5000\frac{P}{I(t + 0.8d)}\ \text{Hz}$$

where I = depth of airspace, t = thickness of panel, d = diameter of holes and p = percentage open area of panel.

27.6.3.3 Panel

This absorber is basically a panel attached to a structural wall which is designed to absorb energy. The absorber is therefore frequency dependent and has an absorption peak at its resonant frequency. This type of absorber is not commonly used.

27.7.4 Vibration isolation

Vibration in machinery or plant can be induced in a number of ways, e.g.:

Out-of-balance forces on shafts;
Magnetic forces in electrical apparatus;
Frictional forces in sliding objects.

The first course of action in vibration isolation is reduction at source. This may be achieved by balancer shafts in engines, stiffer coils in electrical apparatus or better lubrication between adjacent sliding surfaces.

When all possible vibration reduction has been obtained, the machine must be isolated from the structure. This is achieved by some form of spring mounting. Spring mounts have a resonant frequency dependent on the stiffness of the spring and the weight of the object placed on it. It will be apparent that the static deflection of the spring will also be proportional to the resonant frequency.

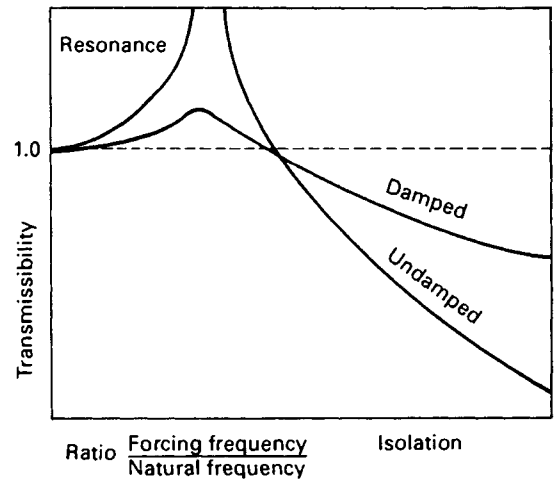


Figure 27.9 Performance of anti-vibration mounting

As the driving force of the mass/spring increases from zero up to the resonant frequency, the amount of transmission of the vibration increases until resonance is reached and the transmission becomes infinitely large. As the resonant point is passed, the transmission begins to reduce until at some point the transmissibility falls below one (see Figure 27.9), i.e. isolation occurs.

In practice, however, spring systems have some in-built damping, and this will have the effect of reducing the amplitude of the resonance below infinity. This is very necessary in real systems to avoid excessive excursions of mounted machinery. A damped mounting will follow the second curve on the graph in Figure 27.9, and it will be noted that the vibration isolation at high-frequency ratios is less than that for undamped systems. It is important therefore to use the lowest degree of damping necessary.

27.7 Practical applications

27.7.1 Acoustic enclosures

Panels of multi-resonator material are made from perforated plate sandwiched with solid plate and an intermediate absorber layer between them. These panels can be built up in enclosures, taking care to seal all junctions adequately. Typically, these enclosures are made to surround small machines (e.g. compressors). They may be fitted together with spring catches to allow for dismantling for maintenance purposes.

Ventilation may be a problem but can be dealt with in several ways:

1. Acoustic louvres constructed of the absorbent panel material (suitable for a small degree of noise reduction only);
2. A silencer fitted to the ventilation duct (see below);
3. Baffled enclosures to the ventilation duct.

27.7.2 Building insulation

Single-panel insulators have been described above, but in buildings it is usual to provide double insulation. In theory, if the insulation panels had no interconnection it should be possible arithmetically to add the sound reduction of the two elements of the structure. In practice, it will be found that there is bridging, by the structure, wall ties or flanking transmission or by the air between the two elements acting as a spring. If the two elements of the wall were in rigid connection the insulation would be 3 dB more than the single element alone (mass law), and if totally separated it would be the sum of the figures. In practice, a cavity wall with ties and a 50 mm cavity gives approximately 10 dB more reduction compared to a single-skin wall of half the surface mass.

Double-glazed windows work on the same principle. It is important to avoid the coincidence of the resonant frequencies of the two elements, and hence it is usual to arrange for the glazing panels to have different thicknesses (and hence a different resonant frequency). This is not necessary if one element is sub-divided by glazing bars to give different-size panes to its opposing element.

The reveals of a double-glazed window should be lined with acoustically absorbent material to damp the sound within the cavity. The width of the cavity should not be less than 150 mm.

If insulation panels are not of uniform construction (as in the case of a wall containing a window) the average sound-insulation value must be derived for use in calculations. The total transmission coefficient for the composite panel will equal the sum of the individual coefficient times their respective areas divided by the total area. Thus:

$$t_{\text{average}} = \frac{t_1 s_1 + t_2 s_2 + t_3 s_3}{s_{\text{tot}}} \text{ etc.}$$

and the SRI of the total panel is derived from

$$\text{SRI} = 10 \log \left(\frac{1}{t_{\text{av}}} \right) \text{dB}$$

27.7.3 Control of noise in ducts

Fans produce the least noise when operating at their maximum efficiency. It is therefore important to select the correct fan for the airflow and pressure characteristics required. It is also important to remember that the noise generated within the system (as opposed to at the fan) is a factor of air velocity, and hence, for a required airflow rate, a larger cross-section duct (with a correspondingly lower velocity) will give quieter results. It will also have other advantages when providing extra noise attenuation and fitting silencers.

In the design of systems it is most important to eliminate as much turbulence as possible, and to achieve this the fans should be mounted some distance away from bends (at least one and a half duct diameters). Junctions between pipes and connectors should present a smooth internal profile and inlets to systems must be tapered and not plain. Outlet grills should be of larger diameter than the duct and have aerodynamically smooth profiles where possible.

If it is necessary to add extra attenuation to a duct it is essential to decide on the required amount. If only a relatively small degree of absorption is required, first a part of the duct must be lined with absorber. The length of duct to be lined will be determined by the degree of attenuation required and the thickness by the noise frequency. Data for these factors are available from many sources and are usually published as tables.

For further attenuation it is necessary to provide a centre-pod-type attenuator (Figure 27.10). This increases the area of the absorber and also aids low-frequency attenuation. For further low-frequency attenuation an in-line splitter silencer is employed (Figure 27.11). These are capable of providing a high degree of attenuation, dependent on the width between the elements. The smaller the gap, the higher the attenuation. Again, performance tables are published by the major manufacturers. In order to decide on the design of the silencer to be installed it is necessary to know the required attenuation (and the frequency/noise level profile) and the permitted pressure loss in the system. Manufacturers' data can then be consulted. Splitter silencers are also available in bent shapes, and these can provide even higher degrees of attenuation as well as aiding installation. Silencers should ideally be fitted in systems as near to the noise source as possible to avoid noise break-out from the duct. Other obstructions in the duct must, however, be considered, as they may generate further aerodynamic noise which, if it occurs after the silencer, will not be attenuated.

27.7.4 Anti-vibration machinery mounts in practice

Again, the characteristics of the system need to be considered. The weight of the machine and the frequency will determine the static and dynamic deflections of the mounts and hence the material of which the mount is to be constructed. At very high frequencies mats may be placed under machinery, and these may consist of rubber, cork or foam. At middle frequencies it is usual to use rubber in-shear mounts. At low frequencies metal spring mounts are employed.

27.7.5 Mounts

Anti-vibration mats are very useful for frequencies above 25 Hz. They have the disadvantage of being liable to attack by oils and, if they become saturated or deteriorated, they will compress and lose their efficiency.

27.7.6 Rubber mounts

Although these are loosely termed rubber mounts, they are often composed of synthetic rubbers which are not readily attacked by oils and can operate over a much wider temperature range. Typical maximum static deflections are 12.5 mm.

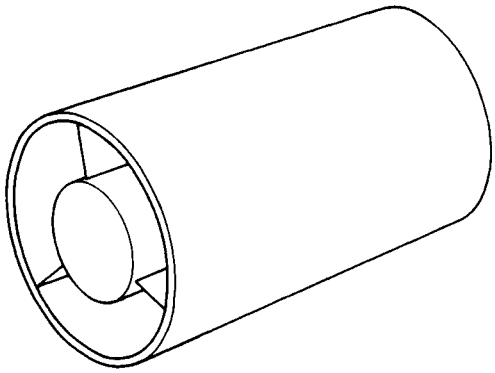


Figure 27.10 Centre-pod silencer

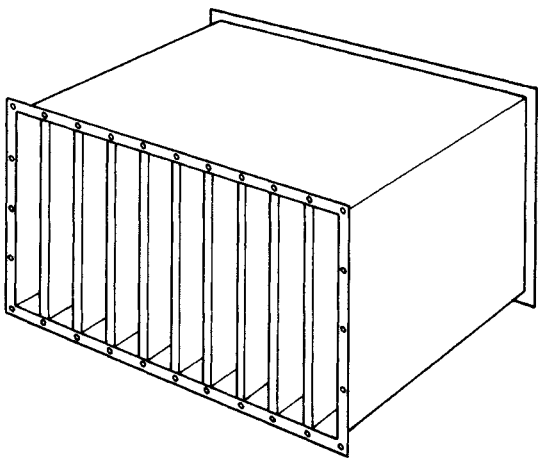


Figure 27.11 Splitter silencer

27.7.7 Steel spring mounts

Steel springs have the disadvantage of transmitting the high frequencies along the length of the spring. It is usual to mount the spring with a rubber or neoprene washer under its base. Steel spring mounts are also most vulnerable to resonance problems, and the solution is to build in a damper device. This has the disadvantage of reducing the isolator's efficiency.

27.7.8 Positioning of anti-vibration mounts

Machinery must be positioned so that all mounts are equally loaded, and failure to do so will result in the possibility of a rocking motion developing. This may require mounting the machine on a sub-frame. If this is not possible, the load should be assessed at each mounting point and mounts of different stiffness used.

27.7.9 Installation

Mounts should be installed so that the whole machine is isolated from the structure. Services (e.g. power, hydraulics, etc.) should also be mounted flexibly. Bridging is the most common fault when providing vibration isolation to machines and building structures, and should be carefully avoided. Services should be designed to withstand the degree of movement permitted by the anti-vibration mounts without suffering damage.

27.8 Legislation on noise and vibration of concern to the plant engineer

27.8.1 The UK and World context

27.8.1.1 The EU and World Health Organization

The World Health Organization recommends daytime noise levels of 55 dB (A) L_{eq} for outdoor noise in residential areas and 35 dB (A) L_{eq} for avoidance of sleep disturbance. *(WHO Environmental Health Criteria 12, 1980).*

The EU's fifth Action Programme on the Environment, *Towards Sustainability*, sets provisional targets for exposure to night-time noise and proposes a number of measures to achieve them. These include noise abatement programmes and Directives on infrastructure planning to control disturbance from transport and industrial noise.

At the time of writing (2000), a framework Directive is under consideration. As well as the possible implementation of obligatory noise target values, one of the key features will be the requirement to carry out computer noise mapping in large urban areas in order to assess noise climate. Another issue which will need to be addressed is harmonization of noise assessment methodologies.

27.8.1.2 The United Kingdom

The notes below apply to the United Kingdom and, specifically, to England and Wales; while the law applying to Scotland and Northern Ireland is generally very similar in its effect, there are some detail variations.

EU Directives are binding on member states, including the United Kingdom. This means that their main requirements must find expression in each member state's legislation, although the details of how this is done will depend on national legislative tradition.

Much of the more recent UK legislation will therefore parallel that of other EU countries and this will be extended in coming years. Where UK legislation is based on EU Directive, it is noted in the individual paragraphs below.

In most cases the same issues will be addressed by legislation world-wide and, in that sense, this section can be treated as a "checklist". However, readers outside the United Kingdom or the EU are urged to check the precise requirements of relevant legislation in the State concerned.

27.8.2 Planning controls

In the United Kingdom, new development or the change of use of existing developments between specified categories requires permission ("Planning Permission") from the Local Authority ("Planning Authority"). *(Town and*

Country Planning Act 1990 and various Regulations and Orders made under that Act.)

The Planning Authority must have in place and periodically review a plan ("Local Plan") for its whole area, indicating what it considers to be appropriate land uses in different parts of the area and laying down detailed policies governing different kinds of land use.

The Government has issued a Planning Policy Guidance document, *PPG 24, (1994)* to guide Planning Authorities: This lays down general principles for the protection of residential amenity from noise from various noise sources. For the classification of noise exposure in relation to proposed residential developments, it lays down four categories, "A" to "D": These range from situations in which noise is not a significant factor in granting Planning Permission, through those in which protective measures should be required by Planning Conditions, to those in which development would normally be refused altogether.

An application for planning permission must be submitted for each individual proposed development (or material change of use). This will be considered in terms of the guidelines laid down in the Planning Policy Guidance and the Local Plan, and on its own merits, according to various criteria.

Where planning consent is sought for a building, or change of use to an existing building, which places that development in the "Light Industrial", as opposed to "General Industrial" category, then, by definition, the development must be capable of operation in a residential area without loss of residential amenity due to, among other things, noise or vibration.

The Planning Authority will consider the impact of noise/vibration from the proposed development on surrounding occupiers and whether the appearance of the finished structures is acceptable. Clearly, the location of a project will be significant: What will be acceptable in an industrial zone remote from housing may not be acceptable in close proximity to residential property.

The application may be refused or granted with Conditions, subject to appeal to the Secretary of State for the Environment.

Planning Conditions may lay down requirements to minimize the impact of generated noise: These may include one or more of the following: -

- Permitted hours of use of premises.
- The manner of their use, for example the keeping closed of external doors.
- The position, orientation or layout of buildings or plant.
- Specific design requirements to reduce the generation or breakout of noise (See Sections 27.1 to 27.7, above):
  - ☐ Acceptable forms of construction for buildings.
  - ☐ Specified standards of sound attenuation for plant or buildings.
- Purely acoustic criteria for the development:
  - ☐ Site boundary noise limits (Sound Pressure Levels)
  - ☐ Noise limits at other specified positions, e.g. at nearby residential buildings.
  - ☐ Sound Power Levels for noise sources.

(These limits may be specified in terms of specific frequency descriptor, e.g. frequency weightings or octave bands. They may also be different for different times of day or week, which may influence the permissible hours of use or the standard of design of a specific item of plant, depending on the requirements of the user.)

It is therefore important to give careful consideration to the design and positioning of mechanical plant at the planning stage, in the context of the structures in which it will be located. It is often useful to consult with the Planning Authority at the outset in order to establish what standards of acoustic performance need to be "designed in" to the submission for Planning Permission.

In certain cases, particularly where plant is added to existing buildings classified by the Planning Authority as being of aesthetic merit, the appearance of the finished installation may be a significant factor. Visible external mounting of plant may therefore be unacceptable to the Authority and it is worthwhile establishing this at the planning stage.

27.8.3 Integrated Pollution Prevention and Control (IPPC)

This regime originated with an EU Directive and came into force in 2000. It regulates specified industrial sites through a system of Permits. It extends previous controls on pollution to include matters of noise. Further details can be found in Section 26.4.2.

27.8.4 Statutory nuisance

A characteristic of UK legislation is the concept of "Statutory Nuisance". This originated in the nineteenth Century but is currently found enacted in Part III of the Environment Act 1990 (Sections 79–82).

27.8.4.1 The scope of statutory nuisance

Among other things, the Act defines "noise which is prejudicial to health or a nuisance" as a *statutory nuisance*, i.e. a matter actionable by the Local Authority. "Noise" is defined as including vibration The Authority has a statutory duty to inspect its district for nuisances or may act on complaint.

Industrial processes which are specified in legislation as falling within the IPC/LAPC and IPPC regimes (see Section 26.4.2) are exempted from the requirements of the Law of Statutory Nuisance. They are subject to their own, detailed regulatory regime and it is not reasonable to impose duplicate legislative requirements. Statutory Nuisance Law therefore applies to all premises, domestic, commercial or industrial not covered by these more specific controls.

A peculiarity of the legislation is that it does not define the scope of nuisance. Reliance is placed on the Common Law definition of nuisance, some of which originates in the nineteenth Century. Nuisance is divided into two categories:

"*Public Nuisance*" is an unlawful act or omission to discharge a legal duty, which endangers the life, safety, health or comfort of a significant proportion of the public. This is a criminal offence and may, on indictment, be tried in the Crown Court, although this is extremely rare.

More relevant to the application of Statutory Nuisance legislation, "*Private Nuisance*" is "*unlawful interference or annoyance which causes damage to an occupier or owner with respect to his use or enjoyment of land*". It should be noted that Private Nuisance is also a civil wrong, or *tort*, for which the perpetrator can be sued in the civil courts. Case law has thrown up a number of principles which the Local Authority needs to consider in dealing with cases of Statutory Nuisance:

- *It is no defence that the plaintiff came to the nuisance.* I.e., if a person moves into a house and is affected by noise from a long-established factory, it is no defence for the operator of the factory to claim that he was there first.
- *The noise nuisance must be substantial* and not fanciful. I.e. it must be considered by a "reasonable person" to amount to a nuisance. Thus, the quality, level, frequency, duration or time of noise emissions may be a significant factor.
- *The character of an area* must be taken into account in assessing nuisance: Thus, what would be considered a nuisance in a quiet, predominantly residential area might not be so considered in a busy industrial district.
- *Malice or intent* may be a factor but it is *not essential* to establish nuisance.
- *Only the lawful owner or occupier* (tenant, mortgagee or lessee) of land is *entitled to the protection* of this legislation. Thus passers-by or guests in a hotel would not have a valid complaint, although the proprietor of the hotel might, if affected by a persistent noise problem which affected his business.
- Similarly, the nuisance must generally *arise on premises* (which includes land), although the *Noise and Statutory Nuisance Act 1993* has added a section which extends nuisance procedure to cover Vehicles, Machinery and Equipment in the street (see Section 27.8.5.b, below).
- Persons with a *special degree of sensitivity* are *not entitled to special protection*: For example, the law assumes that a normal person gets up in the morning to go about his business and goes to bed at night. Thus, daytime noise from a factory which provokes complaints from a night-worker who sleeps through the day, may not be viewed as seriously as the same noise emission taking place through the night. An additional, acoustic factor here is the fact that background noise levels will tend to be much lower during the night, therefore the additive effect of noise from plant in relation to the background will be more severe. (See Section 2.8.6, below).

In acoustic terms, there is no statutory guidance as to what noise amounts to a Statutory Nuisance and what does not. Similarly, there is no generally accepted code of practice in the design of noise emitting plant. In monitoring and assessing noise, the Local Authority must therefore treat each case according to its context and merits.

One document which may be applied in assessing nuisance from industry is British Standard 4142, (1995) which lays down a "*Method for Rating Industrial Noise Affecting Mixed Residential and Industrial Areas*". This is covered in more detail in Section 2.8.6, below. While this Standard may carry weight, for example in court proceedings, it is not legally binding: More, or less, onerous requirements might be acceptable in specific cases.

To summarize, in considering proceedings for noise nuisance under Part III of the Environmental Protection Act 1990, the Local Authority will take into account a number of factors:

- The level of the noise *at the critical receptor*, e.g. a house: This will normally be assessed in relation to the degree to which it emerges above the prevailing background, i.e. the noise climate which exists when the noise giving rise to complaint is not being emitted:-
  - ☐ The character of the area will be relevant because the nuisance value of a particular emission will be greater in a quiet environment.
  - ☐ The time of day will be relevant for similar reasons: It is quieter at night and the operation of plant which may not cause a problem in the day may be objectionable at night.
- The quality of the noise: Tonal or impulsive noise is known to be more intrusive at a given level above background than broad-band noise. (This is a weighting factor in British Standard 4142). Since many items of plant (fans, electric motors etc.) by their nature emit tonal noise (whines, drones, hisses etc.), this is an important factor for the Plant Engineer to take into account at the planning stage.
- The duration and frequency of the noise: A noise incident which occurs once a week for a few minutes may be regarded less seriously than noise which is constant for long periods or recurs every few minutes.

27.8.4.2 Procedure in case of statutory nuisance

Where the Local Authority is satisfied that a statutory noise nuisance exists, or is likely to occur or recur it *must* serve a Notice (an "Abatement Notice") on the person responsible for nuisance, containing all or any of the following:-

- The requirement to abate the nuisance or the prohibition or restriction of its occurrence or recurrence.
- The requirement to execute such works or to take such other steps as will achieve the above.

The Notice must specify the time within which it must be complied with.

Where the person responsible for the nuisance cannot be found, or the nuisance has not yet occurred, the Notice is served on the owner or occupier of the relevant premises. Where the nuisance arises from a defect of a structural character, the Notice is served on the owner of the premises.

It will be noted that the Act covers nuisances which are continuous or intermittent or which have not even happened yet. The Notice may (although it need not) specify actual works to be done to abate the nuisance, e.g. sound insulation. Alternatively, it may specify steps

to be taken, for example, not operating a particular item of plant outside certain hours. The Notice could also specify an actual standard of acoustic performance for plant, e.g. a Sound Pressure Level not to be exceeded at a particular location, and leave the details of how this is achieved to the operator.

The recipient of the Notice has the right of appeal to a Magistrate's Court within 21 days of service. Regulations lay down various grounds of appeal:-

- The Notice is not justified, i.e. the noise to which it relates is not a nuisance.
- There is a material defect in the Notice (e.g. it is addressed to the wrong person).
- The serving Authority has unreasonably refused to accept alternative means of abating the nuisance to those required by the Notice; alternatively, the requirements of the Notice are in some other way unnecessary or unreasonable in character or extent.
- The time allowed in the Notice for compliance is insufficient.
- The requirements of the Notice are more onerous than requirements of an existing Notice or Consent issued under Construction Site Noise procedure (see Section 27.8.5.a, below) or Noise Abatement Zone procedure (see Section 27.8.5.c, below).
- The Notice should have been served on some other person(s) as well as, or instead of, the recipient.
- In the case of a trade or business, the *Best Practicable Means* have been used for preventing the noise to which the Notice relates.

If an appeal is entered, the Notice is suspended pending the hearing of the Appeal, if the Notice does not specify otherwise. However, if the Local Authority specifically states in the Notice that it is *not* suspended on appeal, then it is not suspended pending the appeal hearing. This would be specified if:-

- The case is one of emergency, or
- The suspension of the Notice would defeat the object of the Notice, (e.g. the Notice sought to prevent a "one-off" occurrence which would be over before the appeal could be heard).
- The public benefit derived from complying with the Notice greatly outweighs the costs of doing so, (e.g. a very disturbing noise could be abated by some simple action such as keeping a door closed, or by ceasing some activity not essential to an industrialist's operation, such as turning off loud, amplified music played for employees).

A Local Authority, in specifying that a Notice is not suspendable on appeal, runs the risk that, if the appeal is upheld, they could be liable for compensation. Therefore, this will not normally be done in cases where compliance with the Notice implies that production processes would temporarily cease or very substantial expenditure incurred on works.

If a court accepts an appeal, it may uphold the Notice, quash it altogether or vary it, e.g. by imposing less onerous requirements on the recipient.

Failure to comply with the terms of the Notice within the time allowed without reasonable excuse is a criminal offence, prosecutable in a Magistrates' Court. As well as imposing a substantial fine, the Court may impose a recurring fine for each day on which the nuisance continues or is repeated.

In cases of failure to comply with a Notice, the Local Authority, *instead of or as well as prosecuting*, may carry out the works or steps which the Notice specifies and recover costs reasonably incurred from the recipient of the Notice.

The Act lays down defences which are available in proceedings for breach of a Noise Abatement Notice:-

- *Best Practicable Means*, as well as being a ground of appeal, is also a defence available to any trade or business, if prosecuted. It is defined in the Act:-
  - ☐ *Practicable* includes consideration of local circumstances and what is technically or financially feasible. For example, it would be unreasonable to expect a small company to spend huge sums of money out of all proportion to its financial resources.
  - ☐ *Means* includes design, installation, maintenance and manner and periods of operation of *plant and machinery* and the design, construction and maintenance of *buildings and structures*.
  - ☐ The defence is only available when compatible with any duty imposed by law.
  - ☐ The defence is only available when compatible with safety and with the exigencies of emergencies or unforeseen circumstances.

It must be noted that the defence of Best Practicable Means is only available if the noise to which it relates amounts to a simple nuisance; if the noise is so severe as to be *prejudicial to health*, the statutory nuisance *must* be abated.

- *Reasonable Excuse* is also a defence for breach of, or non-compliance with, a Notice, e.g. because of circumstances which are not reasonably foreseeable.

There is no formal mechanism for withdrawing an Abatement Notice, (although a court may quash it or alter it on appeal): In some cases, the requirements of a Notice may be discharged by carrying out the steps which it specifies, e.g. by carrying out specified work. Since Notices are served on companies or individuals, a change of ownership of the premises may render the Notice invalid. Similarly, the Notice may refer to a noisy item of plant or a process which no longer exists e.g. due to an upgrade.

However, a Notice may be worded in such a way as to impose a continuing obligation upon the recipient, e.g. by setting a sound pressure level not to be exceeded at a specified location. Under these circumstances, the recipient should take ongoing care that changes, such as the addition of extra plant or the maintenance deterioration of existing plant, do not place him in breach of the Notice.

The Act also gives private individuals the right to make a complaint of noise to a Magistrate, who may take similar action to the Local Authority.

Rarely, where a nuisance is considered so severe that normal nuisance procedure does not afford a sufficient

remedy, the Local Authority, *instead of or in addition to*, taking standard nuisance action up to and including prosecution, may seek an *injunction* in the *High Court* against the person causing the nuisance. Breach of an injunction constitutes Contempt of Court and very severe penalties may be imposed, including imprisonment.

27.8.5 Other statutory controls on noise

27.8.5.1 Construction site noise

Construction site noise is regulated by Part III of the Control of Pollution Act 1974:

Anyone intending to carry out construction works may apply in advance to the Local Authority for consent as to the methods to be used, (Section 61) although this is not mandatory. (If consent is refused, the contractor has the right of appeal). The advantage to the contractor of using this procedure is that, provided the terms of the consent are complied with, the Local Authority is not permitted to take other action under the relevant legislation.

Where the consent procedure is not invoked, the Local Authority may serve a notice on the contractor specifying the way in which the construction work is to be carried out. (Section 60).

Construction is defined as:-

- Erection, construction, alteration, repair or maintenance of buildings, structures or roads.
- Breaking up, opening or boring under any road or adjacent land in connection with the construction, inspection, maintenance or removal of works.
- Demolition or dredging.
- (Whether or not previously defined), any work of engineering construction.

Guidance on compliance with this legislation is provided by *British Standard 5228*. The Codes of Practice which form part of BS 5228 are *Approved Codes of Practice* under the terms of Section 71 of the Control of Pollution Act 1974. Although infringement of the Codes is not therefore a criminal offence, compliance or otherwise may be taken into account by a court in any proceedings for noise nuisance.

27.8.5.2 Noise in streets

The *Noise and Statutory Nuisance Act 1993* extends the provisions of Part III of the Environmental Protection Act 1990 (Statutory Nuisance, see Section 27.8.4, above) to enable Local Authorities to deal with noise nuisances caused by *vehicles, machinery or equipment* (VME) in the street. An Abatement Notice is served on the person responsible, but, if that person cannot be found, the Notice may be affixed directly to the VME. If the nuisance is not abated within a reasonable time, the Local Authority may take any necessary steps to abate the nuisance.

27.8.5.3 Noise abatement zones

The powers relating to *Noise Abatement Zones* (NAZ) are contained in Sections 63–67 of the Control of Pollution Act 1974. The aim is to control long-term noise from premises in order to contain "creeping" increases in ambient noise and to effect reductions, where practicable.

A Local Authority may declare all or part of its area to be an NAZ. Existing noise levels are then measured by the Local Authority and recorded in a Register. Procedures are laid down in the *Control of Noise (Measurement and Registers) Regulations 1976*. The measurements are performed at a series of points around the exterior of each premises. The Register is open to public inspection.

Registered levels of noise may not be exceeded without the consent of the Local Authority. In addition, the Local Authority may seek to achieve a reduction over registered noise levels by serving a *Noise Reduction Notice*. However, this is subject to appeal and is only permissible if it can be shown that:-

- The reduction in noise can be achieved at reasonable cost; and
- A public benefit would result.

If a new building is proposed within an NAZ, the Local Authority is empowered to determine acceptable levels of noise emission for the development.

It is of interest to note that, in order to invoke any of the procedures in this legislation, the Local Authority *does not have to prove nuisance*. (See Section 2.8.4, above).

NAZ procedures have been little used in the UK, possibly because they are cumbersome in relation to any benefits derived. Recommendations have been made to review the legislation and to simply procedures but no action has been taken at the time of writing.

27.8.6 Assessment of industrial noise: British Standard 4142

British Standard 4142, which was last revised in 1997 (at time of writing), lays down a "*method for rating industrial noise affecting mixed residential and industrial areas*". It can therefore be useful to Local Authorities and industrialists in gauging whether noise amounts to a nuisance (see Section 27.8.4) or in considering Planning Applications (see Section 27.8.2). However, it has no formal, legal status. The procedure can be summarized as follows:

- Noise from industrial premises is assessed in terms of the difference between the *Specific Noise* and the prevailing *Residual* noise level (i.e. the background noise which exists in absence of the Specific noise). A method is given for separating the Specific noise from the total *Ambient* noise (Specific + Residual), by applying a correction to subtract the effect of the background noise.
- The Specific noise is measured (or, if this is not practicable due to interference from other sources,) calculated in terms of L_{Aeq}, taken over 5 minutes at night and 1 hour during the day.
- The Specific noise is given a corrective weighting, if it is continuously tonal (whine, hiss screech hum etc.) or impulsive in character (bangs, clicks, clatters thumps etc.) or sufficiently irregular to attract attention.

- The background noise level is measured in terms of an *A-weighted* L_{90}.
- The assessment is performed by subtracting the background noise level from the corrected Specific noise level (*Rating Level*). The greater the positive difference between the two values, the greater the likelihood of complaints: An exceedance of around 5 dB by the Specific noise is considered to be of marginal significance; an exceedance of around 10 dB or more indicates that complaints are likely. If the Rating Level is more than 10 dB *below* the background level, this indicates that complaints are unlikely.

Full details are given in British Standard 4142 of measurement and calculation methodologies to be used, information to be recorded etc.

27.8.7 Occupational health: the Health and Safety at Work etc. Act 1974

In the UK, the above Act and Regulations and Guidance issued under it regulate the health, safety and welfare of persons at work, and of the public inasmuch as they may be affected by the carrying on of work activities. General duties are imposed upon employers to provide:

- Plant and systems of work,
- Information, instruction, training and supervision,
- Places of work and working environment, which are safe and without risks to health. These duties extend to protection from the harmful effects of exposure to noise at work.

Similarly, there is a duty upon anyone who designs, manufactures, imports or supplies any article for use at work to ensure that it is safe and without risks to health and to provide adequate information about its safe use: This includes protection from the harmful effects of noise.

It is the duty of employees to take reasonable care of themselves and others while at work and to co-operate with their employer in the carrying out of his duties under the Act. No-one must deliberately interfere with or misuse anything provided to secure their health or safety. Again, these duties extend to equipment provided for noise protection.

Specific requirements relating to noise at work were laid down by EU Directive 86/188/EEC and these were enacted in UK law in *the Noise at Work Regulations 1989 (SI 1790)*, made under the Health and Safety at Work etc. Act:

The Regulations require employers to assess and, where necessary, to measure noise levels to identify employees whose exposure falls within one of three action levels:

- *First Action Level*: Daily personal noise exposure (*LEP,d*) of 85 dB(A).
  Where this level is reached or exceeded, personal ear protectors must be made available to those employees who ask for them.
- *Second Action Level*: Daily personal noise exposure (*LEP,d*) of 85 dB(A).
- *Peak Action Level*: Peak sound pressure levels exceed 200 pascals.
- At these levels, employers must ensure that personal ear protectors are used and employees have a duty to use them.

At all Action Levels, employees must use protective equipment supplied and defects must be reported to the employer. Areas where the various levels are exceeded must be demarcated by signs and access controlled.

Where it is likely that noise exposures of employees will surpass the First Action Level or the Peak Action Level, the employer must carry out a *noise assessment*. This should identify all employees at risk and enable appropriate action to be taken, subject to review where significant change takes place. Records of noise assessments must be kept and made available to employees.

There is a general duty upon employers to reduce exposure of employees to noise *as far as reasonably practicable*; this means taking into account technical feasibility and availability of measures for noise control, preferentially at source. (I.e. engineering controls at source are preferable to controlling the effects at the receiver by personal protection.) There is a duty upon manufacturers, designers, importers and suppliers to supply adequate noise data with any equipment for use at work which might result in daily noise exposures of 85 dB(A) or more.

The *Health and Safety Executive* publishes Guidance Notes giving advice on the detailed implementation of the Regulations.

28

Air pollution

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28.1 Effects of air pollution

It is easy to take the air which we breathe for granted: Most human activity contributes in some way to atmospheric pollution. These effects can be divided into:

- GLOBAL EFFECTS: Acidification; depletion of the ozone layer; global warming.
- LOCAL EFFECTS: Direct harm to human health; damage to plants, materials and buildings; loss of amenity.

28.1.1 Global effects

28.1.1.1 Acidification

Carbon dioxide, sulphur dioxide and nitrogen oxides are all emitted in large quantities through the combustion of fossil fuels. This has been most marked in the northern countries but industrialization is now advancing in the southern hemisphere.

Direct fallout of acid pollutants takes place as *dry deposition*. When these pollutants dissolve in atmospheric moisture to form acids, they fall in precipitation as *wet deposition*. This form of pollution may be transported over long distances and it therefore constitutes an international issue. For example a substantial percentage of acid deposition in Scandinavia originates in the United Kingdom. Various forms of environmental damage are caused:

- Fresh waters become acidified to an extent dependent on the capacity of the local geology to neutralize acids. At a pH of 5, fish begin to disappear and when pH falls to 4.5, virtually all aquatic life is eliminated. Acid rain also releases toxic metals from the environment into lake water. These harmful effects impact on dependent food chains. The effect has accumulated over a period of time and would require a sustained long-term reduction in emissions to achieve reversal.
- There has been a marked deterioration and die-back of trees in many parts of Europe in recent years. Sulphur dioxide emissions are toxic to plant life but, while pollution is undoubtedly implicated, the mechanisms involved are complex and not yet fully understood.
- Acidic deposition has caused serious damage to historic building in recent times, especially those constructed of limestone or marble. As well as acid attack, sulphur dioxide reacts with these materials to form calcium sulphate, which, lacking mechanical strength, slowly crumbles away.

28.1.1.2 Global warming

Energy from the sun passes through the atmosphere and falls on the Earth, heating it; it is then re-radiated at a longer wavelength. This energy is absorbed by certain gases in the atmosphere and has a warming effect. This is the so-called *greenhouse effect*, which makes the atmosphere much warmer than it otherwise would be.

This has always occurred naturally and, indeed, is vital to life on Earth as we know it. However, industrialization in the last couple of centuries has resulted in the emission of large quantities of these gases, thereby, it is thought, raising temperatures. The most significant "greenhouse gases" are indicated below, together with their anthropogenic sources and relative contribution to the enhancement of the greenhouse effect.

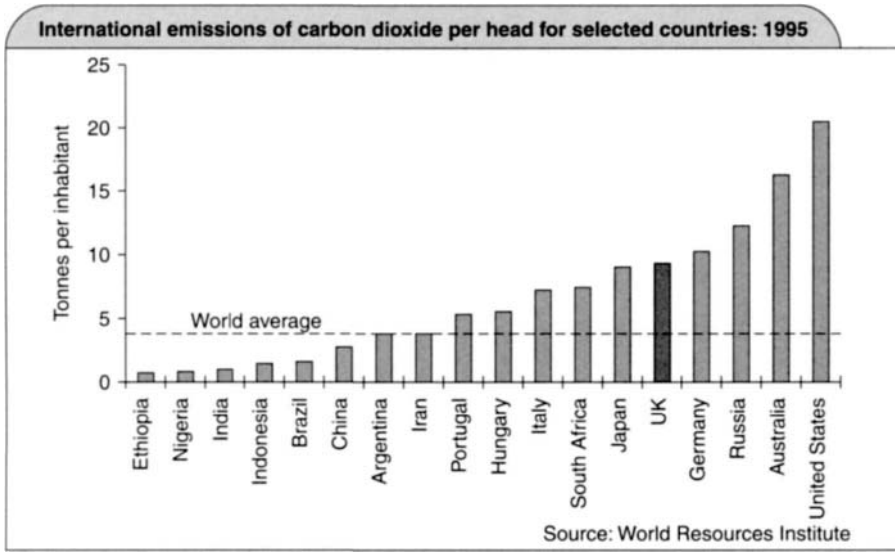
Greenhouse gas	*Sources*	*Contribution to greenhouse effect (%)*
Carbon dioxide	Combustion of fossil fuels Destruction of forests	72
Methane	Agriculture Coal and natural gas production Refuse and sewage disposal	10
Nitrous oxide	Fertilizer use Nylon manufacture	5
Chlorofluorocarbons (CFC's)	Refrigerants Solvents Aerosol propellants	13

Some greenhouse gases absorb radiation more strongly than others. For example, CFC's are particularly effective and are also very persistent. Therefore they have an important effect, although they are present in relatively small quantities. CFC's are additionally harmful in that they damage the ozone layer (see Section 28.1.1.3, below) and considerable effort has been devoted to finding substitutes.

The magnitude of the enhanced greenhouse effect is difficult to quantify: Several natural cycles of temperature variation, of lengths varying from thousands of years to a few years, are known to be superimposed upon each other. However, there is evidence that average atmospheric temperatures have risen by an estimated 0.5 degrees Celsius since the middle of the nineteenth century and the world's five hottest days in the twentieth century have all occurred since 1980. Recently, there has been a marked reduction in the extent of the Antarctic ice-cap and glaciers have retreated dramatically in many parts of the world.

It is probably fair to say that there is now a consensus among scientists and many governments that the effect is real and that urgent corrective action is required. Certainly, the UK Government and the EU have accepted the need for action for a number of years. (See Section 28.4.1).

It even more difficult to forecast the exact consequences of global warming. The *Intergovernmental Panel on Climate Change* (IPCC) estimates that there will possibly be a rise in mean global temperature of 1 degree Celsius by 2025 and 3 degrees Celsius by the end of the 21st century. Some have posited the possibility of "feedback" effects: Reductions in the amount of snow and ice cover (highly reflective of incoming solar energy) and the release of trapped carbon dioxide from melting polar ice, for example, could trigger a classic "vicious circle", resulting in a dramatic acceleration of the process. Conversely, certain effects, such as increased cloud cover,



[2]The greenhouse gases covered by the Kyoto Protocol are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride.

Figure 28.1

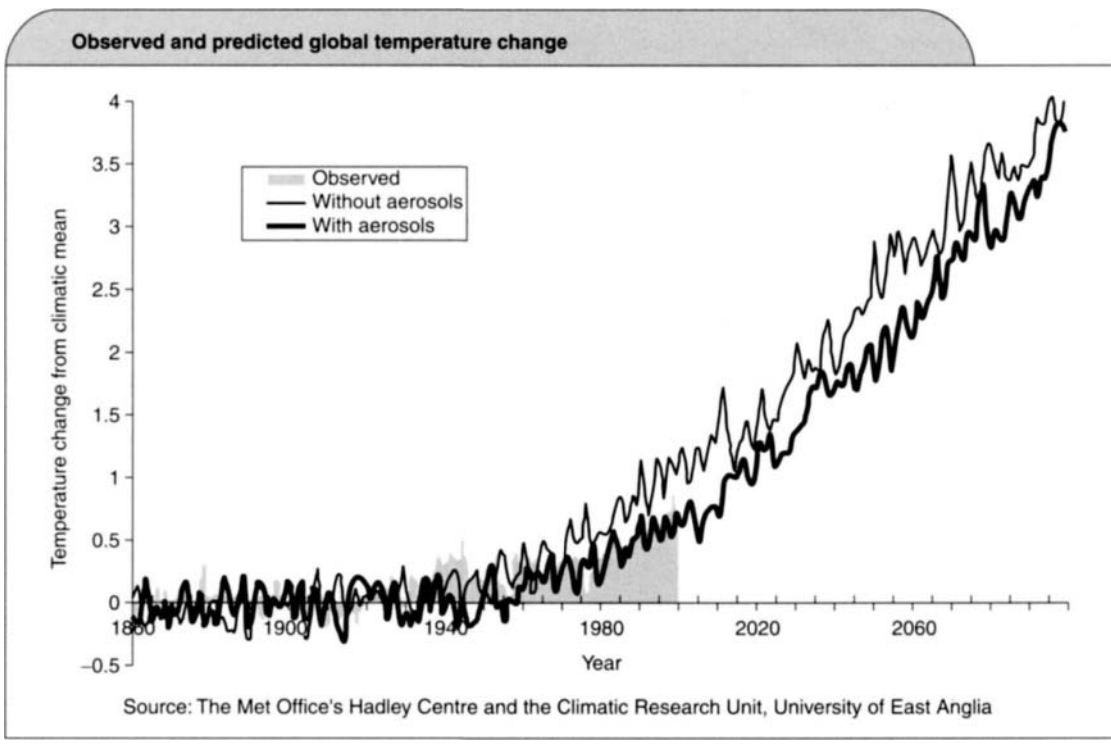


Figure 28.2 Predicted increase in global temperature

could offset the increase in temperature (Figures 28.1 and 28.2).

At worst, the predicted effects will seriously affect life on earth: Sea levels will rise and inundate low-lying coastal areas. More available atmospheric heat will mean more, and more violent, storms. Particular regions will become much warmer or cooler as ocean currents and weather systems shift. Large areas will be affected by droughts or excessive rainfall and flooding. Effects on agriculture and ecosystems will be catastrophic. Tropical

diseases and pests will spread to areas where they are not now encountered. Crop failures and displacement of populations will lead to famines and other humanitarian disasters.

Measures in hand in the industrialized world to minimize the emission of greenhouse gases include the elimination and substitution of CFC's and programmes to reduce the consumption of fossil fuels and consequent emissions of carbon dioxide. (See Section 28.4.1). However, these are, to some extent, being offset by advancing industrialization and rising standards of living elsewhere in the world.

It is vitally important, when designing and operating plant and buildings to ensure the highest possible degree of energy efficiency for a number of reasons:

- Contribution to the greenhouse effect, with its potentially far-reaching consequences is minimized.
- Fossil fuels are a finite resource and should be conserved as far as possible to avoid economically damaging future shortages and price increases.
- In the UK, the EU and elsewhere, government programmes of advice and subsidy are available to operators to assist in achieving energy efficient operation.
- Reductions in energy consumption represent reductions in costs to the industrialist (and everyone else).

28.1.1.3 Depletion of the ozone layer

Ground level ozone is a pollutant but stratospheric ozone (15–20 km. above the earth's surface) performs a vital role in filtering out harmful ultraviolet solar radiation. Indeed, in the absence of this filtering effect, life could not exist on earth.

Exposure to increased intensities of ultraviolet radiation increases the risk of skin cancers and eye cataracts and depresses the human immune system. Harm is also caused to aquatic systems and crops.

In the 1970's it became apparent that marked seasonal depletion of the ozone layer was taking place over Antarctica. The evidence pointed to the cause lying in the growing manufacture, consumption and emission of chlorinated chemicals such as chlorofluorocarbons (CFC's). These have found extensive use as refrigerants, aerosol propellants and industrial solvents.

Urgent international measures have therefore been put in hand to phase out the problematical chemicals and to find substitutes, (see Section 28.4.1). The substances implicated in ozone depletion include Chlorofluorocarbons (CFC's), Halons, Carbon tetrachloride, 1,1,1-trichloroethane, Methyl bromide, Hydrochlorofluorocarbons (HCFC's) and Hydrobromofluorocarbons (HBFC's).

28.1.2 Health effects

The UK Government has estimated that between 12 000 and 24 000 people die early each year in the United Kingdom from the effects of poor air quality. For comparison, about 327 500 people were injured and about 3500 died in road accidents in 1997. Numerous studies have demonstrated correlations between pollutant levels and ill-health and that hospital admissions due to respiratory problems increase after certain pollution incidents.

Pollutants can have short-term effects on the subject or cause more insidious long-term health effects. The health effects of some of the major pollutant species are summarized below:

Benzene is a liquid at ambient temperature but readily evaporates. It is a recognized carcinogen and long-term exposure can cause leukemia. There is no known level below which there is zero risk.

1,3-butadiene is a gas at ambient temperatures and is present in trace amounts in the atmosphere. It is known to cause various cancers and their is no known level at which it can be said that there is zero risk.

Sulphur dioxide is a gas at normal temperature but readily dissolves in moisture and oxidizes to sulphuric acid. Because of its acidic nature, it is irritant when inhaled and high concentrations may cause breathing difficulties. Exposure at high ambient concentrations may provoke asthma attacks.

Lead is a dense, unreactive metal which also occurs widely in its compounds. It is toxic, causing damage to the nervous system, blood, gastrointestinal tract, joints and reproductive system. These effects can be chronic if sufficiently high environmental levels are experienced on a regular basis. Most atmospheric lead is in the form of fine particles with an aerodynamic diameter of less than 1 micrometre.

Carbon monoxide is a gas formed by the incomplete combustion of carbon containing fuels. It is toxic through its impairment of the oxygen carrying capacity of the blood and high concentrations in confined spaces can prove fatal. Environmentally, exposure may exacerbate existing heart-problems.

Nitrogen dioxide is a toxic gas, reddish-brown in bulk. In elevated environmental concentrations, it exacerbates respiratory conditions.

Ozone is a secondary pollutant formed by the interaction of sunlight with nitrogen oxides and volatile organic compounds. It is an irritant and can provoke asthma attacks.

Particulates differ from the other pollutants discussed in this Section in that they are not a single substance. Particulate matter in the atmosphere is composed of a wide range of materials of various origins.

This pollutant is defined by particle size and not by its chemical nature. This is because it is necessary to look at the size fraction of particles most likely to be deposited in the lung, i.e. "PM_{10}", which approximates to particles up to 10 μm in size.

In recent years, a clear association has been established between respiratory or cardiovascular ill-health and exposure to fine atmospheric particles. The precise mechanism of these effects has not been identified with certainty, at time of writing, although various theories have been advanced.

Studies have suggested that the smaller fractions of airborne particulates, for example $PM_{2.5}$ (particles up to 2.5 μm aerodynamic diameter), or even finer fractions, e.g. $PM_{0.1}$ (particles up to 0.1 μm aerodynamic diameter) are of greatest significance for morbidity and mortality.

Particle numbers and/or surface area may be a significant factor: It has been demonstrated that, while the $PM_{0.1}$ fraction accounts for only 1% of the total mass of a sample of atmospheric $PM_{2.5}$, it might account for almost three-quarters of the total number of particles.

28.1.3 Effects on plants, materials and buildings

Elevated levels of certain pollutants have marked, identifiable pathological effects on plants. Pollutants documented as causing visible damage and growth/yield deficiencies at ambient concentrations include:

- Sulphur dioxide
- Nitrogen oxides
- Hydrogen fluoride and other fluorides
- Chlorine and hydrogen chlorides
- Ammonia
- Ethylene and other organic compounds
- Hydrogen sulphide
- Carbon monoxide

Additionally, a range of dusts and aerosols cause plant damage.

Sulphur and nitrogen oxide emissions can form acid pollution by combination of with atmospheric moisture, or undergo dry deposition, and attack building materials, especially limestone. There are many well-known cases of historic buildings being seriously eroded through the industrial era. Other materials which deteriorate under the effects of this pollution include marble, many metals, concrete/concrete reinforcement and paint finishes.

Atmospheric ozone damages some materials such as rubbers and plastics.

28.2 Dispersion, atmospheric stability and meteorological effects

It should be borne in mind that one of the most important factors in determining the level of a given pollutant, at a given point in space and time is the *weather*, assuming broadly similar levels of human activity on each successive day.

28.2.1 Small scale dispersion

28.2.1.1 Localized wind effects on chimneys

When wind impinges upon structures such as buildings and chimneys, a region of turbulence is created in the lee of the obstruction, i.e. the downwind side. A plume of pollution emitted into the influence of this turbulent wake will be drawn down to ground level. This effect is termed *downdraught*. Typically, the vortices so formed extend vertically to about twice the height of the building and horizontally downwind to a distance of roughly six times the building height. The width of a building also influences the extent of the turbulent wake: If the building width exceeds the height, this zone may be extended (Figure 28.3).

Chimneys and associated structures will also generate trailing vortices in their wake, both in the horizontal and the vertical plane. These may capture emissions from the top of the stack and draw them down nearer to the ground.

There will also be a low pressure region extending down the lee side of the stack. If efflux velocity is insufficient, this zone will suck emissions down that side of the chimney for a certain distance, reducing its effective height. This phenomenon is termed *downwash*. Pollution thus trapped may also migrate into the region of

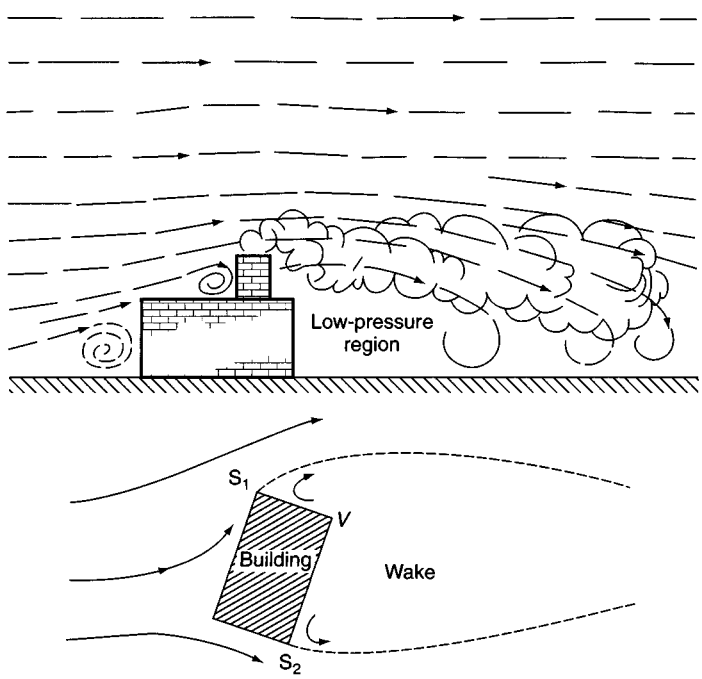


Figure 28.3 Downdraught affecting a chimney

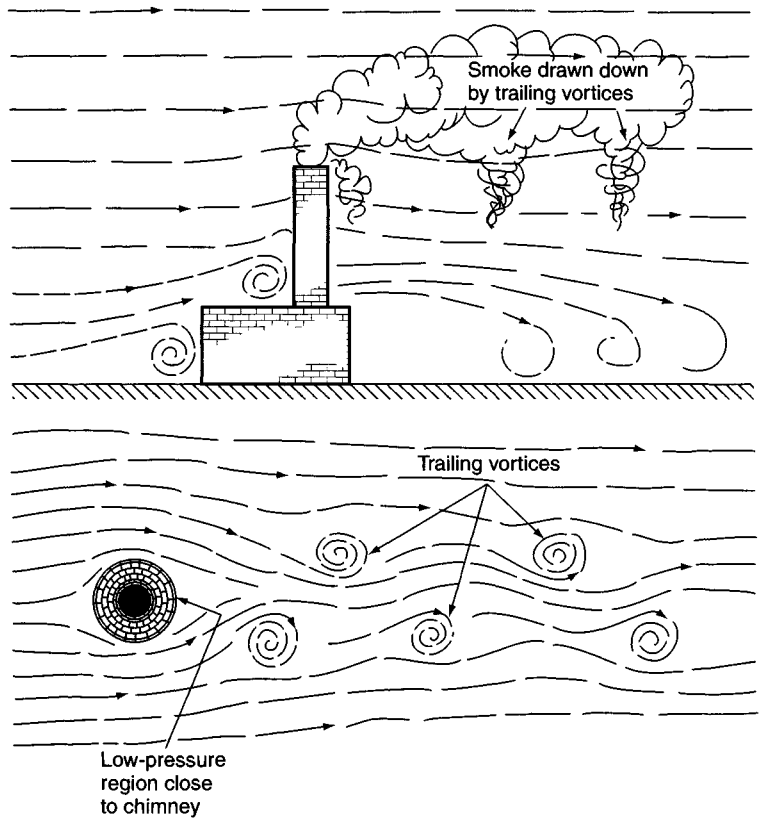


Figure 28.4 Downwash affecting a chimney

downdraught turbulence caused by the stack or adjacent buildings, or vice-versa, and be further drawn down to ground level (Figure 28.4).

To minimize *downdraught*, chimneys should be circular in section and of as high an aspect ratio as other design considerations (structural strength, multi-core design, thermal insulation) permit.

To minimize *downwash*, the efflux velocity of the gases must be sufficient to avoid capture by the downwind low pressure region of the stack. The following chart (Figure 28.5) shows approximate efflux velocities required to avoid downwash, with varying wind speed.

The aspirating effect of wind passing across the top of a chimney may create an area of low pressure inside the chimney mouth. This, coupled with inadequate efflux velocity may allow cold air to be drawn down the inside of the flue for a distance, in countercurrent to the hot efflux gases. This cools the gases and may cause undesirable condensation effects, such as *acid smut*.

Often associated with uninsulated steel chimneys, acid smut arises from the condensation of acids in the combustion gases of fossil fuels, especially those with a high sulphur content. The acid forms a liquid film to which carbon particles adhere, building up on the inner surface of the stack. Apart from corroding the stack, this deposit will be periodically dislodged by changes in gas flow, as working load varies, and carried away out of the chimney. Being typically of relatively large size, these agglomerations are deposited within a short distance, causing severe nuisance and damaging buildings, cars, washing etc.

Wind direction is rarely constant and, as it varies, the leeward low pressure area of a stack will shift. This will tend to exert bending and rotating forces on the stack. Also, vortices tend to be shed downwind alternately on either side of the stack, which can create oscillatory forces on the stack of relatively high frequency. In cases of modern, free-standing steel chimneys, it is the practice to put a helical vane around the top third of the stack. As well as acting as a structural stiffener, this deflects the air-flow into an upward swirl around the circumference, equalizing pressures acting on the stack. Although this device is primarily to resist the mechanical effects of wind, it is also beneficial in reducing downdraught and downwash.

28.2.1.2 Localized wind effects on minor building vents and flues

Emissions from building vents may not be toxic and there may not be any detailed methodology for calculating the minimum flue height (see Section 28.3.1). However, the emissions may be odorous and it will therefore be necessary to ensure that the exhaust is not drawn down to ground level in the locality. An example would be the discharge from a local exhaust ventilation system serving the kitchen of a restaurant or hot food "take-away".

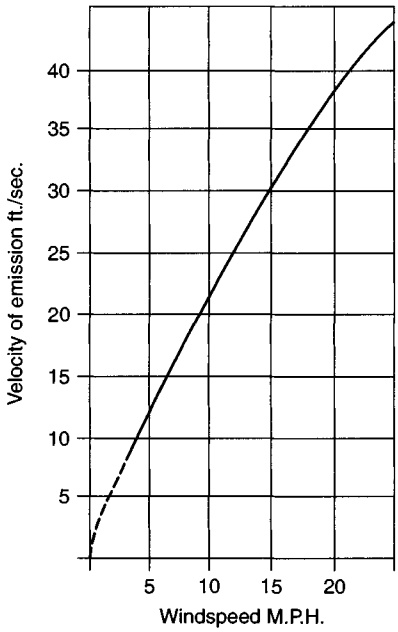


Figure 28.5 Chart for estimating efflux velocity required from a stack to avoid downwash for given wind velocities

Because of the *downdraught* effect described above, (see Figure 28.4) it is good practice to arrange the exhaust to discharge at a point above the highest point on the building (excluding minor excrescences). On a building with a pitched roof, this would be the ridge of the roof.

Small-scale abatement devices such as kitchen extraction hood filters, are generally ineffective at dealing with odours. They are also notoriously susceptible to deterioration from the initial standard of performance, if not conscientiously maintained. They should not, therefore, represent an alternative to this requirement but should be complementary to it.

As a rule of thumb, in the case of odorous emissions from a two-or three-storey building with a pitched roof (assuming the height of surrounding buildings is generally similar), the point of discharge should be a *minimum* of one metre above the level of the roof ridge. If there are taller structures in the vicinity, then more detailed consideration will be required. In such installations, devices such as cowls, covers and terminal bends are best avoided: They impair efflux-velocity, aggravate turbulence and deflect the exhaust sideways or downwards.

28.2.1.3 Atmospheric stability

When wind flows over the ground, its velocity is reduced near ground-level by its interaction with the surface, which also produces a turbulent mixing layer. The diameter of these mechanically forced eddies or *mixing length* is proportional to their height above the ground, so varies from 0.4 cm. at a height of 1 cm. to, say, 200 m. at a height of 500 m. The interaction is also influenced by the structure and texture of the ground surface.

Superimposed on *mechanical turbulence* are the effects of buoyancy (*thermal turbulence*), or lack thereof, caused by variations in air temperature at different altitudes: Atmospheric pressure falls with increasing altitude. So, therefore, does air temperature, at a rate of approximately 1°C for every 100 m. increase in altitude. This is termed the *dry adiabatic lapse rate.*

Solar radiation has little heating effect as it passes through the atmosphere. However, when solar energy falls on the ground, for example on a hot summer's day, the latter is heated. Some of this heat is transferred to the air near the ground, causing it to rise. At other times, usually at night, the earth loses heat by radiation and cools. This has a chilling effect on the air nearest the ground, which becomes colder than the air above it.

The actual drop in temperature of the air through which a rising "parcel" of air passes is not, in practice, constant and may be less than, the same as or greater than the theoretical adiabatic lapse rate. This is termed the *environmental lapse rate.*

If environmental lapse rate > adiabatic lapse rate, the "parcel" will have a strong tendency to rise and there will be convective turbulence. Under these conditions, the atmosphere is said to be ***unstable****.*

If environmental lapse rate ≈ adiabatic lapse rate, little or no convective turbulence takes place and the air is said to be ***neutral****.*

If environmental lapse rate < adiabatic lapse rate, the rise of the "parcel" will tend to drop or its tendency to rise will be inhibited. Convective turbulence will not take place and the air is said to be ***stable****.*

The relative temperature of air and ground will vary with the day/night cycle and changes in the weather. Typically, during the day a convectively mixed boundary layer develops in response to surface heating. Around sunset, as the ground cools, a stable layer develops at the surface. This deepens progressively with progressive cooling through the night. Above this, is a fairly neutral residual layer containing dispersed pollutants introduced into it during daytime convective mixing. After sunrise, warming of the ground causes a new convective boundary layer to develop and deepen as the day progresses, ultimately destroying the stable layer.

This is most marked on clear, cold, still winter nights, when the lack of cloud cover allows heat from the ground to radiate into space. The ground cools and strongly chills the layer of air next to it. Temperature increases, instead of falling with altitude up to the limit of the chilled layer of air. Beyond this point, temperature commences to fall with increasing altitude in the normal way, i.e. the slope of the graph of temperature against height sharply reverses. This is known as a *temperature inversion.* Within the inversion layer, both convective mixing and mechanical turbulence are inhibited, i.e. the air is highly stable.

An inversion layer can exist at any height, and will rise as the sun heats the ground in the morning. Pollution emitted *below* the upper boundary of a stable layer is trapped near the ground and concentrated. It is this effect which causes *winter smog*, the combination of suspended water droplets condensed out in the chilled air and accumulating pollution.

High wind velocity increases the dilution of emissions at source and reduces the influence of stability. It also

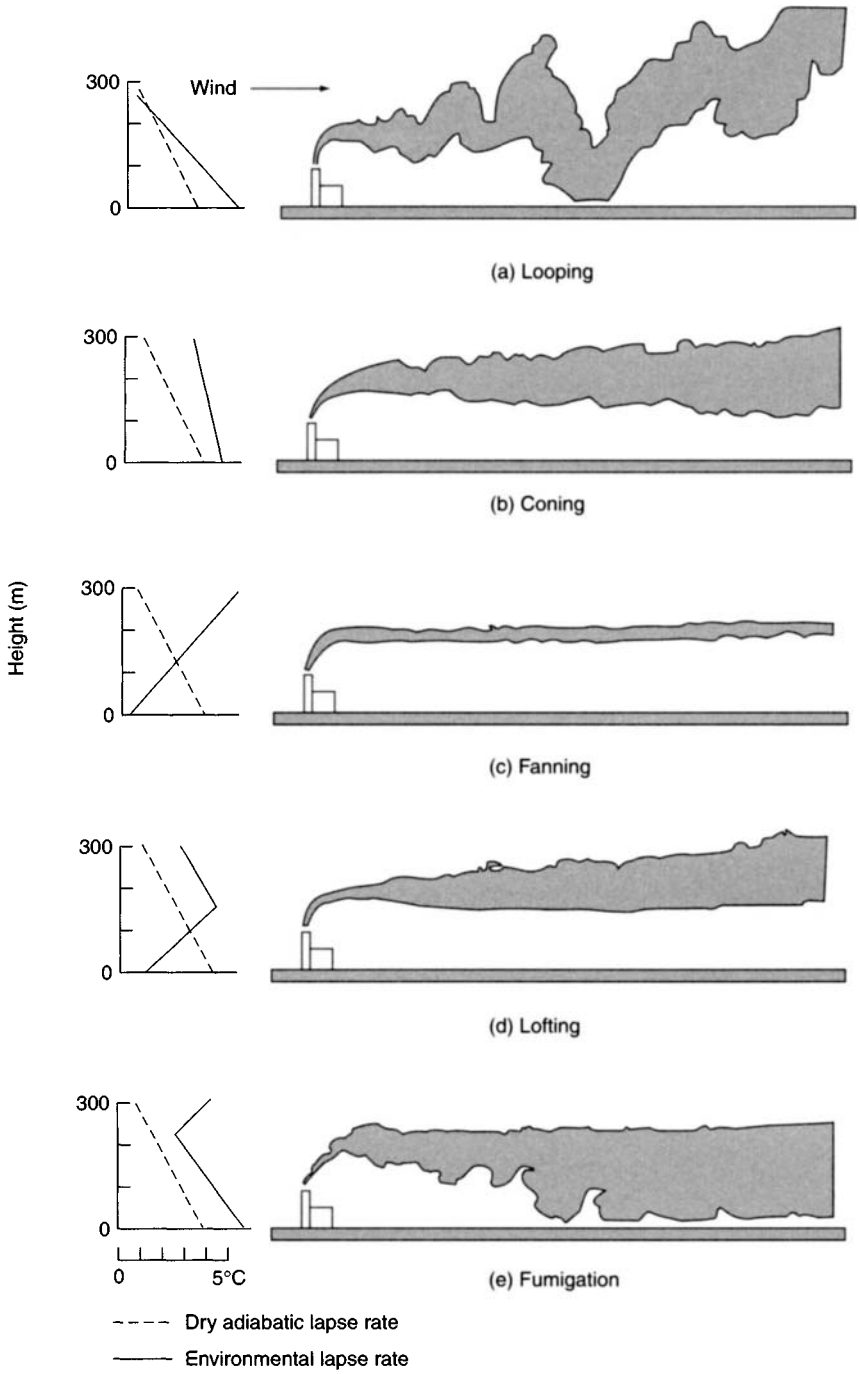


Figure 28.6 Characteristic plume patterns under different stability conditions

affects the distance of pollutant travel and its concentration. Light winds and high stability will tend to favour high, steady ground level pollutant concentrations. However, higher winds and strong turbulence can bring transient peaks of pollution to ground level.

A plume from a tall stack will behave in various ways according to prevailing conditions (Figure 28.6).

Looping plume The boundary layer of the atmosphere is *unstable* on a sunny day with light winds: The ground surface warms up and transfers its heat to the lower atmosphere. Temperature *(lapse rate)* falls with altitude and so the buoyant, relatively warm air near the surface readily rises. Free convective mixing takes place over a considerable depth of atmosphere and any pollution

present is diluted and dispersed. Near-ground sources of pollution produce relatively low concentrations. However, levels of pollutant which are experienced at a given point on the ground from an elevated emission source (i.e. a stack) can fluctuate considerably as the plume spirals up and down in the strong turbulence. This may be important for toxic or odorous pollutants.

Coning plume A neutral boundary layer is will arise, for example, under conditions of relatively strong winds and cloudy skies. The ground surface is not gaining or losing heat to an appreciable degree and so the air is not being heated or cooled by it. The atmosphere is relatively well-mixed, the lapse is *adiabatic* (without gain or loss of heat) and vertical motion is not promoted or suppressed by buoyancy. A plume from a stack will spread downwind at equal rates laterally and vertically, producing a cone-shaped plume. This may reach the ground but at a much greater distance downwind than with looping plumes.

Fanning plume Under conditions of high stability and weak turbulence, with an inversion layer at very low level, a plume emitted from a chimney will "fan", i.e. spread laterally but not vertically, resulting in very little ground level pollution.

Lofting plume Where a plume from a stack is emitted at sufficient height to be dispersed into relatively unstable air above the upper boundary of a stable inversion layer, little downward transport occurs. Ground level concentrations are low.

Fumigation Conversely, when a nocturnal inversion begins to break down in the morning due to surface heating, conditions near the ground will be relatively buoyant, while the rising inversion layer still inhibits upward dispersion. As the mixing layer rises above the level of the emission, the pollution will suddenly be freely brought down to ground level while still being contained vertically by the inversion layer. This will result in high ground level concentrations of the emitted pollutant at points along the track of the plume.

Wind speed, *insolation* (positive or negative flux of solar energy) and degree of cloud cover are combined to characterize the influence of atmospheric stability on pollutant dispersion in the *Pasquill stability criteria*. Six categories, A–F are assigned. A more recent technique, often used as an input in computer dispersion modelling, determines the height at which stability effects become significant (*the Monin-Obukhov length*).

28.2.2 Large scale dispersion

Pollution is carried downwind, but, on a large scale, winds circulate around high and low pressure weather systems. After about a day, dispersion of a plume of pollutant is controlled by differential ("chaotic") advection: It is stretched into "tendrils" or folded and sheared into "whorls". Anticyclones (areas of high pressure) may form a barrier to the movement of pollutants from sources outside the circulation. Thus, dispersion of pollutants is not linear on a large scale but circulatory.

Pollution can migrate over considerable distances: E.g. a considerable proportion of acidification in northern Europe originates in UK emissions (see Section 28.1.1.1). Some pollutants additionally undergo chemical transformations during transport over long distances: A significant proportion of the ozone experienced during summer ozone episodes in the UK originates as emissions of nitrogen oxides and Volatile Organics in continental Europe.

European mainland emissions contribute around 20% of the mass of *primary* particulates (particles directly emitted by combustion processes etc.) measured in Britain.

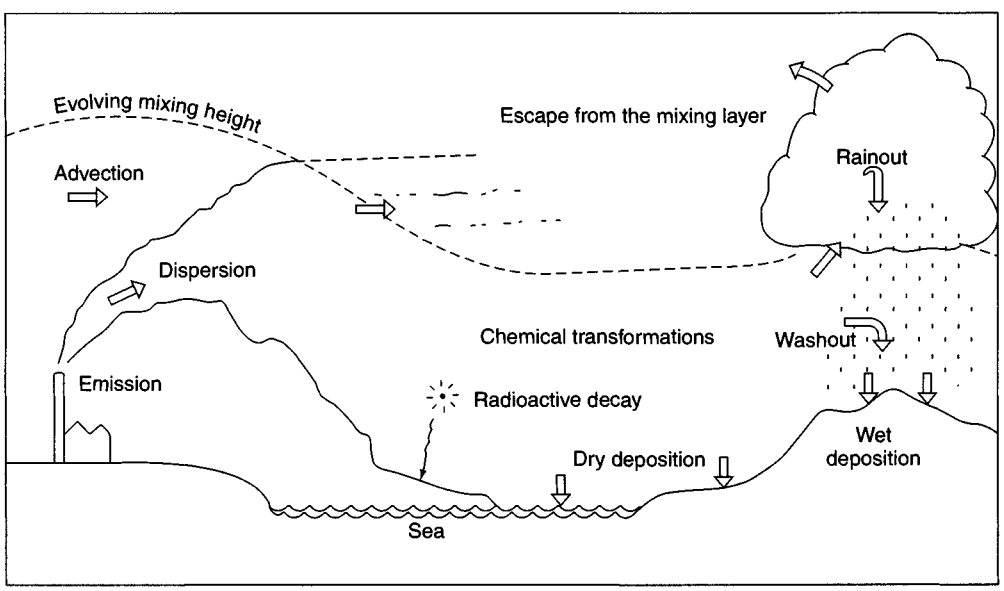


Figure 28.7 Some of the processes affecting airborne pollution



Figure 28.8 Forecast ozone concentrations (ppb) and associated back trajectories

Similarly, in a typical year, it has been estimated that 50% of *secondary* particulates (sulphate and nitrate particulates formed from sulphur and nitrogen oxide emissions) measured in the UK originate in continental Europe. This latter corresponds to about 15% of *total* PM_{10} particulates. These are proportions of the annual mean and may be much higher during short-term peak episodes. Similarly, the imported annual mean proportion has been much higher in typical years with an unusually high prevalence of easterly winds (Figures 28.7 and 28.8).

28.3 Calculation of flue heights and dispersion modelling

28.3.1 Flue height calculations ("Paper" systems)

28.3.1.1 The chimney height memorandum (conventional combustion plant)

Under the Clean Air Act, (see Section 28.4.3), guidance is provided to Local Authorities and others in calculating

chimney-heights in cases where approval is required under the Clean Air Acts: This is the *1956 Clean Air Act Memorandum on Chimney Heights (Third Edition, 1981)*, in which it is assumed that the primary objective of a flue serving a conventional fossil fuel burning appliance (steam raising boiler, indirect heating plant) is to ensure the adequate dispersal of sulphur dioxide and nitrogen oxides.

The Memorandum therefore starts with the sulphur content of the fuel burnt and covers furnaces with a gross heat input in the range 0.15–150 MW. The Clean Air Act 1993 requires approval of the height of a proposed chimney by the Local Authority, if that chimney serves plant burning:

- Pulverized fuel.
- Any other solid matter at a rate 45.4 kg per hour or more.
- Any liquid or gaseous matter at a rate equivalent to 366.4 kilowatts or more.

The method assumes certain efflux velocities at full load:

For boilers up to 2.2 MW:	$6\,m.s^{-1}$*
For boilers up to 9 MW:	$7.5\,m.s^{-1}$
For boilers where the rating > 135 MW:	$15\,m.s^{-1}$

*This efflux velocity may in practice be difficult to achieve with small installations.

For ratings between 9 and 135 MW, efflux velocities *pro rata*.

Step 1 – uncorrected chimney height (U) For very low sulphur fuels, e.g. natural gas, this is obtained from the formula

$$U = 1.36Q^{0.6}[1 - (4.7 * 10^{-5}Q^{1.69})]$$

where Q is the heat input in MW. (For heat inputs <30 MW, the part of the equation in brackets may be omitted). Q is derived from:

$$Q = \frac{WB}{3600}$$

where W = maximum rate of combustion of fuel ($kg\,h^{-1}$ for mass or $m^3.h^{-1}$ for volume).
B = gross calorific value of the fuel ($MJ.kg^{-1}$ or $MJ.m^{-1}$).

For other fuels, the rate of emission of sulphur dioxide [R] is first calculated using:

Oil firing: $R = 0.020\,WS$

Coal firing: $R = 0.108\,WS$

where R = Rate of emission of sulphur dioxide ($kg\,h^{-1}$)
W = Maximum rate at which fuel is burned ($kg\,h^{-1}$)
S = Sulphur content of the fuel (%)

Class of area	*Characteristics of area*	*Weighting factor*
A	Undeveloped area where development is unlikely	0.55
B	Partially developed area with scattered houses	0.78
C	Built-up residential area	1.00
D	Urban area of mixed industrial and residential development	1.30
E	Large city or urban area of mixed heavy industrial and dense residential development	1.60

The equations are different because, in the case of coal firing, it is assumed that some sulphur is retained in the ash.

For coal and oil firing, a weighting factor is then applied according to the class of area in which the proposed chimney is located:

The uncorrected chimney height U is then determined either by plotting the emission rate R and the area classification A–E on a nomogram or by multiplying by the corresponding factors to give a corrected rate of emission, R_a:

If $R_a < 10\,kg\,h^{-1}$: $U = 6\,R_a^{0.5}$

If $R_a > 10$, $<100\,kg\,h^{-1}$: $U = 12\,R_a^{0.2}$

If $R_a > 100$, $<800\,kg\,h^{-1}$: $U = 5\,R_a^{0.5} - 0.9\,R_a^{0.67}$

Step 2 – corrected chimney height (C) A correction is then applied to the uncorrected height U to take account of tall buildings near to the stack (within $5U$) or the case where the height of building to which the stack is attached is less than $2.5U$.

The simplest case is that of one tall building near the stack which is wider than it is tall:

$$C = H + 0.6U$$

where C = corrected chimney height
H = building height

In other cases, for example with more than one building, a more complex procedure is followed. All buildings within $5U$ of the chimney should be assessed and the following factors determined for each:

H_m = the maximum value of each building's height
K = the lesser of each building's height or width
$T = H + 1.5\,K$
T_m = the largest value of T for the buildings under consideration

If $U > T_m$: $C = U$

If $U \leq T_m$: $C = H_m + U(1 - H_m/T_m)$

Notwithstanding the calculated value of C, certain rules are applied:

- A chimney outlet should never be less than 3 m. from any area where there is access (i.e. ground level, roof areas, openable windows).
- C must never be less than U.
- A chimney must never be lower than the attached building within $5U$.

Special requirements apply to fan dilution (air dilution) systems, which are commonly used with gas fired boilers. Provided that very low sulphur (VLS) fuels are used (sulphur content <0.04%), *or* fuels with sulphur content in the range 0.04–0.2% are used *and* the VLS fuels chimney height calculation gives a lower value of U than the calculation used for coal/oil fuels, the permitted height of the flue may = U, *provided also that:*

- The flue gas is diluted with air at a ratio F, where $F = V/V_0$ (V = *actual flue gas volume and* V_0 = *the stoichiometric combustion volume)*
- The actual value of F *approximates* to 20 (in practice, this is a compromise).
- The emission velocity is at least 75 $m.s^{-1}$
- The outlet must not be within 50 U/F of a fan assisted air intake (except for intakes of combustion and/or fan dilution air for the boiler in question).
- The outlet must not be within 20 U/F of an openable window on the emitting building.
- The distance to the nearest building must >60 U/F.
- The lower edge of the outlet must be at least 2 m. high for boilers below 1 MW and 3 m. for others.
- The outlet should be directed at an angle above the horizon (preferably about 30°) and must not be under a canopy or emit into an enclosed wall or courtyard.

28.3.1.2 Flue heights for other chemical species

The *1956 Memorandum on Chimney Heights (1981 edition)* has the limitation that it is only applicable to flues serving conventional combustion plant where the pollutants of concern are sulphur and nitrogen dioxide. A number of combustion technologies have emerged since its publication to which it was never intended to apply (e.g. fluidized bed combustors, small generating plant, cogeneration systems). There was also increasingly a need for a method of assessing discharges from combustion plant burning non-fossil fuels and discharges of a wide range of chemical species from industrial processes of all sizes.

The *Memorandum* was therefore adapted and expanded to cover a wider range of pollutants and discharge conditions, in the form of *Technical Guidance Note (Dispersion) D1, Guidelines on Discharge Stack Heights for Pollution Emissions (June 1993).* This was produced by the predecessor of the present UK Environment Agency as part of the Guidance issued under the Part I of the Environmental Protection Act 1990 (see Section 28.4.2). The *1956 Memorandum on Chimney Heights* should continue to be used in cases which fall within its scope.

Technical Guidance Note (Dispersion) D1 aims to provide a method of calculating minimum stack heights which will limit ground level emission concentrations below a maximum level which might occur for periods of from a few minutes to up to an hour. Maximum concentrations are determined on the basis of protecting human health. The method is not intended to deal with the effects long-range transport of pollutants or long-term pollutant levels arising from multiple sources.

The method is restricted to controlled discharges of known characteristics and rate through a vertical stack. The discharge can be of any substance, in the form of a gas or particulates of aerodynamic diameter of less than about 40 μm, for which a guideline concentration has been determined.

The method is *not* suitable for controlling odorous, as opposed to harmful, discharges. Determinations are based on the "worst case" experienced in normal meteorological conditions, i.e. the 98th percentile envelope of wind velocity (<20 $m.s^{-1}$) and atmospheric stability.

Cases where topographical effects on dispersion around the stack are significant are excluded from the scope of the method. Stack heights can be calculated up to 200 m. but above 100 m. the stack height derived will be increasingly approximate. In either of these cases, more specialized methods will need to be applied.

In outline, the procedure is as follows:

Stage 1 – calculating the pollution index

Identify the significant pollutants The major pollutant(s) are those which produce the highest *pollution index*. This is the emission for which the minimum stack height is calculated. Multiple or closely co-located stacks can be treated together. Synergistic combinations of pollutants may need to be considered and a method for doing this is given below.

Determine the guideline concentrations for the pollutants There are no formal guideline environmental concentrations for many species in the UK. The following Table gives some short-term Ambient Guideline Concentrations commonly used for key pollutants, as set out in *Technical Guidance Note (Dispersion) D1:*

Pollutant	*Guideline Concentration*		*Source*[b]
	ppm	*mg.m*$^{-3}$[a]	
Sulphur dioxide	0.17	0.44	CA
Nitric oxide	0.83	1.00	CA
Nitrogen dioxide	0.10	0.20	EC
Hydrogen chloride	0.06	0.10	CA
Carbon monoxide	50.00	57.00	WHO
Ozone	0.09	0.18	EC
Formaldehyde	0.08	0.10	WHO
Suspended particulate matter	–	0.30	EC

[a] Converted from ppm at 20°C and 1 atmosphere pressure.
[b] CA = Commonly applied value.
EC = European Community Limit.
WHO = World Health Organization Guideline.

The above are intended to be used as guide limits for ground level exposure to pollutants in a typical plume from a stack. That is, they are acceptable for continuous periods of between five minutes and up to one hour and may be repeated intermittently but not too frequently (say 10% of the time). This therefore corresponds roughly to the 90th percentile concentration value.

These should be compared and contrasted with more recent UK (EU) and WHO air quality standards in Section 28.4.7. UK statutory Air Quality Objectives with comparable averaging times are on p. 28/10:

It is apparent from inspection of these, more recent, Air Quality Objectives that there is a possibility of their being more onerous for intermittent, elevated, short-term exposures than the guide-values set out in *Technical Guidance Note (Dispersion) D1*, which might therefore be considered to be obsolete in this respect. Thus, while the methodology for stack height calculation set out in the *Note "D1"* is still valid, actual guideline exposures for input into the calculations should be selected with some care, in the light of current available knowledge.

In the case of other pollutants, the *Note "D1"* uses modified values of occupational guideline concentrations. In the UK, the main document used for this purpose is the *List of Occupational Exposure Limits (EH40)* published by the *Health and Safety Executive*. These standards take into account the EU document *Indicative Limit Values* published under Directive 91/332/EEC. Other national lists include *List of MAK and BAT values, Verlag Chemie* (Germany) and *ACGIH Documentation of threshold limit values for substances in workroom air (American Conference of Government Industrial Hygienists)* (USA). These documents are produced in regularly updated editions.

Where *EH40* specifies a *Short Term Exposure Limit (STEL)* or a *Time Weighted Average (TWA)* for a substance, the guideline concentration is taken as one fortieth of the quoted value. Where a substance is scheduled under the UK *Control of Substances Hazardous to Health (COSSH) Regulations*, and has a *Maximum Exposure Limit (MEL)*, then a guideline level of one hundredth of the MEL is used.

The method used in the *Note "D1"* is not readily applicable to substances which have long-term exposure limits, e.g. lead. Likewise, substances like benzene and 1,3-butadiene are acknowledged to have no safe limit below which they can be said to pose no hazard to health: Their ambient Objectives in the UK *Air Quality Regulations* are based in part on considerations of practicability. The *Note "D1"* suggests two approaches to such substances: First, a method for screening for their relative importance in mixed discharges; second, a means of finding upper bound chimney heights which will be effective but higher than necessary.

Correct for background levels of pollution, if necessary Background levels of some common pollutants are sufficiently high to need taking into account. In these cases, the background value be subtracted from the Guideline Concentration in calculating the Pollution Index. If there is no significant ambient concentration, $B_c = 0$. If the background pollutant is a similar species to the discharged pollutant, then its *Polluting Equivalent Concentration*, B_e should be calculated and used instead:

$$B_e = B_c * (G_d/G_b)$$

where B_c = actual concentration of background pollutant
G_d = guideline concentration of discharged pollutant
G_b = guideline concentration of background pollutant

For cases where it is not possible to establish background concentrations of a pollutant, a tabulation of typical background concentration of common pollutants in different types of area is provided.

Consider combinations of discharged pollutants, if they occur Combinations of different pollutants should

Pollutant	*Objective*		*Averaging Time*	*Remarks*
	ppm[a]	*mg.m*$^{-3}$[b]		
Nitrogen dioxide	0.105	0.200	1-hour mean, 18 exceedances permitted per year.	Approximates to 99.98th percentile value.
Sulphur dioxide	0.100	0.266	15 minute mean, 35 exceedances permitted per year	Approximates to 99.99th percentile value.
	0.132	0.350	1-hour mean, 24 exceedances permitted per year	Approximates to 99.97th percentile value.
PM_{10} particulates	–	0.050	24-hour mean, 35 exceedances permitted per year	Approximates to 90th percentile value.

[a] Expressed in the Objective as ppb.
[b] Expressed in the Objective as $\mu g.m^{-3}$.

be treated separately, and the "worst case" stack height adopted. However, for similar pollutants, (e.g. groups of acid gases, organic solvents) a combined Pollution Index should be calculated and used in the stack height calculations. Conversion factors (G_d/G_b) are provided for common acid gases in relation to background levels of sulphur dioxide. However, emissions of oxides of nitrogen from combustion processes should be treated individually, because, as well as being acid gases, they have characteristic physiological effects and, in the case of NO_2, a UK/EC short term air quality Objective is set.

$P_i(\text{combined}) = P(1) + P(2) + P(3) \ldots$

where P_i (combined) = combined Pollution Index

$P(1) + P(2) + P(3) \ldots$ etc. = Pollution indices of the different but similar pollutants

Having assembled the above data, the Pollution Index P_i is given by:

$$P_i = [D/(G_d - B_c)] * 1000 \quad (\text{m}^3.\text{s}^{-1})$$

where D = discharge rate of pollutant (g.s^{-1})
G_d = guideline concentration of discharged pollutant (mg.m^{-3})
B_c = background concentration of discharged pollutant (mg.m^{-3})
(B_c may be replaced by polluting equivalent B_e if appropriate)

Stage 2 – calculating the discharge stack height

This is done using the Pollution Index P_i in conjunction with information about the discharge and surrounding buildings. Two uncorrected stack heights are calculated, based on buoyancy, U_b, and momentum, U_m, respectively.

Calculate the uncorrected discharge stack height for buoyancy, U_b For most cases, where the emission comprises either combustion products or a small proportion of contaminants diluted in air, the buoyancy is given directly by the heat release $Q(MW)$ at the stack outlet. If $Q < 0.03MW$, U_b is not calculated and the procedure passes directly to calculation of U_m, below.

Where heat release Q is not known, it may be determined by one of a number of methods:

Provided that the discharge comprises either combustion products or a small proportion of contaminants diluted in air, Q can be read off from the relevant nomogram provided in the *Note "D1"*. Alternatively, it can be calculated from the equation:

$$Q = \{V[1-(283/T_d)]\}/2.9 \quad (MW)$$

where V = total volume rate of discharge at discharge conditions ($\text{m}^3.\text{s}^{-1}$)
T_d = temperature of discharge gases (K); the ambient temperature is assumed to be 10°C (283 K)

In the rarer case where the discharge does not meet these criteria, the equivalent heat release of the buoyant discharge is given by:

$$Q = \{V[1 - (\rho_d/\rho_a)]\}/2.9 \quad (MW)$$

where ρ_d = density of discharge gases
ρ_a = density of ambient air

Alternatively, Q can be calculated using:

$$Q = \{V[1-(283m_w/29T_d)]\}/2.9 \quad (MW)$$

where m_w = mean molecular weight of the discharge gases

The calculated heat release should only include sensible heat and not the latent heat of condensation of any water vapour present. If water droplets are present, the calculated heat release should be reduced by:

$$0.0023\, n \quad (MW)$$

where n = rate of discharge of water droplets (g.s^{-1})

If $n < 13\,\text{g.s}^{-1}$ heat loss by these means may be disregarded.

If discharge gases are denser than air due to low discharge temperature, high molecular weight or the presence of a large amount of liquid water, the equivalent heat release can be calculated using one of the three equations above but will negative. If the calculated value is between zero and −0.03 MW, U_b should not be calculated and the procedure should move directly to calculation of U_m, below.

If $Q < 0.03MW$, the present method should not be used and specialist advice sought on the dispersion of heavier-than-air gases. The reader may wish to consult the *Workbook on the Dispersion of Dense Gases*, Britter and McQuaid (1988). Alternatively, increasing the heat release in the discharge may be considered.

Having determined, P_i and Q, U_b can now be read off from the relevant nomogram provided in the *Note "D1"*. Alternatively, it can be calculated using the equation:

$$U_b = 10^a P_i^b$$

where for $Q = <1\,MW$, $a = -1.11 - 0.19.\log_{10} Q$
$b = 0.49 + 0.005.\log_{10} Q$

and for $Q > 1\,MW$, $a = -0.84 - 0.1.\exp(Q^{0.31})$
$b = 0.46 + 0.011.\exp(Q^{0.32})$

The limits of application of the equation are:

$1\,\text{m.} < U_b < 200\,\text{m.}$

$0.03\,\text{kW} < Q < 100\,MW$

$50 < P_i < 10^7$

The nomogram shows overriding minimum values of U_b irrespective of the value of P_i. These minimum values can also be calculated from:

if $Q = <1\,\text{MW}$, $U_{\text{b, minimum}} = 1.95.Q^{0.19}$

and $Q > 1\,\text{MW}$, $U_{\text{b, minimum}} = 1.7 + 0.25.Q^{0.9}$

The lowest value of U_b for any heat release = 1 m. The *Note "D1"* is not applicable to values of P_i beyond about 10^7.

Calculate the uncorrected discharge stack height for momentum U_m This is calculated using the Pollution Index P_i and the discharge momentum M and is defined as:

$$M = (\rho_d/\rho_a).V.w \quad (m^4.s^{-1})$$

or

$$M = (\rho_d/\rho_a).[(\pi.w^2d^2)/4] \quad (m^4.s^{-1})$$

where ρ_d = density of discharge gas
ρ_a = density of atmospheric air
w = discharge velocity ($m.s^{-1}$)
V = volume rate of discharge at discharge temperature ($m^3.s^{-1}$)

Where the discharge comprises combustion products or air containing a small proportion of contaminants, more simple equations can be used, depending on available information:

$$M = (283/T_d).V.w$$

or

$$M = (283/T_d).(\pi.w_2.d^2/4)$$

Alternatively to the above, M can be found from the relevant nomogram provided in the *Note "D1"*, using stack diameter d and discharge velocity w, provided that the discharge comprises combustion products or air containing a small proportion of contaminants or is otherwise at ambient density.

Determinations of M from the nomogram can be corrected for other temperatures or densities by using the nomogram to determine the value of M for ambient temperature (assumed to be 10°C) by applying:

$$M = M_0(283/T_d)$$

or

$$M = M_0(\rho_d/\rho_a)$$

where M_0 = uncorrected discharge momentum from the nomogram.

In practice, if combustion gases are in the range 100–150°C, either of the above ratios can be taken to be = 0.7, which can be multiplied by the nomogram result.

Having determined M and P_i, U_m can be read off from the appropriate nomogram provided in the *Note "D1"*. Alternatively, it can be calculated using the equation:

$$\text{Log}_{10}U_m = x + [(y.\log_{10}P_i) + z]^{0.5}$$

where $x = -3.7 + (\log_{10}M)^{0.9}$
$y = 5.9 - 0.624.\log_{10}M$
$z = 4.24 - 9.7\log_{10}M + 1.47(\log_{10}M)^2 - 0.07(\log_{10}M)^3$

The limits of application of the equation are:

$1\,m. < U_b < 200\,m.$

$1 < M < 2.10^4$

$50 < P_i < 10^7$

The nomogram shows overriding minimum values of U_m irrespective of the value of P_i. These minimum values can also be calculated from:

$$U_{m,\,minimum} = 0.82M^{0.32}$$

The lowest permissible value of U_m for any value of M is 1 m.

Calculate final discharge stack height C, correcting for the presence of tall buildings, if necessary Having determined U_b and U_m, the uncorrected chimney height U is taken as the lesser of the two values. (If no value of U_b has been calculated then $U = U_m$).

The general principles of correcting the height to take account of surrounding buildings are similar to those in the *1956 Chimney Heights Memorandum (1981 edition)*. All buildings within $5U_m$ are considered. If $U > 2.5$ times the height of the tallest building, $C = U$. If U is less than this height, a correction for building effects is required.

In the common case where there is a single, significant building which is wider than it is high:

$$C = H + 0.6[U + (2.5H - U)(1 - A^{-U/H})]$$

where H = building height (measured to the ridge or other highest point, ignoring lift or tank rooms and other protrusions less than 1% of the roof area).
$A = U_m/U_b$.
If there is no value of U_b or, if $U_b > U_m$, then $A = 1$. In this case, the above equation reduces to:

$$C = H + 0.6U$$

(the same correction as in the previous Memorandum.)

In cases more complex than the above, the following particulars should be obtained for all buildings within $5U_m$:

H = building height, as above
B = building width (measured at right angles to a line joining the stack and the nearest point on the building).
K = the lesser of H or B
$T = H + 1.5K$
H_m = the largest value of H for the buildings
T_m = the largest value of T

If $U > T_m$, then $C = U$ (no correction required)
Otherwise, calculate C using the equation:

$$C = H_m + [1 - (H_m/T_m)] \cdot \{U + [(T_m - U) \times (1 - A^{-U/H}m)]\}$$

If there is no value of U_b or, if $U_b > U_m$, then $A = 1$. In this case, the above equation reduces to:

$$C = H_m + U[1 - (H_m/T_m)]$$

(the same correction as in the previous Memorandum.)

Various graphs for determining C are also provided in the *Note "D1"*.

Stage 3 – other considerations

Minimum discharge velocity and other flue exit conditions A minimum discharge velocity is required in order to prevent aerodynamic downwash from drawing the discharge plume down the outside of the stack, thereby reducing its effective height. The *Note "D1"* therefore specifies minimum discharge velocities for various values of both heat release and discharge momentum. The value which gives the greatest velocity should be adopted:

Heat release:	< 0.1 MW:	10 m.s^{-1}
	> 1 MW:	15 m.s^{-1}
	> 0.1 MW : <1 MW:	pro rata

Discharges should be vertically upwards and unimpeded by cowls etc., although coning or flame traps may be used. Stacks should extend at least 50% of the greatest lateral dimension beyond any shroud or casing.

Overriding minimum requirements for discharge stack heights There are minimum heights noted above for heat release and discharge momentum.

No stack should be less than 3 m. above the ground or any area to which there is general access, e.g. roof areas or walkways.

No stack should be lower than its uncorrected stack height, U.

No stack should be lower than the height of any building within a radius of $5U$.

No stack should terminate less than 3 m. above any opening window or ventilation air inlet within a distance of $5U_m$.

Some process Guidance Notes issued under the IPC/LAPC and IPPC regimes recommend minimum stack heights (see Section 28.4.2). These requirements should normally override stack height values calculated using the *Note "D1"*, where the latter indicate a lower value.

Discharge stack heights for plant with a wide operational range Some types of plant operate over a high turndown ratio or a wide range of throughput, giving wide variations in stack discharge conditions. Part load conditions may produce more severe pollution problems due to reduction in heat release or discharge momentum. Stack heights should be calculated for low loadings as well as maximum capacity and the highest calculated value adopted.

Multiple sources, nearby sources and combining emissions It is common to find situations in which similar discharges are made via multiple stacks, either combined in one structure or in close proximity. The advice in the *Note "D1"* assumes that separate multiple stacks are of similar height. This is the preferred option, because the taller of two stacks of dissimilar height will have a similar effect to a tall building on the shorter stack and should be treated as such. Considering downwash problems, it follows that low stacks should be *at least* $5U_m$ (calculated from the Pollution Index of the lower discharge) from taller stacks.

Multiple flue single stacks are treated as a single discharge, using the method described in the *Note "D1"* for combining Pollution Indices for individual pollutants. Heat release Q and momentum M can be summed and the stack height calculation followed as normal.

Stacks in close proximity are considered to be stacks within $5U_m$ of each other. If the stacks are within 3 stack diameters of each other, they should be treated as a single, multi-flue stack, as above. The procedure for stacks in proximity but further apart than this is summarized in the Table below.

Difficult siting In some locations, the presence of tall buildings in the vicinity but beyond $5U_m$ radius needs to be considered even if the requirements for minimum stack height calculated according to the *Note "D1"* are met. Buildings taller than the stack within *roughly* five building heights may cause plume meandering and intermittent problems with downdraught and plume impingement. Particular consideration should be given in this respect to ventilation inlets in such buildings.

Low stacks should not be situated in courtyard wells or enclosed areas except in the case of very small discharges. As a "rule of thumb", discharges into enclosed spaces less than $20U_m$ across and where the building heights are more than 20% of the spacing between them should be treated with caution and consideration given to placing the point of discharge above the buildings, using the building correction procedure set out in the *Note "D1"*.

Highly abated emissions Some plant operates with a high degree of emission abatement and, using the residual discharge values, low discharge heights may be generated by the above calculations. In such cases, consideration should be given to increased discharge height due to:

- ◇ The consequences of failure or deterioration of the abatement plant.
- ◇ The effects of visible droplet laden plumes or residual odour, as opposed to the identified, major pollutant(s).
- ◇ The existence of an emergency bypass stack which operates in case of plant failure.

In general, stack heights, even for highly abated discharges, should be sufficient to clear the immediate surroundings. For wide buildings, stack height of 1.5 times the height of the tallest adjacent buildings and, in other cases a height of $T + 1.5$ K, is recommended.

28.3.2 Computer-based dispersion modelling

In recent years, "paper" systems, while still being useful, have been overtaken by the major advances in the capabilities of computers: This has made proprietary computer-based atmospheric dispersion models practicable. Some

Spacing between stacks	*Pollution index, P_i*	*Heat release Q*	*Discharge momentum M*
Spacing < 3d	Sum values	Sum values	Sum values
3d < spacing < $U_m/2$	Sum values	Sum values	Use individual values
$U_m/2$ < spacing < $5U_m$	Sum values	Use individual values	Use individual values
$5U_m$ < spacing	Use individual values	Use individual values	Use individual values

require, e.g., a "UNIX" environment, but many PC-based models are commercially available.

Models have been developed which operate over a range of spatial scales: Some simulate the behaviour of pollutants on a global or continental scale; some take as input the emission sources of a pollutant of interest over the scale of a single City and predict concentrations at given points, or plot contours of distribution of the pollutant over the area; others model the behaviour and distribution of emissions from a single stack or highway. Nowadays, many "paper" dispersion models or workbooks are ultimately based on work done with computer dispersion models.

A major advantage of computer models is that the impact of proposed installations can be evaluated at the planning stage. The effects of alternative proposals or policy options can also be compared.

Models are based on various mathematical treatments of pollutant transport:

Gaussian models are based on the assumption that the concentration of a pollutant within an emission plume from a stack, at any given downwind distance from the point of emission, has independent Gaussian distributions in both the horizontal and the vertical planes. Such models can be adapted to calculate long-term average concentrations at any given point.

Eulerian models assume that a pollutant is inert and solve the Eulerian atmospheric diffusion equation (conservation of mass of the pollutant) over an array of three-dimension cells. In practice, these models are usually embedded in meteorological models and include submodels for the description of turbulence.

Lagrangian models treat pollutant plumes by dividing them into elements consisting of segments or "puffs" of fictitious particles in order to simulate the dynamics of the emission. Monte Carlo techniques of random sampling are used to calculate particles motion. Transport caused by average wind and motions due to turbulent, fluctuating wind can be taken into account (Figures 28.9 to 28.10).

Calculation of the dispersion of certain pollutants is complicated by the fact that they undergo chemical reactions whilst in the atmosphere. Some reactions are

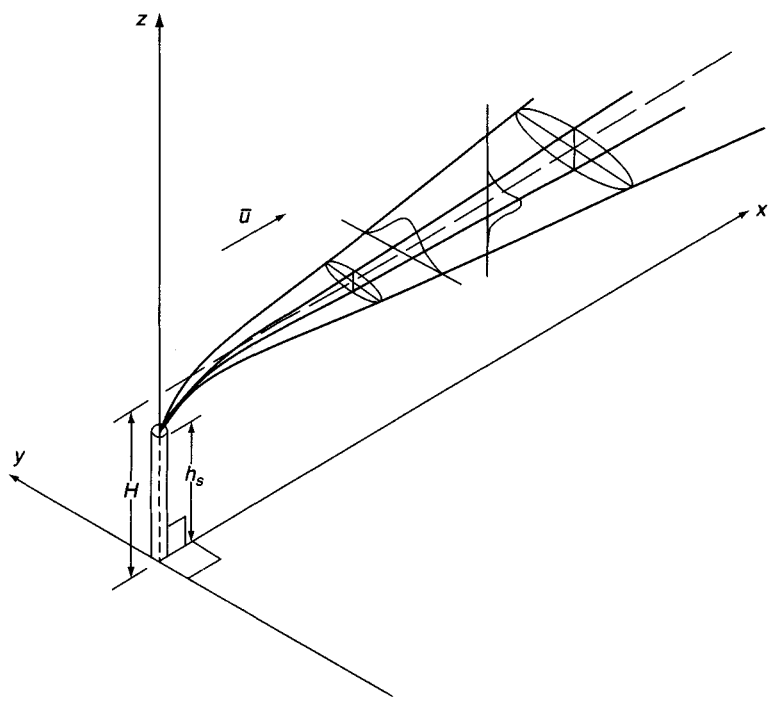


Figure 28.9 Gaussian Plume Rise (Source: Dobbins, 1979)

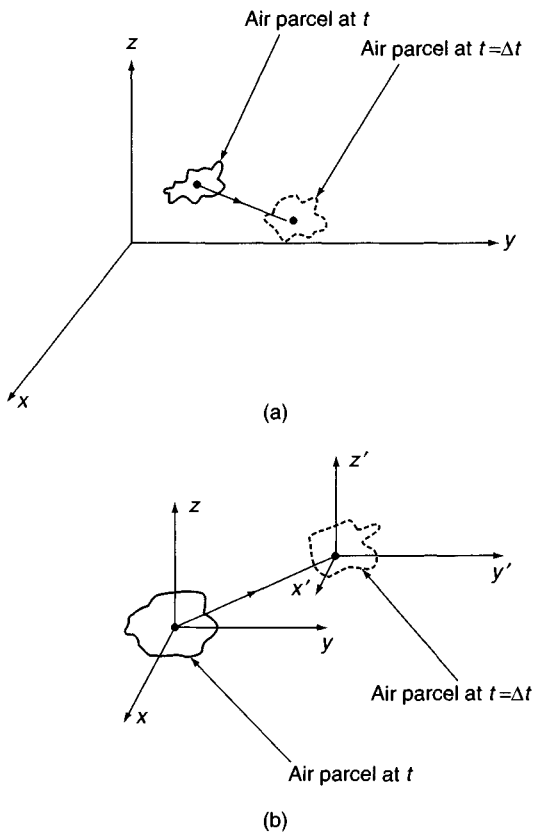


Figure 28.10 Eulerian (a) and Langragian (b) reference systems for the atmospheric motion. (Source: Lamb, 1980)

relatively simple, e.g. the formation of sulphates from sulphur dioxide. Others are very complex, e.g. the photochemical formation and subsequent breakdown of ozone, involving other species which are themselves pollutants. Clearly, if a model is to simulate the behaviour of reactive pollutant species, some mathematical treatment of the chemical transformations involved has to be built in: In Eulerian photochemical models, the computational domain is divided into cells in which chemical reactions are simulated at each time step. In Lagrangian photochemical models, a cell or array of cells is advected along the direction of the wind and emissions encountered along the trajectory of advance are injected.

Models generally incorporate statistical facilities to calculate trends, correlations and long-term concentration standards. Some models are designed to forecast the evolution of short-term pollution episodes.

Dispersion models require various forms of input data, depending on their characteristics and desired outputs *(Emissions Inventory)*:

Where a *point source*, generally a large stack, is modelled, specified input data about the installation, including stack height, diameter, efflux temperature etc. will need to be acquired.

Where an urban area as a whole is being modelled, it is not usually practicable to gather data on the large number of minor pollution sources such as individual vehicle movements or dwellings. It is therefore normal practice to aggregate such sources and make simplifying assumptions about their characteristics.

The two normal forms of this treatment are:

Line sources, usually major roads. Input data required will include traffic flows and speeds, traffic composition and emission factors for different types of vehicle.

Area sources. These are aggregations of, e.g. vehicle emissions in blocks of minor roads between major distributor roads, or combustion emissions from areas of housing or minor industry. They will usually be constructed from surrogate data such as vehicle kilometres or gas consumption per household.

One of the most important factors in pollutant dispersion is the weather (see Section 28.2) and meteorological data is therefore an essential input to dispersion models.

28.4 Legislation on air pollution of concern to the plant engineer

28.4.1 The UK, EU and world context

28.4.1.1 The global picture

There are certain, general issues which arise in the control of atmospheric pollution throughout the world:

- *Sustainable development:* This is the maintenance of economic activity which meets the needs of the present generation without depleting natural resources or damaging the environment to the extent that the interests of future generations are compromised.
- *The "Polluter pays" principle:* This was first stated in the proceedings of the United Nations Conference on the Human Environment, Stockholm, 1972, namely that the cost of preventing pollution or of minimizing the environmental damage which it causes must be borne by the person responsible. This may take various forms:
  - ◇ Taxes on polluting activities in order to encourage the use of alternatives and/or to fund pollution control.
  - ◇ Charges for permits to generate specific quantities of particular pollutants. These may be tradable: Operators who have more advanced pollution control may recoup the cost of their investment by selling a proportion of their "allotted" emission to companies in a less favourable position.
  - ◇ Cost recovery schemes, whereby charges are levied for permits to cover the costs of regulation. A example of this is the European Community IPPC regime (see Sections 28.4.1.2 and 28.4.2)
- *Best Practicable Environmental Option:* This is the principle that an holistic view must be taken of the environment and the option for disposal of pollutants taken which causes the least harm. For example, arresting an atmospheric emission might give rise to solid or liquid residues which themselves need disposal. Again, a toxic liquid waste may cause emissions of harmful pollutants to atmosphere when incinerated but the alternative might be landfill or discharge to water. These alternatives must be carefully weighed against each other. This principle is written into the EU IPPC legislation.

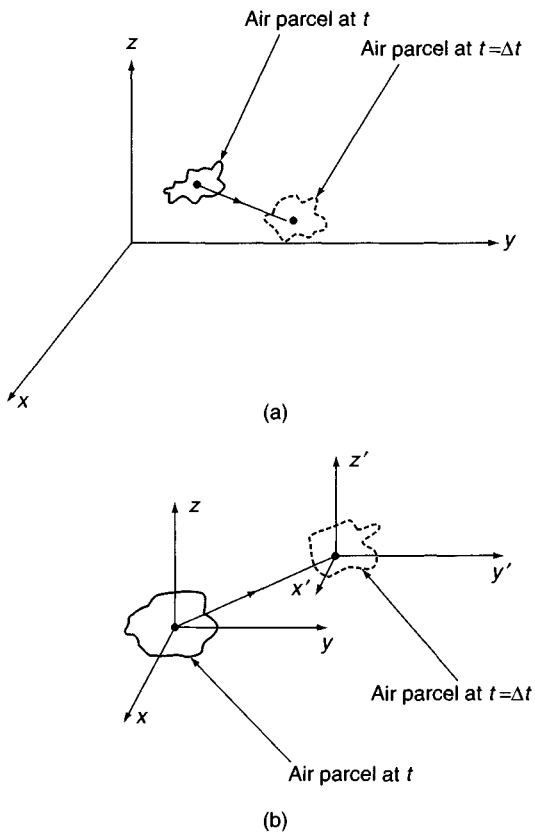


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- *Best Available Techniques (Not Entailing Excessive Cost) (BAT(NEEC)):* This, in effect, extends the previous principle to include the concept of *cost effectiveness.* It is recognized that industry must function and so a consensus must be reached as to those forms of pollution control which are:
  - ◇ *Technically feasible*, in the light of current knowledge.
  - ◇ *Economically feasible*, inasmuch as the costs of pollution control are proportionate to the environmental benefits derived and the costs to the operator.

  Again, this principle is enshrined in the EU IPPC regime: Guidance issued under the legislation, based on consultation with the relevant industries, represents the best consensus of what is reasonably practicable.
- *Emission Concentration Limits and Mass Limits, versus Environmental Standards:*
  An *Emission Limit* can be expressed as, for example, mass of a pollutant per unit volume passing through a stack or, alternatively, as a total mass emission of a pollutant over a given period, e.g. tonnes/year.
  The advantage of the former is that it can be monitored, possibly automatically, and both operator and regulator have a view over time of the performance of the plant. Using models, it will be possible to calculate ground level concentrations and, hence, public exposure. Conversely, it will be possible to back-calculate from a desired level of environmental exposure to derive desirable plant characteristics, such as stack height or abatement plant efficiency.
  The latter approach avoids the costs of detailed monitoring because it is based on inventory: Emission equals amount of material, for example an organic solvent, entering a factory minus the amount recovered or incorporated in the product. A criterion can be set in terms of mass of solvent consumed per unit of production. In any case, this method may be the only feasible means of estimating fugitive, as opposed to captured, emissions. Provided that no nuisance or health hazard is caused to the surrounding population, inventory alone may be a cost-effective form of control.
  An *Environmental Standard* has the advantage that more freedom may be permitted to individual industrialists in the approach which is adopted to pollution control. However, operators in already heavily polluted areas may be disadvantaged and subject to greater costs than their competitors elsewhere. Conversely, an industrialist in a comparatively "clean" area may not be so constrained and may, indeed, emit more pollution than is strictly necessary. The other side of the coin, of course, is that an operator subject to an *emission limit* in a relatively unpolluted region could argue that he is subjected to unnecessary costs of abatement.
  Historically, there has a tendency to impose emission limits on individual processes by "permit"; this approach has a pedigree extending back to the nineteenth century. A good example is the European IPPC regime, and its predecessors in the United Kingdom. (see Sections 28.4.1.2 and 28.4.2). More recently, there has been a focus on the complementary approach of setting Environmental Standards and targets, for example the EU Air Quality Daughter Directives (see Section 28.4.1.2). This implies a more strategic approach to regional, national and, ultimately, global pollution control.
- *Regulation versus Fiscal Measures:* Traditionally, much pollution control has been through "command and control" regulatory regimes and they continue, for example, in the EU IPPC regime. These have the advantage that everyone within the regime, both operator and regulator know where they stand; uncertainty is minimized for the industrialist and there is a "level playing field". However, it has been argued that fiscal instruments, e.g. pollution taxes, are ultimately more cost-effective in controlling pollution, because the allow the free operation of the market: Regulators are not necessary the best placed to "pick winners" in terms of control measures. Industrialists are less constrained and will develop innovative solutions to existing problems, whether through new abatement technologies, new processes or alternative products.
- *The Global Economy*: A consensus within a given regulatory regime of what is the best reasonably practicable form of pollution control has the advantage that all operators under that regime are on a "level playing field". Similarly, operation of a fiscal regime within a particular region, which benefits best available forms of control, encourages the general adoption of the best standards or of alternative products and technologies. The drawback, in a global economy, is that companies elsewhere may not be under the same level of constraint: This may have implications for costs and hence for international competition and for decisions by multinational companies as to the actual siting of installations.
- *The Rewards of Good Environmental Performance:* It can be argued that, "Good environmental performance is good business": The public is becoming ever more environmentally aware and environmentally sophisticated. Customers in many cases demand an "environmentally friendly" product. Companies increasingly scrutinize the environmental credentials of their suppliers. There is a *cachet* in many markets for being known to be environmentally responsible.
  Companies which do not develop new products and markets ultimately perish and environmental performance is an important factor here. Environmental controls are not necessarily all "downside": There are many, well-documented instances of companies which have comprehensively reviewed their processes and procedures and which have thereby made substantial savings on raw material and other costs. More fundamentally, there is an enormous global market for innovative environmental control technologies and processes and for new, environmentally-friendly products: Innovative companies will reap these rewards.

There are many pressing global pollution issues which have implications for the very existence of humanity, global warming, depletion of the ozone layer, acidification, disposal of hazardous wastes (see Section 28.1): They must therefore be addressed in the global dimension:

The *United Nations Conference on Environment and Development (UNCED)*, the "Earth Summit" was held in Brazil in 1992. Among other initiatives, the *Framework Convention on the Atmosphere*, the "Climate Treaty" emerged. This set targets for the reduction of emissions of greenhouse gases to 1990 levels by the year 2000. By October 1996, this had been ratified by 159 countries. In 1997 at Kyoto, parties to the Treaty agreed to binding targets for reducing emissions of six greenhouse gases, carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride. Different targets were agreed for different countries and the principle established that permitted emissions could be traded between countries, although, at time of writing, the details of how this will work have not been finalized. By April 1998, this agreement had been endorsed by 34 states.

Following a summit at Montreal in 1987, an agreement was signed *on substances which deplete the ozone layer, (the "Montreal Protocol")*, which has to date been ratified by 160 countries. It committed the industrial nations to a 50% reduction in consumption of chlorofluorocarbons (CFC's) by 1999. The protocol is regularly reviewed, strengthened and extended in the light of the latest scientific evidence.

The *Convention on Long-Range Transboundary Air Pollution* was adopted in Geneva in 1979 and has generated various sub-treaties:

- The *Helsinki Protocol* of 1985 set targets for emission or transboundary transport of *sulphur dioxide*. It was extended by the *Oslo Protocol* of 1994, which was based on individual countries' contribution to acid deposition.
- The 1991 *Sofia Protocol* similarly places limits on *nitrogen dioxide*.
- A protocol was agreed in 1991 at *Geneva*, controlling *volatile organic compounds* (VOC's).
- Two protocols signed at *Aarhus* in 1998 sought to control *heavy metals* and *persistent organic pollutants*.

28.4.1.2 The European community

The eleven, fundamental environmental principles on which EU environmental legislation is based are set out in the first *Environmental Action Programme* and elaborated in subsequent Action Programmes:

- Prevention is better than cure. Pollution should be rectified at source, not when it has escaped into the environment.
- Environmental effects should be taken into account at the earliest possible stage in decision making.
- The natural environment has a finite capacity for absorbing pollution; exploitation of natural resources which causes significant damage to the ecological balance must be avoided.
- Scientific knowledge should be advanced to enable the best possible environmental decisions to be taken.
- *The Polluter pays* for the prevention and elimination of environmental problems which he causes.
- Activity in one member state should not have adverse effects on the environment of another.
- Environmental policies must take account of the interests of developing countries.
- EU member states should act together in international organisations and promote international environmental policy.
- Citizens must be educated as to the importance of protecting the environment.
- Action must be taken at the most appropriate level to be effective, whether local, regional, national, EU-wide or international.
- National environmental policies must be co-ordinated within the EU, without affecting progress at national level.

EU legislation is issued as EU *Directives*. Often, broad objectives, conforming to the principles stated above, are set out in *Framework Directives*, aspects of which are then worked out in detail in *Daughter Directives*. Directives are binding on member states as to requirements, although the precise details of how these are embodied in national legislation is left up to individual countries. Members states can maintain or introduce protective measures more stringent than those contained in the Directive.

Legislation originates in the *Commission*, which has one or two members appointed by each member state. The Commissioners are assisted by officials organized into *Directorates General* covering different aspects of the EU's work, a sort of European "civil service".

Draft legislation then comes before the *Council*, which consists of one Minister from each member state and supporting working groups. In the first stage of formulation, the Council, in consultation with the *European Parliament* and the *Economic and Social Committee* arrive at a broad outline of the nature and shape of prospective legislation. This is known as the *Common Position*.

In the second stage of environmental legislation, if the primary purpose is protection of the environment or human health, decisions must be taken by a qualified majority of the Council of Ministers, although certain measures, e.g. those with fiscal implications, require unanimity. The Parliament can propose amendments, before the legislation is finalized.

In 1998, the Commission published a discussion paper, *Clean Air for Europe*, which proposed integrating all of the EU's air pollution control programmes within a single strategy.

The key EU measures on atmospheric pollution are:

Air quality *Framework Directive on Ambient Air Quality Assessment and Management (96/62/EU)*. This had to be implemented by member states by 21st May 1998: It required:

- Setting air quality objectives and limit values.
- Assessing air quality in a standardized manner.
- Making air quality information available to the public.
- Maintaining or improving ambient air quality.

This generated a number of Daughter Directives setting detailed air quality objectives, limit values and alert

thresholds and laying down common monitoring methodologies for sulphur dioxide, nitrogen dioxide, carbon monoxide, particulates, lead, ozone, benzene, PAH's, cadmium, arsenic, nickel compounds and mercury.

In the UK, this Directive resulted in the review and amendment in 2000 of the UK *Air Quality Strategy for England, Scotland, Wales and Northern Ireland* and the subsequent issue of revised Regulations setting new air quality Objectives, both under the provisions of Part IV of the *Environment Act 1995*. (See Section 28.4.5).

Greenhouse gases Following the 1998 Kyoto Protocol, the members of the EU are committed to reducing emissions of six greenhouse gases, the most important of which is carbon dioxide, by 8% by 2012, based on a 1990 baseline. Agreement on apportionment of this among member states has resulted in an allocation of 12.5% of this target to the United Kingdom.

The *Directive to Improve Energy Efficiency (93/76EC)* aims to reduce carbon dioxide emissions by around 25% by measures such as periodic inspections of emitters (e.g. motor vehicles and boiler plant), energy auditing of businesses and requirements for the thermal insulation of new buildings. Council Decisions have resulted in a rolling programme of energy efficiency promotion and improving arrangements for monitoring emissions of carbon dioxide.

At time of writing (2000) a Strategy Paper foreshadows measures for controlling methane, the second most important greenhouse gas.

Substances which deplete the ozone layer Under the terms of the Vienna convention and the subsequent Montreal protocol of 1987, the EU has adopted Regulations for the control and phasing out of chemicals which deplete stratospheric ozone: Chlorofluorocarbons (CFC's), other fully halogenated CFC's, halons, carbon tetrachloride,1,1,1-trichloroethane, methyl bromide, hydrochlorofluorocarbons (HCFC's) and hydrobromofluorocarbons (HBFC's). At time of writing (2000), the production, supply and use of most of these substances is banned. The use of HCFC's within the EU is to be phased out by 2009 with a final prohibition on production in 2025.

Industrial emissions Various measures have been put in place, aimed at reducing emissions of pollutants thought to contribute to the problem of *acidification*, (see Section 28.1.1.1:

A proposed Directive was published in 1999 to set national emission ceilings for sulphur dioxide, nitrogen oxides, volatile organic compounds (VOC's) and ammonia. This will augment the *Large Combustion Plant Directive (88/609/EU)*, which imposed specific reductions on member states in emissions from large fossil fuel burning plant over 50 MW. At time of writing (2000), proposals are under consideration to strengthen this Directive.

The Directive *On the Limitation of Emissions of Volatile Organic Compounds due to the Use of Organic Solvents in Certain Activities and Installations (99/13/EU)* is due to come into effect in 2001 and aims to reduce emissions by about 50% by 2010, based on 1990 levels. This will mainly affect the paint coating and pharmaceutical industries. Annexes specify in detail the processes covered and set annual solvent consumption and emission limits.

The *Directive on Integrated Pollution Prevention and Control (96/61EC)* creates a regime for regulation of specified industrial processes through the issue of Permits. The industrial sectors covered are: Energy, metallurgy, minerals, chemicals, waste management and "other activities", including pulp, paper and board production, treatment of fibres, and various animal, carcase and food operations.

The approach is an integrated one aimed at achieving a "high level of protection to the environment taken as a whole", using *Best Available Technology* (BAT): Not only are requirements to adhere to and to monitor pollutant emission limits imposed, but matters including materials consumption/energy efficiency, heat, noise, vibration and light emissions, accident prevention, waste management and site reinstatement are also regulated.

In the UK, the requirements of the Directive found expression in the *Pollution Prevention and Control Act 1999 (IPPC regime)*, (see Section 28.4.2).

28.4.1.3 The United Kingdom

The legal notes below apply specifically to the United Kingdom context and, more particularly, to England and Wales; many Acts and Regulations applying to Scotland and Northern Ireland, respectively, are different, although generally very similar in their principles and effect. There are also some variations relating to Greater London. Similarly, the structure of enforcement agencies differs in various parts of the United Kingdom.

The UK reader is therefore advised to refer to detailed, local provisions, where this is critical. The Local Authority will generally be happy to advise or to point enquiries towards the appropriate Governmental agency.

EU Directives are binding on member states, including the United Kingdom. This means that their main requirements must find expression in each member state's legislation although the details of how this is done will depend on national legislative tradition.

Much of the more recent UK legislation will therefore have parallelism with that of other EU countries and this will be extended in coming years. Where UK legislation is based on EU Directive, it is noted in the individual paragraphs below.

In most cases the same issues will be addressed by legislation world-wide and, in that sense, this Section can be treated as a "checklist". However, readers outside the United Kingdom, and particularly outside the EU, are urged to check the precise requirements of relevant legislation in the State concerned.

28.4.2 Integrated pollution prevention and control (IPPC)

Since 1990, the regulatory regime for specified industrial processes has been contained in Part I of the Environmental Protection Act. (Integrated Pollution Control/IPC and Local Authority Pollution Control/LAPC) However,

during the course of 2000, a phased process of extension and replacement by the *Integrated Pollution Prevention and Control (IPPC)* regime commenced. This has been enacted in UK legislation in compliance with the EU IPPC Directive (96/61/EU) (see Section 28.4.1.2) as the *Pollution Prevention and Control Act 1999*. Once all existing regulated processes have been transferred to control under the *Pollution Prevention and Control (England) Regulations 1999* (and similar provisions for Scotland and Wales), Part I of the Environmental Protection Act will be repealed. This is expected to be accomplished by 2007 so, at time of writing, some Authorizations issued under Part I of the Environmental Protection Act are expected to continue in force for some time.

Like its predecessor, the IPPC regime lays down that specified polluting industrial processes shall only be carried on subject to an *"Authorization"* (the term used under the old system) or *"Permit"* (the new term) and subject to conditions contained therein. Also as with its predecessors, the Environment Agency and local councils both play a role in its enforcement in England and Wales. In Scotland, the Scottish Environmental Protection Agency (SEPA) has responsibility for issuing all Authorizations/Permits.

A key principle of the legislation is that the Best Available Technique (BAT) is adopted to ensure a high level of protection to the environment as a whole, consistent with economic and technical feasibility. A holistic approach is taken and the best environmental option for disposing of each form of pollution must be considered. Emission standards, preferred abatement technologies, monitoring regimes and management procedures are laid down in Technical Guidance Notes.

Processes subject to this regime are specifically exempted from the application of many of the requirements of the general Law of Statutory Nuisance (Section 28.4.4, below) and the Clean Air Act 1993 (Section 28.4.3, below).

A statutory scheme of charges is laid down, which the regulatory authorities are required to follow in issuing and administering permits. The intention is that the scheme will result in enforcement activities being self-financing.

Under Part I of the Environmental Protection Act, detailed administrative procedures are prescribed in the *Environmental Protection (Applications, Appeals and Registers) Regulations 1991 (SI 507)* (as amended). Appeals by industrialists against regulatory decisions (e.g. revocation or refusal to grant an Authorization, conditions attached to an authorization) lie with the Secretary of State for the Environment. Details of each authorization and specified, associated documentation (monitoring data, legal proceedings etc.) must be kept by the regulatory authorities in a Register which is kept available for public inspection. These features are continued under the IPPC regime as it supersedes IPC/LAPC.

Unlike Part I of the Environmental Protection Act, IPPC does not solely regulate pollution of the atmosphere (plus pollution of water and land in the case of processes allocated to the Environment Agency): It is expanded to include the wider environmental impact of industrial installations, including site reinstatement, energy efficiency, noise and vibration, raw material consumption, waste disposal, accident prevention and environmental impact assessment. Some of these aspects clearly overlap with other legislation.

It has been estimated that the number of installations which will fall within the scope of IPPC in England and Wales represents a substantial increase over those covered by IPC/LAPC. Even where local authorities do not have primary enforcement responsibility for a particular process, they will have an important role as statutory consultees for certain aspects.

Under Part I of the Environmental Protection Act 1990, the regulated processes are specified in detail in the *Environmental Protection (Prescribed Processes and Substances) Regulations 1991 (EP-PPS Regulations) (SI 472)* (with various amendments). Processes are divided into *"Part A"* and *"Part B"* Processes:

"Part A" Processes are those which have the potential to pollute the air, water *or* land, so consideration must be given to the *Best Practicable Environmental Option (BPEO)* for dealing with their pollution. "Part A" Processes also tend to be those of relatively large size and/or those giving rise to particularly difficult or harmful pollutants. These processes are administered in England and Wales by the UK Environment Agency (by the Scottish Environmental Protection Agency *(SEPA)* in Scotland).

"Part B" Processes are those for which the primary focus of concern is on emissions to atmosphere only. In addition, they tend to be those of relatively smaller size than their "Part A" counterparts and/or not to involve the emission of really hazardous pollutants. Some processes are included irrespective of size and, for others, a threshold in capacity is specified in the *EP-PPS Regulations* below which authorization is not required. Moreover, processes whose emissions are "trivial" are exempted from authorization. Processes in the "Part B" category are regulated in England and Wales by the Local Authority in whose area they are situated (by the Scottish Environmental Protection Agency *(SEPA)* in Scotland).

Processes specified under the new IPPC system are classified as *"Part A1"* (Environment Agency) and *"Part A2"* (Local Authority or "LA-IPPC") processes. Processes regulated by local authorities under the existing EPA Part I regime and which are not within the scope of the IPPC Directive have been subsumed into the legislative framework as *"Part B"* processes.

Processes listed under the IPPC regime include: energy generation, metal processes, mineral industry, chemical processes, waste management and "other processes"; the latter includes pulp, paper and board production, pretreatment or dying of fibres, tanning, slaughterhouses and carcase processing, various food processes and intensive poultry and pig rearing.

Detailed guidance notes are provided under EPA Part I, separately for processes regulated by the Environment Agency *("IPC Notes")* and the Local Authorities *(Process Guidance ["PG"] Notes)*. These lay down emission standards and approved abatement technologies for specified processes. Under the incoming IPPC regime, UK national

industry sector guidance is based on *the European BAT Reference Documents ("BREF" Notes).*

Other, detailed guidance documents produced under this legislation, which may be of interest to the plant engineer are:

28.4.2.1 Technical guidance notes (abatement)

A1: Guidance on Effective Flaring in the Gas, Petroleum, Petrochemical and Associated Industries. (December 1993).

A2: Pollution Abatement Technology for the Reduction of Solvent Vapour Emissions. (October 1994).

A3: Pollution Abatement Technology for Particulate and Trace Gas Removal. (April 1994).

28.4.2.2 Technical guidance notes (dispersal)

D1: Guidelines on Discharge Stack Heights for Polluting Emissions. (July 1993).

[This is summarized in Section 28.3.1.2].

28.4.2.3 Technical guidance notes (monitoring)

M1: Sampling Facility Requirements for the Monitoring of Particulates in Gaseous Releases to Atmosphere.

M2: Monitoring Emissions of Pollutants at Source.

At time of writing (2000) these are likely to be updated within the IPPC regime in the foreseeable future.

28.4.3 The Clean Air Act 1993

28.4.3.1 Control of dark smoke

This Act finds its origin in severe smogs caused in the UK by emissions of smoke, grit and sulphur dioxide from combustion appliances in the early 1950's. It re-enacts and consolidates the provisions of previous Clean Air Acts and other legislation.

Definition of *Dark* and *Black Smoke* for the purposes of the Act:

For the purposes of this legislation, the shade of smoke is defined by comparison with a *British Standard Ringelmann Chart*. This is a simple comparator on which five squares obscured to various degrees by grids of black lines are printed on a white background. *Dark* smoke is defined as being as dark or darker than Shade 2 (40% obscuration) on the Chart. *Black* smoke is as dark or darker than Shade 4 (80% obscuration). The British Standard lays down a protocol for the use of the Chart although equivalent devices are permitted.

NB: The Act explicitly states that, for a court to be satisfied that smoke was or was not dark smoke, no actual comparison with the Chart needs to have been made.

Section 1 of the Act makes it an offence to emit *dark* smoke from the chimney of any building. It also extends to chimneys serving fixed boilers or industrial plant which are not attached to a building.

This prohibition is subject to several exemptions, singly or in combination:

- Lighting up from cold.
- Unavoidable mechanical failure.
- Unavailability of suitable fuel, the most suitable fuel being used.

  [NB: None of the above is an absolute defence but is in turn subject to the condition that all practicable steps have been taken to prevent/minimize the emissions.]
- The emission of dark smoke was within the periods allowed by *The Dark Smoke (Permitted Periods) Regulations 1958 (SI 498).*

  These regulations allow defined, permitted *aggregate* periods of *dark* smoke emission from any chimney over any period of 8 hours:
  - ◇ For a chimney serving one furnace, the permitted aggregate is 10 minutes. For chimneys serving more than one furnace, the permitted period increases in steps according to the number of furnaces, up to a maximum of four. For each case, additional time is permitted if soot blowing is carried out during the period in question.

  In addition:
  - ◇ *Continuous* emission of *black* smoke must not exceed 4 minutes, otherwise than by soot blowing.
  - ◇ No *aggregate* emission of *black* smoke may exceed two minutes in any thirty minute period.

  It can thus be seen that the Regulations prescribe three tests for smoke emission which must simultaneously be satisfied by any one chimney.

Section 2 of the Act makes it an offence to cause or permit the emission of *dark* smoke from industrial or trade premises other than from a chimney. An example would be a bonfire of waste material within the grounds of industrial premises which caused dark smoke. The *Clean Air (Emission of Dark Smoke) (Exemption) Regulations 1969 (SI 1283)* exempt specified cases involving research/demonstration or the disposal of materials otherwise difficult to dispose of, subject to various conditions to ensure that emissions are minimized.

28.4.3.2 Control of smoke, grit, dust and fumes

[NB: The somewhat arbitrary quantities appearing below are due to the legislation having been originally enacted in Imperial units and the specified quantities subsequently translated into SI units].

Definitions:

Grit: The *Clean Air (Emission of Grit and Dust from Furnaces) Regulations 1971* define "grit" as particles exceeding 76 μm in diameter.

Fumes: The Clean Air Act 1993 Section 64 defines "fumes" as any airborne solid matter smaller than dust.

Dust: British Standard 3405 defines "dust" as small, solid particles between 1–75 μm in diameter.

These definitions should be compared with those specific to the law of Statutory Nuisance (see Section 28.6.4, below).

The Local Authority must be informed before a furnace is installed in a building or fixed boiler. *Domestic furnaces*, defined as having a maximum heating capacity of less than 16.12 kilowatts are exempt. *(Act, Section 4).*

Notifiable installations must be capable of continuous operation without emitting smoke when burning the fuel for which they were designed. There is no definition of

"furnace" but, under this legislation it is taken to mean *"any enclosed or partly enclosed space in which liquid, solid or gaseous matter is burned, or in which heat is* [thereby] *produced"*.

Made under *Section 5* of the Act, the *Clean Air (Emission of Grit and Dust from Furnaces) Regulation 1971 (SI 162)*. Maximum permissible hourly mass emissions of grit and dust are tabulated for:

- Furnaces rated stepwise by heat *output* (maximum continuous rating in steam/hr. [from and at 100 degrees Celsius] in thousands of BTU/hr or MW). This applies to boilers and indirect heating appliances where the medium being heated is a gas or a liquid (for example an air heater).
- Furnaces rated stepwise by heat *input* (defined as above). This applies to indirect heating appliances other than those covered by the above, and direct heating appliances (i.e. where the combustion gases are in contact with the material being heated) but where that material does not itself contribute to the emission of grit and dust.

Maximum mass emissions of solids may be found in cases of heat input/output intermediate between those tabulated by interpolation. Specified maximum percentages of grit are laid down for different cases, in relation to the total mass emission of grit/dust. Provisions are made in the Regulations for the special cases of multiflue chimneys, multi-purpose chimneys, and high working loadings.

The Regulations do *not* apply to incinerators burning waste or solid/liquid waste matter, whether or not the resultant heat is put to other use. However, incinerators in general are covered by the provisions of the IPPC regime (see Section 28.4.2).

Section 6 requires specific furnaces (except domestic furnaces, as defined above) to be fitted with grit and dust arrestment plant approved by the Local Authority. This must also be properly maintained and used. This latter requirement must be borne in mind by those specifying and operating arrestment plant because the efficiency of such equipment will inevitably decline from the initial value under the typical, hostile conditions of operation.

The relevant furnaces are those used to:

- Burn pulverized fuel.
- To burn any other solid matter at a rate 45.4 kg per hour or more.
- To burn any liquid or gaseous matter at a rate equivalent to 366.4 kilowatts or more.

It should be noted that there are two possibilities under the Act for exemption from the requirement to fit arrestment plant:

- The Local Authority may exempt a specific installation on application, if satisfied that its emissions will not be *prejudicial to health or a nuisance*. A written decision must be given within 8 weeks and is subject to appeal.
- The Secretary of state for the environment has granted extensive exemptions for various classes of furnace under the *Clean Air (Arrestment Plant) (Exemption) Regulations 1969 (SI 262)*, when used for the purposes specified:
  - ◇ Mobile or transportable furnaces, when used for providing temporary heat or power during:
    Building or engineering work.
    Investigation or research.
    Agriculture.
  - ◇ Furnaces other than furnaces designed to burn solid matter at a rate of 1.02 tonnes per hour or more, in which the matter being heated do not contribute to the emission of grit and dust, *not being used for the purpose of incinerating refuse*, which fall within any of the following descriptions:
  - ◇ Furnaces burning liquid matter, gas or both.
    Hand-fired sectional furnaces designed to burn solid matter at not more than 11.3 kg per hour per square foot of grate.
    Magazine type gravity-fed furnaces designed to burn solid matter at not more than 11.3 kg per square foot of grate.
    Furnaces fitted with an underfeed stoker designed to burn solid matter at not more than 11.3 kg per square foot of the plan area of the combustion chamber.
    Furnaces fitted with a chain grate stoker designed to burn solid matter at not more than 11.3 kg per square foot of grate.
    Furnaces fitted with a coking stoker designed to burn solid matter at not more than 11.3 kg per square foot of area covered by the firebars, excluding the solid coking plate.

It is an offence for an exempted furnace to be used for any purpose other than that prescribed in the exemption, without arrestment plant.

Section 10 of the Act enables the Local Authority to serve notice requiring the periodic measurement of grit, dust and fume from specified furnaces (or ranges of furnaces served by a single chimney). The relevant furnaces are those used to burn:

- Pulverized fuel.
- Other solid matter at a rate 45.4 kg per hour or more.
- Any liquid or gaseous matter at a rate equivalent to 366.4 kilowatts or more.

The notice can require suitable adaptations to the chimney and the provision and maintenance of measuring equipment. The Local Authority must be informed of the measuring results and must be allowed to be present during the measurements.

If the plant burns:

- Solids, other than pulverized fuel, at less than 1.02 tonnes per hour, or
- Liquids or gases at less than 8.21 MW,

the recipient may serve a *counter notice* on the local authority requiring them to carry out periodic measurements at its own expense. The recipient must still provide the necessary adaptations and facilities.

Methodology and administrative procedures are provided by the *Clean Air (Measurement of Grit and Dust*

from Furnaces) Regulations 1971 (SI 161). Measurements should be made according to *British Standard BS 3405, 1983 (Simplified) Method for the Measurement of Particulate Emissions Including Grit and Dust* and the provisions of *Measurements of Solids in Flue Gases (Institute of Energy).*

The method is *gravimetric*, using *isokinetic* extraction at a grid of points across the section of the flue, determined by its size and geometry.

Section 12 permits Local Authorities to serve a notice on the occupier requesting information about furnaces and the substances being burnt in them.

Sections 14–16 are concerned with the regulation of chimney heights: The height must be approved if the proposed chimney serves a furnace used to burn:

- Pulverized fuel.
- Any other solid matter at a rate 45.4 kg per hour or more.
- Any liquid or gaseous matter at a rate equivalent to 366.4 kilowatts or more.

An application for approval must contain adequate information to enable the appropriate minimum height to be calculated. The procedure is contained in the 1956 *Clean Air Act Memorandum "Chimney Heights", (3rd Edition).* (Summarized in Section 28.3.1.1).

A written decision must given within 28 days of the application, unless the Local Authority and the applicant agree a longer period in writing. Failing this, unqualified approval is deemed to be given to the applicant.

The Local Authority must not approve the height of the proposed chimney unless satisfied that it is sufficient to prevent the smoke, grit, gases or fumes emitted from being prejudicial to health or a nuisance, so far as is "reasonably practicable" having regard to:

- The purpose of the chimney.
- The position and nature of surrounding buildings.
- The levels of local topography.
- "Any other matters requiring consideration in the circumstances".

Where consent is refused, reasons must be given in writing and the minimum acceptable height specified. Appeal lies with the Secretary of State for the Environment, who must provide similar information.

Conditions may be attached to the approval regarding the rate of quality of emissions from the chimney.

Section 16 of the Act applies outside Greater London to plans for any chimney not covered by Section 15, above, which are submitted for Building Regulations approval, other than those serving dwellings, shops or offices: A similar procedure applies.

In addition to the requirements of the Clean Air Act, the *Building Regulations 1991, Part J, Schedule 1* apply, irrespective of the capacity of the fireplace served, to the following heat-producing appliances:

- Solid fuel and oil burning appliances of rated output up to 45 kW.
- Gas fired appliances of rated input up to 60 kW.

The specified installations must:

- Receive sufficient air for the proper combustion of the fuel and operation of the flue.
- Be capable of normal operation without combustion products becoming a hazard to health.
- Be capable of normal operation without damaging the fabric of the building by heat or fire.

28.4.3.3 Smoke Control Areas

Section 18 of the Act enables a Local Authority to make an Order, declaring all or part of its area to be a *Smoke Control Area.* This has the effect of regulating fireplaces (combustion appliances) and fuels used in the designated area. The Order usually takes effect not more than 6 months after it is made and may specify or exempt classes of building or fireplace to which it applies.

In seeking to control smoke emissions, it is recognized that even smokeless fuels and efficient appliances will cause a modest emission of smoke, for example when lighting up. Therefore, the Act *(Sections 20–22)* makes it an offence to emit smoke from a chimney in a Smoke Control Area *other than* when burning *authorized fuels*, detailed in Regulations made under the Act. These comprise various proprietary cokes and briquettes manufactured from coal and other materials. In addition, electricity, gas, anthracite, semi-anthracite and low-volatile steam coals are authorized.

In practice, bituminous coal, oil and wood cannot be burnt in a Smoke Control Area except on an appliance specifically designed for smokeless operation. Appliances which are permitted are detailed in *Smoke Control (Exempted Fireplaces) Orders* and include:

- Appliances designed to burn liquid fuel.
- Coal burning appliances fitted with a mechanical stoker, having a heating capacity greater than 150,000 Btu/hr.
- Various specified proprietary appliances, including some designed to burn specific waste materials, e.g. wood waste.

Appliances are generally classed as "authorized" subject to their being used to burn the exact specification of fuel for which they are designed and their being installed, maintained and operated so as to minimize the emission of smoke, in accordance with their manufacturers' instructions.

Refuse cannot be burned in an incinerator in a Smoke Control Area unless the plant is capable of smokeless operation at all times or unless it is exempted in the Smoke Control Order.

The Clean Air Acts provided for extensive programmes of upgrading of combustion appliances within Smoke Control Areas, funded by grants from Local Authorities to owners of private dwellings. These were in part subsidized by central Government but this ceased for Orders made after 1995.

Many areas in the United Kingdom, especially in large cities, remain covered by Smoke Control Areas made in the period from the 1950's through to the 1970's. Although the regulatory powers remain in force, new

Smoke Control Orders are, at time of writing, relatively rare. This is in part due to most suitable areas having been dealt with and partly due to constraints on funding in recent years.

The Clean Air Act has been something of a post-war legislative "success story": It has been possible to clean public buildings in the expectation that they will remain so, in marked contrast to the situation in large towns when the first Clean Air Act was passed in the 1950's. In some cities, measured levels of sulphur dioxide and black smoke particles have fallen tenfold over this period. The emphasis of policy and legislation has now passed to the "invisible" pollutants, as discussed in Section 28.4.5, below.

28.4.4 Statutory nuisance: the Environmental Protection Act 1990, Part III

As stated in Section 27.8.4, a characteristic of UK legislation is the concept of "Statutory Nuisance". This originated in the nineteenth Century but is currently found enacted in Part III of the Environment Act 1990 (Sections 79–82).

28.4.4.1 The scope of statutory nuisance

The Act defines a range of matters, when they are *"prejudicial to health or a nuisance"*, as *statutory nuisances*, i.e. actionable by the Local Authority. These include:

- *Smoke emitted from premises.* This *excludes* the following cases, because they are covered by specific provisions of the Clean Air Act 1993 (See Section 28.4.3, above).
  - Smoke from the chimney of a private dwelling in a Smoke Control Area.
  - Dark smoke emitted from the chimney of a building, or a chimney serving the furnace of a boiler or industrial plant attached to a building or installed on any land.
  - Dark smoke otherwise emitted from industrial or trade premises (i.e. not from a chimney, e.g. by a bonfire).

    Smoke is defined as including *soot, ash, grit and gritty particles included in smoke.*

    Chimney is defined as including *structures and openings of any kind from or through which smoke may be emitted.*

    Premises is defined as including land.

    Industrial, trade or business premises is defined as including premises used for any industrial, trade or business purposes *and* premises on which matter is burnt in connection with any industrial, trade or business process. *Industrial purposes* includes *any treatment or process*, as well as *manufacturing.*
- *Fumes or gases emitted from premises.* This is restricted to premises which are private dwellings and is intended to deal with problems caused by defective domestic heating appliances.

  Fumes is defined as any airborne matter smaller than dust.

  Gas includes vapour and moisture precipitated from vapour.

  Dust, steam, smell or other effluvia arising on trade or business premises (as previously defined).

  Dust does not include dust emitted from a chimney as an ingredient of smoke (because it is dealt with under another heading).
- *Any accumulation or deposit.*

The Authority has a statutory duty to inspect its district for nuisances or may act on complaint.

Industrial processes which are specified in legislation as falling within the IPPC and LAPPC regimes (see Section 25.8.3) are exempted from the requirements of the Law of Statutory Nuisance. They are subject to their own, detailed regulatory regime and it is not reasonable to impose duplicate legislative requirements.

Statutory Nuisance Law therefore applies to all premises, domestic, commercial or industrial not covered by these more specific controls or unless they are excluded by the provisions of Part III of the Environmental Protection Act detailed above. It can be seen that a range of emissions and other nuisances, including odour are covered.

A peculiarity of the legislation is that it does not define the scope of nuisance. Reliance is placed on the Common Law definition of nuisance, some of which originates in the nineteenth Century. Nuisance is divided into two categories:

"Public Nuisance" is an unlawful act or omission to discharge a legal duty, which endangers the life, safety, health or comfort of a significant proportion of the public. This is a criminal offence and may, on indictment, be tried in the Crown Court, although this is extremely rare.

More relevant to the application of Statutory Nuisance legislation, *"Private Nuisance"* is *"unlawful interference or annoyance which causes damage to an occupier or owner with respect to his use or enjoyment of land"*. It should be noted that Private Nuisance is also a civil wrong, or *tort*, for which the perpetrator can be sued in the civil courts. Case law has thrown up a number of principles which the Local Authority needs to consider in dealing with cases of Statutory Nuisance:

It is no defence that the plaintiff came to the nuisance. I.e., if a person moves into a house and is affected by dust, smell or smoke from a long-established factory which amounts to a statutory nuisance, it is no defence for the operator of the factory to claim that he was there first.

The nuisance must be substantial and not fanciful. I.e. it must be considered by a "reasonable person" to amount to a nuisance. Thus, the nature, frequency, duration or time of emissions may be a significant factor.

The character of an area must be taken into account in assessing nuisance: Thus, what would be considered a nuisance in an exclusive residential area might not be so considered in a busy industrial district.

Malice or intent may be a factor but it is *not essential* to establish nuisance.

Only the lawful owner or occupier (tenant, mortgagee or lessee) of land is *entitled to the protection* of this legislation. Thus passers-by or guests in a hotel would not have a valid complaint, although the proprietor of the

hotel might, if, for example, affected by a persistent dust problem.

Similarly, the nuisance must generally *arise on premises* (which includes land).

Persons with a *special degree of sensitivity* are *not entitled to special protection*: For example, a person who is particularly sensitive to an emission from a factory, which does not trouble the "average" person, may not be entitled to the protection of this legislation.

Within the categories prescribed in the Act, there is no statutory guidance as to what amounts to a Statutory Nuisance and what does not. Similarly, there are no generally accepted emission limits or standards for the design of process plant, abatement equipment etc. In assessing nuisance, the Local Authority must therefore treat each case according to its context and merits.

To summarize, in considering proceedings for noise nuisance under Part III of the Environmental Protection Act 1990, the Local Authority will take into account a number of factors:

- The effect of the emission at a critical receptor e.g. the nearest house.
- The character of the area: This is relevant because the nuisance value of a particular emission will be greater in a high-amenity environment.
- The duration and frequency of the nuisance: An emission which occurs once a week for a few minutes may be regarded less seriously than one which is constant for long periods or recurs every few minutes.

28.4.4.2 Procedure in case of statutory nuisance

Where the Local Authority is satisfied that a statutory nuisance exists, or is likely to occur or recur it must serve a Notice (an *"Abatement Notice"*) on the person responsible for nuisance, containing all or any of the following:

- The requirement to abate the nuisance or the prohibition or restriction of its occurrence or recurrence.
- The requirement to execute such works or to take such other steps as will achieve the above.

The Notice must specify the time within which it must be complied with.

Where the person responsible for the nuisance cannot be found, or the nuisance has not yet occurred, the Notice is served on the owner or occupier of the relevant premises. Where the nuisance arises from a defect of a structural character, the Notice is served on the owner of the premises.

It will be noted that the Act covers nuisances which are continuous or intermittent or which have not even happened yet. The Notice may (although it need not) specify actual works to be done to abate the nuisance, e.g. the installation of a particular type of abatement plant. Alternatively, it may specify steps to be taken, for example, keeping external doors closed. The Notice could also specify an actual result which the operator must achieve, for example, no deposition of dust at a particular location, and leave the details of how this is achieved to the operator.

The recipient of the Notice has the right of appeal to a Magistrate's Court within 21 days of service. Regulations lay down various grounds of appeal:

- The Notice is not justified, i.e. the matter to which it relates is not a nuisance.
- There is a material defect in the Notice (e.g. it is addressed to the wrong person).
- The serving Authority has unreasonably refused to accept alternative means of abating the nuisance to those required by the Notice; alternatively, the requirements of the Notice are in some other way unnecessary or unreasonable in character or extent.
- The time allowed in the Notice for compliance is insufficient.
- The Notice should have been served on some other person(s) as well as, or instead of, the recipient.
- In the case of a trade or business, the *Best Practicable Means* have been used for preventing the nuisance to which the Notice relates.

If an appeal is entered, the Notice is suspended pending the determination of the Appeal, if the Notice does not specify otherwise. However, if the Local Authority specifically states in the Notice that it is *not* suspended on appeal, then it is not suspended pending the appeal hearing. This would be specified if:

- The case is one of emergency; or
- The suspension of the Notice would defeat the object of the Notice, (e.g. the Notice seeks to prevent a "one-off" occurrence which would be over before the appeal could be heard); or
- The public benefit derived from complying with the Notice greatly outweighs the costs of doing so (e.g. an unpleasant emission could be abated by some simple action such as keeping a door closed).

A Local Authority, in specifying that a Notice is not suspendable on appeal, runs the risk that, if the appeal is upheld, they may be liable for compensation. Therefore, this will not normally be done in cases where compliance with the Notice implies that production processes would temporarily cease or very substantial expenditure would be incurred on works.

If a court accepts an appeal, it may uphold the Notice, quash it altogether or vary it, e.g. by imposing less onerous requirements on the recipient.

Failure to comply with the terms of the Notice within the time allowed without reasonable excuse is a criminal offence, prosecutable in a Magistrates' Court. As well as imposing a substantial fine, the Court may impose a recurring fine for each day on which the nuisance continues or is repeated.

In cases of failure to comply with a Notice, the Local Authority, *instead of or as well as prosecuting*, may carry out the works or steps which the Notice specifies and recover costs reasonably incurred from the recipient of the Notice.

The Act lays down defences which are available in proceedings for breach of a Noise Abatement Notice:

Best Practicable Means, as well as being a ground of appeal, is also a defence available to any trade or business, if prosecuted. It is defined in the Act:

- *Practicable* includes consideration of local circumstances and what is technically or financially feasible. For example, it would be unreasonable to expect a small company to spend huge sums of money out of all proportion to its financial resources.
- *Means* includes design, installation, maintenance and manner and periods of operation of *plant and machinery* and the design, construction and maintenance of *buildings and structures*.
- The defence is only available when compatible with any duty imposed by law.
- The defence is only available when compatible with safety and with the exigencies of emergencies or unforeseen circumstances.

It must be noted that the defence of Best Practicable Means is only available if the matter to which it relates amounts to a simple nuisance; if it is so severe as to be *prejudicial to health*, the Statutory Nuisance *must* be abated.

Reasonable Excuse is also a defence for breach of, or non-compliance with, a Notice, e.g. because of circumstances which are not reasonably foreseeable.

There is no formal mechanism for withdrawing an Abatement Notice (although a court may quash it or alter it on appeal): In some cases, the requirements of a Notice may be discharged by carrying out the steps which it specifies, e.g. by carrying out specified work. Since Notices are served on companies or individuals, a change of ownership of the premises may render the Notice invalid. Similarly, the Notice may refer to an item of plant or a process which no longer exists e.g. due to an upgrade.

However, a Notice may be worded in such a way as to impose a continuing obligation upon the recipient, e.g. by setting a requirement to be met at a specified location. Under these circumstances, the recipient should take ongoing care that changes, such as the addition of extra plant or the maintenance deterioration of existing plant, do not place him in breach of the Notice.

The Act also gives private individuals the right to make a complaint of nuisance to a Magistrate, who may take similar action to the Local Authority.

Rarely, where a nuisance is considered so severe that normal nuisance procedure does not afford a sufficient remedy, the Local Authority, *instead of or in addition to*, taking standard nuisance action up to and including prosecution, may seek an *injunction* in the *High Court* against the person causing the nuisance. Breach of an injunction constitutes Contempt of Court and very severe penalties may be imposed, including imprisonment.

28.4.5 The Environment Act 1995, Part IV: local air quality management

Under the Environment Act 1995, the Government produced, and subsequently revised, the *National Air Quality Strategy* (January 2000): This document outlines the way in which air quality is managed in the UK and sets out the concept of *Local Air Quality Management*.

Government advisers considered the best available evidence from around the world and proposed Air Quality *Standards* for the key pollutants. These are based on pollutant levels at which it is considered that adverse human health effects will be avoided, even among vulnerable groups.

Realistically, air quality Standards cannot always be achieved overnight. Also, it is conceded that, for certain pollutants, a small number of exceedances of the Standards are unavoidable each year due to meteorological effects.

The Standards are therefore translated into *Air Quality Objectives*, by incorporating:

- Various target dates for compliance between 2003 and 2005
- In the case of certain pollutants, a small number of permitted exceedances each year.

The *Air Quality Regulations, 2000*, made under the Act give the Objectives legal force. The specified atmospheric pollutants are:

- Benzene
- 1,3-butadiene
- Carbon monoxide
- Lead
- Nitrogen dioxide
- Particles (PM_{10})
- Sulphur dioxide

An air quality Standard has been laid down for ozone but this has not been translated into a statutory Objective. The air quality Objectives are tabulated in Section 28.4.7, below.

Under the Act, Local Councils have a duty to carry out a periodic *Review and Assessment* of their air quality and publish the results. The aims of Review and Assessment are to:

- Identify parts of Local Authority areas where national measures will not achieve the Objectives by themselves, so local action is needed.
- Provide a basis for integrated local policy on air quality.

Councils are expected to consult widely on the Review and Assessment and to work in partnership with local communities and business.

The effort devoted to Air Quality Review and Assessment should be proportionate to the risk of the Objectives being breached. Therefore, the Government prescribes a phased approach, of progressively increasing complexity: The results of each stage indicate whether it is necessary to go on to the next. The final Stage consists of detailed and accurate investigation using monitoring, emissions inventories and dispersion modelling.

Where the Review and Assessment identifies areas in which the Air Quality Objectives will not be met, they must be formally declared as *Air Quality Management Areas*.

In Air Quality Management Areas, Councils must draw up a time-based *Action Plan*, integrating the full range of their functions in order to ensure that the Air Quality Objectives are met. Where the analysis performed under the Review and Assessment of air quality indicates that a stationary source, or category of sources, contributes significantly to an exceedance of the Objective for a particular pollutant, action may be taken under one or other of the regulatory procedures described in this Chapter.

28.4.5.1 Averaging times

Pollutants vary in the time-scale over which they have their effects: Benzene and 1,3-butadiene cannot be assigned a level below which there is absolutely no cancer risk. Similarly with lead, it has not proved possible to define a level of in the blood below which there are no effects. Therefore the Objectives for these pollutants are set at a level where the medical evidence suggests that significant health effects are very unlikely over a long averaging period for exposure, i.e. one year. At the other end of the scale, sulphur dioxide is noted for its acute, short-term effects and so one of the three Objectives for this pollutant is based on a 15 minute averaging time, in addition to 1 hour and 24 hour Objectives. Nitrogen dioxide has both acute effects at high concentrations and more insidious health effects at lower concentrations. Therefore, Objectives are set both with an hourly and a one-year averaging period.

28.4.5.2 Percentile compliance

In the case of nitrogen dioxide, PM_{10} particulates and sulphur dioxide, Objectives are set which have relatively short averaging times. There will inevitably be short periods of exceedance due to weather conditions for which allowance is made by adopting a *percentile* approach. For example, an annual *90th percentile* Objective is adopted for one of the Objectives for PM_{10} particulates and for one of the sulphur dioxide Objectives: I.e. the criterion can be exceeded for about 10% of the days in each calendar year: Allowing for rounding, the daily maxima can therefore exceed the limit value on 35 days in each year before the Objective is breached.

28.4.5.3 Running means

Monitoring values at a single, fixed point are likely to fluctuate over short periods because of variations of microclimate and nearby transient sources. Short-term variations are therefore smoothed out by expressing the Objective for some pollutants as a running mean over an appropriate time-scale. E.g., the problem for benzene is caused by exposure over a long period, so the Objective is stated as a running annual mean of hourly values. Similarly, the Objective for carbon monoxide is expressed in terms of a running 8-hour mean.

28.4.5.4 Exposure

The purpose of the Air Quality Objectives is to protect human health: Exceedances of the Objectives are only therefore a valid basis for further action where they occur at outdoor locations at which members of the public (*not* persons occupationally exposed) are regularly present *for periods equal to the averaging time specified for the relevant pollutant.*

28.4.6 The Town and Country Planning Acts and other planning controls

In the United Kingdom, new development or the change of use of existing developments between specified categories requires permission ("Planning Permission") from the Local Authority ("Planning Authority"). *(Town and Country Planning Act 1990* and various Regulations and Orders made under that Act.)

The Planning Authority must have in place and periodically review a plan ("Local Plan") for its whole area, indicating what it considers to be appropriate land uses in different parts of the area and laying down detailed policies governing different kinds of land use.

An application for planning permission must be submitted for each individual proposed development (or material change of use). This will be considered in terms of the guidelines laid down in the Planning Policy Guidance and the Local Plan, and on its own merits, according to various criteria.

Where planning consent is sought for a building, or change of use to an existing building, which places that development in the "Light Industrial", as opposed to "General Industrial" category, then, by definition, the development must be capable of operation in a residential area without loss of residential amenity due to, among other things, smell, fumes, smoke, soot, ash, dust or grit.

The Planning Authority will consider the impact of atmospheric emissions from the proposed development on surrounding occupiers and whether the appearance of the finished structures is acceptable. Clearly, the location of a project will be significant: What may be acceptable in an industrial zone remote from housing may not be acceptable in close proximity to residential property.

The application may be refused or granted with Conditions, subject to appeal to the Secretary of State for the Environment.

Planning Conditions may lay down requirements to minimize the generation or emission of atmospheric emissions unless the development is regulated under the IPPC regime (see Section 28.4.2).

It is therefore important to give careful consideration to the design and positioning of mechanical plant at the planning stage. It is often useful to consult with the Planning Authority at the outset in order to establish what standards of performance need to be "designed in" to the submission for Planning Permission.

In certain cases, particularly where plant is added to existing buildings which are classified by the Planning Authority as being of aesthetic merit, the appearance of the finished installation may be a significant factor. Visible external mounting of plant may therefore be unacceptable to the Authority and it is worthwhile establishing this at the planning stage.

28.4.7 Environmental air quality standards

Table of United Kingdom Air Quality Objectives (2000)

Pollutant	*Sources*	*UK 1995 emissions (1,000's of tonnes)*	*Per cent of UK emissions from traffic*	*Air Quality Objective*	*Date for Compliance with Objective (31st December of year).*
Benzene	Petrol use	35	67	16.25 $\mu g.m^{-3}$ (5 ppb) annual mean	2003
1,3-Butadiene	Petrol use	9.6	77	2.25 $\mu g.m^{-3}$ (1 ppb) annual mean	2003
Carbon monoxide	Poor combustion of carbon fuels	5478	75	11.6 $mg.m^{-3}$ (10 ppm) running 8 hour mean	2003
Lead	Industry. Being phased out in petrol	1.5	78	0.5 $\mu g.m^{-3}$, annual mean	2004
				0.25 $\mu g.m^{-3}$, annual mean	2008
Nitrogen dioxide	Motor vehicles. Combustion plant	2293	46	200 $\mu g.m^{-3}$ (105 ppb), 1 hour (18 exceedances permitted per year)	2005
				40 $\mu g.m^{-3}$ (21 ppb) annual mean	2005 (provisional)
Particulates (PM_{10})	Primary: Motor vehicles and combustion plant. Natural sources	232	26	50 $\mu g.m^{-3}$, 24 hour (35 exceedances permitted per year)	2004
	Secondary: Remote combustion plant.			40 $\mu g.m^{-3}$, annual	2004
Sulphur dioxide	Combustion plant (power stations)	2365	22	266 $\mu g.m^{-3}$ (100), 15 minute mean (35 exceedances permitted per year)	2005
				350 $\mu g.m^{-3}$ (132 ppb), 1 hour mean (24 exceedances permitted per year)	2004
				125 $\mu g.m^{-3}$ (47 ppb), 24 hour mean (3 exceedances permitted per year)	2004
Ozone	Secondary from action of sunlight on NO_x and VOC's			**NO STATUTORY OBJECTIVE SET** Provisionally: 1000 $\mu g.m^{-3}$ (50 ppb), daily maximum of running 8 hour means. (10 exceedances permitted per year)	(2005)

Table of World Health Organization Air Quality Guidelines

Substance	*Time-weighted Average*	*Averaging Time*
Classical Air Pollutants		
Nitrogen dioxide	$200\,\mu g.m^{-3}$	1 hour
	$40\,\mu g.m^{-3}$	Annual
Ozone	$120\,\mu g.m^{-3}$	8 hour
Sulphur dioxide	$500\,\mu g.m^{-3}$	10 minutes
	$125\,\mu g.m^{-3}$	24 hour
	$50\,\mu g.m^{-3}$	annual
Carbon monoxide	$100\,mg.m^{-3}$	15 minutes
	$60\,mg.m^{-3}$	30 minutes
	$30\,mg.m^{-3}$	1 hour
	$10\,mg.m^{-3}$	8 hours
Particulate matter	Exposure-effect under review at time of writing (2001)	
Organic Pollutants		
PAH (benzo-a-pyrene)	$8.7 \times 10^{-2}\,\mu g.m^{-3}$	lifetime
Benzene	$(4.4 - 7.5) \times 10^{-6}\,\mu g.m^{-3}$	
Inorganic Pollutants		
Lead	$0.5\,\mu g.m^{-3}$	annual
Arsenic	$1.5 \times 10^{-3}\,\mu g.m^{-3}$	lifetime
Cadmium	$5 \times 10^{-3}\,\mu g.m^{-3}$	annual
Mercury	$1.0\,\mu g.m^{-3}$	Annual

29 Dust and fume control

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29.1 Introduction

The presence of dusts and fumes in the workplace has been a part of industrial life for many years and the hazards associated with them are well known. Systems have been developed to control these and reduce the exposure of them to personnel. Many of the techniques used were based on empirical data and often the resulting control system was a compromise between effective control and cost. Although industrial activity was subject to The Factories Acts it was only specific hazardous substances such as lead and asbestos that had clearly defined permitted levels of exposure. The introduction of The Health and Safety At Work Act 1974 completely changed attitudes to dust and fume control not only at the workplace but also at points of emission of dusts and fumes to the outside atmosphere. The attitude towards working conditions has changed from one of accepting some work as "dirty" to one where these conditions will not be accepted. To ensure that control measures are effective in controlling hazardous substances specific regulations, which are part of The Health and Safety At Work Act 1974, have been introduced.

The effect of these changes on the Plant Engineer has resulted in a greater increase in the burden of work and in the content and level of knowledge of the subject. Account must now be taken of the work and activities within the plant, its effect on personnel inside and people and surroundings, outside. To effectively control dusts and fumes it is imperative that those responsible for the specification and running of the plant are well versed in the nature of dusts and fumes, methods of entrainment, available equipment and inspection and testing techniques. Whilst the plant engineer need not necessarily design control plant they should have sufficient knowledge and experience to assess its effectiveness. **It is the responsibility of the owner or user of the plant to conform to the regulations and not a third party contractor.** The contractor, will of course, have commercial obligations to meet and these should be made known to all parties before a contract is placed. To assist in this briefing the purchaser should carry out a formal risk assessment of the activity. This will establish the substances being used and checked with HSEEH40 to ascertain whether specific exposure levels or any other hazards exist. **If a substance is not listed in EH40 it does not mean that the substance could not be a danger to health.** If that is the case then the general exposure for all substances would apply. Having carried out the risk assessment the plant engineer **must** become familiar with the relevant regulations and approved codes of practice (ACOP's) and it is advisable to read the guidance booklets on dust and fume control. The table below gives the relevant documents and sources.

The new legislation has had its effect on the dust and fume supply industrial. The quality of equipment, support, and technical competence of personnel have all improved. The supply industry is better placed to give the purchaser what is required as a result of the development of sensible standards effectiveness which are verifiable. Effectiveness is measured by what degree the plant controls the contaminant both at the source of the contaminant, that is usually the workplace, and the air discharge to atmosphere. Efficiency, on the other hand, is measured by the overall–cost power relationship. It is the job of the dust and fume control engineer to produce the most effective system to meet current legislation in the most efficient way.

References

Legislation

- SI 1974 No. 1439 Health and Safety at Work etc Act 1974
- SI 1999 No. 437 The Control of Substances Hazardous to Health Regulations 1999 (COSHH)
- SI 1987 No. 2115 The Control of Asbestos at Work Regulations 1987
- SI 1998 No. 3235 The Control of Asbestos at Work (Amendment) Regulations 1998
- SI 1998 No. 543 The Control of Lead at Work Regulations 1998
- SI 1985 No. 1333 The Ionizing Regulations 1985
- SI 1992 No. 2051 The Management of Health and Safety at Work Regulations 1992
- SI 1998 No. 2306 The Provision and Use of Work Equipment Regulations 1998
- SI 1997 No. 1713 Confined Spaces Regulations 1997

Note: SI denotes Statutory Instrument.

Health and Safety Executive

HSE. guidance

* **HSG37** An introduction to local exhaust ventilation
* **HSG54** Maintenance, examination and testing of local exhaust ventilation
* **L5General** COSHH ACOP (control of substances hazardous to health) and Carcinogens ACOP (Control of carcinogenic substances) and Biological agents ACOP (Control of biological agents)
* EH40 Occupational exposure limits (Periodically revised)
* L27 The control of asbestos at work. Control of Asbestos at Work Regulations 1987. ACOP
* COP2 Control of lead at work. Approved Code of Practice.
* MDHS82 The dust lamp: a simple tool for observing the presence of airborne particles.
* HS(G)97 A step-by-step guide to COSHH assessment
* HS(G)53 The selection, use and maintenance of respiratory protective equipment: a practical guide
* L101 Safe Work in Confined Spaces. Confined Spaces Regulations 1997. Approved Code of Practice, Regulations and Guidance.

Other publications

- Industrial Ventilation 'A Manual of Recommended Practice', American Conference of Governmental Hygienists (Revised at approximately two year intervals)

- BOHS Tech.Guide 7, Controlling airborne contaminants in the workplace. British Occupational Hygiene Society.
- A Guide to Risk Assessment. The Institution of Plant Engineers.

29.2 The nature of dusts and fumes

Dust can be said to be a solid broken down into powder, and the form that it takes will have different effects on the body. Fibrous dusts can attack tissue directly while others may be composed of poisons which are absorbed into the bloodstream. For the purpose of this chapter fume can be regarded as very small particles resulting from chemical reaction or condensation of vapour. It is not necessary for the plant engineer to have an in-depth knowledge of the pathology but must be aware that dust and fumes can enter the body by inhalation, ingestion and absorption through the skin. The standard unit for measuring particles is the micron(μ). The smallest particle visible to the naked eye is between 50 and 100 μ and the most dangerous sizes are between 0.2 and 0.5 μ. It could be assumed that particles larger that 50 μ are safe from inhalation. This is not so, as dust and fume clouds seldom consist of particles of one uniform size. Analysis would show percentages of different sizes and it is for this reason that the concentration and distribution of the particles is a better indication of its possible harmful effects on the body. Concentrations are measured in Mg of substance per cubic metre of air (Mg/M^3) As contaminants can enter the body by three routes it is also necessary to know the chemical composition of the substance so that its toxicity can be determined, also the shape and form of the particles. The adoption of a concentration standard, not only for toxic substances but all substances, was a major step forward in providing healthy working conditions at the workplace.

The United Kingdom level of concentration for any dust, irrespective of whether or not it is classified in HSE EH40 is:

10 Mg/M^3 Total dust irrespective of type both levels 8 hour time weighted average	4 Mg/M^3 respirable dust

Clearly the assessment of dust clouds cannot be left to the casual practitioner and this has now become the specialized field of the industrial hygienist.

29.3 Control of dusts and fumes

The purpose of the control plant is to maintain a working environment that is acceptable in terms of any statutory regulations and the custom and practice within the industry. All control plants should have the five elements shown in Figure 29.1.

Hoods
Ducting
Fan
Collector or separator
Disposal system

29.3.1 Hood

This is the inlet into the system, and is the most important single element in determining the effectiveness of the system. A study of the contaminant producing process is necessary to ensure that the twin aims of effectiveness and efficiency are met. A small hood close to the source requiring less air is better than a large hood or small hood far from the source requiring high volumes or catchment velocities. Hoods that totally enclose may prevent the operator from carrying out the process for which the control was needed.

There are four rules for the **design** of effective hoods, irrespective of the process:

1. The hood should be placed as close to the source of generation as possible.
2. The location and shape of the hood is such that the contaminant is thrown into the hood.
3. The air flowing past the source and into the hood has a velocity at the source greater than the escape velocity of the contaminant.
4. The hood must be located so that the operator is never between the source and the hood.

Using these rules hoods can be designed to suit any substance. These can range from wood waste to highly toxic material comprising particles of very fine size to large chippings. Manufacturers of many machines have standard hood designs which are supplied with the machine. This is a trend to be encouraged as the best design of hood can be achieved when a the machine is at the design stage. For all other types of hoods it is necessary to look at each application and make to suit. The following examples will illustrate the application of the rules.

29.3.1.1 Enclosures

These can be totally enclosed such as in Figure 29.3(a) with the operator standing outside the enclosure and through glove ports is able to work safely inside. The enclosure is placed under negative pressure thereby eliminating any leakage to the operator and this arrangement is particularly adaptable for highly toxic substances. The use of total enclosures has now found wide application where robots are used. Repetitive operations which are best done by robots do, by their nature, produce more unwanted dust, fumes and noise than the same operations carried out by humans. Putting the process in an enclosure and removing the unwanted dust and fume via an exhaust system will produce a very friendly working environment for operators outside the booth.

This approach has been used in the plastics industry. Plastic mouldings produce large amount of "flash" which has to be removed. In the removing operation not only has flash to be carried away but also the dust caused by de-flashing.

A good starting point in designing any hood is to completely enclose the operation. If the process is unaffected by the enclosure the control of any substances will be satisfactory; should it not be possible to carry on the process, observe what part of the enclosure has to be removed to

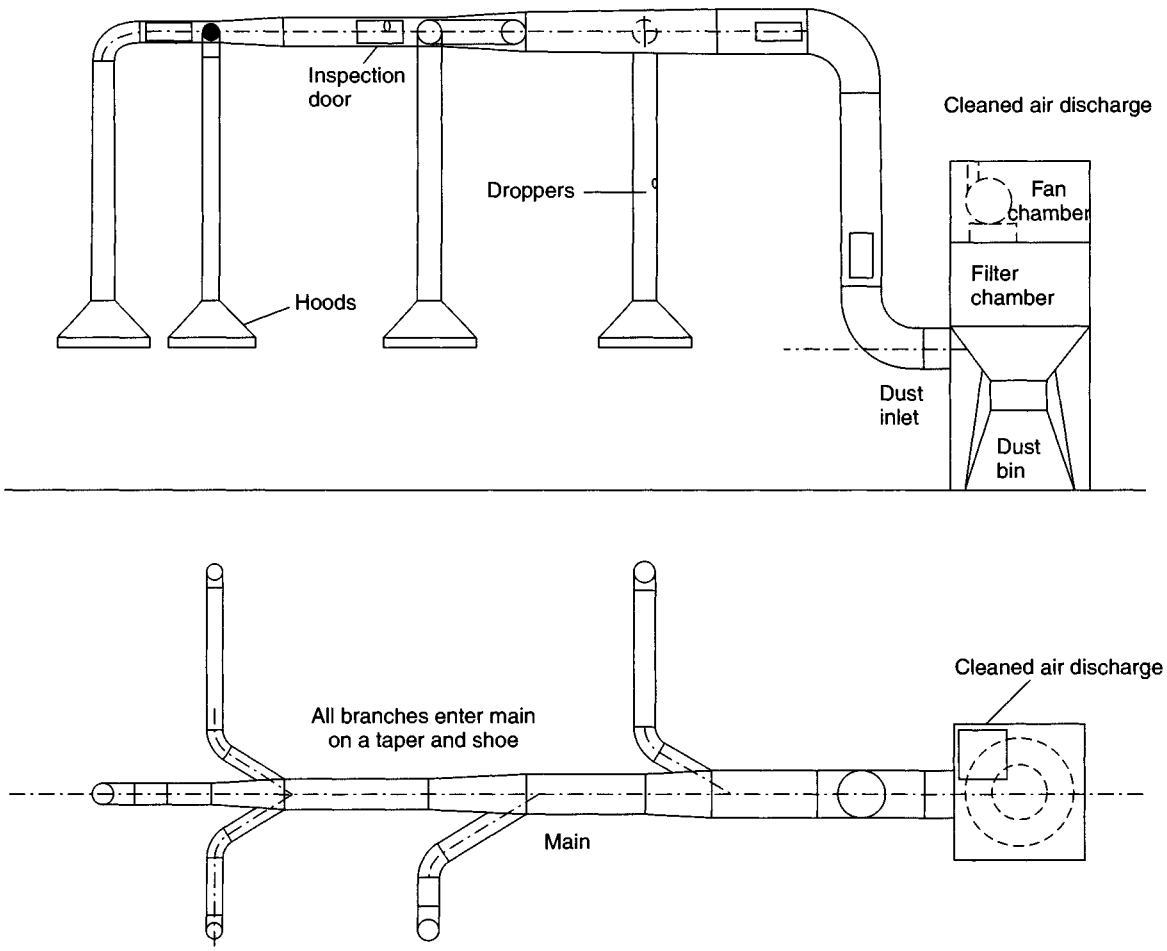


Figure 29.1 All Ductwork to have a conveying velocity that is near constant throughout the system

allow this to happen. The principle being that the more a process is enclosed the better will be the control.

29.3.1.2 Booths

These are really enclosures with one whole side removed and where the contaminant source is deep within the booth. The operator would normally stand either just outside the booth as in spraying operators or inside for filling and weighing operations. The restraining or control velocities across the face of these booths would be 0.5 M/sec. If a booth is used for grinding or fettling the restraining velocity would need to be in excess of 1.0 M/sec.

29.3.1.3 Captor Hoods

In some processes it is not possible to use enclosures or booths without imposing unacceptable operational restraints. The hood must be placed some distance from the source, with the natural projection of the contaminant not necessarily being into the hood. Figure 29.2 is an example of a captor hood used on an open top salt bath furnace. The temperature within the furnace pot can be as high as 1200°C and the chimney effect projects contaminants upwards. The hood control velocities can be as high as 10 M/sec depending upon the furnace temperature. Another captor hood is shown in Figure 29.3 (c) serving a dipping tank. The tank temperatures are unlikely to be as high as those in furnaces, consequently the restraining velocities can be much lower and hence more economical to run. These use two high velocity slots for control which would not be higher than 5 M/sec. It is usual on this type of application to design on the basis of a restraining velocity across the surface of the tank. This velocity will depend upon the contents of the tank and the temperature of the liquor it contains. In general terms velocities of the order of 0.75 M/sec. will be suitable for many applications.

29.3.1.4 Receptor Hoods

These derive their name from the method of entrainment. The hood is placed in the path of the particle and uses its momentum to assist in the control. It is important to have a clear understanding of the process, the direction

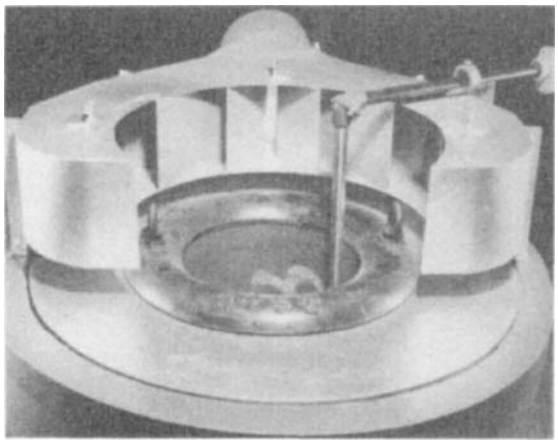


Figure 29.2 Captor-type claw hood for a furnace

the particles take and the effect of air movement created by the process. Grinding, sawing and cutting are examples of receptor hoods which are now frequently supplied by the manufacturer as original equipment. Figure 29.3 (b) is a typical hood for saws and it is now common to fit an air connection to catch any particles that cling to the saw which would otherwise be thrown into the face of the operator.

29.3.2 Ducting

The purpose of ducting is to convey the contaminants away from the source to air separation equipment. It is often the most neglected part of the control plant. Ideally the ducting should be purpose designed to suit the application but a worrying trend has been the growth in "off the shelf" ducting of limited standard sizes. Whilst this is very convenient for dealing with clean air and light fumes its use on dust applications has to be treated with extreme caution. If a standard sized duct is used, where a none standard is required, the conveying velocity is likely to be incorrect. The result could be too low a velocity, which allows particles to settle in the duct, or too high a velocity which means increased turbulence in the system and wasted power. Ducting should be selected to suit the application and Table 29.1 is a guide to help this selection.

The design of the ducting system must ensure that it is both effective and efficient. Sharp bends and abrupt entries into mains cause unnecessary pressure losses. It is a requirement of the COSHH Regulations that the inside of ducting should be inspected to check for fall out and blockage, and that it is supported and safe in its location. Inspection doors should be fitted near bends, the supports no more than 5 metres apart. The termination point in any system is the discharge cowl or collector outlet. The Environment Protection Acts recommend that cowls discharge vertically upwards at velocities of 15 M/sec with the termination point above the ridge of the building where ever possible. This is particularly critical when

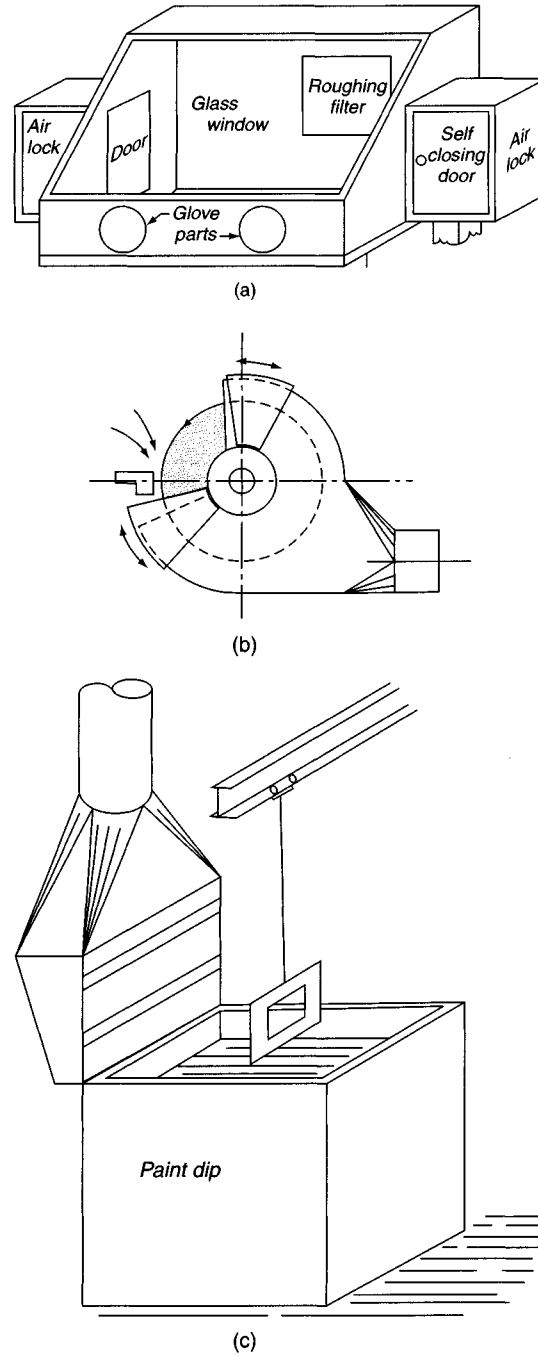


Figure 29.3 Types of hoods. (a) Enclosure; (b) receptor; (c) captor

dealing with discharges which have not been cleaned and expert advice should be obtained.

29.3.3 Fans

Fan engineering is a basic technology, with its origins in ancient times. It was developed from the wheel and pump

Table 29.1 Selection of ducting

Application	*Duct Diam. MM*	*Gauge MM*	*Jointing System*	*Material & Construction*
Wood waste extraction, general nuisance dust work	0–450 450 & over	1.0 1.5	Slip flanged	Galvanized sheet steel lockformed. bends & sets one gauge thicker
Foundry work and heavy abrasive applications, grinding and conveying	0–450 450 & over	1.5 2.0	Slip flanged	Galvanized sheet steel and/or welded. bends & sets one gauge thicker
Wet & oily fumes not excessively corrosive	0–450 450 & over	1.0 1.5	Sealed slip flanged	Galvanized sheet steel lockformed and welded bends & sets same gauge as duct
High temperature work above 200°C	0–450 450 & over	1.0 1.5	Slip flanged	Stainless steel fully welded, heat resistant quality to suit contaminants
Chemical applications, plating baths, cleaning baths, process plant	0–300 over 300	1.5 2–3	Sealed slip flanged	Extruded plastic & glass fibre as above, careful selection of materials to withstand the chemicals.
Light duty dust and fume	0–450 over 450	0.8 1.0	Slip and clip slip, clip and flanged	Galvanized sheet steel longitudinal lockformed on light fume work spiral wound duct can be used

Application data for fans

Type	*Pressure/volume Range Pascals (Pa) × M^3/Sec.*	*Efficiency*	*Industry*	*Application*
Aerofoil section Axial flow	60–700 Pa Per. 5M^3/Sec plus	Very high	H & V Refrigeration cooling	Ventilation, heating on low pressure systems, fume extraction, engine and compressor cooling
Curved blade propeller axial	125 Pa per stage 5 M^3/sec	Low	H & V cooling refrigeration	Produced in almost any materials at low cost, same application as aerofoil but lower efficiency
Bifurcated aerofoil section and plain curved	600 Pa per stage 5M^3/sec	Medium due to bifurcation of fan casing	Fume extraction heat extraction	Motor not in air stream. Wet & dry fume extraction, high temperature & potentially explosive work
Centrifugal paddle bladed flat section radial	3700 Pa 15M^3/sec	Medium	Dust and fume containing bulky chippings	General dust and fume extraction low cost. Used in wood waste extraction and conveying
Multivane centrifugal forward curved blades	1500 Pa 30 M^3/sec	High efficiency prone to overloading if incorrectly applied.	H & V most compact fan, best volume size for size for any centrifugal	Will only handle clean air. Used where large volumes are required in ventilation systems
Backward curved centrifugal. Plain curved and aerofoil section blades	6000 Pa 30 M^3/sec	High efficiency, none overloading best on clean air	Dust and fume extraction	General dust and fume work requiring high pressure. More expensive than other types of centrifugal
Centrifugal blowers & exhausters shrouded radial straight bladed often with curved tip	15000 Pa per stage 2.5 M^3/sec	Medium efficiency	All industries	Furnace blowing fast process cooling conveying systems, vacuum systems very robust construction
Forward curved plain section centrifugals	4000 Pa 3.75 M^3/sec	High efficiency prone to overloading	Dust and fume extraction	Compact design often direct driven. Widely used on dust collectors, fume collectors

The above table is not exhaustive and is based on average duties. At all times it is advisable to consult the manufacturers to obtain the best fan for any application.

as the need grew for continuous quantities of moving air at low pressures. By the nineteenth and early twentieth centuries much of the design and research had been done, resulting in an unsophisticated but reliable air mover. Fans are capable of operating over a wide range of duties, albeit with varying degrees of efficiency, and this has led to their misapplication and abuse in dust- and fume-extraction work. Without the fan a system will not function and it is therefore necessary to select the fan to ensure both effective and efficient running of the plant. A selection of fan types together with application data is shown in Figures 29.4 and 29.5 and Table 29.1.

29.3.3.1 Fan performance and laws

In selecting a fan for a system the two most important characteristics to consider are volume and pressure. This can be said to be the movement of air (m^3/h) against the system resistance (mm water). As the majority of these systems operate at near-normal temperatures and altitude, density is usually ignored. If the system is to work at temperatures and altitudes other than 25°C and at sea level then density must be considered in the selection. Air movement is not a precise science and fans selected for systems rarely operate at the exact design duty. Furthermore, the system can change, and the fan performance will also need to change to meet the new conditions. If the performance varies by no more than 5–10% it is seldom necessary for remedial action. To alter the performance of a fan without changing the geometry, the fan speed must be increased or decreased. When the speed is changed it is prudent to check the performance from the following fan laws:

Fan speed varies – size and density constant

1. Volume flow varies directly as fan speed:

$$\frac{\text{Volume 1}}{\text{Volume 2}} = \frac{\text{Speed 1}}{\text{Speed 2}}$$

2. Pressure varies as the square of the fan speed

$$\frac{\text{New Pressure}}{\text{Original Pressure}} = \frac{(\text{New Speed})^2}{(\text{Original Speed})^2}$$

3. Power varies as the cube of the Speed

$$\frac{\text{New Power}}{\text{Original Power}} = \frac{(\text{New Speed})^3}{(\text{Original Speed})^3}$$

A typical example will illustrate their use. A 600 mm diameter paddle bladed centrifugal fan delivers 5100 M^3/Hr against a system resistance of 200 mm water and absorbs 5.16 Kw when running at 1665 rpm when driven by a 7.5 Kw 2 pole speed motor through vee belts and pulleys. What will be the new speed, pressure and power required if the new volume is to be 7000 M^3/Hr?

First calculate the new speed from:

$$\frac{\text{New Volume}}{\text{Original Volume}} = \frac{\text{New Speed}}{\text{Original Speed}}$$

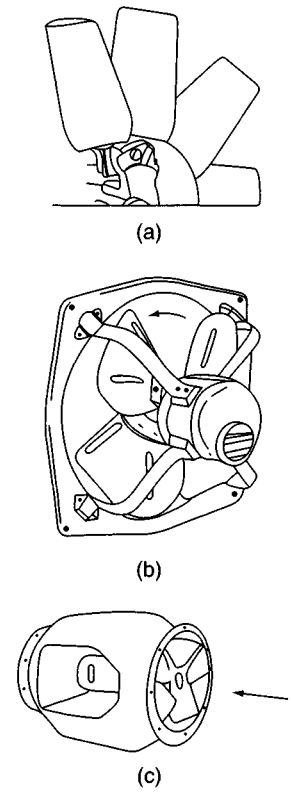


Figure 29.4 Axial-flow fans. (a) Axial flow; (b) propellor; (c) bifurcated

therefore

$$\text{New Speed} = \frac{\text{New Volume} \times \text{Original speed}}{\text{Original Volume}}$$

Substituting values

$$\text{New speed is } \frac{7000 \times 1665}{5100} = 2285.29 \text{ rpm}$$

for which we would use 2285 rpm

This will give the speed at which the fan will run to give the new volume and three further calculations are needed before the speed can be changed. The first is the new absorbed power to establish whether the original motor has sufficient power available.

$$\frac{\text{New Power}}{\text{Original Power}} = \frac{(\text{New Speed})^3}{(\text{Original Speed})^3}$$

therefore

$$\text{New Power} = \frac{(\text{New Speed})^3 \times \text{Original Power}}{(\text{Original Speed})^3}$$

Substituting values

$$\text{New Power is } \frac{(2285)^3}{(1665)^3} \times 5.16 = 13.34 \text{ Kw}$$

The Original 7.5 Kw motor does not have sufficient power and 11 Kw would be a suitable choice. The second

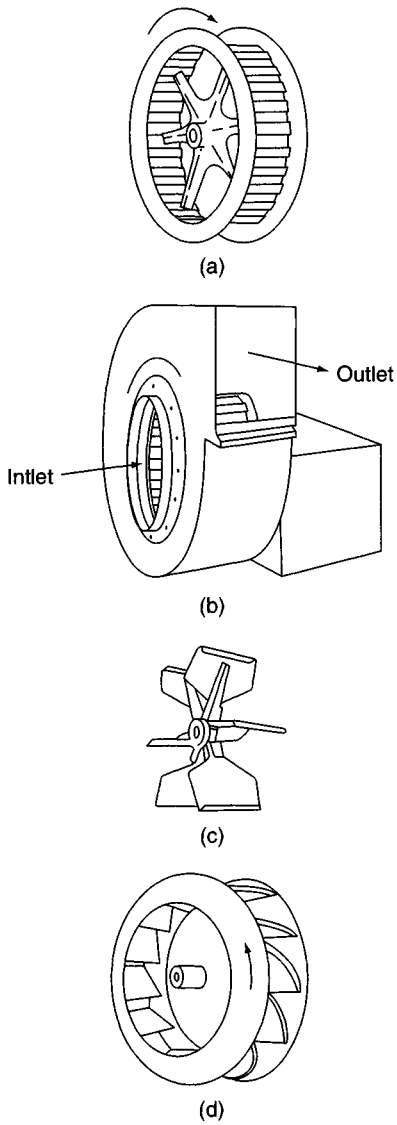


Figure 29.5 Centrifugal types of fan. (a) Centrifugal; (b) paddle or radial bladed; (c) forward curve; (d) backward curve

calculation is the new pressure that the fan would develop and this will give an indication on whether the system has sufficient constructional strength.

$$\frac{\text{New Pressure}}{\text{Original Pressure}} = \frac{(\text{New Speed})^2}{(\text{Original Speed})^2}$$

therefore

$$\text{New Pressure} = \frac{(\text{New Speed})^2 \times \text{Original Pressure}}{\text{Original Speed}^2}$$

Substituting values

$$\text{New Pressure is } \frac{(2285)^2}{(1665)^2} \times 200 = 376.68\,\text{mm}$$

The fan will pressurize the system by an extra 176.68 mm and this may require investigation to ascertain whether the ductwork gauges will withstand this. The problem will be more acute on suction systems with large ducts of below recommended gauge thicknesses. The final calculation is for the peripheral speed of the impeller to be checked to ensure that it falls with the safe speed of the design and construction. Peripheral Speed of any rotating wheel is given by speed(rps) × diameter in metres × ð

Substituting values

$$\text{Peripheral Speed is } \frac{2285 \times 0.6 \times \pi}{60} = 71.8\,\text{M/sec}$$

No absolute guidelines can be given to cover all fans on the maximum peripheral speed due to the many designs and differing materials used in its construction. If the new speed exceeds 76 M/sec no action should be taken to speed up the fan until the manufacturer has been consulted.

29.3.4 Collectors

The purpose of the collector is to separate the entrained dust and fume and deposit it in a safe and convenient form for ultimate disposal. The four groups of collectors are:

Mechanical separators such as Cylones.
Fabric filters.
Wet collectors.
Electrostatic filters.

29.3.4.1 Cyclones

These separate due to the action of the system creating centrifugal force within the cyclone. They can be under pressure or suction depending upon the application and can be either dry or irrigated known as wet. The smaller the diameter the greater the centrifugal force and greater the separating efficiencies. This has led to the development narrow of slim line cyclones able to handle finer particles. These are not successful on bulky materials such as wood waste for which modified cyclone designs have evolved. In recent years cyclones have been little used, due to their low average efficiencies of approximately 80% with visible discharges for the outlets. *However, because of simplicity and low cost, a design by the author called a "Flexible Bodied Cyclone" (Patent applied for) has been used to great effect on conveying plants.* The air is aspirated through the walls of the cyclone, and hence filtered, with the product being conveyed falling though a rotary valve to its destination and further use. The introduction of The Environmental Acts has seen many discharges from all types of systems and collectors being tested and analysed. Work on cyclone discharges has shown surprising results, where in some cases the particulates in the air streams were below acceptable limits set by the Act. It is possible therefore that correctly applied cyclones still have use in dust control.

29.3.4.2 Wet collectors

There are two types: self-induced spray and pressure spray. Many designs have been developed to suit specific dust or fume problems, and it is now possible to use wet collectors on the treatment of solids and fumes down to very small particle sizes.

Self-induced spray wet collectors This is the most common type, and relies on its separating action by the induced air from the fan pulling the contaminated air through a curtain of water. It is simple in operation with no pumps or moving parts except for the fan, which is set on the clean side of the collector. The scrubbing action is dependent on the pressure drop across the collector. When set, this is constant and is determined by the water level within the collector. The removal of sludge is either by automatic ejection or manual drag-out.

This type of collector has found wide application in general engineering and very high collection efficiencies are possible, but at the expense of considerable power requirements. General-purpose collectors at pressure drops across the collector of 150 mm will have collection efficiencies of 98% at 10 μm and above. Units with pressure drops of 800 mm and efficiencies of more than 99% on sub-micron particles are available.

Spray-type collectors In this system water is sprayed or cascaded onto the contaminated air directly or through packed towers, and the fumes or dust are washed away by absorption. These collectors are used extensively on the treatment of fumes of all types and have low-pressure drops and hence low power requirements compared to induced spray. A development of this collector is the venturi scrubber, which injects high-pressure water into a venturi through which the fume-laden air is passing. The intimate contact of the two ensures absorption and removal from the airstream. These collectors are used in fume removal and have efficiencies of more than 99% on sub-micron particles.

The general rule with wet collectors is that the higher the collection efficiency, the greater the pressure drop and hence the power absorbed.

29.3.4.3 Fabric filters

Fabric filters are capable of separation efficiencies approaching 100% if correctly applied. The ideal filter is permeable to the airstream but not to the dust requiring separation. Separation occurs by impaction of the dust particles upon fabric fibres, resulting in a dust cake forming on the fabric. Although aiding filtration, this cake does increase the resistance to air flow. If allowed to go unchecked it would result in a reduction of the total air being exhausted in the system.

Two methods are used to remove the dust cake, both of which require interruption of the air flow. The difference in dust-cake removal conveniently divides filters into intermittent and continuous rating. In the intermittent type the pressure increases (with time) up to a pre-arranged level. The air flow is then stopped and the fabric is mechanically shaken. In the continuously rated filter the pressure drop rises to a low set point, after which it remains constant across the filter as a whole. The cleaning is done by isolating a part of the filter from the airstream and that section is cleaned.

Intermittent filters are best suited to small applications which will allow the process to be stopped at intervals. The interval used is 4 h (i.e. a morning or afternoon shift). Shaking is done by either hand or electric motor. The application of these filters is limited to the incoming dust burden of the order of 5 g/m^3 and is known as nuisance dust.

Continuously rated filters have whole sections of the filter shut off from the air flow and then those sections are shaken or cleaned. Shaking is carried out in sequence, usually by electric motor. Where the filter is cleaned it is done by a jet of compressed air being blown in reverse to the air flow through the fabric. This system does not require whole sections to be shut down, as the reverse blow is carried out when the filter is on-stream. The time of blow is very small and are measured in parts of a second rather than in minutes, as in the case of shaking filters. The application of these filters is in continuous processes and where the dust burdens are high (in excess of 100 g/m^3).

The shaking and continuous filters are regenerative, but there is a third group usually associated with ventilation work rather than dust and fume. These are throw-away filters which, as the name implies, means that when they become too caked with dust to operate correctly the filters are removed and replaced with new ones. They will only handle low incoming dust burdens, but their efficiencies are the highest of any filter. Typical applications are fresh air input plants, clean-room filtration and nuclear processes.

29.3.4.4 Electrostatic precipitators

These remove particles by means of applied electrical forces, and are used extensively on cement and fly ash removal from airstreams. The particles are first given an electric charge and are then passed through an electric field to apply a precipitation to them. They are then captured on the collecting surface (normally an electrode). The collection surface is the cleaned by rapping or water wash and the dust collected in a hopper below. The efficiencies achieved are 99% at particle sizes above 1 μm. They are cheap to run but the capital costs are high, especially for large collectors. In recent years small units have been developed to control oil and welding fumes.

29.3.4.5 Disposal

Many control plants fail in their objective when the collected waste is removed from the inlet. The practice of dropping dust into sealed bins at the base of the collector is both sensible and practical. It is when the bins are to be emptied that a secondary dust problem arises. If the waste is simply put into a larger container with no control, dust will be released back into the workplace. If dangerous dusts are being collected, sealed inner liners to the dustbins can be used, thereby preventing this release.

On the larger installations the collected dust is retained under sealed conditions at all times and the discharge from collectors is by rotary valve and screw conveyor. These will feed into bulk containers for further processing. In the case of fumes these are collected by absorption into liquors, and these liquors are treated in an effluent plant separate from the fume plant.

29.4 System design and application

In selecting the best system to control the hazard the following should be noted:

1. The problem must be surveyed under actual working conditions and data collected and recorded in a logical manner. The survey must establish:
   (a) The origin of the dust or fume and its nature. Is it toxic, explosive or hazardous in any way?
   (b) The process which produces the contaminant. Is it wet or dry?
   (c) Whether the problem can be solved by elimination of the process;
   (d) The source or sources of the problem. Does it occur at more than one point?
   (e) Do any special regulations apply to the hazard and are the materials being handled listed in any published form as having control limits?
   (f) Is a control system in use at the time of the survey?

Having completed the survey, the next stage is to draw the system showing the sources of dust and the duct runs. An assessment must then be made on the air volumes and velocities required to give control. This is largely a matter of experience, as air-entrainment rates are derived empirically. It is possible to calculate the rates but is unusual in general engineering. There are published lists for air rates and many companies have their own standards. Table. 29.2 shows rates for metal-working machines. When the total air volume has been established the collector and fan can be sized. The total air volume and the type of dust will determine the size and type of collector to be used. Table. 29.3 shows the types of collector for various applications.

To size the fan it is necessary to know the total air volume and the pressures in the system. These are calculated from the losses in the system on the longest or index leg, and begin with the hood. The hood entry loss can be expressed as 0.6 of the velocity head and is accurate enough for first estimates. The losses are then calculated on the velocities in the ducts. Each change of direction means a small loss in each length of duct. Added to the pressure drop loss across the collector and the outlet losses, these give the total static pressure required in the system.

The formula used in the calculation of system losses for first estimates favoured here is:

Loss in water (mm)/length of duct (m)

$$= \frac{(\text{Velocity (m/s)})^2 \times 1.243}{\text{Diameter of duct (mm)}}$$

Table 29.2

Type of machine	*Size (mm)*	*Air volume (m^3/h)*
Grinders (double end)	200–250	680
Grinders (double end)	280–406	1189
Grinders (double end)	430–455	1495
Grinders (double end)	480–560	1870
Grinders (double end)	585–762	2720
Grinders (double end)	787–915	3738
These figures are for bottom connections only and average duties		
Toolroom grinders (double ends)	Up to 200	510
Cutter grinders (single end)	Up to 150	510
Banding machines		
Horizontal	Up to 100	595
Horizontal	125–200	1019
Backstands	38 belt	595
Backstands	50 belt	866
Backstands	75 belt	1053
Backstands	100 belt	1257
Backstands	125 belt	1699
Backstands	150 belt	2243
Double-end hand-polishing machines	Up to 150	1019
	178–225	1359
	250–355	2209
Wire mops	Up to 200	1699
Cut-off machines		
Abrasive discs	Up to 405	934
Abrasive discs	430–610	1699

Velocity head or velocity pressure is the pressure required to accelerate the following mass from rest to its flowing velocity:

$$\text{Velocity pressure in water (mm)} = \frac{(\text{Velocity (m/s)})^2}{(4.04)^2}$$

Static pressure is the pressure to overcome resistance and is expressed in millimetres of water. Total pressure is the sum of velocity and static pressures.

The basic formula for air flow under all conditions is:

$$Q = A \times V$$

where Q = volume (m^3/s), A = area (m^2) and V = velocity (m/s). The nominal velocities used in dust and fume control depend on the materials being handled, but the following will suffice for most work:

Metalworking	Ducts 23 m/s	Branches 20 m/s
Woodworking and light dusts	Ducts 20 m/s	Branches 18 m/s
Gases and vapours	Ducts 10 m/s	Branches 9 m/s

It is now possible to calculate the total system resistance and select a suitable fan and collector. The following will illustrate the use of the formula.

Table 29.3

Application	*Type of collector*
Sand foundry dusts	Self-induced wet collectors
Magnesium and aluminium working	Self-induced wet collectors
Hot applications	
Sparks from grinding	Self-induced wet collectors
Heat treatment	
Small grinding machines, polishing machines	Self-contained intermittent filters
Batch operations (e.g. filling, tipping, mixing)	Self-contained intermittent filters
Process plant	Continuously rated filters
Heavy dust burdens	Continuously rated filters
Difficult dusts (e.g. carbon black sugar dust)	Continuously rated filters
Cement and fly ash production	Electrostatic precipitators
Woodworking and initial separation	Cyclones

A simple duct system of length 50 m serving a double-end grinding machine requires an exhaust volume of 6000 m^3/h. The duct velocity would be 23 m/s, giving a diameter of 300 mm and a velocity pressure of 32.41 mm.

The hood loss $= 0.6 \times 32.41 = 19.45$ mm

$$\text{Duct losses in 50 m} = \frac{(23)^2 \times 1.243}{300\,\text{mm}} = 109.59\,\text{mm}$$

The total pressure

$$= VP + SP = 32.41 + 109.59 + 19.45$$

$$= 161.45\,\text{mm}$$

To this figure must be added the pressure drop across the collector, which in this case would be a wet unit having a drop of 150 mm.

The fan would then be selected to handle 6000 m^3/h at a total pressure of 311.45 mm water. As this is a high-pressure fan, it would be a centrifugal backward laminar type.

29.5 Testing and inspections

After the plant has been installed, it will require a test and inspection to determine whether the design meets with the original objectives and requirements of relevant legislation. The primary function of industrial dust and fume control plants is to remove airborne particulate from the workplace and deliver it in a convenient and safe form for ultimate disposal. The principal objective being to provide acceptable working conditions at the workplace. With notable exceptions such as LEAD and ASBESTOS common dust plants did not require Statutory Inspections until The European Community(EC) Framework Directive 80/1107/EEC was invoked in the United Kingdom.

The result of this directive has been a series of Approved Codes of Practice which are part of The Health & Safety at Work Act 1974, The most important of these Approved Codes of Practice is **The Control of Substances Hazardous to Health Regulations 1988 (COSHH)** and subsequent amendments. These Regulations now affect all substances except lead and asbestos, which have their own special regulations, and they have led to a rapid increase in the number of inspections and tests carried out.

This increase in inspections and tests has pin-pointed the following problems:

a) The total absence of standard forms of reporting.
b) The growth of unqualified and inexperienced personnel doing the testing and inspecting.
c) Inconsistent results due to the use of non standard instruments.
d) The omission of important information on the report forms.

This haphazard approach can give rise to incorrect conclusions being drawn and expensive and unnecessary remedial action being undertaken. It may also place the owner or responsible person for the plant, at risk from prosecution and/or litigation.

The COSHH Regulations place a duty on the user or owner of control plants to have them tested at regular intervals not exceeding fourteen months. The person or persons carrying out the tests and inspections should be competent to do so, and have experience of the process and the control measures used. It is a further requirement that formal recognized qualifications are held by the inspector, such as membership of a professional institution and registration with The Engineering Council.

The purpose of the inspection and tests will be to assess whether the control plant is controlling the substance to the level now demanded by law. The generic term given to these plants is **LOCAL EXHAUST VENTILATION PLANT(LEV)** All inspectors should have a detailed knowledge of the design and operation of an LEV system, together with knowledge and experience of the substances being controlled and the possible effects on the health and safety of the user personnel.

29.6 Inspection and testing procedures

29.6.1 Inspections

The first stage for the inspection and testing of any LEV plant must always begin with an assessment of substances being used and the process being controlled. Without this assessment any subsequent inspection or test could be irrelevant. The process and materials used must be checked against known standards to establish whether exposure limits apply, as listed in the HSE publication EH 40, and whether the process itself is hazardous. This approach takes account of safety which is usually immediate in its effect, and health which is long term in its effect. The second stage is to decide, on the evidence obtained, whether the substances and the process are liable for inspection under The COSHH Regulations or any other statutes that may apply.

Any ventilation plant is necessary for control under COSHH or other statute if:

On turning off the plant, but leaving all other work activities constant, the operator at the process (and all others in the vicinity) now becomes exposed to concentrations of dust, fumes or vapours in air above the statutory levels.

If however, on shutting off, the exposure concentrations are below the statutory levels, then the plant can be best described as 'welfare or process' and under these conditions examination under COSHH is not required.

The third stage is to carry out an initial inspection of the LEV plant using eyes, ears, nose and touch as this will show if there are any obvious and possibly dangerous faults. The inspector should observe the work function in addition to the LEV system and wherever possible the work operations should be carried out by the usual operator. This should be verified by a more senior member of staff. Consultation with operators is very important as they know more about what happens than possibly anyone else. It is not uncommon to inspect a LEV system with the work operation not being done; should this be the case then it must be recorded on the reports.

The fourth stage of the inspection is to record all the significant details of the LEV system and the work operations. In general terms this need not be an engineering drawing to scale as a schematic line drawing will suffice, but when special circumstances dictate, the usual procedure is to file with the reports a copy of the original installation drawing, if available.

It is at this point that a decision is made on whether an air monitor of the operation is required. It is the authors opinion that if a substance is listed in HSE EH40 then an air monitor is obligatory but if the substances are not listed then the general exposure limits of 10 mg/M3 total particulate and 4 mg/M3 respirable apply and an air monitor is not obligatory as other assessment methods can be used. These can be Tyndall Lights or observation.

29.6.2 Field Testing of LEV Plants

Testing is concerned with physical measurement to establish data either as a first commissioning visit or to be used as a comparison with previous data. It is invaluable for the detection of changes and for predictions on future performance. On many first time tests, often long after the plant has been installed, they form the commissioning report and are given the title Part 1 Report and are a benchmark for all subsequent tests.

Any testing carried out on operating plant is done under less than ideal conditions and errors up to 10% can be expected. The important feature of field testing is consistency and this is the reason why sensible, logical and easy to understand reporting forms are used. In the United Kingdom no official reporting forms exist and consequently each inspecting company produces its own. *The reporting forms used here are the result of many years experience and are copyright to the author.*

The instruments used for routine and regular testing are.

a) Precision manometers. The most practical being digital types which do not require liquids.
b) Vane or electronic anemometers.
c) Various sizes of pitot tubes.
d) High intensity portable lamps.
e) Smoke generators.
f) Clamp testers for measuring current to electric motors.

When all the inspection work has been done the plant should be run at operating speed and the measurements taken and noted down on the relevant form as shown in Figure 29.6.

29.6.3 Reporting forms

The form shows the results of the inspection and testing of a small grinding section operating on low risk materials such as mild steel and it will be seen that all the necessary data has been collected to give a complete picture or benchmark of the installation. Subsequent changes in the plant's performance will be noted on the next inspection usually called the Part 2. This form is much simpler and must always be read in conjunction with the Part 1 form. It will be noted from the Part 2 that changes have taken place and it is now necessary to establish the causes for the changes and the remedial action required.

29.6.4 Interpretation of results

The changes illustrate a typical set of results which are not a major problem considering the nature of the substances being used but the reasons for the changes must be isolated. The numerical order of testing has been used and first real changes occurs at number 7 & number 8 where the static pressure has increased. This indicates that some restriction is in the branches, it could be a damper being shut or an obstruction. The second point to change is number 9 which indicates a drop in available pressure to all the grinders and if this is read with the increase in pressure drop across the filter it can be deduced that some blinding on the filter has occurred. The final change is number 10 which is the discharge from the filter, this has gone down indicating a drop in resistance. This could be due to the outlet cowl being removed or missing or a reduction in the outlet ducting. Whatever the reasons the report must show what the inspector found and the remedial action to be taken. This is shown on the Part 2 report form.

On completion of the inspection and tests the reports are filed and kept with the health and safety documents. They must be made available to any member of the workforce or their representative and kept for a minimum of five years.

29.6.4.1 The control of inspectors

In the United Kingdom all aspects of health and safety at work are under the control of the governments' Health and Safety Executive who make visits on a regular basis to all employers. In addition to making their own inspections within the establishment they will require that all records are up to date and correct. They have the power to make improvement orders, stop processes or take any action appropriate to ensure the health and safety of all work personnel. In extreme cases they have the power to take

©J.B.AUGER (MIDLANDS) LTD	SHEET 1
NAME OF EMPLOYER	**DATE**
TJA GRINDING SERVICES LIMITED	17.7.92
ADDRESS BELL LANE, ALDERSTON, HICKLEY MARSH B81 4DW	
DEPARTMENT OR SITE OF PROCESS GRINDING SHOP ALDERSTON PLANT	**REFERENCE NUMBER** T5560-1
LOCATION OF LEV PLANT **SERVICE ROAD REAR OF BUILDING**	**TYPE OF LEV PLANT** UNIT DUST COLLECTOR
IS THE EXHAUST AIR RETURNED TO THE WORKPLACE, IF SO IN WHAT CONCENTRATION NO AIR EXHAUSTED TO ATMOSPHERE. NO VISIBLE DISCHARGE	**IS SECONDARY FILTRATION PROVIDED** NO
SUBSTANCE/PROCESS CONTROLLED **MILD STEEL EN1A** DUST FROM GRINDING SMALL COMPONENTS	**HAZARD ASSESSMENT** LOW RISK 5 Mg/M^3 RESPIRATORY 10 Mg/M^3 TOTAL
ASSESSMENT OF LEVEL OF CONTROL AND TYPE OF TEST **VERY GOOD** VISUAL INSPECTION USING TYNDALL LIGHT SYSTEM	**CONDITION AT TIME OF TEST** NORMAL WORKING
FREQUECY OF TEST 14 MONTHS	**REGULATION** 9
COMMENTS WELL MAINTAINED PLANT NO FURTHER ACTION REQUIRED	
NAME OF PERSON RESPONSIBLE MR. JOHN SMITH	**DATE FOR PART 2** JULY 1994
SIGNATURE	**EMPLOYER**

Figure 29.6 A typical assessment sheet

owners or managers to court where severe penalties can imposed, not excluding a custodial sentence.

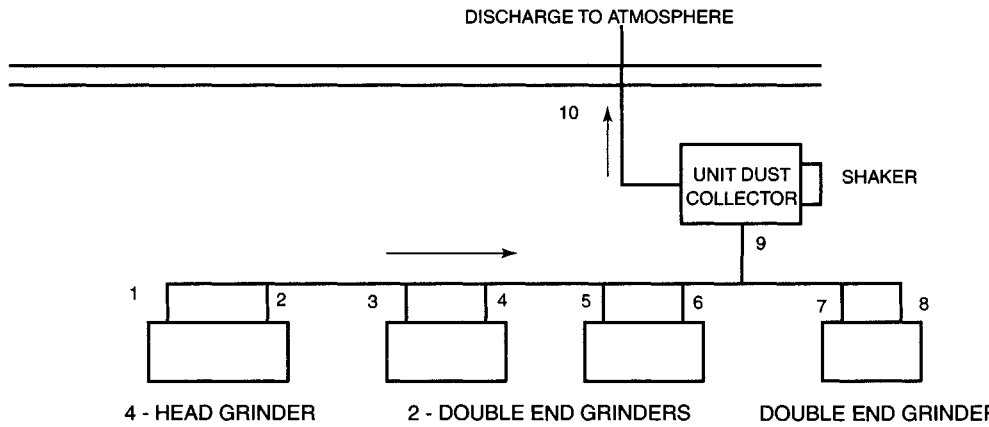
If it is shown that an inspector is at fault, then that inspector is also liable to prosecution and/or fine or custodial sentence.

The day-to-day inspections and tests are carried out by companies or individuals and there is strong support for control of their activities by a central authority not necessarily part of government. At the time of writing the authority which has the backing and participation of The Health and Safety Executive is the **United Kingdom Accreditation Service (UKAS).** Membership is voluntary at this point in time but failure to subscribe to this organization may in the future preclude companies or individuals from certain types of inspections and tests.

The professional organization to which inspectors as individuals belong is The Bureau of Engineers which is a Division of The Institution of Plant Engineers. It is through these two organizations that the training and experience of the inspection industry is shared.

COSHH LEV RECORD

LAYOUT SHOWING POINTS OF MEASUREMENT



GRINDING SHOP

Date Installed **NOT KNOWN**

PRIMARY COLLECTOR/FILTER				**SECONDARY FILTER**			
MAKE	DCE	**S.P.OUTLET**	250 MM	**TYPE**		**S.P.OUTLET**	
SIZE/AREA	93M^2	**S.P.INLET**	150 MM	**SIZE/AREA**		**S.P.INLET**	
MEDIA	COTTON TWILL	**P.D.ACROSS**	100 MM	**MEDIA**		**P.D.ACROSS**	
MOTOR				**FAN SET**			
SUPPLY	400V	**MAKE**	GEC	**SIZE**	21	**VOLUME**	6630M^3/HR
AMPS	14.5	**TYPE**	INDUCTION	**TYPE**	CENTRIF.	**SPEED**	2850 RPM
POWER	7.5 KW	**SPEED**	2-POLE	**HANDING**	N/A	**S.P.INLET**	250MM
STARTING	D.O.L.	**ENCL.**	IP55	**DRIVE**	DIRECT	**S.P.OUTLET**	270MM

HOOD & DUCT SIZES, VELOCITIES AND VOLUMES.

POINT	HOOD SIZE/AREA	DUCT SIZE/AREA	V.P. MM	S.P MM	VELOCITY m/s	VOLUME m^3/Hr	COMMENTS
1	N/A	100 DIA.	25.4	40.64	20.3	595	
2	N/A	100 DIA.	25.0	40.0	20.0	578	
3	N/A	120 DIA.	25.00	40.64	20.3	833	
4	N/A	120 DIA.	23.15	35.6	19.4	799	
5	N/A	100 DIA.	25.4	40.64	20.3	595	
6	N/A	100 DIA.	27.13	43.18	21.0	612	
7	N/A	150 DIA.	25.4	40.64	20.3	1326	
8	N/A	150 DIA.	25.0	40.00	20.0	1292	
9	N/A	350 DIA.	22.92	120	19.3	6630	
10	N/A	350 DIA.		20			

NOTES

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J.B.Auger (Midlands) Ltd. ☎ :01527 870798 Fax:01527 870008 **LEV NO.** T5560-1

PART 2 COSHH LEV REPORT

NAME & ADDRESS OF EMPLOYER	**DEPARTMENT OR SITE OF PROCESS**
TJA GRINDING SERVICES LTD., BELL LANE ALDERSON, HICKLEY MARSH B81 4DW	GRINDING SHOP ALDERSTON PLANT
ATTN.	**☎:** **FAX:**

REGULATION	**PERIOD BETWEEN TEST**	**LAST PART 2 TEST**	**DATE OF LAST PART 1**
9	14 MONTHS	JULY 1992	JULY 1992

HOODS, ENCLOSURES, DUCTING

POINT	**STATIC PRESSURE MM**	**VELOCITY M/SEC**	**ARE ELEMENTS IN WORKING ORDER ANSWER "YES, NO, N/A" HOOD**	**ENCL.**	**DUCT**	**ASSESSMENT OF CONTROL/REMARKS.**
1	40.1	20.0	YES	N/A	YES	OK
2	38.00	19.4	YES	N/A	YES	OK
3	41.00	20.2	YES	N/A	YES	OK
4	33.00	12.0	NO	N/A	NO	POOR BROKEN CONNECTION
5	40.6	20.3	YES	N/A	YES	OK
6	43.00	24.00	YES	N/A	YES	OK
7	100.00	0.0	NO	N/A	NO	POOR BLOCKAGE IN DUCT
8	100.00	0.0	NO	N/A	NO	POOR BLOCKAGE IN DUCT
9	110.00	N/A	N/A	N/A	YES	OK
10	10.00	N/A	N/A	N/A	NO	COWL REMOVED
			N/A			

COLLECTOR/FILTER	**PRIMARY**	**SECONDARY**	**SHAKER/CLEANING MECH.**	OK	**MONITORING**	NA
S.P. OUTLET	250MM	N/A			**EQUIPMENT**	
S.P. INLET	110MM	N/A	**DISPOSAL SYSTEM**	OK	**IF FITTED**	
P.D. ACROSS	140MM	N/A				
CONDITION OF	OK		**CONDITION OF FAN**			
COLLECTOR/			**S.P. INLET**	OK	**DRIVE**	OK
FILTER			**S.P. OUTLET**	•	**IMPELLER**	NOT SEEN
			DISPOSAL SYSTEM	OK	**CONNECTIONS**	OK

PARTICULARS OF ANY MODIFICATION TO SYSTEM
NONE SINCE LAST VISIT

HAVE RECOMMENDATIONS FROM PREVIOUS REPORT BEEN CARRIED OUT: IF *NO* SEE BELOW

COMMENTS & DETAILS OF ANY REMEDIAL WORK
* REPLACE OUTLET COWL
REPAIR BROKEN CONNECTONS AT 4
CLEAR BLOCKED AIRWAYS AT 7 & 8

30 Insulation

Original by **Pilkington Insulation Ltd.**

Revised by **John Willoughby**
Energy & Environmental Design Consultant

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30.1 Introduction

Insulation is one of those ubiquitous techniques that is always around, always impinging on our work, social and domestic activities and yet for most of the time is hardly noticed. Insulation is a passive product; once installed, it works efficiently, quietly and continually, usually out of sight, enclosed within a structure or a casing or under cladding.

It comes to the fore when new design of buildings, plant, equipment or production processes is being considered. It is at this stage that the right specification must be made. Any shortfall in the thickness or error in the type and application details will prove costly to rectify at a later data.

30.1.1 Why insulate?

There are many reasons why professional engineers, architects and laymen use insulation, e.g.:

1. To comply with mandatory legislation (i.e. Building Regulations);
2. To reduce heat loss/heat gain;
3. To reduce running costs;
4. To control process temperatures;
5. To control surface temperatures;
6. To reduce the risk of freezing;
7. To provide condensation control;
8. To reduce heating plant capacity;

Other reasons why insulation is used are to provide:

9. Acoustic/correction and noise control;
10. Fire protection.

30.1.2 Scope

This chapter will deal primarily with thermal insulation. Acoustic and fire-protection properties and applications will be treated as subsidiary to the thermal insulation aspects.

30.1.3 Thermal insulation

A thermal insulation material is one which frustrates the flow of heat. It will slow down the rate of heat loss from a hot surface and similarly reduce the rate of heat gain into a cold body. It will not stop the loss or gain of heat completely.

No matter how well insulated, buildings will need a continual input of heat to maintain desired temperature levels. The input required will be much smaller in a well-insulated building than in an uninsulated ones – but it will still be needed. The same applies to items of plant – pipes, vessels and tanks containing hot (or cold) fluids. If there is no heat input to compensate for the loss through the insulation, the temperature of the fluid will fall. A well-insulated vessel will maintain the heat of its contents for a longer period of time but it will never, on its own, keep the temperature stable.

Thermal insulation does not generate heat. It is a common misconception that such insulation automatically warms the building in which it is installed. If no heat is supplied to that building it will remain cold. Any temperature rise that may occur will be the result of better utilization of internal fortuitous or incidental heat gains.

30.2 Principles of insulation

30.2.1 Heat transfer

Before dealing with the principles of insulation it is necessary to understand the mechanism of heat transfer. When a hot surface is surrounded by an area that is colder, heat will be transferred and the process will continue until both are at the same temperature. Heat transfer takes place by one or more of three methods:

Conduction
Convection
Radiation

30.2.2 Conduction

Conduction is the process by which heat flows by molecular transportation along or through a material or from one material to another, the material receiving the heat being in contact with that from which it receives it. Conduction takes place in solids, liquids and gases and from one to another. The rate at which conduction occurs varies considerably according to the substance and its state.

In solids, metals are good conductors – gold, silver and copper being among the best. The range continues downwards through minerals such as concrete and masonry, to wood, and then to the lowest conductors such as thermal insulating materials.

Liquids are generally bad conductors, but this is sometimes obscured by heat transfer taking place by convection. Gases (e.g. air) are even worse conductors than liquids but again, they suffer from being prone to convection.

30.2.3 Convection

Convection occurs in liquids and gases. For any solid to lose or gain heat by convection it must be in contact with the fluid. Convection cannot occur in a vacuum. Convection results from a change in density in parts of the fluid, the density change being brought about by an alteration in temperature.

30.2.3.1 Convection in gases

If a hot body is surrounded by cooler air, heat is conducted to the air in immediate contact with the body. This air then becomes less dense than the colder air further away. The warmer, light air is thus displaced upwards and is replaced by colder, heavier air which, in turn, receives heat and is similarly displaced. There is thus developed a continuous flow of air or convection around the hot body removing heat from it. This process is similar but reversed if warm

air surrounds a colder body, the air becoming colder on transfer of the heat to the body and displaced downwards.

30.2.3.2 Convection in liquids

Similar convection processes occur in liquids, though at a slower rate according to the viscosity of the liquid. However, it cannot be assumed that convection in a liquid results in the colder component sinking and the warmer one rising. It depends on the liquid and the temperatures concerned. Water achieves its greatest density at approximately 4°C. Hence in a column of water, initially at 4°C, any part to which heat is applied will rise to the top. Alternatively, if any part is cooled below 4°C it, too, will rise to the top and the relatively warmer water will sink to the bottom. It is always the top of a pond or water in a storage vessel which freezes first.

30.2.3.3 Natural convection

The process of convection that takes place solely through density change is known as 'natural convection'.

30.2.3.4 Forced convection

Where the fluid displaced is accelerated by wind or artificial means the process is called 'forced convection'. With forced convection the rate of heat transfer is increased – substantially so in many cases.

30.2.4 Radiation

The process by which heat is emitted from a body and transmitted across space as energy is called radiation. Heat radiation is a form of wave energy in space similar to radio and light waves. Radiation does not require any intermediate medium such as air for its transfer. It can readily take place across a vacuum.

All bodies emit radiant energy, the rate of emission being governed by:

1. The temperature difference between radiating and receiving surfaces;
2. The distance between the surfaces;
3. The emissivity of the surfaces. Dull matt surfaces are good emitters/receivers, bright reflective surfaces are poor ones.

30.2.5 Requirements of an insulant

In order to perform effectively as an insulant a material must restrict heat flow by any (and preferably) all three methods of heat transfer. Most insulants adequately reduce conduction and convection elements by the cellular structure of the material. The radiation component is decreased by absorption into the body of the insulant and is further reduced by the application of a bright foil outer facing to the product.

30.2.5.1 Conduction inhibition

To reduce heat transfer by conduction, an insulant should have a small ratio of solid volume to void. Additionally, a thin-wall matrix, a discontinuous matrix or a matrix of elements with minimum point contacts are all beneficial in reducing conducted heat flow. A reduction in the conduction across the voids can be achieved by the use of inert gases rather than still air.

30.2.5.2 Convection inhibition

To reduce heat transfer by convection an insulant should have a structure of a cellular nature or with a high void content. Small cells or voids inhibit convection within them and are thus less prone to excite or agitate neighbouring cells.

30.2.5.3 Radiation inhibition

Radiation transfer is largely eliminated when an insulant is placed in close contact with a hot surface. Radiation may penetrate an open-cell material but is rapidly absorbed within the immediate matrix and the energy changed to conductive or convective heat flow. It is also inhibited by the use of bright aluminium foil, either in the form of multi-corrugated sheets or as an outer facing on conventional insulants.

30.3 Calculation of heat loss

30.3.1 Glossary of terms

Terms and symbols used in computing heat loss are as follows.

30.3.1.1 Heat (J or kWh)

The unit of quantity of heat is the joule (J). A joule is defined as a force of 1 newton acting over a distance of 1 meter.

$1\ J = 1\ Nm$

A newton is the force which gives a body one kilogram in weight an acceleration of 1 meter per second every second. i.e.

$1\ N = 1\ kg\ m/s^2$

Thus a joule can be defined in basic SI units as:

$1\ J = 1\ Nm = 1\ kg\ m^2/s^2$

A more common unit to describe a unit of heat is the kilowatt hour (kWh).

1 kWh = 3.6 megajoules or 3.6 MJ

30.3.1.2 Heat flow (J/s or W)

Heat flow is measured in joules per second. A heat flow of 1 J/s is usually referred to as a heat flow of 1 watt (1 W). As seen above, the amount of energy resulting from a heat flow over a period of time is often expressed as kilowatt hours or alternatively as watt seconds (Ws).

30.3.1.3 Temperature (°C or K)

For ready identification, actual temperature levels are expressed in degrees Celsius (°C) while temperature difference, interval or gradient is expressed in Kelvin (K).

30.3.1.4 Thermal conductivity (λ)

Thermal conductivity, now denoted by the Greek letter lambda (previously known as the *k*-value), defines a material's ability to transmit heat, being measured in watts per square meter of surface area for a temperature gradient of one Kelvin per unit thickness of one meter. For convenience in practice, its dimensions Wm/m^2K be reduced to W/mK, since thickness over area m/m^2 cancels to 1/m.

30.3.1.5 Thermal resistivity (r)

This is the reciprocal of thermal conductivity. It is expressed as mK/W.

30.3.1.6 Thermal conductance (C)

Thermal conductance defines a material's ability to transmit heat measured in watts per square metre of surface area for a temperature gradient of one kelvin in terms of a *specific thickness* expressed in metres. Its dimensions are therefore W/m^2K.

30.3.1.7 Thermal resistance (R)

Thermal resistance is the reciprocal of thermal conductance. It is expressed as m^2K/W. Since the purpose of thermal insulation is to resist heat flow it is convenient to measure a material's performance in terms of its thermal resistance, which is calculated by dividing the thickness expressed in metres by the thermal conductivity. Being additive, thermal resistances facilitate the computation of overall thermal transmittance values (*U*-values).

30.3.1.8 Surface coefficient (f)

This is the rate of heat transfer from a surface to the surrounding air (or fluid) due to conduction convection and radiation. It is generally used only in still-air conditions and when the temperature difference between surface and ambient is of the order of 30 K. It is obtained by dividing the thermal transmission per unit area in watts per square metre by the temperature difference between the surface and the surrounding air. It is expressed as W/m^2K.

30.3.1.9 Surface resistance (R_s)

Surface resistance is the reciprocal of surface coefficient. It is expressed as m^2K/W.

30.3.1.10 Thermal transmittance (U)

Thermal transmittance (*U*-value) defines the ability of an element of structure to transmit heat under steady-state conditions. It is a measure of the quantity of heat that will flow through unit area in unit time per unit difference in temperature of the individual environments between which the structure intervenes. It is calculated as the reciprocal of the sum of the resistance of each component part of the structure, including the resistance of any air space or cavity and of the inner and outer surfaces. It is expressed as W/m^2K.

30.3.2 Fundamental formulae

In calculating heat loss from surfaces freely exposed to air it is necessary to deal separately with both radiant and convective losses.

30.3.2.1 Radiation

The following Stefan–Boltzmann formula applies to both plane and cylindrical surfaces:

$$Q_r = 5.673 \times 10^{-8} E((T_s + 273.1)^4 - (T_{rm} + 273.1)^4) \quad (30.1)$$

30.3.2.2 Natural convection – plane surfaces

$$Q_c = C(T_s - T_a)^n \quad (30.2)$$

The factor C and index n can be assumed to have the following values for plane surfaces of differing orientations:

Horizontal – downward heat flow	$C = 1.3$	$n = 1.25$
Vertical	$C = 1.9$	$n = 1.25$
Horizontal – upward heat flow	$C = 2.5$	$n = 1.25$

30.3.2.3 Natural convection – horizontal cylinders and pipes

$$Q_c = 0.53 \frac{\lambda_a}{d_o} (Gr \cdot Pr)^{0.25} (T_s - T_a) \quad (30.3)$$

However, as the Grashof and Prandtl numbers can be difficult to determine, the following formula, which gives a close approximation, can be used for cylinders freely exposed to air:

$$Q_c = (T_s - T_a) 1.32 \left(\frac{T_s - T_a}{d_o} \right)^{0.25} \quad (30.4)$$

In the above equations:

Q_r = heat loss by radiation (W/m^2),
Q_c = heat loss by convection (W/m^2),
E = surface emissivity (see Section 30.4) (dimensionless),
T_s = surface temperature (°C),
T_a = ambient air temperature (°C),
T_{rm} = Mean radiant temperature of enclosure (°C),
Gr = Grashof number (dimensionless),
Pr = Prandtl number (dimensionless),
λ_a = thermal conductivity of air (W/mK),
d_o = outside diameter of cylinder/pipe (m).

30.3.2.4 Forced convection

It is not proposed to deal with forced convection here. Experimental work has yielded considerably differing results for ostensibly similar conditions. It is sufficient to note that forced convection affects small-bore pipes to a greater extent than large-bore and is dependent on temperature differences. While the heat loss from uninsulated surfaces may increase by a factor of up to

200–300%, the increase in heat loss from the insulated surface would be considerably less (of the order of 10%).

30.3.3 Insulated heat loss

Heat loss through insulation can be calculated from a knowledge of the thickness and thermal conductivity of the insulation and the emissivity of the outer surface of the insulation/cladding system.

30.3.3.1 Single-layer insulation

$$q = \frac{T_1 - T_2}{R} = \frac{T_1 - T_m}{R + R_s} \tag{30.5}$$

$$q_1 = 10^{-3}\pi d_o q \tag{30.6}$$

For plane surfaces:

$$R = 10^{-3}\frac{L}{\lambda} \tag{30.7}$$

$$R_s = \frac{1}{f} \tag{30.8}$$

For cylindrical surfaces:

$$R = 10^{-3}\frac{d_o}{2\lambda}\ln\frac{d_1}{d_o} \tag{30.9}$$

$$R_s = \frac{d_o}{f d_1} \tag{30.10}$$

30.3.3.2 Multi-layer insulation

$$q = \frac{T_1 - T_2}{R_1 + R_2 + \cdots R_n} = \frac{T_1 - T_m}{R_1 + R_2 + \cdots R_n + R_s} \tag{30.11}$$

$$q_1 = 10^{-3}\pi d_o q$$

For plane surfaces:

$$R_1 = 10^{-3}\frac{L_1}{\lambda_1} \tag{30.12}$$

$$R_2 = 10^{-3}\frac{L_2}{\lambda_2} \tag{30.13}$$

$$R_n = 10^{-3}\frac{L_n}{\lambda_n} \tag{30.14}$$

$$R_s = \frac{1}{f} \tag{30.15}$$

For cylindrical surfaces:

$$R_1 = 10^{-3}\frac{d_o}{2\lambda_1}\ln\frac{d_1}{d_o} \tag{30.16}$$

$$R_2 = 10^{-3}\frac{d_o}{2\lambda_2}\ln\frac{d_2}{d_1} \tag{30.17}$$

$$R_n = 10^{-3}\frac{d_o}{2\lambda_n}\ln\frac{d_n}{d_{(n-1)}} \tag{30.18}$$

$$R_s = \frac{d_o}{f d_n} \tag{30.19}$$

30.3.3.3 Symbols

In the above formulae the following symbols apply:

q = heat loss per square metre of hot surface (W/m^2)
q_1 = heat loss per linear metre of pipe (W/m)
R = thermal resistance of insulation per m^2(m^2K/W)
R_1 = thermal resistance of inner layer of insulation (m^2K/W)
R_2 = thermal resistance of second layer of insulation (m^2K/W)
R_n = thermal resistance of nth layer of insulation (m^2K/W)
R_s = thermal resistance of outer surface of insulation system (m^2K/W)
T_1 = temperature of hot surface (°C)
T_2 = temperature of outer surface of insulation (°C)
T_m = temperature of ambient still air (°C)
d_o = outside diameter of pipe (mm)
d_1 = outside diameter of inner layer of insulation (mm)
d_2 = outside diameter of next layer of insulation (mm)
d_n = outside diameter of nth layer of insulation (mm)
λ = thermal conductivity of insulating material (W/mK)
λ_1 = thermal conductivity of inner layer of insulation (W/mK)
λ_2 = thermal conductivity of second layer of insulation (W/mK)
λ_n = thermal conductivity of nth layer of insulation (W/mK)
f = surface coefficient of outer surface (W/m^2K)
ln = natural logarithm

Note: the values taken for λ, λ_1, λ_2, ..., λ_n should be those applicable to the mean temperature of the hot and cold surfaces of the appropriate layer.

30.3.4 Surface emissivity

Emissivity values are needed to calculate the radiation component of heat loss from high-temperature surfaces. Accurate values which reflect actual conditions are difficult to obtain, as the emissivity value varies with temperature and with contamination or oxidation of the surface.

For most non-critical calculations the following values may be used:

Steel, paint (matt surface)	0.90–0.95
Galvanized steel (new)	0.40
Galvanized steel (weathered)	0.85
Aluminium (polished)	0.05

30.3.5 Surface coefficients

These present similar problems to emissivities, and BS 5422 has standardized on three values:

1. $f = 5.7$ for surfaces of low emissivity (e.g. polished aluminium);
2. $f = 8.0$ for surfaces of medium emissivity (e.g. planished or galvanized steel, aluminium paint, stainless steel and aluminium/zinc amalgam);
3. $f = 10.0$ for surfaces of high emissivity (e.g. matt-black surfaces, steel, brick and plain insulation surfaces).

30.3.6 *U*-value calculation

The insulation effectiveness of elements of building structures is represented by the U-value or thermal transmittance. As defined in Section 30.3.1, the U-value is the reciprocal of the sum of the thermal resistances and can be expressed as:

$$U = \frac{1}{R_{so} + R_1 + R_2 \cdots R_n + R_{as} + R_{si}} \qquad (30.20)$$

where

R_{so} = thermal resistance of outer surface,
R_1 = thermal resistance of first material,
R_2 = thermal resistance of second material,
R_n = thermal resistance of nth material,
R_{as} = thermal resistance of any air space in the construction,
R_{si} = thermal resistance of inner surface.

In calculating R-values of the material elements of construction their λ values should be taken at 10°C mean temperature (which is assumed to be normal building temperature).

30.3.7 Standardized resistances

Actual thermal resistances of surface and air spaces within a construction vary according to size, exposure and nature of the material. Standardized resistance values are given in BS EN ISO 6946. These values are now collected in the CIBSE Guide A3, from which Tables 30.1–30.4 were prepared.

Table 30.1 Internal surface resistance, R_{si} (m^2K/W)

Building element	*Direction of heat flow*	*BS EN ISO 6946 design value*
Walls	Horizontal	0.13
Ceilings, roofs and floors	Upward	0.10
Ceilings and floors	Downward	0.17

Source: Chartered Institution of Building Services Engineers Guide, Section A3.

Table 30.2 External surface resistance, R_{so} (m^2K/W)

Building element	*Direction of heat flow*	*BS EN ISO6946 design value*
Walls	Horizontal	0.04
Roof	Upward	0.04
Floor	Downward	0.04

Table 30.3 Thermal resistances for continuous air spaces

Air space thickness (mm)	*Surface emissivity*[a]	*Thermal resistance ($m^2 \cdot K \cdot W^{-1}$) for heat flow in stated direction*[b]		
		Horizontal	*Upward*	*Downward*
5	High	0.11	0.11	0.11
	Low[c]	0.17	0.17	0.17
≥25	High	0.18	0.16	0.19
	Low[c]	0.44	0.34	0.50

[a]High emissivity: $\varepsilon > 0.8$; low emissivity: $\varepsilon \leq 0.2$.
[b]Normal to the surface in the direction of heat flow.
[c]Assumes that the air space is bounded by one low emissivity surface and one high emissivity surface.
Source: Chartered Institution of Building Services Engineers Guide, Section A3.

Table 30.4 Thermal resistances for highly ventilated air spaces

Type of air space (minimum thickness 25 mm)	*Thermal resistance*
Air space between sheeted cladding with unsealed joints, and lining; air space within ventilated flat roof	0.16
Air space between tiles and roofing felt or building paper	0.12
Air space behind tiles on tile-hung wall or roof or profile cladding on wall[a]	0.12
Air space in cavity wall construction	0.18

[a]Includes thermal resistance of tiles or cladding

Thermal resistances for roof spaces (reproduced from *BS EN ISO 6946* by permission of the British Standards Institution)

Item	*Description*	*Thermal resistance ($m^2 \cdot K \cdot W^{-1}$)*
1	Tiled roof with no felt, boards or similar	0.06
2	Sheeted roof or tiled roof with felt or boards or similar under the tiles	0.2
3	As 2 but with aluminium cladding or other low emissivity surface at underside of roof	0.3
4	Roof lined with boards and felt	0.3

30.4 Standards of insulation

In the UK the Building Regulations contain the mandatory requirement for thermal insulation of building structures, and heating and hot water services. Thermal insulation of cold water supply pipes is dealt with under the water supply bye-laws, but there are no national requirements to insulate pipes, vessels or equipment used in commercial or industrial processes.

30.4.1 Building regulations 2000

The mandatory requirement is that 'reasonable provision shall be made for the conservation of fuel and power in buildings'.

30.4.2 Approved document L

The DETR's interpretation of reasonableness is given in the Approved Document L. Part L1 covers dwellings and Part L2 covers buildings other than dwellings. Part L2 states that reasonable provision shall be made for the conservation of fuel and power by:

a) Limiting heat losses and gains through the building fabric
b) Limiting heat losses from hot water pipes, hot air ducts and hot water vessels
c) Providing efficient heating and hot water systems
d) Limiting exposure to solar overheating
e) Making provision that where air conditioning and mechanical ventilation systems are installed, that no more energy needs to be used than is reasonable in the circumstances
f) Limiting heat gains to chilled water and refrigerant vessels and pipework and air ducts that serve air conditioning
g) Providing energy efficient artificial lighting systems
h) Providing operation and maintenance information

In terms of this publication the sections involving insulation are a), b) and f).

Limiting heat losses and gains through the building fabric Three options are given for demonstrating compliance.

The Elemental Method This method considers the performance of each element of the building fabric. Maximum U-values are given for each element as shown in Table 30.5 below.

The Whole-Building Method This method considers the performance of the whole building. Calculation techniques are used to demonstrate that the proposed building will emit no more carbon per square meter per annum than a benchmark building. This method is available for offices, schools and hospitals.

The Carbon Emissions Calculation Method This method also considers the performance of the whole building but can be applied to any building type. To comply using this method, the proposed building must be shown to emit less carbon than a building that meets the compliance criteria of the Elemental Method.

There is a limit to the area of windows and doors under the Elemental Method. These are shown in Table 30.6.

There is flexibility to 'trade-off' between construction elements. If one element is above the required U-value, it can be compensated by improvements in other elements so that the overall heat loss is less than or equal to the value if all the elements had deemed-to-satisfy U-values.

Table 30.5 Standard U-values of construction elements

Exposed Element	*Maximum U-value (W/m^2K)*
Pitched roof with insulation between rafters	0.20
Pitched roof insulation between joists	0.16
Flat roof	0.25
Walls	0.35
Floors and ground floors	0.25
Windows, roof windows and doors (area weighted average for the whole building) glazing in metal frames	2.2
Windows, roof windows and doors (area weighted average for the whole building) glazing in wood or PVC frames	2.0
Rooflights	2.2
Vehicle access and similar large doors	0.7

Table 30.6 Maximum area of openings

Building Type	*Windows and doors as a per cent of internal exposed wall area*	*Rooflights as a per cent of area of roof*
Residential buildings	30	20
Places of assembly, offices and shops	40	20
Industrial and storage buildings	15	20
Vehicle access doors and display windows	As required	

Table 30.7 Poorest U-values acceptable when trading off between construction elements

Element	*Poorest acceptable U-value (W/m^2K)*
Parts of roof	0.35
Parts of wall or floor	0.70

However when trading off there is a limit placed on the U-value as shown in Table 30.7.

It should be noted that the U-values quoted must be calculated taking into account the effects of thermal bridging. If insulation is bridged by an element of higher conductivity, such as timber or steel, the overall U-value will be higher than if the insulation alone had been considered. Thermal bridging can have a significant impact on the overall insulation of a structure. When calculating the U-value of a structure, thermal bridging must be taken into account by carrying out the calculation in accordance with BS EN ISO 6946: 1997 Building components and building elements – Thermal resistance and thermal transmittance – Calculation method. This method is also used in the Chartered Institution of Building Services Engineers (CIBSE) Guide A: Environmental design, Section A3: Thermal properties of building structures, CIBSE 1999.

It should also be noted that the 2000 Regulations require buildings to be reasonably airtight. For buildings with a floor area of over 1000 m^2, a pressure test is required to meet an air permeability standard of 10 m^3/h per m^2 of external surface area at an applied pressure difference of 50 pascals.

Insulation of hot water storage vessels, pipes and ducts This section of Approved Document L is not intended to apply to storage and piping systems for commercial and industrial processes. It concerns only the central heating and the domestic supply of all buildings. The standards are presented in three sections for:

Storage vessels
Pipes
Ducts

Insulation of hot water storage vessels The requirements for these tanks and cylinders will be met if the storage systems meet the insulation requirements of BS699: 1984. BS 1566: 1984: Parts 1 & 2. BS 3198: 1981 or having a cylinder jacket complying with BS 5615: 1985 will all meet the requirements.

Insulation of pipes The general requirements for pipes is that they should be insulated to a thickness at least equal to the outside diameter and with an insulant of thermal conductivity not greater than 0.035 W/mk.

Two limiations are imposed: the insulation thickness need not be greater than 40 mm whatever the pipe outside diameter, and insulation is not needed on pipes whose heat loss contributes to the useful heat requirements of the room or space through which it runs.

As an alternative option, the insulation should meet the recommendations of BS 5422: 1977 which is currently undergoing a number of amendments.

This standard tabulates thickness of insulation too numerous to mention within this section, according to whether (1) the pipes carry central heating or domestic hot water, (2) the system is heated by gas, oil or other fuels, (3) the water temperature or (4) the thermal conductivity of the insulant at the appropriate mean temperature.

Insulation of ducts The requirements for warm air heating ducts is that they also should meet the recommendations of BS 5422: 1977, which again is undergoing major amendments. As with the other requirements that if ducts offer useful heat to the areas through which they run then they need to be appropriately insulated.

30.4.3 Water supply bye-laws

Like the Building Regulations, Bye-law 49, 'Protection from damage by freezing and other causes', is a functional requirement. It does not quote specific details but requires that 'every pipe or other water fitting, so far as is reasonably practicable shall be effectively protected ... by insulation or other means against damage from freezing and other causes'. Generally, this would be satisfied by insulating to BS 6700: 1987 recommendations which, for an insulant of thermal conductivity 0.035 W/mK (which applies to most fibrous and plastic insulants) at the temperatures appropriate to freezing, would mean insulation thicknesses of approximately 25 mm for all pipes in indoor installations and 30 mm for those outdoors.

BS 5422 (which also gives insulation thicknesses for protection against freezing) recommends thicknesses of 32 mm and 38 mm, respectively, for pipes of 48 mm outside diameter or less. It must be emphasized that these thicknesses only give protection for a relatively short period of time (i.e. overnight). It is not possible by means of insulation alone to protect permanently static water.

30.4.4 BS 5422, Method for specifying thermal insulating materials on pipes ductwork and equipment

Much mention has been made of this Standard with regard to insulation. It contains definitions, physical characteristics and recommended thicknesses of insulation for a wide range of industrial applications, including:

1. Refrigeration;
2. Chilled and cold water supplies for industrial applications;
3. Central heating and domestic hot and cold water supplies;
4. Process pipework and equipment.

It also contains heat loss calculation methods. This Standard should be the basis for any specification drawn up by a company that does not have its own in-house insulation standards manual.

30.5 Product selection

In selecting an insulation product for a particular application consideration should be given not only to its primary function but also to the many secondary functions, and often unappreciated requirements which the insulation of pipe or vessel may place on the insulation product. Some of these product requirements are discussed below.

30.5.1 Limiting temperatures

Ensure that the insulation selected can operate effectively and without degradation at temperatures beyond the design temperature called for. Temperature control of the process system can fail and systems can overheat. Hot surfaces exposed to ambient air will become hotter when insulated if there is no control of the process temperature. As with multi-layer systems, the addition of an extra layer of insulation will change the interface temperatures of all inner layers. Do not use an insulant close to a critical temperature limit.

30.5.2 Thermal movement

Large vessels and equipment operating at extreme temperatures exhibit large expansion or contraction movements. Any insulant specified for these applications should be capable of a sympathetic movement such that it will not

cause itself or any cladding to burst, nor should it produce gaps that lead to dangerous hot spots in the cladding system.

30.5.3 Mechanical strength

Many insulants are made in a wide range of densities and thus mechanical strengths. Ensure that where insulation is required to be load bearing, to carry cladding, to support itself across gaps or drape down the sides of buildings or high equipment, the selected product has the necessary strength to accommodate these mechanical requirements as well as the primary thermal one.

30.5.4 Robustness

Insulation is subjected to abuse on-site, in storage and often in transit. To ensure minimum wastage through breakage, contamination or deformation, select products which are resilient or robust enough to tolerate site conditions and malpractice.

30.5.5 Chemical resistance

No matter how well installed, insulation is always at risk of contamination from outside sources. Overfilling of vessels, leaking valves and flanges, oil thrown off from rotating transmission shafts and motors can all penetrate protective cladding or lining systems. Consideration of any insulant's compatibility with possible contaminants should be considered in these situations.

30.5.6 Weather resistance

As mentioned above, insulation applied to externally located equipment can be subjected to rain and weather contamination if the outer cladding fails. Insulants with water-repellant, water-tolerant or free-draining properties offer an additional benefit in this type of application. In the structural field insulants used as cavity-wall fills must be of those types specially treated and designed for this application.

30.5.7 Surface emissivity

The effects of surface emissivity are exaggerated in high-temperature applications, and particular attention should be paid to the selection of the type of surface of the insulation system. Low-emissivity surfaces such as bright polished aluminium reduce heat loss by inhibiting the radiation of heat from the surface to the surrounding ambient space. However, by holding back the heat being transmitted through the insulation a 'dam' effect is created and the surface temperature rises. This temperature rise can be considerable, and if insulation is being used to achieve a specified temperature the use of a low-emissivity system could necessitate an increased thickness of insulation. For example, a hot surface at 550°C insulated with a 50 mm product of thermal conductivity 0.055 and ambient temperature of 20°C would give a surface temperature of approximately 98°C, 78°C and 68°C when the outer surface is of low (polished aluminium), medium (galvanized steel) or high (plain or matt) emissivity, respectively. Conversely, to achieve a surface temperature of 55°C with the same conditions the insulation would need to be approximately 120 mm, 87 mm and 70 mm, respectively.

30.5.8 Acoustics

Because of their cellular or open-matrix construction, most insulants have an inherent ability to absorb sound, act as panel dampers and reduce noise breakout from plant by their ability to be a flexible or discontinuous link between an acoustically active surface and the outer cladding. This secondary aspect of thermal insulation specification is an important feature in maintaining quiet conditions in which people can work.

30.5.9 Fire safety

Large volumes of insulation are used in industry, and most is hidden under cladding behind linings and between sheeting. However, much is located in voids and open to view in workplaces.

Fires do occur and accidents happen. In selecting the appropriate material, consideration should be given to its fire-safety properties and also to methods of maintaining the integrity of the protective cladding in fire situations.

Fire properties of insulation materials range from the highest to the lowest, from non-combustible to flammable with toxic fume emission. Generally, inorganic materials tend to be non-combustible while organic (or oil-based) materials are combustible, but many have surface treatments to improve their fire-safety rating.

30.6 Thermal conductivity

Thermal conductivity is not a static property of a material. It can vary according to the density, operating temperature and type of gas entrapped within the voids.

30.6.1 Density effects

Most materials achieve their insulating properties by virtue of the high void content of their structure. The voids inhibit convective heat transfer because of their small size. A reduction in void size reduces convection but does increase the volume of the material needed to form the closer matrix, thus resulting in an increase in product density. Further increases in density continue to inhibit convective heat transfer, but ultimately the additional benefit is offset by the increasing conductive transfer through the matrix material and any further increase in density causes a deterioration in thermal conductivity (see Figure 30.1).

Most traditional insulants are manufactured in the low- to medium-density range and each particular product family will have its own specific relationship between conductivity and density. One particular group of products (insulating masonry) is manufactured in the medium- to high-density range. Thermal conductivity is improved by reducing density.

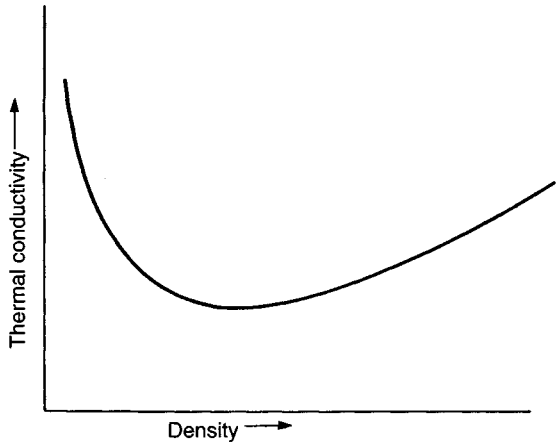


Figure 30.1 Typical relationship between thermal conductivity and density

30.6.2 Temperature effects

Thermal conductivity increases with temperature. The insulating medium (the air or gas within the voids) becomes more excited as its temperature is raised, and this enhances convection within or between the voids, thus increasing heat flow. This increase in thermal conductivity is generally continuous for air-filled products and can be mathematically modelled (see Figure 30.2). Those insulants which employ 'inert gases' as their insulating medium may show sharp changes in thermal conductivity, which may occur because of gas condensation. However, this tends to take place at sub-zero temperatures.

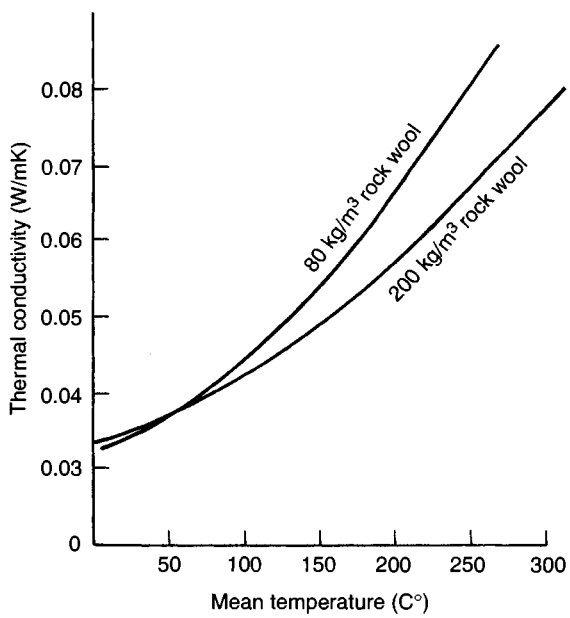


Figure 30.2 Typical relationship between thermal conductivity and mean temperature

30.6.3 Chlorofluorocarbons

Chlorofluorocarbons or CFCs used to be used in the manufacture of a range of plastic insulants, including polyurethanes, phenolics, polyisocyanurates and extruded polystyrenes.

CFCs are the main cause of the hole in the ozone layer. The 1990 Montreal Protocol called for the phasing out of CFCs in refrigeration, insulation and fire fighting equipment. An EC regulation has banned the production of CFCs since 1997. Manufacturers now use other blowing agents in foam insulation products. However, these are often hydrochlorofluorocarbons or HCFCs. While the potential of these gases to cause damage to the ozone layer is less than CFCs, there is still a potentially damaging effect. It is usually the case that when a product is advertised as being CFC-free it is in fact foamed with HCFCs.

It is planned to phase out the use of HCFCs by 2010. In the meantime, since there are many insulants on the market which are not foamed with ozone damaging gases, many specifiers are now insisting that the insulation should have a *Zero Ozone Depletion Potential –ZODP.*

30.7 Physical forms

The extensive range of insulation types and the numerous forms in which they are manufactured ensures that any listing can never be comprehensive. It becomes even more so when one acknowledges the fact that within the insulation industry there is a secondary network of fabricators and laminators who will take manufacturers' basic products and cut, shape, mould, laminate and enclose them to almost any requirement. The following gives the basic physical forms and some of the uses to which insulation materials are put.

30.7.1 Slab or board

Material of a rectangular shape and of uniform thickness. The basic product supplied by almost all manufacturers in forms ranging from 'flexible' to 'rigid'. Dimensions determined by manufacturing facility and handling ability, but usually in 600 mm and 1200 mm modules. May be used in most applications on plane surfaces. As lining panels, under cladding, within casings, in partitions, in buildings or plant and equipment.

30.7.2 Pipe sections

Rolled, moulded or cut to shape as annular cylinders for the insulation of pipes. Made by most manufacturers usually in one or two segments but occasionally in three or four. Sizes available for most steel and copper pipes of up to approximately 1120 mm outside diameter.

30.7.3 Bevelled lags

Slabs of narrow width bevelled on edges (and sometimes radiused on faces). Fitted longitudinally on large-sized

pipes with face conforming closely to the circumference. Another product available from most manufacturers.

30.7.4 Loose fill

Granulate, particle-size material specifically manufactured or produced from basic product off-cuts. Supplied by most manufacturers and used for packing or pouring into irregular-shaped enclosures.

30.7.5 Mat or blanket

Flexible material of low density and long length generally supplied in rolls available with or without facings. Mineral wool and flexible foams are the most usual type of product. Widely used in buildings as roof insulation and in steel- and timber-frame walls. Sound insulation in partitions, on low-temperature heating ducts and in equipment casings.

30.7.6 Rolls

Mat or blanket supplied in the form of helically wound cylindrical packs.

30.7.7 Mattress

Medium- to heavy-density mineral wool mat with wire netting or expanded metal mechanically secured on one or both sides. Used for irregular-shaped surfaces and on large pipes and vessels. Also used as large-cavity fire barriers.

30.7.8 Quilt

Medium-density mat with flexible facings of paper or scrim stitched through. Used for acoustic absorption behind perforated or slatted panels and ceilings.

30.7.9 Lamella

Paper- or foil-backed mineral wool product fabricated from low-density slabs in which the slats stand upright with the fibres predominantly perpendicular to the major faces. Used on circular and elliptical ducting, pipes and vessels to give a compression-resistant insulant. Supplied in roll form.

30.7.10 Blowing wool

Nodulated mineral wool produced for application through pneumatic hoses into areas of restricted access.

30.7.11 Sprayed insulation

Insulation dry mixed in factory with inorganic fillers and binders for application by wet spraying. Usually mineral wool or vermiculite based, used for thermal and acoustic treatments and for fire protection of steelwork.

30.7.12 Sprayed foam

A cellular plastic – usually of the urethane or isocyanurate families – where chemical components are mixed at the spray head.

30.7.13 Moulded products

Insulation formed by slurry casting or heat curing under pressure in moulds in a number of insulation types. Most common mouldings are preformed bends, valve boxes and flange covers.

30.8 Facings

While all insulation products are supplied in their natural 'as-produced' finish, they are also available with a variety of facings which are either applied 'on-line' during manufacture or as a secondary 'off-line' process. The facings are applied for functional, technical or aesthetic reasons, generally as follows.

30.8.1 Paper

Brown Kraft paper is generally used on mineral wool products to give added tensile strength, ease of handling, aid positive location between studs or rafters, or prevent contamination when used under concrete screeds. Paper is often laminated with polythene to give vapour control layer properties.

30.8.2 Aluminium foil

Glass-reinforced aluminium foil with either a bright polished or white lacquer surface is utilized with most types of insulant. Primarily it is used as a vapour control layer or as a means of upgrading the fire properties of plastic foams, but it does give a semi-decorative finish to the insulation. It is therefore often used where the insulation is open to view but located away from direct risk of mechanical damage.

30.8.3 PVC

Generally used with mineral wool products where, in its decorative forms, it gives attractive facings to ceilings and wall tiles and enhances their sound-absorption characteristics. PVC is also used as a vapour control layer facing.

30.8.4 Tissue

Glass-fibre tissue or non-woven fabrics are used for decorative purposes on many insulants. They also give improved strength to foam plastics and enhanced sound-absorption characteristics to mineral wools.

30.8.5 Glass cloth

As with tissue, woven glass cloth is used for decorative or acoustic purposes. Additionally, close-woven fabrics give improved fire-safety properties and are resistant to

mechanical abuse. Glass cloth or scrim of an extremely open weave is used on insulants as a key for mastic or hard-setting finishes.

30.8.6 Wire netting

Used to give mechanical strength to mineral wool mattresses and is also an aid to application. Also a key for mastic or hard-setting finishes applied on-site.

30.8.7 Laminates

Insulation is widely used in laminate form with plasterboard, chipboard, cement board, and metal sheeting, etc. Applications are generally as lining board systems in buildings but prefabricated metal panels and ceiling tiles are also produced.

30.9 Insulation types

It is not possible to detail all the many different types of insulation used in production, service and building industries. The following attempts to give a summary of the composition, properties and major areas of use of a representative range of insulation types.

A useful way of classifying insulation materials is to divide them into three groups – Organic 1, Organic 2 and Inorganic.

Organic Group 1 materials come from naturally occurring vegetation. Included in this group are cork, cellulose fibre, flax and sheep's wool. These materials are generally simple in their production techniques, environmentally benign, have a relatively low thermal performance, are relatively permeable, are well established but often need chemical treatment to protect against fire, rot, vermin and insect attack.

Organic Group 2 materials come from fossilized vegetation: petroleum or coal. Included in this group are polystyrenes, polyurethanes, polyisocyanurates and phenolic foams. These materials generally have a high thermal performance, are combustible and are relatively impermeable.

Inorganic Group materials are silica or calcium based. Included in this group are mineral fibres, calcium silicate, cellular glass, vermiculite and perlite. These materials are generally incombustible, vermin and rot proof, they are relatively permeable and have a medium thermal performance.

30.9.1 Mineral wool

Mineral wool is perhaps the best known of the whole range of insulation types. It is widely used in all sectors of industry, transport and building for thermal, acoustic and fire-protection purposes. Despite this, there is still a common misconception that mineral wool is a specific product type – it is not. Mineral wool is a generic name for a range of man-made non-metallic inorganic fibres. The following definitions should help to clarify the situation:

1. *Mineral fibre*: A generic term for all non-metallic inorganic fibres.
2. *Mineral wool*: A generic term for mineral fibres of a woolly consistency, normally made from molten glass, rock or slag.
3. *Glass wool*: A mineral wool produced from molten glass.
4. *Rock wool*: A mineral wool produced from naturally occurring igneous rock.
5. *Slag wool*: A mineral wool produced from molten furnace slag.

From these it can be seen that rock wool, slag wool and glass wool are all mineral wools.

30.9.2 Glass wool

Glass wool is made from borosilicate glass whose principal constituents are sand, soda ash dolomite, limestone, ulexite and anhydrite. They are melted in a furnace at about 1400°C and then fed along a channel to a forehearth, where the glass flows through bushings into spinners. These rapidly rotating spinners have several thousand small holes around the perimeter through which the glass is forced by centrifugal force to become fibreized. Immediately after formation, the fibres are sprayed with resinous binders, water repellents and mineral oils as appropriate and fall under suction onto a moving conveyor which takes the wool to one of three production lines (Figure 30.3).

30.9.2.1 Main line

The wool passes through an oven which cures the resinous binder and determines the thickness of the product. On leaving the oven, the insulation is trimmed, slit and chopped into the appropriate product length prior to reaching the packing station, where it is either packaged as rolls or slabs.

30.9.2.2 Pipelines

The uncured wool from the forming conveyor is separated into 'pelts' which are converted into pipe sections by being wrapped around a heated mandrel and the wall thickness set by counter rollers. The sections are then passed through a curing oven before being trimmed, slit, covered and packaged.

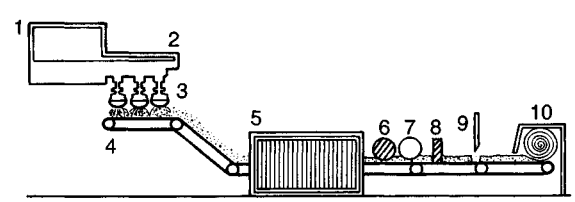


Figure 30.3 The glass wool manufacturing process. 1 Tank; 2 forehearth; 3 spinners; 4 conveyor; 5 curing oven; 6 trimmers; 7 slitters; 8 bandsaw; 9 guillotine; 10 rolling machine

30.9.2.3 Blowing wool line

The water-repellent wool is shredded by a flail and pneumatically transferred to a rotating drum nodulator to be further processed before bagging.

30.9.2.4 Product range

A wide product range, from lightweight mats through flexible and semi-rigid, to rigid slab. Pipe sections, loose wool, blowing wool, moulded products and mattresses.

30.9.2.5 Typical properties

Glass wool products have a limiting temperature of 540°C but are mostly used in buildings and H & V applications where a limiting working temperature of 230°C is recommended.

Fire safety Basic wool is non-combustible to BS 476: Part 4.

Density range 10–75 kg/m^3.

Thermal conductivity 0.04–0.03 W/mK at 10°C mean: 0.07–0.044 W/mK at 100°C mean.

Ozone depletion ZODP

30.9.2.6 Special applications

Acoustic absorption in duct lining and splitters. Decorative facings for ceiling and lining panels. Tensile strength for good draping qualities. Loft insulation up to 200 mm thick, cavity wall insulation. Fire stopping and small-cavity fire barriers.

30.9.3 Rock wool

Rock wool is made from basalt or dolomite rocks. The crushed rock, together with limestone and coke, is loaded into a cupola furnace where, with the aid of oxygen, it is melted at about 1500°C. The molten rock then runs down channels and cascades onto a train of rotating discs which sling the melt off as fibres. Resin binders, water repellents and mineral oil are sprayed onto the fibres as they leave the discs and fall under suction onto the forming conveyor. From this stage the wool follows a similar processing sequence to glass wool.

30.9.3.1 Product range

Lightweight mats, flexible, semi-rigid and rigid slabs, pipe sections, loose wool, blowing wool, mattresses, sprayed fibre, lamella mats.

30.9.3.2 Typical properties

Rock wool special products can be used up to 1100°C, but generally a maximum operating temperature of 850°C is recommended. Like glass wool, the lower density products used in buildings and H & V applications have recommended limits of 230°C.

Fire safety Basic wool is non-combustible to BS 476: Part 4.

Density range 23–200 kg/m^3.

Thermal conductivity 0.037–0.033 W/mK at 10°C mean: 0.052–0.042 W/mK at 100°C mean.

Ozone depletion ZODP

30.9.3.3 Special applications

High-temperature work, fire protection, acoustics, sprayed fibre, moulded products, cavity-wall insulation, loft insulation.

30.9.4 Ceramic fibres

As with mineral wools, there are different types of ceramic fibre, but basically they are all made from a combination of alumina, silica and china clay and may be made by blowing or extruding the liquid melt.

30.9.4.1 Product range

A wide basic range of blankets, slabs, block and pipe sections, especially moulded products, felts and gaskets.

30.9.4.2 Typical properties

Ceramic fibres are used at temperatures up to 1600°C but their melting point can be in excess of 2000°C.

Fire safety Basic wool is non-combustible to BS 476 Part 4.

Density range 50–300 kg/m^3.

Thermal conductivity 1.8–0.8 W/mK at 500°C mean.

Ozone depletion ZODP

30.9.4.3 Special applications

Furnace linings, 'refractory blocks', gaskets, expansion joints, very high-temperature work.

30.9.5 Magnesia

Magnesium carbonate is extracted from dolomite rock, and after mixing with fibre reinforcement is slurry cast into appropriate moulds. After drying, the products are machined to size.

30.9.5.1 Product range

Rigid slabs, pipe sections, bevelled lags and moulded products. Also as a powder mix for use in a wet cement form.

30.9.5.2 Typical properties

Temperature range Up to 315°C.

Fire safety Non-combustible to BS 476: Part 4.

Density 190 kg/m^3.

Thermal conductivity 0.058 W/mK at 100°C mean.

Ozone depletion ZODP

30.9.5.3 Special applications

Where load-bearing capacity is required and in food, pharmaceuticals and cosmetics processing industries.

30.9.6 Calcium silicate

A chemical compound of lime and silica with fibre reinforcement for added strength. It is cast as a wet slurry into moulds and charged into autoclaves, finally being machined to accurate size.

30.9.6.1 Product range

Rigid slabs, pipe sections, bevelled lags, moulded products and as a dry mix for wet plastic application.

30.9.6.2 Typical properties

Standard products have limiting temperatures of 800°C but special formulations enable applications up to 1050°C.

Fire safety Non-combustible to BS 476: Part 4.

Density range 240–400 kg/m^3.

Thermal conductivity 0.054–0.068 W/mK at 100°C.

Ozone depletion ZODP

30.9.6.3 Special applications

Industrial process applications where compressive strength is needed. Also used in underground pipework district heating mains.

30.9.7 Cellular glass

Powdered glass and crushed carbon are placed in moulds and heated to 1000°C, at which temperature the carbon is oxidized, forming gas bubbles which causes expansion of the glass mix. The cellular material is then annealed and, after cooling, cut to size.

30.9.7.1 Product range

Rigid slabs, pipe sections, bevelled lags, moulded products.

30.9.7.2 Typical properties

Temperature range −260°C to 430°C.

Fire safety Non-combustible to BS 476: Part 4.

Density range 125–135 kg/m^3.

Thermal conductivity 0.043–0.055 W/mK.

Ozone depletion ZODP

30.9.7.3 Special applications

Its closed-cell structure makes cellular glass particularly suitable for refrigeration applications on pipes and cold stores. High load-bearing capacity enables it to be used under rooftop car parks.

30.9.8 Exfoliated vermiculite

Vermiculite is a naturally occurring group of hydrated aluminium–iron–magnesium silicates having a laminate structure. When subjected to direct heat in a furnace, the pulverized material 'exfoliates' or expands in size, and then consists of a series of parallel plates with air spaces between.

30.9.8.1 Product range

Base product produced as a granular loose fill which can be bonded to form boards or dry mixed with fillers and binders for spray application.

30.9.8.2 Typical properties

Limiting temperatures 1100°C.

Fire safety Non-combustible to BS 476: Part 4.

Density 60–80 kg/m^3.

Thermal conductivity 0.062 W/mK at 10°C mean.

Ozone depletion ZODP

30.9.8.3 Special applications

Primarily used in fire-protection applications as dense boards or wet sprays.

30.9.9 Expanded polystyrene

Expandable polystyrene grains are usually heated by stream, which causes them to expand. They are then conditioned and, as they cool, the steam in the voids within the beads condenses, thus permitting air to diffuse into them. After conditioning, the granules are placed in moulds through which more steam is blown, resulting in further expansion. As they are enclosed in the mould the granules tend to fuse together, forming a rigid block. The blocks are later cut to shape by the hot-wire technique.

30.9.9.1 Product range

Rigid slabs, pipe sections, tiles, and loose granules.

30.9.9.2 Typical properties

Limiting temperatures 80°C.

Fire safety Flame-retardant grade. Class P not easily ignitable to BS 476: Part 5.

Density 12–32 kg/m^3.

Thermal conductivity 0.037–0.034 W/mK at 10°C mean.

Ozone depletion ZODP

30.9.9.3 Special application

Used mainly for building insulation and as a laminate. Also employed in cold water tanks and pipes.

30.9.10 Extruded polystyrene

This is produced by a continuous extrusion process which gives the product a smooth-surface skin and enhances the mechanical properties.

30.9.10.1 Product range

Rigid slabs.

30.9.10.2 Typical properties

Limiting temperature 75°C.

Fire safety Classified as Type A to BS 3837.

Density 28–45 kg/m^3.

Thermal conductivity 0.025–0.033 W/mK at 10°C mean.

Ozone depletion Usually foamed with HCFCs but ZODP may be available with a consequent increase in conductivity.

30.9.10.3 Special applications

Used mainly in structural applications. Is suitable for refrigeration and cold stores.

30.9.11 Rigid polyurethane foam

Polyurethanes are manufactured by the mixing of various resins, isocyanates and catalysts to produce an exothermic reaction which liberates the foaming agent and causes the mix to expand. They are made in large block moulds as a batch process or are continuously foamed onto a paper or polythene substrate on a conveyor system.

30.9.11.1 Product range

Rigid slabs, pipe sections, bevelled lags.

30.9.11.2 Typical properties

Limiting temperature 110°C.

Fire safety Class P not easily ignitable to BS 476: Part 5. Can achieve Class 1 surface spread of flame to BS 476: Part 7 when faced with aluminium foil.

Density 30–160 kg/m^3.

Thermal conductivity 0.023 W/mK at 10°C mean.

Ozone depletion Usually foamed with HCFCs but ZODP may be available with a consequent increase in conductivity.

30.9.11.3 Special applications

Used mainly for refrigeration and cold water services, also low-temperature tankage. When laminated to suitable facings is employed in building applications.

30.9.12 Polyisocyanurate foam

Polyisocyanurates are manufactured in a similar way to polyurethanes, the chemical components being selected to enhance their fire-safety properties.

30.9.12.1 Product range

Slabs, pipe sections, bevelled lags.

30.9.12.2 Typical properties

Limiting temperature 140°C.

Fire safety Class 1 surface spread of flame to BS 476: Part 7. Can achieve Class O to Building Regulations when faced with aluminium foil.

Density 32–50 kg/m^3.

Thermal conductivity 0.023 W/mK at 10°C mean.

Ozone depletion Usually foamed with HCFCs but ZODP may be available with a consequent increase in conductivity.

30.9.12.3 Special applications

For cryogenic and medium-temperature pipework and equipment, especially in oil petrochemical industries and on refrigerated road and rail vehicles.

30.9.13 Phenolic foam

Similar production process to polyurethane. Has the best fire-safety properties of all the rigid foams.

30.9.13.1 Product range

Slabs, pipe sections, pipe bends, bevelled lags.

30.9.13.2 Typical properties

Limiting temperature 150°C.

Fire safety Class O to Building Regulations.

Density 35–200 kg/m^3.

Thermal conductivity 0.02 W/mK to 10°C mean.

Ozone depletion Usually foamed with HCFCs but ZODP may be available with a consequent increase in conductivity.

30.9.13.3 Special applications

Commercial and Industrial H & V applications and where Class O fire rating and low smoke-emission characteristics are required.

30.9.14 Expanded perlite

Perlite is a naturally occurring sileceous rock. When heated to over 1000°C the Perlite ore particles expand to between 4 and 20 times their original volume.

30.9.14.1 Product range

The base product is produced as a granular loose fill. When siliconized can be used as a cavity fill or loft insulation. It is also used in the production of lightweight concrete and plasters.

30.9.14.2 Typical properties

Limiting temperature 1200°C

Fire safety Non-combustible to BS 476: Part 4.

Density 32–150 kg/m^3

Thermal conductivity 0.035–0.06 W/mk

Ozone depletion ZODP

30.9.14.3 Special applications

Used as an insulator at high temperatures in the refractory and steel industries.

30.9.15 Flax

Flax is a naturally occurring plant grown widely in Europe. The flax fibres are interwoven and bound with polyester fibres to form batts. Borax is added to give protection from fire and insect attack.

30.9.15.1 Product range

Flax is produced in slab form with a typical thickness of between 40 and 140 mm.

30.9.15.2 Typical properties

Limiting temperature 320°C

Fire safety B2 according to DIN 4102

Density 30 kg/m^3

Thermal conductivity 0.037 W/mk

Ozone depletion ZODP

30.9.15.3 Special applications

Flax can also be used for acoustic insulation.

30.9.16 Cork

Cork originates from the bark of the cork oak tree, which is widely distributed particularly in the Mediterranean. The bark is granulated and then steam baked in moulds.

30.9.16.1 Product range

Cork is produced as a granular loose fill material but more often as boards.

30.9.16.2 Typical properties

Limiting temperature 120°C

Fire safety At present no British Standard – under test conditions a 50 mm slab resisted penetration by an 800°C flame for 4 hours. On combustion does not release any toxic gases, cyanides or chlorides.

Density 100–150 kg/m^3

Thermal conductivity 0.04–0.05 W/mk

Ozone depletion ZODP

30.9.16.3 Special applications

Cork is chemically inert and stable against weak acids, alkalies and most solvents.

30.9.17 Cellulose

Cellulose insulation is manufactured from recycled newspaper and magazines. The newspaper is shredded and Boron salts are added to provide protection against fire, vermin and organic growth.

30.9.17.1 Product range

Cellulose fibre can be used as loft insulation or in other situations, such as timber frame walls, where it will remain dry. It can be blown in dry or wet sprayed.

30.9.17.2 Typical properties

Limiting temperature 65°C

Fire safety Conforms to the flammability and smoulder combustion requirements of BS 5803 Part 4: 1985

Density 24–55 kg/m^3

Thermal conductivity 0.035 W/mk

Ozone depletion ZODP

30.9.17.3 Special applications

Cellulose fibre can also be used for acoustic insulation.

30.9.18 Sheep's wool

With the fall in the use of wool for clothing, there is a growing interest in using it for building insulation. Wool fibres are carded and aligned and bound with coir and polyester fibre. Difficult to state limiting temperatures which may depend on how it is constructed for particular uses.

30.9.18.1 Product range

Sheep's wool is produced in mat form between 30 and 200 mm thick. It's main use is in loft and timber frame wall insulation.

30.9.18.2 Typical properties

Limiting temperatures Difficult to predict due to how it is used and how it is mixed with other products to suit different applications.

Density 25 kg/m^3

Thermal conductivity 0.038 W/mk

Ozone depletion ZODP

31 Economizers

Colin French CEng, FInstE, FBIMgt
Consultant

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31.1 Introduction

Economizers for boilers have been available for nearly 150 years, almost as long as boilers themselves. For modern shell boilers, high efficiencies have made it increasingly difficult to justify the use of an economizer, the final decision being based in terms of payback period, which is also heavily dependent on fuel prices. Watertube boilers, on the other hand, need an economizer section in the gas passes in order to obtain satisfactory efficiency. For this reason, the economizer is integrated into the overall design, normally between the convective super-heater and the air heater if fitted.

In shell boilers with a working pressure of between 7 and 17 bar the temperature of the mass of water in the boiler is typically in the range of 170–210°C. Allowing for, say a temperature difference of 30–50°C between the exhaust gases and the water temperature, the boiler exit gas temperature cannot be economically reduced beneath about 200–260°C, dependent on the operating pressure. It becomes necessary, therefore, to modify the process principles to achieve further heat utilization and recovery. By using an economizer this is done by conducting the feedwater supply to the economizer wherein the exhaust gas passes over tubes carrying the feedwater. The feedwater, normally at temperatures between 30° and 100°C, represents a further cooling medium for the exhaust gases and provides the potential for the extra heat utilization. This is shown in Figure 31.1.

31.2 Oil and coal applications

Although it would be possible to design for an economizer gas exit temperature of 30–50°C above the feedwater temperature, this would result in a temperature too close to the acid dewpoint of the gases. The acid dewpoint is the temperature at which acidic gases begin to condense out of the exhaust gas mixture. This is principally sulphuric acid due to the sulphur contained in the oil or coal. Although the bulk gas temperature may be satisfactory, in practice, the surfaces close to the tube wall will be nearly at water temperature due to the high conductivity of the metal tube. This limits the minimum practical gas exit temperature from the economizer to, say, 170–180°C, remembering, of course, that at low fire this will have fallen closer still to the acid dewpoint (which is typically in the range of 125–140°C, dependent on the excess air and fuel sulphur content). The cold temperature of the heat transfer surface gives rise to heavy corrosion which would reach a peak at about 95°C.

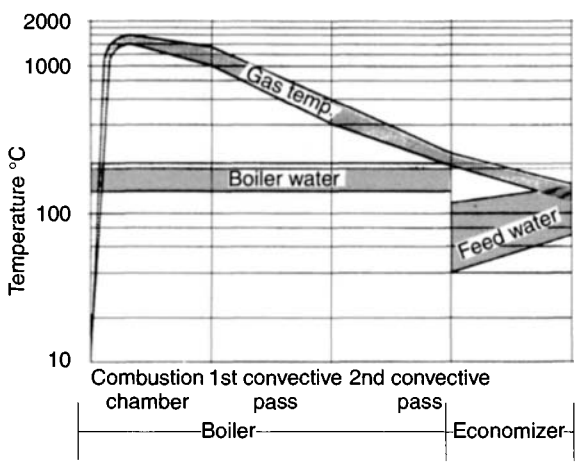


Figure 31.1 Temperatures in three-pass boilers and economizers

The potential to recover heat from the gases of an oil or coal-fired boiler is therefore limited to a temperature drop from 240°C to 170°C. This results in a 3% saving. The average saving would be somewhat lower than this since fouling of the economizer surface is inevitable from the carbonaceous emissions of the firing of coal or oil.

The design of the economizer must be robust enough to survive occasional excursions beneath the acid dewpoint and the effects of the methods used to clean the economizer periodically. This may take the form of rapping equipment to shake off deposits, sootblowing by steam or air and water washing with lances.

Average savings of 2–3% combined with the cost necessary for a robust design have therefore limited the use to times when fuel prices are high or special applications where the boiler exit temperature is higher than usual. Developments using an additive to suppress the dewpoint are worth consideration, since this extends the heat-saving potential but, of course, there is an additional burden with the cost of the additive. Magnesium oxide is the most commonly used suppressant and this is injected into the gas stream to combine with the sulphuric acid to form magnesium sulphate (which also has to be removed regularly in addition to the soot).

31.3 Gas-fired economizers

Far greater potential exists for gas-fired economizers, since the gas is virtually free of sulphur. The limitation in gas temperature is the ability of the water to extract the heat, although the water vapour in the gas caused by the combustion of hydrogen does give rise to a water dewpoint at 55°C. This should be avoided, since general corrosion can take place in the latter rows of the economizer and in the exhaust gas ducts and chimney. Normally, this only occurs for short periods during starting from cold, but it should be minimized.

Since no serious problems exist with corrosion, the materials of construction can be cheaper and the thicknesses reduced. Fouling coefficients do not need to be incorporated into the design calculations as the surfaces remain clean indefinitely. This in itself provides a secondary benefit in that the pitching of fins may be reduced without the risk of reducing flow.

A saving of (typically) 5% can be made with gas-fired economizers, and as this is related to the boiler output it represents a saving of 6.25% in fuel consumed. Gross heat-saving potential may be determined in relation to feedwater temperature and excess air level are shown in Figure 31.2.

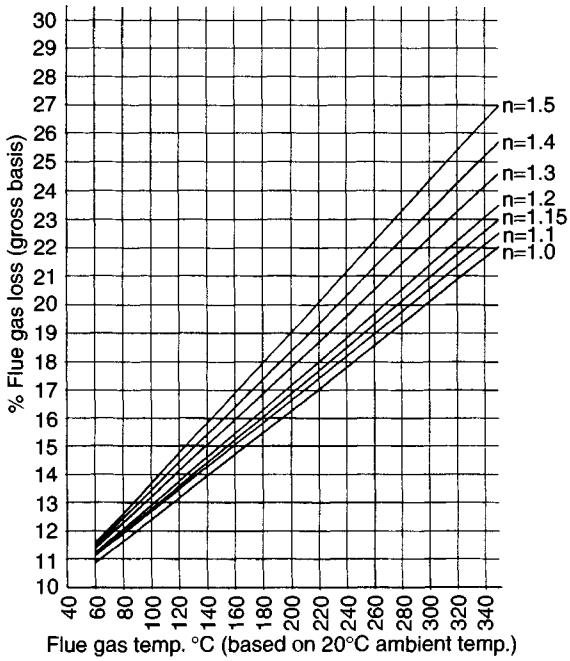


Figure 31.2 Total heat in gas-fired boiler exhaust

31.4 Design

The driving force for heat transfer is temperature difference, and this is maximized through the economizer by arranging for concurrent flow through the passages. In other words, the colder feedwater is made available to the coolest gases. This gives the highest overall average temperature difference throughout the length of the economizer, and is characterized by the logarithmic temperature difference ΔT_{lm}:

$$\Delta T_{lm} = \frac{(T_{g1} - T_{w2}) - (T_{g2} - T_{w1})}{\log_n[(T_{g1} - T_{w2})/(T_{g2} - T_{w1})]}$$

The amount of heat (Q_1) that may be transferred is controlled by:

$$Q_1 = \Delta T_{lm} \cdot U \cdot A$$

where U = overall heat transfer coefficient and A = heat transfer area. To achieve a cost-effective design of economizer it is necessary to maximize the overall heat transfer coefficient and the surface area within the economizer.

The heat transfer coefficient, U, can be maximized by the highest practical velocities that can be achieved for both the water and the gas. Water-side pressure loss is limited by the available spare pressure rise from the feed pump. This is often limited to 0.2–1.0 bar, as it is not generally economic to replace the feed pump. Gas-side velocities are generally limited by the available spare fan head from the burner. Once again, it is not normally economic to replace this in the case of retrofitted economizers or, for that matter, to install an induced-draught fan downstream of the economizer. In addition to maximizing fluid velocities, careful design to promote turbulence by staggered pitching enhances the heat transfer coefficient.

The heat transfer area, A, can be greatly increased by using finned tubes, but care must be taken to ensure good conduction of heat away from the fin into the tube and subsequently into the water. Some common fin types are shown in Figure 31.3 while Figure 31.4 shows some of the attachment methods employed to ensure satisfactory fin to tube heat transfer.

Design and manufacture is normally to BS 1113:1998 but with the advent of the Pressure Equipment Directive 97/23/EC(PED) will be implemented under the Pressure Equipment Regulations SI200011:10999 (PER) throughout Europe and will revert to EN 12952 Watertube Boilers, for most industrial applications there being no lesser Standard which is relevant to economizers. Designs are therefore to very stringent requirements so problems are rarely found. Typical constructional arrangements (including tube layout) are shown in Figure 31.5.

31.5 Installation

Due to interruptible gas tariffs, it is often necessary to adopt gas as the primary fuel and burn oil in periods of interruption when gas is unavailable. This means that the economizer has to be arranged so that when oil firing, the flue gases are bypassed around the economizer. The bypass duct must also contain a damper to simulate the economizer gas resistance so that the burner back pressure remains the same for both fuels. Installation may be simplified by using an economizer where the manufacturer has integrated the dampers for isolating and trimming, together with the bypass ducting into the basic design. Figure 31.6 shows a typical installation layout without this feature.

31.6 Condensing economizers

The restrictions on feedwater temperature dictated by condensate rates and the need to minimize oxygen corrosion limit further development of the performance of conventional economizers. As mentioned earlier, it becomes necessary to revise the whole philosophy if enhanced heat recovery is desired. If the gas can be reduced in temperature to beneath the water dewpoint of approximately 55°C there exists a potential heat saving due to the latent heat of condensation of the water vapour as well as the sensible heat also contained in the exhaust gases. This quantity of water vapour is considerable (in the case of natural gas firing of the order of 1 ton per hour for a 10 ton/h steam boiler). Once again, the potential can only be realized provided a requirement exists for such heat. This heat is of relatively low grade and therefore requires a large mass flow rate of water to absorb it. A typical figure might be of the order of twice the boiler feedwater flow rate and at a temperature of mains water. This precludes the use of the boiler feedwater, and therefore special low-temperature processes must be integrated into condensing economizer scheme. The temperature rise of this water would probably be about 45°C. Assuming the exhaust gases are cooled

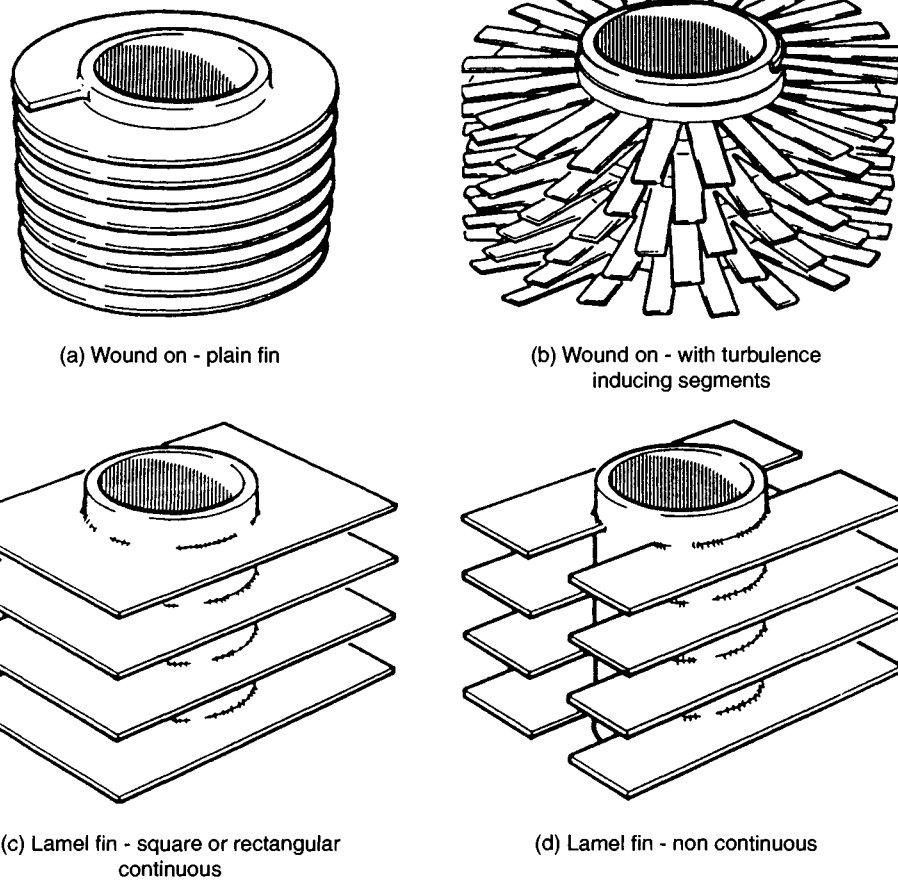


Figure 31.3 Common fin types

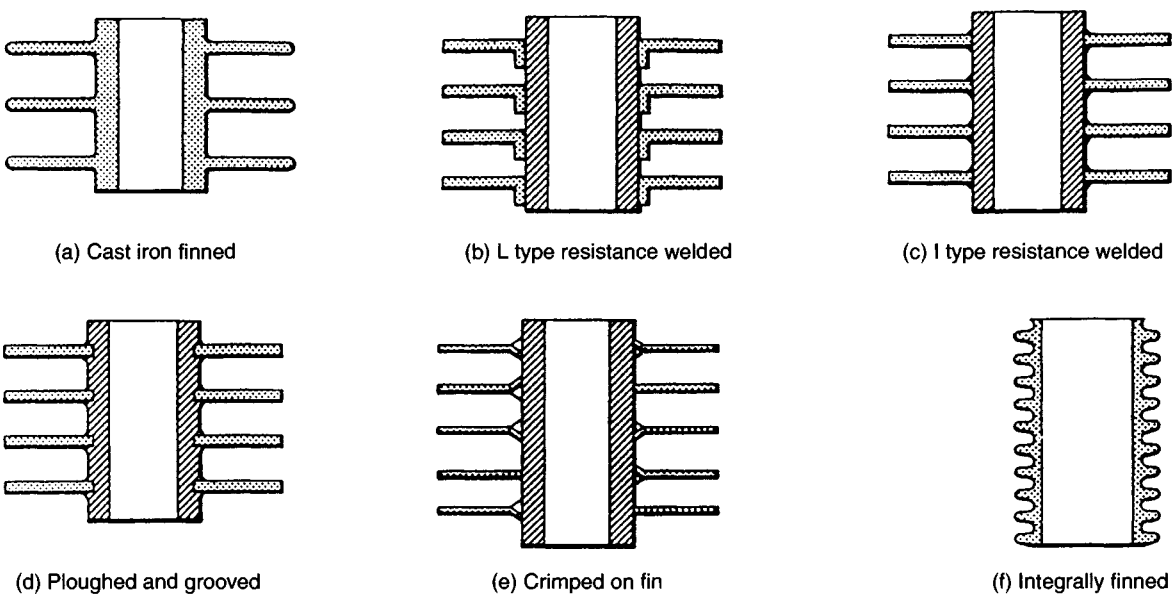


Figure 31.4 Fin attachment methods

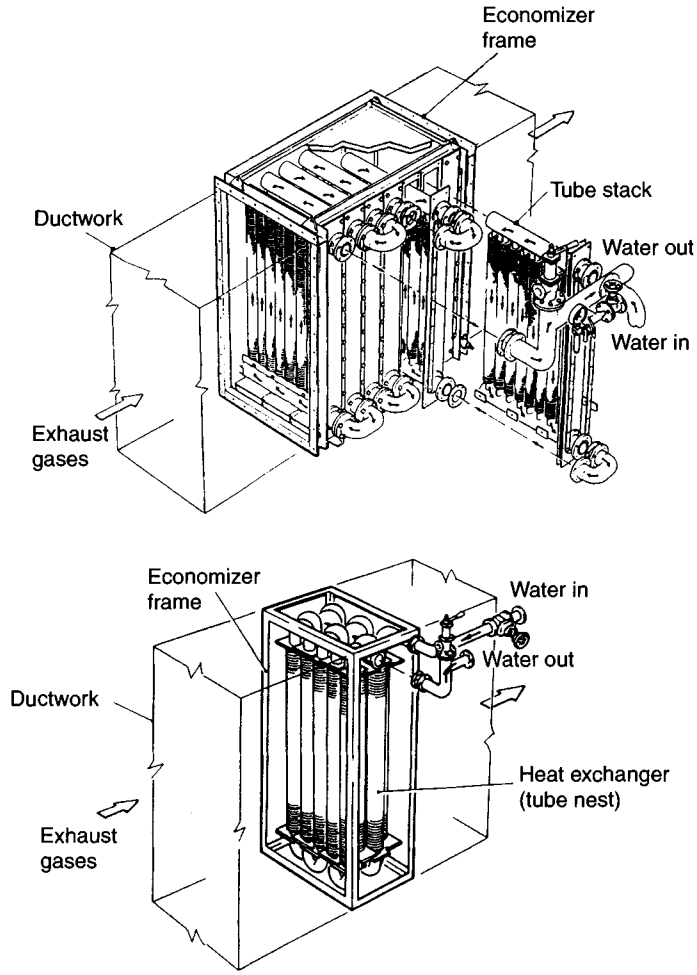


Figure 31.5 Economizer – typical designs

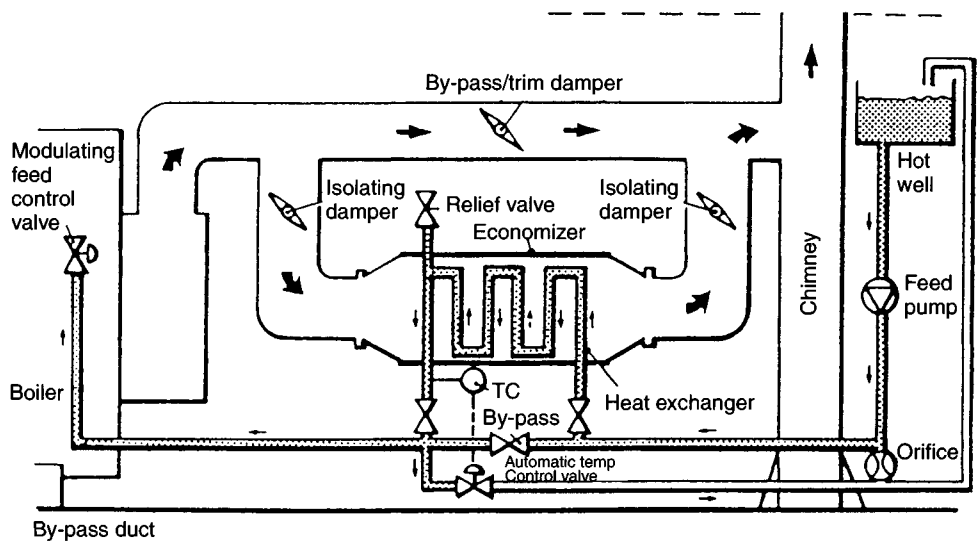


Figure 31.6 Typical installation layout

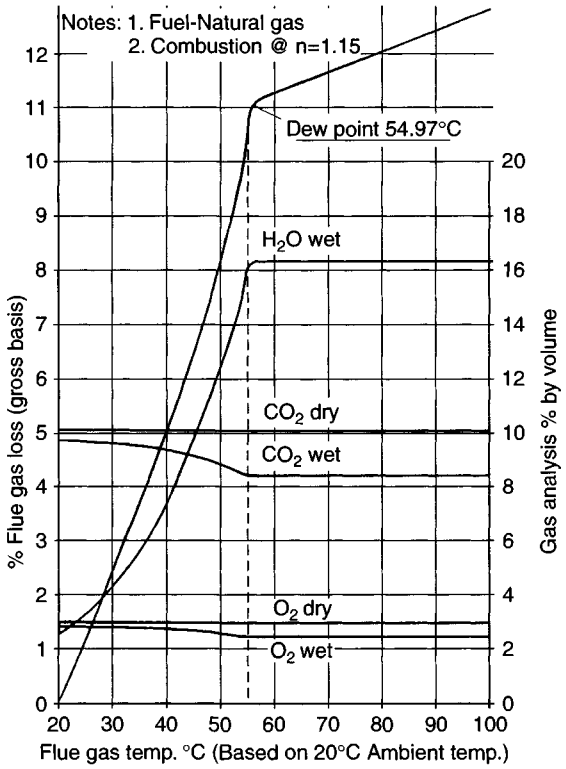


Figure 31.7 Sensible and latent heat savings potential and gas analysis with condensing economizers

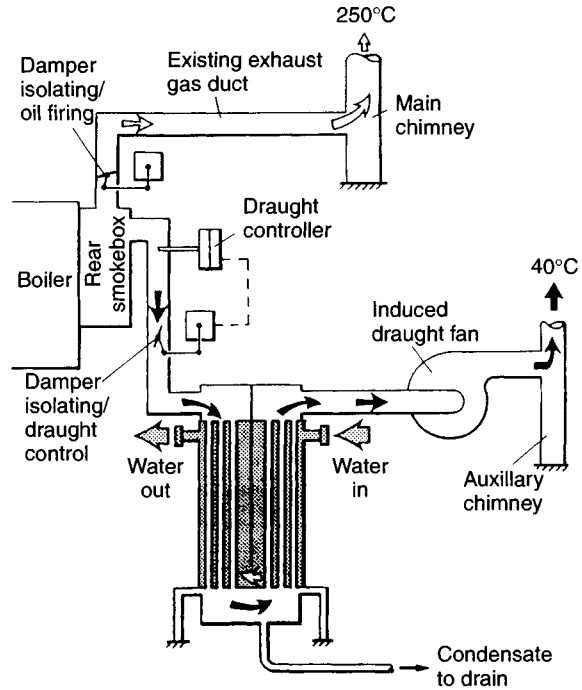


Figure 31.8 Condensing economiser layout

from, say, 230°C to 40°C, the gross heat saving would be approximately 13%, yielding a fuel saving of over 15%.

The term 'fuel saving' needs to be qualified, since the use of the heat in the water will be given to a process which may be unrelated to boiler demand. Examples of suitable applications occur in industrial size laundries, horticultural soil heating, food industries, abattoirs and swimming pool heating.

The success of such schemes is highly dependent on matching supply and demand together with a basic low-grade heat requirement. The total heat remaining in the exhaust gases of the boiler are shown in Figure 31.7 illustrating the potential savings.

Condensing economizers are constructed from corrosion-resistant materials (notably aluminium or stainless steel), since the condensed water vapour in the gas is slightly acidic (typically, with a pH of 3–5). This is because some carbonic and nitric acid is formed in the condensing of the products of combustion and also as a result of other acidic gases in the atmosphere. Provided the correct choice of materials is made, corrosion life should not become problematic.

A typical arrangement of a condensing economizer is shown in Figure 31.8. Note that an induced-draught fan is almost mandatory, since a high pressure loss is inevitable with such low-grade heat recovery. The design of such economizers often takes the form of a large shell and tube heat exchanger, but the conventional economizer construction of watertubes is quite feasible. Condensate from the exhaust gases are normally discharged to the drainage system. More recently condensing economizer technology has found favour in the domestic and commercial heating sectors where the cost has been minimized by integrating the principle into the boiler. Condensing boilers of this type take advantage of relatively low hot water return temperatures especially during warming up of the system and during very cold weather.

32 Heat exchangers

M Ahmed and B Lamb
APV Systems

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32.1 The APV Paraflow heat exchanger

While the original idea for the plate heat exchanger was patented in the latter half of the nineteenth century, the first commercially successful design was introduced in 1923 by Dr Richard Seligman, founder of APV. Initially, a number of cast gunmetal plates were enclosed within a frame in a manner quite similar to a filter press. The early 1930s, however, saw the introduction of plates pressed in thin-gauge stainless steel. While the basic design remains unchanged, continual refinements have boosted operating pressures from about 1 to 25 kgf/cm^2 in current machines.

The APV Paraflow plate heat exchanger consists of a frame in which closely spaced metal plates are clamped between a head and follower. The plates have corner ports and are sealed by gaskets around the ports and along the plate edges. A double seal forms pockets open to atmosphere to prevent mixing of product and service liquids in the rare event of leakage past a gasket.

The plates are grouped into passes with each fluid being directed evenly between the paralleled passages in each pass. Whenever the thermal duty permits, it is desirable to use single-pass, counterflow (Figure 32.1) for an extremely efficient performance. Since the flow is pure counterflow, correction factors required on the Log Mean Temperature Difference (LMTD) approach unity. With all connections on the head of the unit, the follower is free for very quick access to cleaning and maintenance. The effect of multipass operation will be discussed later in this chapter.

32.1.1 Comparative plate arrangements

Clarification of Paraflow heat exchanger plate arrangements with those for a tubular exchanger is detailed in Figure 32.2. Essentially, the number of passes on the tube side of a tubular unit can be compared with the number of passes on a plate heat exchanger. The number of tubes per pass can also be equated with the number of passages per pass for the Paraflow heat exchanger. However, the comparison with the shell side is usually more difficult, since with a Paraflow heat exchanger the total number of passages available for the flow of one fluid must equal those available for the other fluid to within ±1. The number of cross passes on a shell, however, can be related to the number of plate passes, and since the number of passages/pass for a plate is an indication of the flow area, this can be equated to the shell diameter. This is not a perfect comparison but it does show the relative parameters for each exchanger.

An important, exclusive feature of the plate heat exchanger is that by the use of special connector plates it is possible to provide connections for alternate fluids so that a number of duties can be done in the same frame.

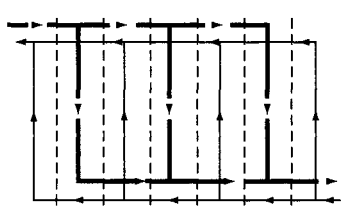


Figure 32.1 Single-pass operation

	Shell and tube	Plate equivalent	
Tube side	Number of passes	Number of passes	Side one
	Number of tubes/pass	Number of passages /pass	
Shell side	Number of cross-passes (number of baffles +1)	Number of passes	Side two
	Shell diameter	Number of passages/pass	

Figure 32.2 Comparison of pass arrangement: plate versus tubular

32.1.2 Plate construction

Paraflow plates are pressed from stainless steel, titanium, Hastelloy, Avesta 254 SMO or any material ductile enough to be formed into a pressing. The specious design of the trough pattern strengthens the plates, increases the effective heat transfer area and produces turbulence in the liquid flow between plates. Plates are pressed in materials between 0.4 and 0.9 mm and the degree of mechanical loading is important. The more severe case occurs when one process liquid is operating at the highest working pressure and the other at zero pressure. The maximum pressure differential is applied across the plate and results in a considerable unbalanced load. There are two alternative trough forms, one using deep corrugations to provide contact points for about every 650–1950 mm^2 of heat transfer surface, the other criss-cross shallow troughs with support maintained by corrugation/corrugation contact. Alternate plates are arranged so that corrugations cross to provide a contact point for every 100–600 mm^2 of area. The plate then can handle large differential pressures and the cross pattern forms a tortuous path that promotes substantial liquid turbulence and a very high heat transfer coefficient. The net result is high rates with moderate pressure drop.

Plates are available with effective heat transfer area from 0.03 to 3.5 m^2 and up to 700 can be contained within the frame of the largest Paraflow heat exchanger, providing over 2400 m^2 of surface area. Flow ports and associated pipework are sized in proportion to the plate area and control the maximum liquid throughput.

Figure 32.3 shows the relationship between port diameter and fluid velocity at 4 and 7 m/s and highlights the nominal maximum velocities for various plates. As the flow through the machine increases, the entry and exit pressure losses also increase. The nominal maximum flow rate for a plate heat exchanger limits these losses to an acceptable proportion of the total pressure losses, and is therefore a function not only of the port diameter but also of the nature of the plate which has been empirically determined.

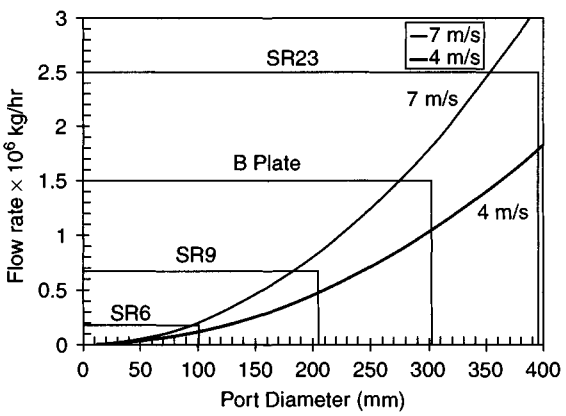


Figure 32.3 Throughout versus port diameter

These velocities seem, at first, rather high compared to conventional pipework practice, but they are very localized in the exchanger and are progressively reduced as distribution into the flow passages occurs from the port manifold.

32.1.3 Gasket materials

As detailed in Figure 32.4, various gasket elastomers are available which have chemical and temperature resistance coupled with good sealing properties. The temperatures shown are maximum, therefore possible simultaneous chemical action must be taken into account.

32.1.4 Thermal performance

Data on thermal performance are not readily available on all heat exchangers because of the proprietary nature of the machines. To exemplify typical thermal data, heat transfer can best be described by a Dittus–Boelter type equation:

$$Nu = A(Re)^n(Pr)^m\left(\frac{\mu}{\mu_\pi}\right)^x$$

Reported values of the constant and exponents are

$A = 0.15 - 0.40$ $\quad m = 0.30 - 0.45$

$n = 0.65 - 0.85$ $\quad x = 0.05 - 0.20$

where

$$Nu = \frac{hd}{k} \qquad Re = \frac{Vd\rho}{\mu} \qquad Pr = \frac{Cp\mu}{k}$$

d is the equivalent diameter defined in the case of the plate heat exchanger as 2× the mean gap.

Typical velocities in plate heat exchangers for waterlike fluids in turbulent flow are 0.3–0.9 m/s but true velocities in certain regions will be higher by a factor of up to 4 due to the effect of the corrugations. All heat transfer and pressure drop relationships are, however, based on either a velocity calculated from the average plate gap or on the flow rate per passage.

Figure 32.5 illustrates the effect of velocity for water at 16°C on heat transfer coefficients. This graph also plots pressure drop against velocity under the same conditions. The film coefficients are very high and can be obtained for a moderate pressure drop.

One particularly important feature of the plate heat exchanger is that the turbulence induced by the troughs reduces the Reynolds number at which the flow becomes laminar. If the characteristic length dimension in the Reynolds number is taken as twice the average gap between plates, the *Re* number at which the flow is no longer turbulent, varies from about 100 to 400, according to the type of plate.

To achieve these high coefficients it is necessary to expend energy. With the plate unit, the friction factors normally encountered are in the range of 10 to four hundred times those inside a tube for the same Reynolds number. However, nominal velocities are low and plate lengths do not exceed 2.3 m, so that the term $V^2L/2g$ in the pressure drop equation is very much smaller than one would normally encounter in tubulars. In addition, single-pass operation will achieve many duties, so that the pressure drop is efficiently used and not wasted on losses due to flow direction changes.

The friction factor is correlated with:

$$\Delta p = \frac{f \cdot L\rho V^2}{2g \cdot d} \qquad f = \frac{B}{Re^y}$$

where y varies from 0.1 to 0.4 in turbulence, according to the plate and B is a constant characteristic of the plate. If the overall heat transfer equation $H = US\Delta T$ is used to calculate the heat duty it is necessary to know the overall coefficient U (sometimes known as the K factor), the surface area S and the mean temperature difference ΔT.

Gasket material	*Approx. maximum operating temp.* °C	°F	*Application*
Paracril (medium nitrile)	135	275	Resistant to fatty materials
E.P.D.M.	150	300	High temperature resistance for a wide range of chemicals
Paradur (fluorocarbon rubber base)	177	350	Mineral oils, fuels, vegetable and animal oils

Figure 32.4 Gasket materials, operating temperatures and applications

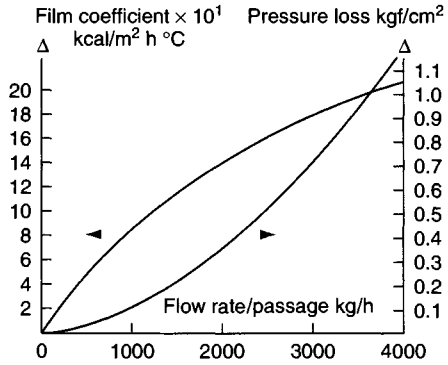


Figure 32.5 Performance details: Paraflow

The overall coefficient U can be calculated from

$$\frac{1}{U} = r_{fh} + r_{fc} - r_w + r_{dh} + r_{dc}$$

The values of r_{fh} and r_{fc} (the film resistances for the hot and cold fluids, respectively) can be calculated from the Dittus–Boelter equations previously described and the wall metal resistance r_α from the average metal thickness and thermal conductivity. The fouling resistances of the hot and cold fluids r_{dh} *and* r_{dc} are often based on experience, but a more detailed discussion of this will be presented later in this chapter.

The value taken for S is the developed area after pressing. That is, the total area available for heat transfer and due to the corrugations will be greater than the projected area of the plate, i.e. $0.17\,m^2$ versus $0.14\,m^2$ for an APV HX plate.

The value of T is calculated from the logarithmic mean temperature difference multiplied by a correction factor. With single-pass operation, this factor is about 1 except for plate packs of less than 20, when the end effect has a significant bearing on the calculation. This is due to the fact that the passage at either end of the plate pack only transfers heat from one side and therefore the heat load is reduced.

When the plate unit is arranged for multiple-pass use a further correction factor must be applied. Even when two passes are counter-current to two other passes, at least one passage must experience co-current flow. This correction factor is shown in Figure 32.6 against a number of heat transfer units (HTU = temperature rise of the process fluid divided by the mean temperature difference). As indicated, whenever unequal passes are used, the correction factor calls for a considerable increase in area. This is particularly important when unequal flow conditions are handled. If high and low flow rates are to be used, the necessary velocities must be maintained with the low fluid flow rate by using an increased number of passes. Although the plate unit is most efficient when the flow ratio between two fluids is in the range of 0.7–1.4, other ratios can be handled with unequal passes. This is done, however, at the expense of the LMTD factor.

32.2 Comparing plate and tubular exchangers

32.2.1 Ten points of comparison

In forming a comparison between plate and tubular heat exchangers there are a number of guidelines which will generally assist in the selection of the optimum exchanger for any application. In summary, these are:

1. For liquid/liquid duties, the plate heat exchanger will usually give a higher overall heat transfer coefficient and in many cases the required pressure loss will be no higher.
2. The effective mean temperature difference will usually be higher with the plate heat exchanger.
3. Although the tube is the best shape of flow conduit for withstanding pressure it is entirely the wrong shape for optimum heat transfer performance since it has the smallest surface area per unit of cross-sectional flow area.
4. Because of the restrictions in the flow area of the ports on plate units it is usually difficult (unless a moderate pressure loss is available) to produce economic designs when it is necessary to handle large quantities of low-density fluids such as vapours and gases.
5. A plate heat exchanger will usually occupy far less floor space than a tubular for the same duty.

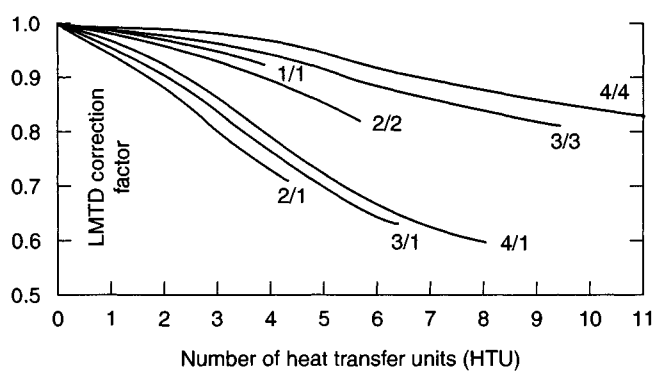


Figure 32.6 LMTD correction factor

6. From a mechanical viewpoint, the plate passage is not the optimum and gasketed plate units are not made to withstand operating pressures much in excess of 25 kgf/cm^2.
7. For most materials of construction, sheet metal for plates is less expensive per unit area than tube of the same thickness.
8. When materials other than mild steel are required, the plate will usually be more economical than the tube for the application.
9. When mild steel construction is acceptable and when a closer temperature approach is not required, the tubular heat exchanger will often be the most economic solution since the plate heat exchanger is not made in mild steel.
10. Plate heat exchangers are limited by the necessity that the gasket be elastomeric.

32.2.2 Heat transfer coefficients

Higher overall heat transfer coefficients are obtained with the plate heat exchanger compared with a tubular for a similar loss of pressure because the shell side of a tubular exchanger is basically a poor design from a thermal point of view. Considerable pressure drop is used without much benefit in heat transfer due to the turbulence in the separated region at the rear of the tube. Additionally, large areas of tubes even in a well-designed tubular unit are partially bypassed by liquid and low heat transfer area are thus created. Bypassing in a plate-type exchanger is less of a problem and more use is made of the flow separation which occurs over the plate troughs since the reattachment point on the plate gives rise to an area of very high heat transfer.

For most duties, the fluids have to make fewer passes across the plates than would be required through tubes or in passes across the shell. Since a plate unit can carry out the duty with one pass for both fluids in many cases, the reduction in the number of required passes means less pressure lost due to entrance and exit losses and consequently more effective use of the pressure.

32.2.3 Mean temperature difference

A further advantage of the plate heat exchanger is that the effective mean temperature difference is usually higher than with the tubular unit. Since the tubular is always a mixture of cross and contra-flow in multi-pass arrangements, substantial correction factors have to be applied to the Log Mean Temperature Difference (LMTD). In the plate heat exchanger where both fluids take the same number of passes through the unit, the LMTD correction factor is usually in excess of 0.95.

32.3 Duties other than turbulent liquid flow

32.3.1 Beyond liquid/liquid

The plate heat exchanger, for example, can be used in laminar flow duties, for the evaporation of fluids with relatively high viscosities, for cooling various gases, and for condensing applications where pressure-drop parameters are not excessively restrictive.

32.3.2 Condensing

For those condensing duties where permissible pressure loss is less than 0.07 kgf/cm^2 there is no doubt but that the tubular unit is most efficient. Under such pressure-drop conditions only a portion of the length of a plate heat exchanger plate would be used and a substantial surface area would be wasted. However, when less restrictive pressure drops are available the plate heat exchanger becomes an excellent condenser, since very high heat transfer coefficients are obtained and the condensation can be carried out in a single pass across the plate.

32.3.3 Pressure drop of condensing vapour

The pressure drop of condensing steam in the passages of plate heat exchangers has been investigated experimentally for a series of different Paraflow heat exchanger plates. As indicated in Figure 32.7, which provides data for a typical unit, the drop obtained is plotted against steam flow rate per passage for a number of inlet steam pressures.

It is interesting to note that for a set of steam flow rates and a given duty the steam pressure drop is higher when the liquid and steam are in counter-current rather than co-current flow. This is due to differences in temperature profile.

From Figure 32.8 it can be seen that for equal duties and flows the temperature difference for counter-current flow is lower at the steam inlet than at the outlet, with most of the steam condensation taking place in the lower half of the plate. The reverse holds true for co-current flow. In this case, most of the steam condenses in the top half of the plate, the mean vapour velocity is lower and

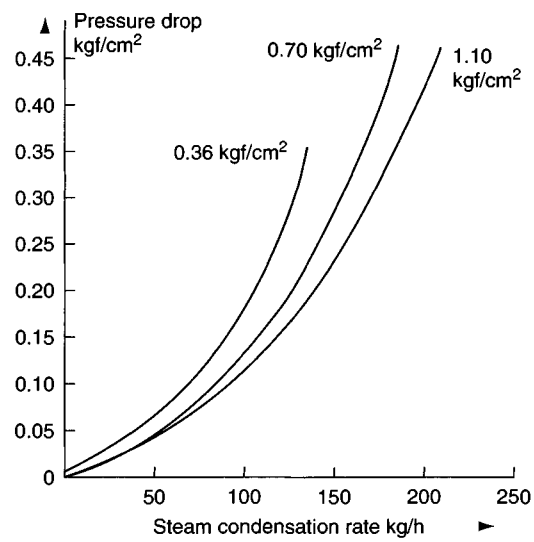


Figure 32.7 Steam-side pressure drop

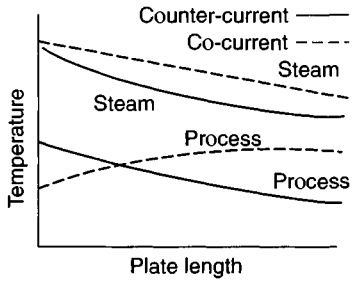


Figure 32.8 Temperature profile during condensation of steam

a reduction in pressure drop of between 10–40% occurs. This difference in pressure drop becomes lower for duties where the final approach temperature between the steam and process fluid becomes larger.

The pressure drop of condensing steam is therefore a function of steam flow rate, pressure and temperature difference. Since the steam pressure drop affects the saturation temperature of the steam, the mean temperature difference, in turn, becomes a function of steam pressure drop. This is particularly important when vacuum steam is being used, since small changes in steam pressure can give significant alterations in the temperature at which the steam condenses.

32.3.4 Gas cooling

Plate heat exchangers also are used for gas cooling. The problems are similar to those of steam heating since the gas velocity changes along the length of the plate due either to condensation or to pressure fluctuations. Designs usually are restricted by pressure drop, therefore machines with low-pressure drop plates are recommended. A typical allowable pressure loss would be 0.035 kgf/cm^2 with low gas velocities giving overall heat transfer coefficients in the region of 244 kcal/m^{2}h°C.

32.3.5 Evaporating

The plate heat exchanger can also be used for evaporation of highly viscous fluids when the evaporation occurs in the plate or the liquid flashes after leaving the plate. Applications generally have been restricted to the soap and food industries. The advantage of these units is their ability to concentrate viscous fluids of up to 50 poise.

32.3.6 Laminar flow

One other field suitable for the plate heat exchanger is that of laminar flow heat transfer. It has been previously pointed out that the Paraflow heat exchanger can save surface by handling fairly viscous fluids in turbulent flow because the critical Reynolds number is low. Once the viscosity exceeds 20–50 cP, however, most plate heat exchanger designs fall into the viscous flow range. Considering only Newtonian fluids since most chemical duties fall into this category, in laminar ducted flow the flow can be said to be one of three types:

1. Fully developed velocity and temperature profiles (i.e. the limiting Nusselt case);
2. Fully developed velocity profile with developing temperature profile (i.e. the thermal entrance region); or
3. The simultaneous development of the velocity and temperature profiles.

The first type is of interest only when considering fluids of low Prandtl number, and this does not usually exist with normal plate heat exchanger applications. The third is relevant only for fluids such as gases which have a Prandtl number of about one. Therefore, let us consider type two.

Correlation for heat transfer and pressure drop in laminar flow can be represented by:

$$Nu = c(RePr)^{\frac{1}{3}} \left(\frac{\mu}{\mu\omega}\right)^{n}$$

where

Nu = Nusselt number (hd/k),
Re = Reynolds number ($vd\rho/\mu$),
Pr = Prandtl number ($cp\mu/k$),
d = equivalent diameter (2 × average gap),
μ/μ_w = Sieder Tate correction factor,
c = construct for each plate (usually in the range 1.86–4.50),
n = index varying from 0.1–0.2, depending on plate type.

32.3.6.1 Pressure drop

For pressure loss in a plate, the friction factor can be taken as

$$f = \frac{a}{Re}$$

where a is a characteristic of the plate.

It can be seen that for heat transfer, the plate heat exchanger is ideal because the value of d is small and the film coefficients are proportional to $d^{-2/3}$. Unfortunately, the pressure loss is proportional to d^{-3}, and pressure drop is sacrificed to achieve the heat transfer.

From these correlations it is possible to calculate the film heat transfer coefficient and the pressure loss for laminar flow. This coefficient, combined with that of the metal and the calculated coefficient for the service fluid together with the fouling resistance, are then used to produce the overall coefficient. As with turbulent flow, an allowance has to be made to the LMTD to allow for either end-effect correction for small plate packs and/or concurrency caused by having concurrent flow in some passes. This is particularly important for laminar flow since these exchangers usually have more than one pass.

32.4 The problem of fouling

32.4.1 The fouling factor

In view of its complexity, variability and the need to carry out experimental work on a long-term basis under actual

operating conditions, fouling remains a neglected issue among the technical aspects of heat transfer. However, the importance of carefully predicting fouling resistance in both turbular tubular and plate heat exchanger calculations cannot be overstressed. This is well illustrated by the following examples.

Note that for a typical water/water duty in a plate heat exchanger it would be necessary to double the size of the unit if a fouling factor of 0.0001 was used on each side of the plate (i.e. a total fouling of 0.0002). Although fouling is of great importance, there is relatively little accurate data available, and the rather conservative figures quoted in Kern (*Process Heat Transfer*) are used all too frequently. It also may be said that many of the high fouling resistances quoted have been obtained from poorly operated plants. If a clean exchanger, for example, is started and run at the designed inlet water temperature, it will exceed its duty. To overcome this, plant personnel tend to turn down the cooling water flow rate and thereby reduce turbulence in the exchanger. This encourages fouling, and even though the water flow rate is eventually turned up to design, the damage will have been done. It is probable that if the design flow rate had been maintained from the onset, the ultimate fouling resistance would have been lower. A similar effect can happen if the cooling-water inlet temperature falls below the design figure and the flow rate is turned down again.

32.4.2 Six types of fouling

Types of fouling can be divided into six distinct categories. The first is crystallization – the most common type of fouling, which occurs in many process streams, particularly cooling-tower water. Frequently linked with crystallization is sedimentation, which is usually caused by deposits of particulate matter such as clay, sand or rust. A build-up of organic products and polymers is often a result of chemical reaction and polymerization. The surface temperature and presence of reactants, particularly oxygen, can have a very significant effect. Coking occurs on high-temperature surfaces and is due to hydrocarbon deposits. Organic material growth is usually linked with crystallization and sedimentation and is common to sea water systems. Corrosion of the heat transfer surface itself produces an added thermal resistance as well as a surface roughness.

In the design of the plate heat exchanger, fouling due to coking is of no significance, since the unit cannot be used at such high temperatures. Corrosion is also irrelevant, since the metals used in these units are non-corrosive. The other four types of fouling, however, are most important. With certain fluids such as cooling-tower water, fouling can result from a combination of crystallization, sedimentation and organic material growth.

32.4.3 A function of time

From Figure 32.9 it is apparent that the fouling process is time dependent, with zero fouling initially. Fouling then builds up quite rapidly and in most cases, levels off at a certain time to an asymptotic value as represented by curve A in the figure. At this point the rate of deposition is equal to that of removal. Not all fouling levels off, however, and curve B shows that at a certain time the exchanger would have to be taken off-line for cleaning. It should be noted that a Paraflow is particularly useful heat exchanger for this type of duty because of the ease of access to the plates and the simplicity of cleaning.

In the case of crystallization and suspended solid fouling, the process is usually of type A. However, when the fouling is of the crystallization type with a pure compound crystallizing out, the fouling approaches type B and the equipment must be cleaned at frequent intervals. In one particularly severe fouling application three Series HMB Paraflow heat exchangers are on a $4\frac{1}{2}$-hour cycle and the units are cleaned in place for $1\frac{1}{2}$ hours in each cycle.

Biological growth can present a potentially hazardous fouling, since it can provide a more sticky surface with which to bond other foulants. In many cases, however, treatment of the fluid can reduce the amount of biological growth. The use of germicides or poisons to kill bacteria can help.

32.4.4 Lower resistance

It generally is considered that resistance due to fouling is lower with Paraflow plate heat exchangers than with tubular units. This is the result of four advantages of the Paraflow heat exchanger:

1. There is a high degree of turbulence, which increases the rate of foulant removal and results in a lower asymptotic value of fouling resistance.

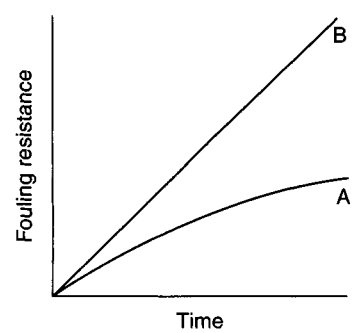


Figure 32.9 Build-up of fouling resistance

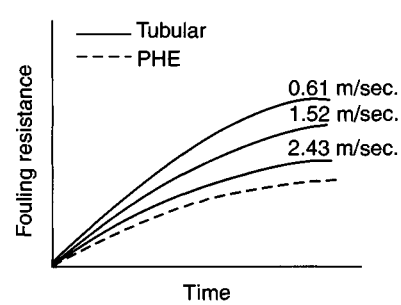


Figure 32.10 Effect of velocity and turbulence

2. The velocity profile across a plate is good. There are no zones of low velocity compared with certain areas on the shell side of turbular exchangers.
3. Corrosion is maintained at an absolute minimum.
4. A smooth heat transfer surface can be obtained. If necessary, the plate can be electropolished.

The most important of these is turbulence. HTRI (Heat Transfer Research Incorporated) has shown that for tubular heat exchangers, fouling is a function of low velocities and friction factor. Although flow velocities are low with the plate heat exchanger, friction factors are very high, and this results in lower fouling resistance. The effect of velocity and turbulence is plotted in Figure 32.10. The lower fouling characteristic of the plate heat exchanger compared to the tubular has been conclusively proved by HTRI's work.

Tests have been carried out which tend to confirm that fouling varies for different plates, with the more turbulent type of plate providing the lower fouling resistances.

33 Corrosion

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33.1 Corrosion basics

33.1.1 Definitions of corrosion

Corrosion is generally taken to be the wastage of a metal by the action of corrosive agents. However, a wider definition is the degradation of a material through contact with its environment. Thus corrosion can include non-metallic materials such as concrete and plastics and mechanisms such as cracking in addition to wastage (i.e. loss of material). This chapter is primarily concerned with metallic corrosion, through a variety of mechanisms.

In essence, the corrosion of metals is an electron transfer reaction. An uncharged metal atom loses one or more electrons and becomes a charged metal ion:

$$M \rightleftharpoons M^+ + \text{electron}$$

In an ionizing solvent the metal ion initially goes into solution but may then undergo a secondary reaction, combining with other ions present in the environment to form an insoluble molecular species such as rust or aluminium oxide. In high-temperature oxidation the metal ion becomes part of the lattice of the oxide formed.

33.1.2 Electrochemical corrosion

The most important mechanism involved in the corrosion of metal is electrochemical dissolution. This is the basis of general metal loss, pitting corrosion, microbiologically induced corrosion and some aspects of stress corrosion cracking. Corrosion in aqueous systems and other circumstances where an electrolyte is present is generally electrochemical in nature. Other mechanisms operate in the absence of electrolyte, and some are discussed in Section 33.1.4.

Figure 33.1 depicts a metal such as iron, steel or zinc immersed in electrolyte such as sodium chloride solution. The fundamental driving force of the corrosion reaction is the difference in the potential energies of the metal atom in the solid state and the product which is formed during corrosion. Thus corrosion may be considered to be the reverse of extractive metallurgy. Metals are obtained by the expenditure of energy on their ores. The greater the energy that is required, the more thermodynamically unstable is the metal and the greater its tendency to revert to the ore or any other oxidized form. Thus gold is found native (i.e. as the metal) and it resists corrosion. Iron, aluminium and most metals exist naturally combined as oxides or sulphides and, once reduced to the metallic state, they attempt to revert to the combined state by corrosion.

In the systems illustrated in Figure 33.1 the anodic reaction has to be electrically balanced by the cathodic reaction, since electrical charge cannot build up at any location. A continuous electrical circuit is required through the metal (for electron conduction) and the environment (for ionic conduction).

There are four main aspects to the corrosion chemistry of this solution:

1. The presence of dissolved ions (an electrolyte) facilitates the passage of an ionic current through the solution.
2. Certain anions, especially chloride, penetrate the protective films which are naturally present on some metals (e.g. aluminium and its alloys and stainless steels). This process is an initiator for corrosion, especially for localized corrosion.
3. The pH of the solution is a measure of the availability of one of the two most important cathodic agents, H^+ (the other being dissolved oxygen, see below). It is also largely responsible for determining whether the metal surface will be active or passive (see below).
4. Dissolved oxygen (and even water) can passivate certain metals such as titanium, aluminium and stainless

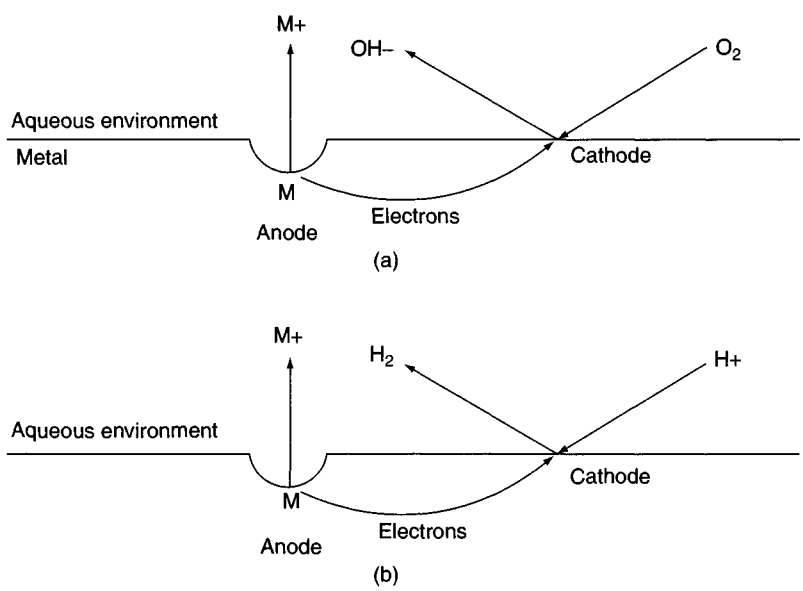


Figure 33.1

steels, thereby rendering them, to varying degrees, corrosion resistant. Because oxygen is a strong cathodic agent it stimulates corrosion of many metals, especially those such as iron and zinc, which tend not to form stable, adherent oxides.

Thus in the system depicted in Figure 33.1, for any metal which is thermodynamically unstable with respect to its dissolved ions in the solution (and this includes most metals of industrial importance) corrosion will occur. The rate of corrosion is determined by several factors:

1. The conductivity of the environment; low conductivity hinders the ionic current flow hence distilled water is less corrosive than a solution of sodium chloride with the same pH and dissolved oxygen content.
2. The presence of cathodic agents; dissolved oxygen and H^+ promote corrosion of most metals in an electrolyte solution (see Figure 33.2).
3. The supply of cathodic agents to the metal surface: stirring a solution or increasing the flow rate in a pipe will increase corrosion rates in systems which are under diffusion control. As soon as corrosion initiates in the system depicted in Figure 33.1 there is a local depletion of cathodic agent and a build-up of metal ions. In stagnant conditions this soon reduces the corrosion rate, and the diffusion of these species governs the overall corrosion rate. The system is then under diffusion control.
4. The build-up of scales or other deposits on the metal surface can stifle corrosion. The reaction of anodically generated M^+ with cathodically generated OH^- can, depending on M^+, be an insoluble product. It may or may not adhere to the metal surface. If it does adhere strongly it can stifle corrosion. Other deposits can form, in addition to corrosion products. The locally high pH at the cathode can precipitate insoluble carbonates. With complete coverage of the cathodic surface corrosion is generally stifled, since the cathodic reaction cannot usually occur through the deposit. However, some cathodic scales (e.g. magnetite (Fe_3O_4)) and some forms of iron sulphides can support the cathodic reaction, and, since anodic area is limited, this can result in intense local attack leading to pitting corrosion at bare areas.
5. The effect of temperature is generally to increase corrosion rate as temperature rises. This is a chemical–kinetic effect and can sometimes be overridden by physical effects such as deposition of scales. The solubility of oxygen in a saline solution decreases from approximately 8–10 ppm at 5°C to virtually zero near the boiling point. Thus in a system in which dissolved oxygen is the only cathodic agent corrosion rates would pass through a maximum and decrease to very low levels as temperature is increased and the availability of cathodic agent is diminished.

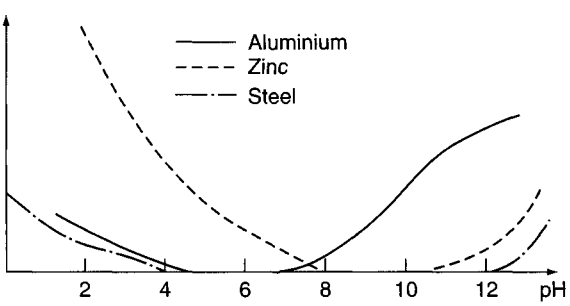


Figure 33.2 Variation in corrosion rate with pH

In Figure 33.1 the region from which metal is lost is the anode. The atoms of the metal are ionized and release electrons:

$$M \longrightarrow M^{n+} + ne^-$$

where M denotes metal, M^{n+} its ion and e^- is an electron.

This reaction can proceed to a significant extent only if the electrons which are released are consumed by a cathodic reaction. The commonest cathodic reactions are essentially:

$$O_2 + 2H_2O + 2e^- \longrightarrow 4OH^-$$

as shown in Figure 33.1(a), in which oxygen is consumed, and

$$H^+ + e^- \longrightarrow H \text{ atoms} \longrightarrow H_2 \text{ gas}$$

in which hydrogen is liberated (Figure 33.1(b)).

Which cathodic reaction is preferred for any combination of metal and environment depends on the relative amounts of O_2 and H^+ available, and kinetics of O_2 reduction and H^+ reduction on the metal surface.

The thermodynamic driving force behind the corrosion process can be related to the corrosion potential adopted by the metal while it is corroding. The corrosion potential is measured against a standard reference electrode. For sea water the corrosion potentials of a number of constructional materials are shown in Table 33.1. The listing ranks metals in their thermodynamic ability to corrode. Corrosion rates are governed by additional factors as described above.

Stainless steels each appear twice in the list. The more active potentials are those which the metal adopts when corroding as in a pit. The more cathodic potential is that adopted by the bare surface around the pit. The potential difference constitutes a significant driving force, analogous to the situation where the coupling of dissimilar metals such as copper and iron promotes the corrosion of the more anodic of the two (see below).

33.1.2.1 Pitting corrosion

Pitting is a form of localized corrosion in which part of a metal surface (perhaps 1% of the exposed area) is attacked. Rates of pitting penetration can be very high; type 316 stainless steel in warm sea water can suffer pit penetration rates of 10 mm per year. This is a natural consequence of the low ratio of anodic area to cathodic area, coupled with the self-acidification processes that occur in some metals.

Figure 33.3 illustrates a pit in a stainless steel such as type 304 or 316 austenitic alloy. Pitting starts at a heterogeneity in the steel surface, such as an outcropping

Table 33.1 Galvanic series in sea water[a]

Metal	*Corrosion potential[b] (V)*
Magnesium and alloys	−1.6
Zinc	−1.0
Aluminum alloys	−0.8/−1.0
Steel (incl. low alloys)	−0.55/ − 0.75
Stainless steels (304, 321, 410, 430)	−0.5[c]
Stainless steels (316, 317)	−0.4[c]
Copper	−0.35/−0.2
Bronzes (Si, Sn)	−0.35/−0.25
Stainless steels (410, 430)	−0.3/−0.2[d]
Lead	−0.25[e]
Copper nickel alloys	−0.25
Bronze (Ni–Al)	−0.15
Nickel	−0.15
Stainless steels (304, 321, 316, 317)	−0.1 − 0[d]
Titanium	0/−0.1
Platinum, graphite	+0.2/0.3

[a]These values are roughly constant across a range of electrolyte environments except where noted but the variations between alloys, heat treatment conditions, etc. creates a range for each metal. For some metals such as iron and steel the range is low (±100 mV), but for lead, nickel, stainless steels a range is given.
[b]The corrosion potential is reported with respect to the saturated calomel reference electrode.
[c]When active, as in a pit or a crevice or when depassivated by mechanical damage of oxide film or chemical removal in non-oxidizing acid.
[d]When passive, on a bare surface around a pit or crevice in normal conditions.
[e]−0.5 V in environments low in chloride ion content.

sulphide inclusion, the shielded region beneath a deposit or even a discontinuity in the naturally present oxide film caused by a scratch or embedded particle of abrasive grit. This initiation phase of pitting corrosion may take seconds or weeks to develop into a feature large enough to be recognized as a pit. Initiation is facilitated by oxidizing conditions. Thus hypochlorite ions are particularly aggressive towards stainless steels since they raise the potential of the steel to such a high level that the protective oxide layer breaks down, allowing localized attack.

The second phase of pitting corrosion is propagation. Because of the geometry of the small pit that has been created, oxygen diffusion to the corroding region is hindered. This creates a potential difference between the pit and the surrounding region. The solution in the pit acidifies through hydrolysis of the Fe^{2+} and Cr^{2+} ions present. The pH in the pit falls to very low values (0.6 in the case of 316 stainless steel), irrespective of the bulk solution conditions, which may be neutral or even alkaline. This enhances corrosion by dissolving the pit walls and ensures that the pit walls cannot be repassivated. The surrounding metal surface is passive (i.e. is covered with an adherent oxide film of mixed $Fe_2O_3 \cdot Cr_2O_3$ oxide). This is dissolved in strongly acidic conditions such as those prevailing in the pit. Because the conditions in the pit promote self-acidification, pit penetration rates often increase with time.

A third phase is sometimes identified in pitting corrosion, i.e. termination. Pits can become stifled by the build-up of insoluble corrosion products at their mouths. Removal of these mounds of corrosion products, either mechanically or through some change in the environmental chemistry, can allow the pits to restart growth.

33.1.2.2 Crevice corrosion

Crevice corrosion of stainless steels (Figure 33.4(a)) has a similar mechanism to pitting corrosion. The initiation phase is assisted by the creation of a crevice of suitable geometry. Crevices are formed by certain fabricational processes including riveted seams, incompletely fused welds, interference fits, O-rings, gasketed joints and even paint markings on components. The solution in the crevice becomes acidified and locally the metal surface anodic compared with the surrounding bare metal, as described above. Crevice initiation is largely dependent on the geometry of the crevice that is present: shorter initiation times are brought about by tighter crevices, since the primary effect is the limitation on inward diffusion of oxygen to maintain passivity. The lower limit of crevice width that will permit crevice corrosion is the point at which the crevice is watertight.

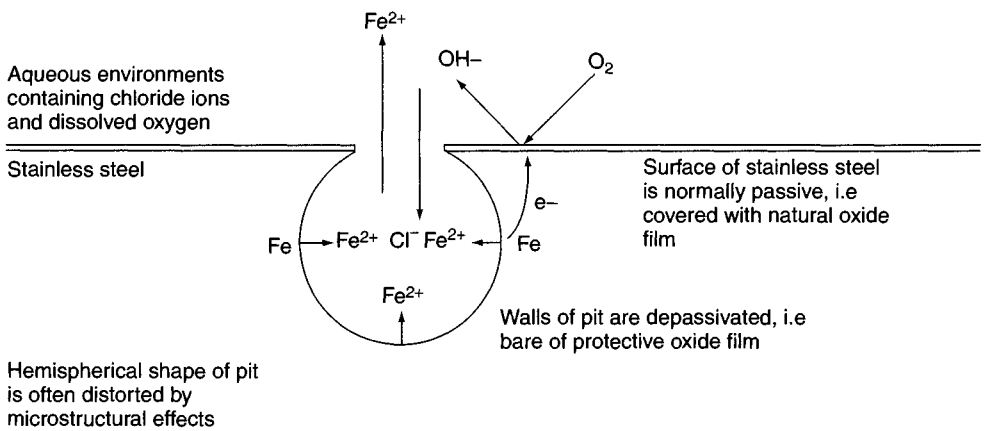


Figure 33.3 Pitting corrosion of stainless steel

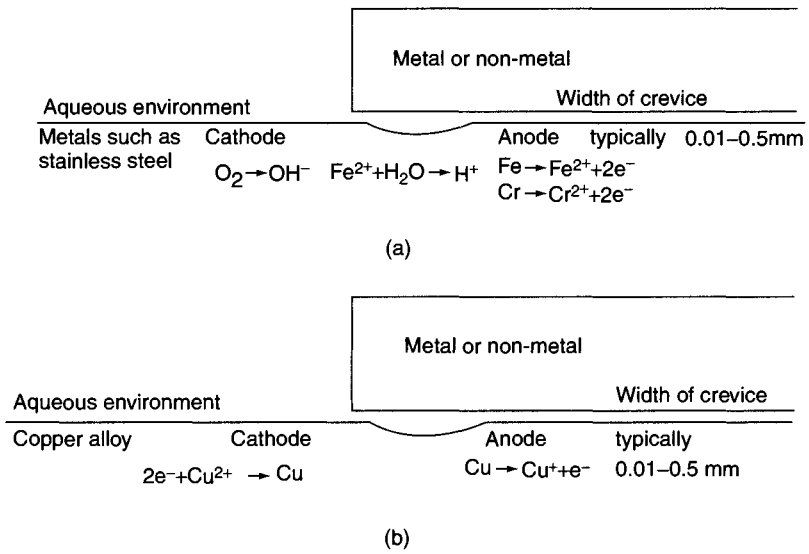


Figure 33.4 Crevice corrosion driven by (a) a differential aeration cell and (b) a differential metal ion concentration cell

Crevice corrosion of copper alloys is similar in principle to that of stainless steels, but a differential metal ion concentration cell (Figure 33.4(b)) is set up in place of the differential oxygen concentration cell. The copper in the crevice is corroded, forming Cu^+ ions. These diffuse out of the crevice, to maintain overall electrical neutrality, and are oxidized to Cu^{2+} ions. These are strongly oxidizing and constitute the cathodic agent, being reduced to Cu^+ ions at the cathodic site outside the crevice. Acidification of the crevice solution does not occur in this system.

33.1.2.3 Galvanic corrosion

Galvanic corrosion is the enhanced corrosion of one metal by contact with a more noble metal (or a conductive non-metal such as graphite). The two metals require only to be in electrical contact with each other and exposed to the same electrolyte environment. By virtue of the potential difference that exists between the two metals, the potential of the less noble (more reactive metal) is raised. This stimulates corrosion of the more reactive metal, simultaneously reducing the corrosion rate of the less reactive metal. This principle is exploited in the cathodic protection (Section 33.7.2) of steel structures by the sacrificial loss of aluminium or zinc anodes.

The metal that corrodes in any couple is that which has the most negative corrosion potential in the galvanic series in that environment. As a guidance, Table 33.1 is of general but not universal applicability. Thus in the case of copper and aluminium the aluminium corrodes unless corrosion inhibitors are employed. Copper and aluminium are therefore not generally used in close contact with each other, but copper ions in solution from the corrosion of copper pipework can plate out onto aluminium items (including saucepans) downstream in the system. Rapid corrosion of the aluminium occurs in the region of the copper deposits. The conductivity of the environment and the potential difference between the metals involved determine whether the corrosion is localized to a small region at the interface between the metals, or spread across a larger region. The exposed areas of the two metals together with the length of the conductance path in the electrolyte determine the intensity of the attack. Other conditions, such as the flow regime and the polarization behaviour of the two metals, influence galvanic corrosion.

Potential reversal is a complicating factor in galvanic corrosion. Zinc is usually anodic to steel and hence it is used to protect steel sacrificially. Galvanized steel is steel coated with zinc. The zinc protects any steel that is exposed (such as cut ends of sheet) and scratches through the zinc layer. At temperatures above 80°C, in low-conductivity water (e.g. condensation) the metals undergo a reversal of polarity. The steel corrodes in preference to the zinc, and this causes rapid loss of the zinc, which can fall off in sheets as corrosion proceeds along the steel surface undermining the zinc. Tin is usually more corrosion resistant than steel, hence its use in tinplate (tin-plated steel). In some organic acids, including some of those encountered in fruit juices, the relative potentials of tin and steel are reversed and the tin corrodes, contaminating foodstuffs with tin corrosion products.

The corrosion potentials of metals and alloys are temperature dependent. The potential of a steel distillation column, heat exchanger or other item of plant varies in the temperature zones in which it is operating. Under some circumstances this creates galvanic corrosion cells between different areas of one item fabricated from one material, leading to localized galvanic corrosion problems.

To avoid galvanic problems, different materials of construction may have to be electrically isolated or at least the electrical resistance between them increased to a level sufficient to reduce the corrosion current to an acceptable value. In some instances it is more practical to paint or otherwise coat the more cathodic of the two parts of the couple. The anodic material should not be coated, since

even more rapid penetration would occur at any breaks in the coating. Guidance on the galvanic hazards posed by the contact of different materials of construction is given in the British Standard publication PD 6484.

33.1.2.4 Microbially induced corrosion

Various bacteria are involved in corrosion processes. Of these the most important are some *Thiobacillus* types (these generate sulphuric acid which dissolves concrete) and sulphate-reducing bacteria (SRB). SRB are ubiquitous but only create significant corrosion problems in conditions suitable for rapid growth. They thrive best in anaerobic conditions, with a supply of sulphate ions and a carbon source. Anaerobic conditions are created in stagnant areas of chemical plant, under slime in industrial cooling systems and soils and seabed muds. Sulphate ions are widely available, especially in the sea and some chemical processes. Suitable carbon sources include organic materials such as acetic acid. SRB produce sulphide ions from sulphate ions. In conditions such as beneath a colony of these bacteria corrosion processes as illustrated in Figure 33.5 occur. Many metals are susceptible to this form of attack, including steel, stainless steels, copper alloys and aluminium alloys. Localized pitting rates in excess of 10 mm/yr are possible on steel and low-alloyed stainless steels such as types 304 and 316 austenitic and 22% Cr duplex. Good resistance has been demonstrated for 25% Cr superduplex and some of the higher grades of superaustenitic stainless steels. Some *Cladosporium* fungi cause pitting attack on aluminium alloys. *Gallionella* bacteria thrive in solutions containing Fe^{2+} and produce deposits under which anaerobic processes can occur.

33.1.3 Cracking mechanisms

Cracking mechanisms in which corrosion is implicated include stress corrosion cracking, corrosion fatigue, hydrogen-induced cracking and liquid metal embrittlement. Purely mechanical forms of cracking such as brittle failure and fatigue are not considered here.

33.1.3.1 Stress corrosion cracking

The conjoint action of a tensile stress and a specific corrodent on a material results in stress corrosion cracking (SCC) if the conditions are sufficiently severe. The tensile stress can be the residual stress in a fabricated structure, the hoop stress in a pipe containing fluid at pressures above ambient or in a vessel by virtue of the internal hydraulic pressure created by the weight of its contents. Stresses result from thermal expansion effects, the torsional stresses on a pump or agitator shaft and many more causes.

The corrosive environments which cause SCC in any material are fairly specific, and the more common combinations are listed in Table 33.2. In the case of chloride stress corrosion cracking of the 330 series austenitic stainless steels it is generally considered that the risk is minimal below approximately 60°C. Above this threshold, if the chloride ion content of the environment is low a higher tensile stress can be tolerated without SCC developing, and vice versa. It is difficult to design for the control of

Table 33.2 Stress corrosion cracking

Metal	*Agent*
Steels	Nitrate ion
	Strong alkali
	Carbonate/bicarbonate
	Liquid ammonia[a]
	Hydrogen sulphide (aqueous)[b]
	Cyanide ion
Austenitic stainless steels	Chloride (and other halide) ion
	Polythionic acids
	High-temperature water
	Hydrogen sulphide (aqueous)
Copper alloys	Ammonia/amines
	Nitric acid/nitrate fumes
Nickel alloys	Strong alkali
	Polythionic acids
	Chloride ion
Titanium alloys	Alcohols[a,b]
	Nitric acid plus nitrogen oxides
Magnesium alloys	Chloride ion[c]
Aluminium alloys	Chloride ion[c]
	Organics
	High-purity hot water

Environments are aqueous unless specified otherwise.
[a]Inhibited by 1000 ppm of water.
[b]Sometimes considered to be a form of hydrogen-induced cracking.
[c]In oxidizing conditions.

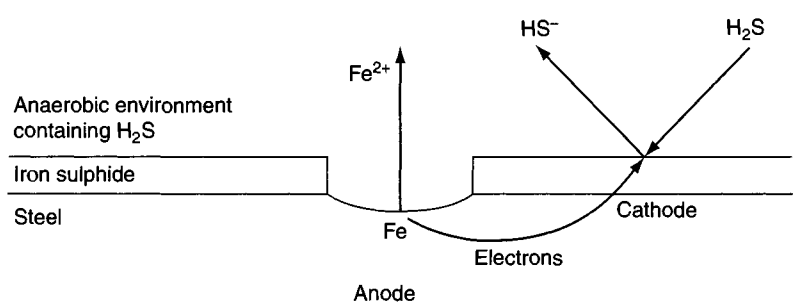


Figure 33.5

SCC since it is the local stress and corrodent concentration rather than average or bulk values that are relevant.

The essential feature of most SCC mechanisms is the rupture of the protective film on the metal (passive oxide layer in the case of stainless steels and aluminium alloys) which allows the corrodent to reach the bare surface of the metal. Cracking is the result of intense corrosion, concentrated by the tensile stress. In austenitic stainless steels, chloride SCC is transgranular in nature and the cracks are typically high branched. In ferritic materials cracking is largely due to a hydrogen embrittlement mechanism brought about by hydrogen created during corrosion.

33.1.3.2 Corrosion fatigue

Many metals suffer fatigue, which is the result of the application of an alternating stress. Corrosion fatigue results from the exposure of a metal, which is subjected to alternating stress, in a corrosive environment. Unlike stress corrosion cracking, corrosion fatigue does not require a specific corrosive environment for any metal. Moist air is adequate in many cases, thus the majority of fatigue failures are actually corrosion fatigue in nature. The alternating stress pattern requires only a small tensile component. This tensile stress may be small relative to the metal's ultimate tensile strength and millions of cycles of the stress pattern may be required to cause failure.

33.1.3.3 Hydrogen-induced cracking

Hydrogen-induced cracking (HIC) is most commonly encountered in steels but other metals are susceptible, as shown in Table 33.3. The presence of hydrogen atoms in a metal degrades some of its mechanical properties, especially its ductility, leading in some cases to embrittlement. Additionally, hydrogen atoms diffuse through metals and coalesce to form hydrogen molecules at certain preferred locations such as inclusions.

Hydrogen atoms are soluble in ferrite (which is the major phase of most steels). At discrete inclusions in the steel (e.g. manganese sulphide, which is present in many steels) the hydrogen atoms combine to form hydrogen molecules. Hydrogen molecules are insoluble in the steel lattice and these molecules associate, producing high tensile stresses which can initiate hydrogen cracking. When laminations are present in the steel hydrogen molecules form at the interface between them, creating blisters. At high temperatures hydrogen atoms can react with carbides in the steel producing methane gas. Methane is insoluble in the steel structure and causes blistering or cracking. In clean steels containing none of these features the hydrogen atoms pass straight through the steel, causing no damage.

Hydrogen can originate from several sources:

1. Electroplating (e.g. zinc, cadmium or hard chromium plating);
2. Acid pickling (e.g. prior to galvanizing);
3. Cathodic protection, especially if overprotected, through inadequate potential control;
4. Corrosion, where H^+ reduction is a cathodic reaction (Section 33.1.2);
5. The process inside the plant.

The amount of the hydrogen that is liberated on or near a metal surface which then enters the metal varies according to the environment and condition of the metal. The main factor that promotes the entry of hydrogen into a metal is the presence on the metal of a surface poison such as sulphide or other species which inhibit the hydrogen recombination reaction.

Table 33.3 Hydrogen-induced cracking

Metal	*Agent*
Steel	Hydrogen gas
	Atomic hydrogen[a]
	Hydrogen sulphide-containing aqueous environments[b]
	Water[c]
Martensitic stainless steels	Hydrogen sulphide-containing aqueous environments
Copper alloys	Sea water[d]
Nickel alloys	Hydrogen sulphide-containing aqueous environments
Titanium alloys	Anhydrous alcohols
Zirconium alloys	High-temperature water

[a]Created by overprotection during cathodic protection, evolved during electroplating or pickling processes and during welding with wet welding consumables.
[b]Steels of strength in excess of 550 MPa.
[c]Steels of strength in excess of 900 MPa.
[d]High-strength alloys, cathodically protected.

33.1.3.4 Liquid metal embrittlement

This is a form of stress corrosion cracking in which the corrodent is a liquid metal. Mercury at ambient temperature and metals including zinc (from galvanized steelwork) and copper (from electric cables) when melted during welding or in a fire cause rapid failure of certain metals.

Steels and austenitic stainless steels are susceptible to molten zinc, copper, lead and other metals. Aluminium and copper alloys are attacked by molten mercury, zinc and lead. Nickel alloys are attacked by mercury, zinc, silver and others. Other low-melting point metals which can attack common constructional materials include tin, cadmium, lithium, indium, sodium and gallium.

33.1.4 Non-electrochemical corrosion

Although all the types of corrosion discussed in this section result in the oxidation of metal and some involve direct electron transfer, they can be described without reference to electrochemistry.

33.1.4.1 Oxidation

In oxidizing atmospheres (i.e. in the presence of oxygen or a source from which oxygen can be derived, such as water vapour) most metals are unstable with respect to their oxides. Oxidation to create the metal oxide depends on several factors, the most important being temperature

Table 33.4 Oxidation in air

Steels	480°C
Low-alloy steels	560°C
Ferritic stainless steel (type 410)	650°C
Austenitic stainless steel (type 316)	900°C
Nickel-based superalloys	1100°C
Superaustenitic stainless steel (type 310)	1150°C
Cobalt-based superalloys	>1150°C

1. Temperatures the those above which oxidation is generally too rapid to permit the metal's safe or economic use.
2. Atmospheres contaminated with acid or halogen gases reduce these values.
3. The mechanical properties including strength, ductility and creep resistance can be affected below these temperature.

(and hence the thermodynamics of the process), availability of oxygen and the protective action of any oxide that is created. Oxygen can migrate through the oxide, where it reacts with the metal. In other metal-oxide systems, metal ions migrate outwards through the oxide and form oxides on the outer surface. The structure and the stability of the oxide, together with its semiconducting properties, control the mechanism of oxidation. Oxidation rates can be linear, parabolic (tending to a steady state oxide thickness) or exponential (termed catastrophic, because the rate increases with time). Table 33.4 gives an indication of the temperature limits for some metals through oxidation in a clean atmosphere.

Sulphidation is analogous, but catastrophic sulphidation is common because of the generally lower melting points of sulphides than the corresponding oxide. This is especially true in the case of nickel alloys, when a nickel/nickel sulphide eutectic is formed.

33.1.4.2 Fretting corrosion

Fretting corrosion occurs as a consequence of oscillating relative motion between touching surfaces. As little as 3×10^{-9} m lateral movement is required. The amount of damage increases as the normal force between the surfaces is increased. In dry conditions the corrosion product is usually the oxide. In the case of steel this is wustite. This is otherwise the high-temperature form of the oxide, which implies that locally high temperatures are created on the fretting surfaces. The surfaces weld together in the high stress conditions at points of contact and are torn apart by the relative motion of fretting surfaces.

Materials with hard oxides, including stainless steels and aluminium and titanium alloys, are particularly susceptible to this form of attack. In steel it is also known as 'false Brinelling' because of the high surface hardness that can be created in work-hardening grades.

33.1.4.3 Molten salt corrosion

Any salt that is present on a hot metal surface can cause corrosion of that surface. This mechanism is often rapid and is due to straightforward dissolution of the metal and any oxide which may be present on the surface. The mechanism is similar to that of aqueous corrosion. The high rate of attack is a consequence of the high activities of the ions present in the molten salt. The problem is greatest for salts of low melting point, since these are present over a wide temperature range and can be very fluid. Low melting-point salts include many chlorides, sulphides and sulphates.

33.2 The implications of corrosion

33.2.1 Economics

The principal economic implications of corrosion of a plant are the initial cost of construction, the cost of maintenance and replacement, and the loss of production through unplanned shutdowns. The initial cost of the plant is influenced by material selection, and a choice of material which is more corrosion resistant than is necessary for the safe operation of the plant over its design life is a very expensive error. This cost involves initial outlay of money, and plants have been built which could never be profitable because of the inappropriate materials selection.

Maintenance costs arising from corrosion can also prove to be unacceptably high. For plant which requires regular maintenance for other reasons (e.g. desludging or batch operation) it is often accepted that certain items are expendable and annual or even monthly repair or replacement with low-cost materials is preferable to the use of expensive ones. Plant handling hot, strong hydrochloric acid is often regarded in this way, since the only possible construction materials which have acceptably low corrosion rates are too expensive to use. Plant which requires to be run continuously or maintenance-free for long periods necessitates high-integrity design and hence the use of more reliable corrosion-resistant materials. The most appropriate approach to studying the economic implications for several alternative materials of construction is considered to be that of life cycle costing. This requires an estimation of interest rates over the design life of the plant.

Significant savings can be achieved by optimum material selection (guidance is given in Section 33.3), by considering corrosion at the design stage (Section 33.4), by employing corrosion-control techniques (Section 33.7) and corrosion monitoring (Section 33.8). In the industrialized countries of the Western world, corrosion is estimated to cost some 4% of each country's GNP. In the UK this represents £12 billion per annum, of which a significant proportion could be saved by the use of existing knowledge. It cannot all be saved, since the gradual deterioration of a plant over its operational life is one of the costs incurred in the process.

33.2.2 Safety

The failure of plant by corrosion can be gradual or catastrophic. Gradual failure has few implications for safety providing it is monitored. Direct corrosion-monitoring techniques are described in Section 33.8. Indirectly, the correct interpretation of records relating to metal contamination of products or the loss of efficiency of heat exchangers, etc. can provide useful information.

Sudden or catastrophic failure of plant through corrosion can result in the loss of product at high velocity from a failed reactor vessel, high-energy steam from a steam line, toxic or inflammable materials from storage vessels. Incidents of this nature from plants around the world have led to the death and injury of plant operatives and nearby householders. The majority of serious incidents in the chemical process industry, however, have been attributed to mechanical failure of plant.

33.2.3 Contamination of product

The metal lost from the inside of pumps, reaction vessels, pipework, etc. usually contaminates the product. The implications of this depend upon the product. White plastics can be discoloured by ppb levels of iron, though at this level the effect is purely cosmetic. The taste of beer is affected by ppm levels of iron and other metals. Products sold to compositional requirements (such as reagent-grade acids) can be spoiled by metal pick-up. Pharmaceutical products for human use are often white tablets or powders and are easily discoloured by slight contamination by corrosion products.

33.3 Materials selection

The materials selection procedure for new or replacement plant is crucial to the safe and economic operation of that plant. There is no one correct way to select the appropriate construction material since for small plant handling toxic or inflammable products the integrity of the plant is high in priority, whereas large plant producing bulk material in a competitive market is more likely to be made of cheaper constructional materials, and the occasional leak or failure may have fewer safety implications.

Wherever possible, items should be made from materials which have proved themselves in similar service. Essential items of plant for which long delivery times are expected should be considered most carefully. The possible interactions between items fabricated from different materials should be considered. Section 33.1.2 discusses galvanic corrosion.

33.3.1 Sources of information

The first source of information for the behaviour of a material in the proposed service environment is the potential supplier of the item of plant. Except for new (or significantly modified) processes, specialist suppliers or fabricators have relevant information and service experience. The supplier should be provided with all process or environmental details that are of possible relevant to corrosion. The most important are listed below:

1. *Environmental chemistry*: including complete typical and worst-case compositional analyses, pH, redox potential, dissolved gas content;
2. *Physical conditions*: temperature ranges in bulk and at surface, heat transfer, mass flow, fluid velocities, the presence of entrained particles and gases;
3. *Operating cycles*: commissioning procedures, heating, cooling and pressure cycling, stagnant periods, cleaning procedures;
4. *External environment*: corrosive gases, humidity, temperature;
5. *Mechanical aspects*: the presence of tensile or cyclic stresses.

If the potential suppliers cannot provide documented service performance for similar plant on similar duties, materials suppliers should be consulted.

For all materials other than basic constructional steels and cast irons, reputable suppliers have information bases and applications laboratories from which information can be obtained. Trade organizations representing categories of materials suppliers are excellent sources of information; some are listed at the end of this chapter. The materials suppliers should be consulted in conjunction with equipment suppliers in order to ensure that the information generated is fully applicable to the end use to which the material is to be put. Fabricational techniques should be agreed between the two types of suppliers, since some materials cannot be cast or welded and some items cannot be made by forging.

For some new or modified processes it will not be possible to obtain sufficient good information to permit material selection to be made. Advise is available from professional corrosion consultants and corrosion-testing facilities are available at a number of laboratories in the UK. The Institute of Corrosion publishes a directory of laboratories and consultants.

The following guidance is intended as a checklist for general use, since there is no universal, definitive guide to the selection of materials. It is based on corrosion and not on mechanical property requirements such as strength, toughness, hardness or fatigue resistance.

33.3.2 Aqueous systems

33.3.2.1 Water supply

For the purpose of corrosion, water is scaling or non-scaling. Scaling water tends to deposit generally protective hardness scales. Soft water does not scale and hence is potentially more corrosive, especially when it contains dissolved gases such as oxygen, carbon dioxide, ammonia and sulphur oxides.

For drinking water, copper has now replaced the use of lead, except in areas of cuprosolvency. The local water authority provides information including analytical data. Stainless steels are being introduced especially for domestic systems. Experience on the Continent is mixed, with some corrosion problems such as pitting and stress corrosion cracking reported.

For process water, steel pipes are used unless iron pick-up is to be minimized. Plastic pipes (polyethylene and polyvinylchloride) are used but they sometimes need external protection from solvents present in industrial atmospheres, ultraviolet radiation (including sunlight), freezing and mechanical damage.

Sudden or catastrophic failure of plant through corrosion can result in the loss of product at high velocity from a failed reactor vessel, high-energy steam from a steam line, toxic or inflammable materials from storage vessels. Incidents of this nature from plants around the world have led to the death and injury of plant operatives and nearby householders. The majority of serious incidents in the chemical process industry, however, have been attributed to mechanical failure of plant.

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For firefighting water, steel pipes are used but corrosion products can block sprinklers. Cement asbestos pipes are utilized but pressure limitations restrict their use. For critical applications, including offshore oil installations, duplex stainless steels have now largely replaced copper–nickel alloys. Fire-retardant grades of fibre-reinforced plastics are now available.

Borehole waters are generally very hard and cast iron pipes are still used because of the low internal corrosion rates permitted by the scaling which occurs naturally. Acidic waters cause graphitic attack on cast irons.

33.3.2.2 Boiler water, steam and condensate

The water supply for boilers is usually treated. Treatment depends on the quality of the water supply, the pressure of the boiler, the heat flux through the tube walls and the steam quality required. Most waters require dealkalization. The water produced in this process is non-scaling and potentially corrosive (see above).

The quality of water thus produced is generally adequate for low-pressure boilers, but deoxygenation is usually achieved through the addition of sodium sulphite in a feedwater tank. This should be designed to prevent further ingress of oxygen, employing a nitrogen blanket if necessary. Pipework from the feedwater tank (or 'hot well' if condensate is returned to it) to the boiler is steel, since the water is low in corrosivity.

For higher-pressure boilers demineralization is necessary to minimize total dissolved solids in the boiler. This water is normally carried in steel pipework, but if condensate is returned and the condensate has become contaminated (for example, with carbon dioxide or copper ions) more corrosion-resistant materials such as copper are required. Downstream of the boiler, steam pipework is usually steel with steel or stainless steel expansion bellows.

The presence of corrosive species in steam, however, creates the following corrosion problems:

1. Oxygen renders the steam corrosive towards steel. If the feed is not deoxygenated a corrosion allowance should be added to the steam piping wall thickness, an oxygen scavenger such as hydrazine can be used or a volatile corrosion inhibitor could be employed. Candidate inhibitors include filming amines such as ethoxylated soya amines. Some amine-based inhibitors can break down and cause corrosion of copper in the steam or condensate system. Some products such as hydrazine are toxic or carcinogenic and cannot be used in food-processing plant, breweries and steam sterilizing equipment for hospitals.
2. Carbon dioxide, from the decomposition in the boiler of temporary hardness salts present in some waters, causes corrosion of steel steam pipework and cast iron valves and traps. Corrosion inhibitors may be used, but the choice of inhibitor must take into account the other materials in the system. Neutralizing amines such as morpholine or cyclohexylamine are commonly used.
3. Condensate return lines are often copper. Copper has good corrosion resistance to oxygen and carbon dioxide individually. When both gases are present in the condensate, copper is susceptible to corrosion. Copper picked up in the condensate system and returned to the boiler causes serious corrosion problems in the boiler and any steel feedwater and steam pipework. Boiler tubes should last for 25 years but can fail within one year in a mismanaged or ill-designed boiler system suffering from these faults.
4. Boiler salts can contain chloride ions. When carried over into the steam (e.g. during priming) this can result in chloride stress corrosion cracking of austenitic stainless steel expansion bellows. In steam systems where freedom from chloride cannot be guaranteed, bellows can be supplied in 9% Cr steel or austenitic alloys containing 40% nickel.

Reputable water treatment specialist companies are able to provide complete chemical treatment and corrosion monitoring services.

33.3.2.3 Aqueous processes

The principal corrosive species as described in Section 33.1.2, combined with the reducing or oxidizing nature of the environment, can be used to select candidate materials for any aqueous system. The process variables discussed in Section 33.3.5 must also be considered.

Steel is the most common constructional material, and is used wherever corrosion rates are acceptable and product contamination by iron pick-up is not important. For processes at low or high pH, where iron pick-up must be avoided or where corrosive species such as dissolved gases are present, stainless steels are often employed. Stainless steels suffer various forms of corrosion, as described in Section 33.5.2. As the corrosivity of the environment increases, the more alloyed grades of stainless steel can be selected. At temperatures in excess of 60°C, in the presence of chloride ion, stress corrosion cracking presents the most serious threat to austenitic stainless steels. Duplex stainless steels, ferritic stainless steels and nickel alloys are very resistant to this form of attack. For more corrosive environments, titanium and ultimately nickel–molybdenum alloys are used.

The following brief summary of materials for acid duty is very simplified, and further guidance should be obtained from the sources of information outlined in Section 33.3.1:

1. *Sulphuric acid*: Plain carbon steel is used at strengths in the range 70–100% at temperatures up to 80°C. In flowing conditions the corrosion rate increases, thereby rendering steels unsuitable for pumps. Storage tanks for sulphuric acid require care in design to prevent the possible ingress of water vapour. This creates a layer of dilute acid on top of the bulk acid, creating rapid attack at the fill line. At strengths below 70°C chemical lead is the preferred material for tanks but at temperatures above 120°C corrosion becomes significant. For castings such as pumps, valves, fittings and some heat exchangers cast iron containing 15% silicon is used at strengths up to 100%, at temperatures up to the boiling point. Where iron pick-up must be avoided, conventional stainless steels can be used in

certain ranges of strength and temperature. Anodically protected titanium is used at 70% (60°C) and 40% (up to 90°C). For higher temperatures and strengths above 100%, nickel-based alloys were molybdenum are used. Glass, gold and platinum are required for specific combinations of acid strength and temperature.

2. *Hydrochloric acid*: The selection of materials for handling hydrochloric is exceptionally difficult on account of the sensitivity of corrosion to minor impurities. Oxidizing hydrochloric acid is highly corrosive; dissolved oxygen or trace levels of metal ions in high oxidation states (especially ferric or cupric) ions are the common oxidizing species. Dilute hydrochloric acid (2% at up to 70°C or 10% at 20°C) is handled by copper, nickel and some of their alloys. Moderate-strength acid (up to 10% at up to 70°C, up to 30% and 30°C and up to 40% at 15°C) requires the use of more resistant materials such as cast iron alloyed with silicon and molybdenum or, in the absence of oxidizing agents, silicon bronze. Strong hydrochloric acid at moderate temperatures (below 70°C) can be handled by some of the nickel–molybdenum alloys or non-metallic linings such as rubber. At higher temperatures silver, platinum, zirconium and tantalum are suitable across the whole range of acid strength.
3. *Nitric acid*: Stainless steels are the most commonly used materials for nitric acid duty. Because molybdenum is widely considered to be detrimental to corrosion behaviour in nitric acid, type 304L is generally preferred to type 316L. It is used at temperatures up to 100°C and acid strengths up to 70%. At 100% strength the temperature limitation is 30°C. Higher alloys, based on 20% Cr, 25% Ni, extend the temperature range to nitric acid's boiling point at concentrations up to 50%. An austenitic stainless steel containing 18% chromium, 10% nickel and 2–3% silicon was developed specifically for this service. Cast iron with 15% silicon is used for valves, pumps, etc. in acid strengths of 0–40% (up to 70°C) and 40–80% (up to 110°C). Some aluminium alloys may be used for nitric acid above 80% strength at temperatures up to 35%. Titanium, gold, platinum and tantalum are used to extend the temperatures range where required.

For alkaline duty, steel can sometimes be used up to approximately pH 11. Zinc, aluminium and similar metals and their alloys have limited use in alkaline conditions because they dissolve, giving complex anions. Iron and steel react in this way above about pH 12. Approximate limits of use for zinc are pH 6–12 and aluminium alloy pH 4–8. Stainless steels, including the lower grades, can be used even in the presence of chloride ions at pH levels of approximately 8. In the absence of halides they can be used up to about pH 13.

Materials selection cannot be based on any simple combination of common corrosive species. There are many complicating factors, including the harmful or beneficial effects of contaminants at the p.p.m. level, the relative proportion in which certain combinations of species are present (H^+ and Cl^- are often synergistic in their effect, whereas SO_4^{2-} and Cl^- often counter each other) and the presence of naturally occurring corrosion inhibitors.

33.3.3 Non-aqueous processes

33.3.3.1 Solvent systems

Most organic solvents, except for protic solvents such as alcohols and amides/amines, have reasonably low ionic conductivities and hence do not support electrochemical corrosion to any significant extent. Steel is commonly used except in systems in which water can separate and where the conductivity is sufficient to permit the flow of ionic current.

33.3.3.2 Dry gases

Standard materials for handling dry gases include: for chlorine, UNS N10276 (steel is used for liquid chlorine); for bromine, UNS N10276 (below 60°C); for fluorine, copper; for hydrogen chloride, UNS N10276; for hydrogen sulphide (sulphur dioxide and trioxide), type 316 stainless steel. The presence of water in even trace quantities changes this significantly.

33.3.4 High-temperature environments

33.3.4.1 Chimneys, flues and ducts

The main corrosion process that occur in these items arise from condensing liquids on the internal surface. Although often lagged, heat loss frequently causes internal skin temperatures to fall below the dewpoint of one or more components of the gas stream, albeit locally, such as at support points. Even at temperatures above its dewpoint a gas can dissolve in condensed water. Rapid corrosion can then occur in this thin film of corrosive liquid.

Condensing species of relevance to corrosion include water and all acid gases. The dewpoint of water is obtained from standard tables, requiring only the water content (i.e. relative humidity) of the gas stream. Above the water dewpoint, corrosion problems include condensing acids (Section 33.3.2), dry acid gases (Section 33.3.3) and erosion. Below the water dewpoint acid gases dissolve in the water film to create an acidic solution, including:

1. Carbon dioxide produces a solution of carbonic acid (as in boiler condensate, see Section 33.3.2). Carbon steel is often employed but corrosion rates of up to 1 mm/yr can be encountered. Coatings and non-metallic materials may be employed up to their temperature limits (Section 33.5.6). Basic austenitic stainless steels (type 304) are suitable up to their scaling temperatures.
2. Sulphur oxides produce sulphurous/sulphuric acid. Because oxygen and halides are often also present, high-nickel alloys are required. Current practice for some flue gas desulphurizer ducts operating in the temperature range 60–120°C involves lining the steel structure with 2 mm thick UNS N10276 or UNS N06022. Non-metallic linings, including glass flake epoxy materials, have limited application in the lower part of the temperature range.

Other acid gases such as hydrogen chloride and oxides of nitrogen produce similar corrosion problems. The

corrosion effects produced by acid condensates are amplified by the motion of the gas stream (typically 20–33 m/s) and erosion effects due to entrained solids and impingement at bends, damper plates, reheaters, etc.

In the complete absence of acid gases, steel or galvanized ducting can be suitable (but 80°C is often the operational temperature limit for galvanized steel).

33.3.4.2 Furnaces

Table 33.4 gives scaling data for classes of heat-resisting alloys in air. Mechanical properties, particularly creep strength, may be reduced significantly at temperatures well below scaling temperatures.

In addition to scaling and loss of mechanical properties the third major factor in material performance in furnaces is the detailed chemical environment. Specific problems are encountered with the following:

1. Oxygen or steam in reformer tubes (typically up to 1000°C), steam superheater tubes (700–900°C), regenerators, etc. promote oxidation. Catastrophic oxidation occurs in some materials including molybdenum-bearing stainless steels because of the volatility of MoO_3. Alloys containing 25% Cr and 20% Ni are used up to 1100°C but it is sometimes necessary to employ 35% Cr, 25% Ni or even 45% Cr, 25% Ni types. Type 316 austenitic stainless steel can suffer catastrophic oxidation at temperatures as low as 760°C, although it is often used up to nearly 900°C provided that a free flow of gas is achieved over the entire surface.
2. Sulphur compounds, whether organic or inorganic in nature, cause sulphidation in susceptible materials. The sulphide film which forms on the surface of many construction materials at low temperatures becomes friable and melts at higher temperatures. The presence of molten sulphides (especially nickel sulphide) on a metal surface promotes the rapid conversion to metal sulphides at temperatures where these sulphides are thermodynamically stable. High-alloy materials such as 25% Cr, 20% Ni alloys are widely used, but these represent a compromise between sulphidation resistance and mechanical properties. Aluminium and similar diffusion coatings can be of use.
3. Carbon sources permit carburization. In cracker furnaces, ethylene pyrolysis tubes, etc. carburization results in rapid metal loss in the temperature range 850–1100°C. A lower-temperature form of this mechanism (sometimes termed 'metal dusting') occurs in the range 400–800°C in the carbon monoxide/carbon dioxide/hydrogen/hydrocarbon gas streams. Preferred materials include HK40 (25% Cr, 20% Ni, 0.4% C) or higher alloys (35% Ni, 25% Cr or 30% Cr, 30% Ni), depending on the severity of the environment.
4. Nitrogen-containing compounds, including ammonia and amines, cause nitriding in susceptible materials. Ammonia synthesis (500–600°C, 250–400 bar pressure) requires the use of austenitic stainless steels or nickel alloys. The rate of penetration of nitriding, which causes severe embrittlement, can be 0.2 mm/yr in basic austenitic grades (e.g. type 304), falling by more than an order of magnitude for 40% Ni base alloys.
5. Molten salts promote rapid corrosion of many constructional materials at relatively low temperatures. Low melting-point salts include sodium salts from saline atmospheres, fireside ash, silicate insulation, contaminants in the feed, etc. Corrosion rates of several mm/yr can be observed at temperatures as low as 520°C. High chromium- and nickel-containing alloys up to 50% Cr/50% Ni are employed.

Other detrimental factors which require to be taken into account in the materials selection process include temperature cycling and the presence of halide gases. Specialist alloys containing rare earth element additions such as cerium, lanthanum and yttrium have been developed for use in certain environments up to 1300°C.

33.3.5 Influence of process variables on material selection

33.3.5.1 Flow

The main effects of flow on corrosion of most materials is deleterious. Increasing flow through the laminar region serves to create a thinner hydrodynamic boundary layer on the metal surface. This increases the rates of diffusion of cathodic species and anodic products, generally increasing corrosion rates. Protective deposits and scales are removed or prevented from forming. Damage is caused at locations such as those shown in Figure 33.6.

The most important exception to this is the behaviour of stainless steels in sea water. Grades which are susceptible to pitting or crevice corrosion, including types 304 and 316, are liable to greatest pitting attack in stagnant conditions where debris settles onto upward-facing horizontal surfaces. In conditions of higher flow (greater than 1 m/s) the debris is less likely to settle and thus pitting (Section 33.5.2) is less likely.

If flow becomes turbulent the corrosion rate increases even more rapidly. In practice, most engineering materials have a 'critical velocity' above which the corrosion rate is unacceptably high. This does not correspond with the laminar-to-turbulence transition. Surface roughness is an important consideration.

Impingement attack (sometimes termed erosion corrosion) is a result of the combined effect of flow and

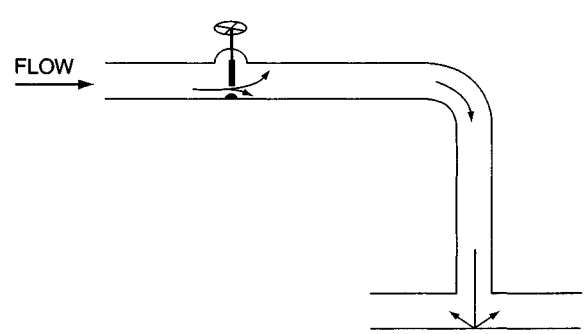


Figure 33.6 Areas affected by erosion corrosion

corrosion on a metal surface and it occurs when metal is removed from the surface under conditions where passivation is insufficiently rapid. It is a function of flow, corrosion and passivation.

At higher flow rates cavitation is a serious degradation mechanism, where vapour bubbles created by pressure fluctuations brought about by the flow of liquid past the surface collapse on the metal surface with tremendous force. This damages any protective oxide which may be present, leading to pitting corrosion. It also causes mechanical damage to the metal.

The corrosive and mechanical effects of flow are observed in pipes, especially at bends and downstream of flow disturbances, tube and shell heat exchangers, valves and pumps. More corrosion resistant and/or harder materials are used in such areas. Austenitic stainless steels work harden and hence are superior in flowing conditions to ferritic stainless steels of otherwise similar corrosion resistance. Hard facings, such as hard chromium electroplate or cobalt based alloys, are used for local improvement of flow-assisted corrosion resistance where it is not required, practical or economic to fabricate the complete item of high resistant material. Hard facing by cobalt-based alloys can be achieved by weld overlay and plasma spray techniques. Correct choice of alloy is important to optimize corrosion resistance, though the resistance of most of the alloys in use is superior to the more common grades of stainless steel. Hard chromium plating contains micro cracks; this allows corrodents to gain access to the substrate. Layers of copper and/or nickel are often required to prevent the corrosion of underlying steel.

The alternative option for counteracting cavitation damage is the use of a resilient material such as rubber. The mechanical forces attendant on collapse of the bubbles are absorbed by elastic deformation of the resilient material.

33.3.5.2 Intermittent operation

This is generally harmful to plant, since deposits can form in periods of stagnation. The common grades of stainless steel, such as types 304 and 316 and other materials (including aluminium alloys and some copper alloys), are susceptible to under-deposit attack and are at risk in circumstances where the process liquid is left to stagnate in between operation cycles. Evaporation can also take place, creating more aggressive conditions than occur during operation. Condensation can form on vessel walls, roofs and support points as heat is lost. This condensation can absorb corrosive gases, creating localized corrosion effects of greater severity than the bulk environment that is normally present.

In rare circumstances, however, intermittent operation is beneficial. Plant which would pit if operated continuously can be operated successfully if the operational cycle is shorter than the initiation period for pitting attack and it is cleaned between batches. This is mainly the case for stainless steel plant operating with high enough chloride levels (or a low pH or high temperature) to initiate pitting if operated continuously. The cleaning regime between batches promotes repassivation; hot water, steam, chloride-free caustic or sodium orthophosphate solution may be required to achieve the required rate of passivation. Plant is rarely designed on this principle, but a significant number of cooking vessels, especially in the food and drink industries, operate this way.

33.3.5.3 Commissioning

The first use of new plant, or start-up after a shutdown, poses corrosion hazards additional to those encountered in normal operation. New plant such as boilers requires special water treatment, involving boil-out, passivation and possible chemical cleaning. Actual requirements depend on the boiler type, the proposed service, the quality of water available during commissioning and the internal condition of the boiler. The condition of the boiler depends on for how long and in what conditions it has been stored. The presence of any salts, dirt or rust is harmful. Boiler internals are covered by an adherent, protective layer of magnetite in normal operation. To create an intact layer of magnetite of the correct thickness, crystal type and morphology all debris must be removed from the boiler, manually or by means of a vacuum cleaner. If rusting is more than superficial, or if millscale is present on the steel of the boiler tubes or shell, chemical cleaning is necessary. BS 2486 contains details of approved chemical cleaning techniques. These are based on inhibited acids (e.g. citric acid). The most appropriate technique is determined by a number of factors, and the most important include the nature of deposits to be removed (i.e. rust, hardness scales, millscale and metallic copper).

Degreasing may be necessary, especially on new plant, and alkaline cleaning techniques are described in BS 2486. For optimum boiler life, passivation treatment is recommended. This is described in BS 2486.

All boiler treatment and cleaning should be carried out by reliable contractors, preferably within the guidelines contained in BS 2486. Boilers are fired pressure vessels and are subject to mandatory insurance inspections. Significant benefits in safe and economic operation, particularly by reducing unnecessary chemical treatment, can be achieved by monitoring the condition of boilers.

Items of plant fabricated from stainless steels should be inspected before first use and after any maintenance work or unplanned shutdown. All materials which rely for their corrosion resistance on the presence of an oxide or similar passive layer are susceptible to localized attack where that layer is absent or damaged. Damage is most commonly caused by scratching, metallic contamination (nearby grinding or touching with ferrous tools), embedding of grit and weld spatter.

Serious damage of this nature should be rectified before the plant is used. Scratches, embedded grit and weld splatter can be removed by careful grinding. All grinding and abrading on stainless steel must be carried out using alumina or a similar abrasive, rather than silicon carbide consumables. Wire brushes must be stainless steel, rather than carbon steel. Local dressing should be fine-finish, since coarse scratches provide sites for the initiation of pitting attack. In critical applications, if stainless steel is to be used near its limit (in terms of corrosion), and for cases such as welds, where a good finish cannot be otherwise achieved, additional passivation is required. Nitric

acid (10–15% by volume) is the best passivator.It also dissolves iron contamination. In circumstances where the use of nitric acid is not possible for safety or physical reasons (such as the underside of vessel roofs) passivation paste is appropriate. Both materials are used at ambient temperature and require a contact time of approximately 30 min. They must be removed by thorough rinsing with low chloride-content water. Guidance is available in ASTM A380.

New plant can be contaminated with corrosive species such as sea salt if it has been transported by sea as deck cargo. Corrosive species present on building sites can gain ingress into items of plant. Many metallic materials, particularly aluminium, zinc alloys and galvanized steel, are susceptible to attack by alkaline cement dust and acid floor cleaners. Significant corrosion can occur by any of these agents before or during commissioning. Titanium and, to a lesser extent, tantalum are at risk of hydriding attack when contaminated by iron smears (see Section 33.5.5).

The materials selection procedure should take into account the commissioning requirements of all parts of the plant in order not to include any materials that cannot safely be degreased or chemically cleaned.

33.3.5.4 Heat transfer

During the materials selection procedure isothermal corrosion testing may indicate the suitability of a material for handling a corrosive process fluid. In many cases where heat transfer is involved the metal wall temperature experienced in service is higher than the bulk process fluid temperature. This, and the actual heat transfer through the material, must be taken into account since both factors can increase corrosion rates significantly.

33.3.5.5 Liquid line

The corrosion conditions can be different at the fluid line from the bulk condition. Aqueous liquids have a concave meniscus which creates a thin film of liquid on the vessel wall immediately above the liquid line. Some corrosion processes, particularly the diffusion of dissolved gases, are more rapid in these conditions. Additionally, the concentration of dissolved gases is highest near the liquid surface, especially when agitation is poor. Locally high corrosion rates can therefore occur at the liquid line, leading to thinning in a line around the vessel. This effect is reduced if the liquid level in the vessel varies with time. Any corrosion tests undertaken as part of the materials selection procedure should take this effect into account.

33.3.6 Influence of external environment

The external environment experienced by plant can be more corrosive than the internal process stream. Any construction material must be chosen to withstand or be able to be protected from external corrosive agents.

33.3.6.1 Corrosive atmospheres

Corrosive species in the atmosphere include water, salts and gases. Clean atmospheres contain little other than oxygen, nitrogen, water vapour and a small quantity of carbon dioxide. These species are virtually non-corrosive to any of the common constructional materials for plant at normal temperatures. Steel is susceptible to corrosion in even fairly clean air where water can exist as liquid. For plant operating at temperatures up to approximately 100°C coatings are employed to protect steel if required. In clean air corrosion rates are low, and corrosion is primarily a cosmetic problem, although it may be necessary to prevent rust staining of nearby materials. Organic coatings (i.e. anti-corrosion paints) are used. Above 100°C the steel will be dry provided it is sheltered from rain. It is also likely to be lagged and therefore not required to be further protected from corrosion. Few organic coatings are suitable for use in this temperature range, but epoxy-based coatings are used up to 120°C and vinylesters up to 160°C. Silicones and inorganic and metallic coatings can be used at higher temperatures. At temperatures above 480°C, oxide scaling is a serious problem for steel, and alternative materials such as stainless steels or nickel-base alloys are required.

Contaminated atmospheres create additional corrosion problems. In marine environments (e.g. coastal power stations, offshore oil platforms and above the splash zone on ships) the chief corrosive agents is sea salt. The chloride content of sea salt precludes the use of stainless steel, bare steel or aluminium in these areas. Steel requires to be coated as described in the previous section. Any coating scheme used for the protection of steel must be properly selected and applied. BS 5493 contains guidelines for coating systems for a variety of environments. The most common reasons for coating failure are incorrect application and inadequate surface preparation. The use of an independent coating inspector, as discussed in Section 33.7, is recommended. Aluminium alloys can be coated with plastics, such as U-PVC, epoxy finishes or conventional paints, with the correct etch primer where applicable to ensure adhesion. Some alloys are suitable for anodizing, but the corrosion protection afforded by anodizing is variable and requires tight specification and control to ensure correct anodized film thickness and sealing efficiency. The lower grades of stainless steels are not suitable for external exposure in marine atmospheric conditions unless they are cleaned regularly with fresh water. Higher grades of stainless steel, nickel alloys and most copper alloys do not normally benefit from additional protection. The development of the coloured patina on copper alloys can, however, be avoided by coating with inhibited lacquer.

Industrial environments can be contaminated with sulphur oxides, other acid gases, ammonia, hydrogen sulphide, nitrogen oxides, chlorine, etc. Most of these are corrosive towards steel, which is normally protected as outlined above. Copper alloys are corroded by hydrogen sulphide at levels above 60 p.p.b. although generally the corrosion product is stable and adherent and further protection is not usually required. Corroded in this way, copper is unsightly and the functioning of electronic

equipment is affected. Ammonia causes corrosion and stress corrosion cracking of some copper alloys and if it is present in significant quantities, most alloys require protection by coating. Chlorine and most acid gases are sufficiently corrosive towards aluminium alloys and the lower grades of stainless steel that protection is required. Coatings are the only practical solution if these gases are present at high enough levels.

33.3.6.2 Corrosion under lagging

Thermal insulation of vessels and pipework usually employs glass fibre or foamed polyurethane products. In their pure forms these pose little corrosion risk. Generally, they are contaminated with leachable acids and/or chloride ions. Chloride-free lagging can be specified and this should be used for contact with metals which are susceptible to chloride pitting or chloride-induced stress corrosion cracking. The lower-grade austenitic stainless steels, including types 304, 321, 347, 316, 317 and their low-carbon variants, are at greatest risk. If the lagging remains dry there is no corrosion problem. Lagging can become wet through rain ingress at damage sites, spillage around entry ports or leakage from steam coils or the lagged vessel wall. Chloride leached from the lagging or introduced with the water tends to concentrate on the pipe or the vessel, and even trace quantities create serious corrosion problems. If chloride-free lagging is not used, or the risk of water ingress cannot be removed, the vessel can be coated prior to lagging. Any barrier coating can be used but if it is damaged it will not prevent corrosion. Aluminium, in the form of foil, is used to prevent chloride-induced stress corrosion cracking of austenitic stainless steels. Applied to the vessel or pipe prior to lagging, it acts as a barrier to water and possibly by slight cathodic protection.

33.3.6.3 Corrosion in concrete

Intact, good-quality, void-free concrete creates an alkaline environment and protects embedded steelwork such as reinforcing steel. Penetration by chloride ions, carbon dioxide, oxygen and other corrosive species reduces this protection. Voids in the concrete created by inadequate compaction at the time of application accelerate this penetration. Carbon dioxide reacts chemically with the concrete, reducing its alkalinity. Chloride and oxygen reach the reinforcing steel and initiate corrosion. The corrosion products occupy a greater volume than the steel from which they were formed. This expansion of some three to fourteen times creates a pressure greater than the tensile strength of the concrete. Spalling of the concrete allows further corrosion to take place. Footings for structural steelwork and vessel supports disintegrate and blocks of detached concrete fall off the roofs and walls of buildings. For reinforced concrete bases for vessels, especially where acidic or chloride- or sulphate-containing spillages are anticipated, the following options should be considered at the materials selection process: acid- and sulphate-resisting concrete are available; specialist coatings can be applied to concrete to prevent the ingress of species that would attack the concrete or corrode the reinforcing steel or the process vessel that is encased in the concrete; reinforcing material can be galvanized steel, stainless steel (BS 6743) or plastic coated; reinforced steel can be cathodically protected.

33.3.6.4 Corrosion in soil

Pipework is the item of plant that is most usually buried in soil. In addition to the internal environment, the soil can present a significant corrosion hazard.

Light, sandy, well-drained soil of high electrical resistivity is low in corrosivity and coated steel or bare stainless steels can be employed. It is unlikely that the whole pipe run would be in the same type of soil. In heavier or damp soils, or where the quality of backfilling cannot be guaranteed, there are two major corrosion risks. Steel, copper alloys and most stainless steels are susceptible to sulphide attack brought about by the action of sulphate-reducing bacteria in the soil. SRB are ubiquitous but thrive particularly well in the anaerobic conditions which persist in compacted soil, especially clay. The mechanism of corrosion where SRB are involved is described in Section 33.1.2. Cathodic protection alone, described in Section 33.7.2, is not completely effective against this type of corrosion. Where SRB activity is likely or the resistivity of the soil is less than 4000 Ω cm the pipeline should be coated. Anti-corrosion paint systems at a minimum thickness of 0.2 mm and rubber, plastic or bituminous coatings are preferred protection systems. Close control of backfill quality is necessary to ensure that sharp stones do not damage the coating, and full on-site inspection is required to ensure defect-free application of site-applied coatings and field joints. It is usually the case that a combination of coating and cathodic protection is the most economic alternative. For critical application or the upgrading of old pipes, cathodic protection is generally suitable. Whether or not cathodic protection is used, care is required to avoid stray current corrosion problems through interaction with nearby cathodic protection or other electrical systems such as electrified railway systems.

33.3.6.5 Corrosion in timber

Metals in contact with or in the proximity of timber can suffer enhanced corrosion attack. Some species of timber, especially oak and Douglas fir, contain high levels of acetic acid. These are volatile and cause corrosion of nearby metals, especially iron, steel and lead alloys.

Metals in contact with timber can be corroded by the acetic acid of the timber and by treatment chemicals present in it. Treatment chemicals include ammonium sulphate and ammonium phosphate flame retardants. These are particularly corrosive towards steel, aluminium and copper alloys. Preservative treatments include copper salts which, at high timber moisture contents, are corrosive towards steel, aluminium alloys and zinc-coated items.

33.4 Design and corrosion

The design of a plant has significant implications for its subsequent corrosion behaviour. Good design minimizes

corrosion risks whereas bad design promotes or exacerbates corrosion.

33.4.1 Shape

The shape of a vessel determines how well it drains (Figure 33.7). If the outlet is not at the very lowest point process liquid may be left inside. This will concentrate by evaporation unless cleaned out, and it will probably become more corrosive. This also applies to horizontal pipe runs and steam or cooling coils attached to vessels. Steam heating coils that do not drain adequately collect condensate. This is very often contaminated by chloride ions, which are soon concentrated to high enough levels (10–100 ppm) to pose serious pitting and stress corrosion cracking risks for 300-series austenitic stainless steel vessels and steam coils.

Flat-bottomed storage tanks tend to suffer pitting corrosion beneath deposits or sediments which settle out. Storage tanks may be emptied infrequently and may not experience sufficient agitation or flow to remove such deposits.

Flange face areas experience stagnant conditions. Additionally, some gasket materials, such as asbestos fibre, contain leachable chloride ions. This creates crevice and stress corrosion cracking problems on sealing surfaces. Where necessary, flange faces which are at risk can be overlaid with nickel-based alloys. Alternatively, compressed asbestos fibre gaskets shrouded in PTFE may be used. Graphite gaskets can cause crevice corrosion of stainless steel flanges.

Bends and tee-pieces in pipework often create locally turbulent flow. This enhances the corrosivity of the process liquid. These effects should be minimized by the use of flow straighteners, swept tees and gentle bends. Flow-induced corrosion downstream of control valves, orifice plates, etc. is sometimes so serious that pipework requires lining with resistant material for some twelve pipe diameters beyond the valve.

33.4.2 Stress

The presence of tensile stress in a metal surface renders that surface more susceptible to many kinds of corrosion than the same material in a non-stressed condition. Similarly, the presence of compressive stress in the surface layer can be beneficial for corrosion, and especially stress corrosion cracking, behaviour.

Tensile stresses can be residual, from a forming or welding operation, or operational from heating–cooling, filling–emptying or pressurizing–depressurizing cycles. The presence of a tensile stress from whatever origin places some materials at risk from stress corrosion cracking, as described in Section 33.1.3. Some items of plant can be stress-relieved by suitable heat treatment, but this cannot prevent operational stress arising.

Cyclic stresses can also give rise to fatigue or corrosion fatigue problems. Information relating to the fatigue life of the material in the service environment is required, together with the anticipated number of stress cycles to be experienced by the item over its operational life. The fatigue life (the number of cycles to failure) or the fatigue strength (the stress level below which it does not exhibit fatigue problems) is then used in the design.

The presence of stress raisers, including sharp corners and imperfect welds, produces locally high stress levels. These should be avoided where possible or taken into account when designing the materials for use in environments in which they are susceptible to stress corrosion cracking or corrosion fatigue.

33.4.3 Fabrication techniques

Most fabricational techniques have implications for corrosion performance. Riveted and folded seam construction creates crevices as shown in Figure 33.8. Those materials which are susceptible to crevice corrosion should be fabricated using alternative techniques (e.g. welding). Care should be taken to avoid lack of penetration or lack of fusion, since these are sites for crevice corrosion to initiate.

Welding should be continuous, employing fillets where possible, since tack welds create locally high stresses and leave crevice sites. Welding consumables should be chosen to create weld metals of similar corrosion resistance to the parent material. This often requires the use of a slightly over-alloyed consumable, to allow for loss of volatile alloying elements during the welding process and

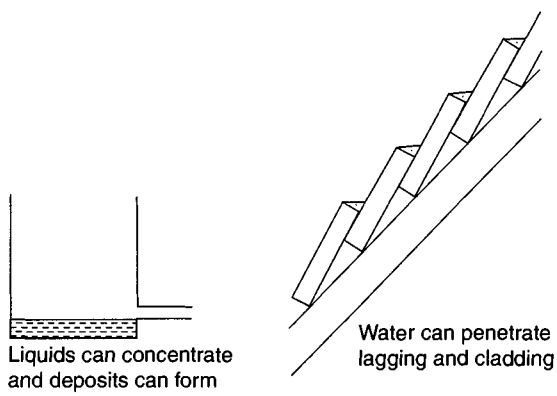


Figure 33.7 Details of design creating corrosion problems

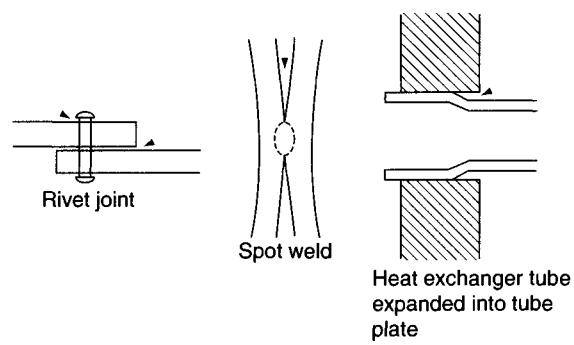


Figure 33.8 Details of jointing processes creating additional corrosion risks (crevices and stress concentrations)

to compensate for the inherently poorer corrosion resistance of the weld metal structure. Strongly over-alloyed weld consumables can create galvanic corrosion problems if the weld metal is significantly more noble than the parent material. In all welds the heat-affected zone is at risk. The new structure which forms as a consequence of the thermal cycle can be of lower corrosion resistance, in addition to the often poorer mechanical properties, than parent material. Austenitic steels such as type 304 and 316 are also susceptible to sensitization effects in the heat-affected zone. In these materials carbide precipitation during the welding thermal cycle denudes the parent material of chromium. This creates areas of significantly diminished corrosion resistance, resulting in knife-line attack in many corrosive environments. This is avoided by the use of the low-carbon equivalents (304L, 316L, etc.) or grades such as type 321 or 347 which are stabilized against sensitization. With correct welding techniques, however, this should be necessary only with thick sections (5 mm for 304 and 8 mm for 316).

Some materials, particularly certain aluminium alloys, duplex stainless steels in certain reducing environments and most steel plate, are susceptible to end-grain attack. Penetration along the end grain can be very rapid, with corrosion exploiting the potential differences that exist between inclusions and ferrite crystals in steel and between austenitic and ferrite grains in duplex stainless steel. Where end-grain attack is significant this should not be exposed to the corrosive environment. It can be covered by a fillet 'buttering' weld if necessary.

33.4.4 Design for inspection

Unseen corrosion can be the most damaging type of attack. Items should be designed to permit periodic inspection. This involves the provision of sufficiently large manways, the installation of inspection pits, the placing of flat-bottomed vessels on beams instead of directly onto concrete bases and the facility for removal of thermal insulation from vessel walls.

33.5 Uses and limitations of constructional materials

33.5.1 Steels and cast irons

Steel is essentially iron with a small amount of carbon. Additional elements are present in small quantities. Contaminants such as sulphur and phosphorus are tolerated at varying levels, depending on the use to which the steel is to be put. Since they are present in the raw material from which the steel is made it is not economic to remove them. Alloying elements such as manganese, silicon, nickel, chromium, molybdenum and vanadium are present at specified levels to improve physical properties such as toughness or corrosion resistance.

Steels are used primarily for their strength and other mechanical properties rather than for corrosion resistance. The corrosion rates of steels is very low only in a few environments, i.e. clean or hard water, certain non-electrolytes, clean atmospheres and properly constituted and compacted ordinary Portland cement. The economics of any high-volume chemical processes, including oil and gas production and transport systems, require the widespread use of steels. By incorporating a corrosion allowance into the design of a plant, corrosion rates of up to 1 mm/yr can be accommodated, particularly for plant designed for an operational life of only a few years. Steels generally corrode in a uniform manner. This is beneficial, since localized attack, as experienced by stainless steels, is very difficult to allow for in plant design. The use of corrosion inhibitors (Section 33.7.4) extends the economic range of use of steels. Steel is also available coated with zinc (galvanized, see BS 729) or aluminium-zinc (BS 6830); see also BS 2659, BS 1706 and BS 4921.

Limitations on the use of steels include:

1. Acidic solutions below about pH 5 due to general corrosion;
2. Alkaline solutions above about pH 11 due to general dissolution and caustic cracking;
3. Marine and industrial atmospheres (without the use of protective coatings), because of high corrosion rates;
4. Atmospheric exposure at temperatures in excess of 480°C, because of oxide scaling;
5. Certain environments containing nitrate, cyanide, carbonate, amines, ammonia or strong caustic, due to the risk of stress corrosion cracking. Temperature is an important factor in assessment of each cracking environment;
6. Solutions of hydrogen sulphide, because of hydrogen-induced cracking. Grades of steel are available for certain ranges of pH and hydrogen sulphide partial pressure.

Cast irons are iron with high levels of carbon. Heat treatments and alloying element additions produce grey cast iron, malleable iron, ductile iron, spheroidal cast iron and other grades. The mechanical properties vary significantly. Nickel-containing cast irons have improved hardness and corrosion resistance. Copper or molybdenum additions improve strength.

Chromium, silicon and other alloying elements are used to create cast irons for corrosion resistance in specific environments. Silicon-containing cast irons are used for sulphuric acid duty.

Limitations on the use of cast irons are similar to those for steel, since in many environments most cast irons have poor corrosion resistance. Most grades are also susceptible to graphitization (the loss of iron, leaving a weak structure of graphite) in acidic environments below a pH of approximately 5.5. This attack occurs in soils.

33.5.2 Stainless steels

Stainless steels are iron-based alloys which contain at least 11% chromium. Hundreds of grades of stainless steel are available with alloying elements including nickel, molybdenum, manganese and copper. Stainless steels are not electrochemically inert, but are protected by a thin

layer of oxide. This passive layer is unstable in oxidizing and reducing environments. If lost completely, the underlying steel corrodes rapidly in corrosive (particularly acidic) environments. Where the oxide is lost locally, pitting, crevice corrosion or stress corrosion cracking can proceed at rates of several millimetres per year. Chemical species including the halide ions assist in the breakdown of the passive film in even mild conditions such as neutral sodium chloride solution. For satisfactory service, stainless steels should be passivated continuously (or intermittently, see Section 33.3.5) with a suitable oxidizing species. The redox potential of an environment is of prime importance in the selection of a stainless steel. In reducing conditions the protective oxide cannot form, and general corrosion takes place; in strongly oxidizing conditions pitting corrosion is possible.

Stainless steels are used in a wide variety of applications and are most often selected because steel or cast iron would corrode at an unacceptably high rate or produce high levels of iron contamination in the proposed service environment. The main limitations on their uses are:

1. The lower grades of austenitic stainless steels suffer chloride-induced stress corrosion cracking at temperatures in excess of 60°C. Note that SCC can occur at lower temperatures in low-pH, high chloride environments. Grades containing high levels of nickel are more resistant. Sensitization (Section 33.4.3) occurs near welds in certain non-stabilized grades. The maximum hardness limitations described in NACE MR-01-75 are necessary to prevent sulphide stress corrosion cracking in hydrogen sulphide-containing environments.
2. Ferritic stainless steels have inferior corrosion resistance compared with austenitic grades of equivalent chromium content, because of the absence of nickel. Stress corrosion cracking can occur in strong alkali.
3. Martensitic stainless steels are of limited use in chemical environments because of their inferior corrosion resistance compared with ferritic and austenitic grades. Their mechanical properties allow them to be used where high hardness is required, but they are susceptible to hydrogen embrittlement.
4. Duplex stainless steels are mostly composed of alternate austenite and ferrite grains. Their structure improves resistance to chloride-induced stress corrosion cracking. In certain reducing acids, such as acetic and formic, preferential attack of the ferrite is a serious problem.

In all categories the lower grades suffer pitting and crevice corrosion in even low-chloride environments. As the chloride content or temperature increases, or the pH falls, higher grades are required. Reducing acids, including acetic and formic, attack most grades, particularly at elevated temperatures. Free-cutting grades, containing deliberate additions of sulphur or selenium, have significantly poorer corrosion resistance than the corresponding standard grade.

33.5.3 Nickel alloys

Commercially pure nickel has good corrosion resistance to a variety of aggressive environments and is specially used for hot caustic service. It has moderate resistance to acid attack but cannot be used in oxidizing acidic conditions, i.e. in oxidizing acids or acidic media containing oxidizing agents. Nickel is widely used for electroplating steel. Electroless nickel plating is used, especially for items of complex shape that cannot be successfully electroplated. As with all coatings, the presence of defects such as pores allow the corrosive environment to reach the substrate. Since nickel is more noble than steel, rapid, galvanically assisted pitting of the substrate steel occurs at defect sites. Nickel is not resistant in the combined presence of ammonium compounds and oxidizing agents.

Nickel is usually alloyed with elements including copper, chromium, molybdenum and iron for strengthening and to improve corrosion resistance for specific applications. Nickel–copper alloys (and copper–nickel alloys; see Section 33.5.4) are widely used for handling water. Pumps and valve bodies for fresh water, sea water and mildly acidic alkaline conditions are made from cast Ni–30% Cu type alloys. The wrought material is used for shafts and stems. In sea water contaminated with sulphide, these alloys are subject to pitting and corrosion fatigue. Ammonia contamination creates corrosion problems as for commercially pure nickel.

Nickel–chromium alloys can be used in place of austenitic stainless steels where additional corrosion resistance is required. These alloys are still austenitic but are highly resistant to chloride-induced stress corrosion cracking when their nickel content exceeds 40%.

Molybdenum-containing nickel alloys are a family of alloys which include grades for handling hot hydrochloric, sulphuric, oxidizing, reducing and organic acids. Some grades are susceptible to attack in ammonia- or sulphide-containing environments.

33.5.4 Copper alloys

Copper has excellent resistance to some corrosive environments, including fresh waters and fluoride-containing atmospheres. Alloying is necessary to achieve good strength, but copper lining with steel for strength is an alternative (BS 5624). Copper and some of its alloys are susceptible to crevice corrosion, but the mechanism is different from that which affects stainless steels.

Alloying with zinc produces brasses. Brasses are generally suitable for fresh and potable waters but dezincification is a problem for grades containing more than 12% zinc, especially in acidic/alkaline conditions. The addition of small amounts of tin, with arsenic or phosphorus, prevents dezincification and is particularly necessary for sea water applications. For handling flowing sea water or other corrosives, copper–nickel alloys are favoured. Brasses are susceptible to stress corrosion cracking in the presence of ammonia or ammonium compounds. This includes lavatory fittings.

Copper–aluminium alloys (aluminium bronze) have good general corrosion resistance but de-aluminification

is possible in some grades in certain environments. Copper–nickel alloys are used where flow-related corrosion is a problem, particularly in sea water heat exchanger tubes. The grades containing a small iron addition have the highest critical velocity. These alloys are all susceptible to pitting by sulphides (created in stagnant conditions in sea water systems), especially in the presence of chlorine and stress corrosion cracking in the presence of ammonia. To minimize their susceptibility to sulphide attack in estuarine or other polluted waters it can be advisable to pre-passivate and, if necessary, inhibit continuously, with ferrous sulphate.

33.5.5 Miscellaneous metallic materials

33.5.5.1 Aluminium alloys

Commercially pure aluminium has good resistance to atmospheric corrosion, except where chloride is present in significant quantities, i.e. within 1–2 km of the coast and in the vicinity of chemical plants. To achieve reasonable strength, alloying additions of silicon, manganese, zinc and copper are made. Aluminium–copper alloys have poor corrosion resistance and should not be used in corrosive environments. The other aluminium alloys have good corrosion resistance to most near-neutral media but are attacked in acidic and alkaline conditions. They are susceptible to pitting corrosion, especially where deposits form. Chloride ions also induce pitting of these alloys; chloride is often generated by the hydrolysis of chloride containing organic chemicals. Other organic materials can be handled safely when dry, except alcohols. Metal ions such as copper, which may be introduced by the corrosion of other plant, storage vessels or pipework, can plate out onto the aluminium and create a galvanic cell which produces intense pitting.

The use of anodic films on aluminium alloys is only applicable to some mildly corrosive environments, including architectural purposes (BS 3987) and where abrasion resistance is required (BS 5599).

The presence of liquid mercury poses a liquid metal embrittlement problem for many alloys. This occurs by the spillage of mercury in aircraft and the condensation of mercury vapour from mercury pumps in cryogenic applications.

33.5.5.2 Titanium

Titanium is available unalloyed in several grades of purity, and alloyed. Each grade or alloy has specific uses. Generally, titanium has excellent resistance to sea water and oxidizing conditions, including acids and concentrated hypochlorite solution. It is susceptible to corrosion in reducing acids, rapid attack in dry chlorine gas, cracking in alcohols and embrittlement by hydriding. Hydriding is possible when titanium or a metal with which it is in contact corrodes, liberating hydrogen. For this reason, titanium plant should be inspected carefully for traces of metallic contamination (e.g. scratch marks from steel-nailed boots). Titanium can be used in the anodized form; a thick anodic coating greatly reduces hydrogen absorption. It is used with anodic protection for handling 40–70% strength sulphuric acid and 36% hydrochloric acid.

33.5.5.3 Other metals

Other metals are available which have very specific uses. Their cost is very high but their use is often justified in certain processes such as fine chemical manufacture. They are generally used as thin cladding or loose lining supported by steel or stainless steel.

1. *Gold* is resistant to many strong acids, but not cyanides or high levels of fluoride, hydrogen fluoride and chlorine.
2. *Platinum* is resistant to strong acids and most halogen gases.
3. *Silver* has reasonable resistance to inorganic and organic acids (not strongly oxidizing acids), hot alkaline conditions and some fluoride-containing environments. It tarnishes in the presence of sulphides.
4. *Tantalum* is inert to many environments including hydrochloric acid at strengths up to 25% at 90°C. It is attacked by fluorine, hydrofluoric acid, fuming sulphuric acid containing free sulphur trioxide, and many alkalines. Above 300°C it reacts with many gases including air. It is subject to hydrogen embrittlement in a similar manner to titanium.

33.5.6 Linings and coatings

Many materials with good corrosion resistance have inadequate strength or other mechanical properties to enable their fabrication or economic use. Organic linings and coatings are used in a range of plant. Organic materials are generally susceptible to organic solvents and have use only within limited ranges of temperature. All coatings and linings must be applied in a manner to control defects within them, since the substrate on which they are applied will be corroded by any contact with the process fluid.

Inspection techniques are available for specific coating and lining systems. Proper bonding to substrate is necessary to avoid blistering and disbonding in case of a vacuum being created in the vessel. BS 6374 provides guidance on materials selection, design application and repair.

33.5.6.1 Resins

Epoxy, polyester, phenolic and other resins are used as coatings and linings with or without reinforcement (see BS 6464 and BS 4994). Glass fibre, silica, carbon and many other materials can be used as filters or reinforcement to produce materials with specific properties of strength, flexibility, wear resistance and electrical conductivity.

33.5.6.2 Plastics

A large range of man-made polymeric materials is available, from polyethylene, which is attacked by most organic chemicals, to fluorinated products such as

polytetrafluoroethylene and polyethyletherketones, which have outstanding resistance to virtually all chemicals. All polymers have their own adhesive, welding and fabricational limitations which must be taken into account in the design of the coated item. These materials can also be used in solid form.

33.5.6.3 Elastomers

Elastomers are used for their flexibility in seals, gaskets and hoses and to resist abrasion (through absorption of the kinetic energy of the impinging particles). The range of materials includes natural and synthetic rubbers and modern elastomers with chemical resistance.

33.5.6.4 Glass

Glass-lined reactor vessels are widely used in pharmaceutical and fine-drug manufacturing processes in which metallic contamination of the products has to be minimal. Most glasses are susceptible to attack in strong acid and alkali media. Manufacture and design of glass-lined vessels is a very specialized area. Such vessels require periodic inspection to ensure the integrity of the lining, which is susceptible to mechanical damage and repair is difficult.

33.6 Specifying materials

Having selected the appropriate material for an item of plant, it is imperative that this material is used in the required state of heat treatment, surface finishes, etc. for its construction.

33.6.1 Compositional aspects

1. *National standards*: British Standards, DIN (Deutsch Industries Normen, from Germany) and ASTM/AISI (American Society for Testing of Materials/American Iron and Steel Institute) are those in most common use for metallic materials. It is always preferable to select a material for which national or international specifications exist. Many materials, including steels and the 300-series austenitic stainless steels, have wide ranges of chemical composition. If an alloy or a grade of stainless steel is to be used in a marginal duty (i.e. where relatively small variations in alloying element content, heat treatment or surface condition could markedly affect its corrosion behaviour) this should be taken into account when the material is specified. For stainless steels and some other materials of construction it is possible to purchase, at a premium rate, the material with specified minima of alloying elements. Type 316 stainless steel, when supplied to AISI specification, can have 10–14% nickel, 16–18% chromium and 2–3% molybdenum. This wide specification produces material across a range of corrosion resistance. It also creates a latitude for mechanical and physical properties, including strength and magnetic permeability. For demanding applications, but where the more resistant type 317 material is not justified, type 316 with a minimum molybdenum content may be specified. Types 304 and 316 are now often dual-certified, i.e. 304 conforms also with the requirement of 304L (the low carbon content grade, to be used when intergranular corrosion is possible) and 316/316L similarly.
2. *Proprietary alloy designation*: Many alloys are the subject of patents and are the registered trade mark of the producer. When produced by the holder of the patent, these alloys are generally of the highest standard, with tight control of composition, and exhibit consistent corrosion behaviour. They are mostly originally developed for a specific corrosive service, but are subsequently marketed more widely. These materials can also be manufactured under licence or, when the patent has expired, by other producers using a generic name. Produced in this way, these materials can be less reliable, with the introduction of unwanted tramp elements. Where proving tests have indicated the suitability of a proprietary alloy for specific application, the same source of material should be used for construction. Published compositional data are typical values; cast analyses should be requested for critical applications.
3. *Government standards*: These are developed by government departments, especially the military, and are primarily for aerospace and marine service materials.
4. *In-house specifications*: End users requiring larger amounts of material and fabricators of specialty plant benefit from preparing their own in-house specifications. These are often based on existing national standards modified to include additional requirements. They include higher compositional ranges of alloying elements, mechanical properties such as strength and surface finish, inspection and certification. These specifications must be written by experts in order to satisfy the users' real requirements without compromising any aspect of the materials' performance.

33.6.2 Mechanical properties

Many available standards, particularly national standards, either do not cover the materials' physical and mechanical properties or leave the user to specify from a range of options. The aspects of mechanical and physical properties which have specific implications for a material's corrosion behaviour include:

1. Strength, particularly where the material will be subjected to fatigue loading or is susceptible to degrading mechanisms such as hydrogen-induced cracking;
2. Hardness, including surface hardness, especially for materials for sour service or environments in which stress corrosion cracking is expected. It is also important where erosion corrosion is likely;
3. Surface finish, since good surface finish retards the onset of certain types of corrosion attack, including pitting and stress corrosion cracking.

All relevant physical and mechanical property requirements should be included in the material specification.

33.6.3 Certification

All aspects of the material's chemical, mechanical and physical properties which are included in the specification should be capable of measurement and certification. For critical duties all material supplied should be fully tested and certified by competent approved, independent test laboratories. The nationally recognized laboratory approval scheme in the UK is NAMAS (National Measurement Accreditation Service), operated by the Department of Trade and Industry through the National Physical Laboratory. For less demanding duties material should be accompanied by test certificates from the supplier. All items of plant should be purchased with material certification. Additional certification is required in cases where the fabricator, in manufacturing an item of plant, uses techniques such as welding or heat treatment which may affect the corrosion behaviour of the construction materials.

All bought-in items of plant, especially those supplied without adequate materials certification, should be subject to random inspection. Portable instruments are available for many types of non-destructive examination, chemical analysis and mechanical testing of fabricated items of plant.

33.7 Corrosion-control techniques

Economic reasons may dictate the use of an inexpensive constructional material (i.e. steel protected by one of the methods discussed below) in place of a more resistant but more expensive material. Although all these corrosion control techniques could be used on a variety of materials, with appropriate design and safeguards, they are only rarely employed to protect any material other than steel.

33.7.1 Painting

Paints are complex formulations of polymeric binders with additives including anti-corrosion pigments, colours, plasticizers, ultraviolet absorbers, flame-retardant chemicals, etc. Almost all binders are organic materials such as resins based on epoxy, polyurethanes, alkyds, esters, chlorinated rubber and acrylics. The common inorganic binder is the silicate used in inorganic zinc silicate primer for steel. Specific formulations are available for application to aluminium and for galvanized steel substrates.

Because of their generally poor resistance to solvents, acids, alkalis and other corrosive agents, paints are not normally used to protect plant internals handling anything other than waters. Even clean (i.e. potable or better) water is damaging to most epoxy-based coatings. Limitations on the use of paint systems include:

1. *Erosion resistance*: The mechanical properties of paints prevent their use in conditions where impingement or erosion by entrained solids is expected.
2. *Solvent resistance*: This varies from very poor (for chlorinated rubbers) to good (for polyurethanes). All paint binders have specific susceptibilities and the presence of small quantities of the appropriate solvent in the atmosphere in the region of an item of plant can cause rapid failure.
3. *Saponification*: Paints are most commonly used to protect steel from corrosion by sea water in marine applications and soil in the case of buried structures. Additional protection is often supplied by the application of cathodic protection to the steel. Any paint coating used in conjunction with cathodic protection must be resistant to the alkali which is produced on the steel at defect sites in the coating. The amount of alkali generated depends on the potential to which the steel is polarized. Some paint binders such as alkyds and vinyl ester are very susceptible to saponification, and should not be used on cathodically protected structures. Cathodic disbondment testing, to BS 3900: Parts F10 and F11, should be undertaken if the relevant information is not available.
4. *Temperature*: Thermal breakdown of the binder limits the service temperature for painted items to 70°C (e.g. chlorinated rubbers and polyvinylacetates), 120°C (many epoxies) and 160°C (for vinylesters). The commonest reason for coating failure is incorrect application. This is a skilled task, involving surface preparation (usually by grit blasting) and a tight control over environmental factors (temperature and relative humidity of the local atmosphere), the cleanliness of the steel (national standards, including Swedish Standard SIS 05 59 00, BS 4232 and ISO 8502, cover the testing of residual contamination and freedom from millscale, rust, etc.), the paint and the application procedure. All coating should be supervised by an independent, qualified inspector certified to a recognized standard such as the National Association of Corrosion Engineers International Coating Inspector Training and Certification Scheme.

The selection of an anti-corrosion paint coating scheme should be undertaken by a qualified expert. BS 3900 covers most aspects of paint coating testing.

33.7.2 Cathodic protection

Cathodic protection (CP) is an electrochemical technique of corrosion control in which the potential of a metal surface is moved in a cathodic direction to reduce the thermodynamic tendency for corrosion. CP requires that the item to be protected is in contact with an electrolyte. Only those parts of the item that are electrically coupled to the anode and to which the CP current can flow are protected. Thus the inside of a buried pipe is not capable of cathodic protection unless a suitable anode is placed inside the pipe. The electrolyte through which the CP current flows is usually sea water or soil. Fresh waters generally have inadequate conductivity (but the interiors of galvanized hot water tanks are sometimes protected by a sacrificial magnesium anode) and the conductivity of air is far too low to permit the cathodic protection of buildings or vehicles.

The operating principle of CP is shown in Figure 33.9. Good CP practice is embodied in BS Code of Practice CP 1021. For buried pipelines the power source is most frequently d.c. voltage derived from a rectified mains power supply, or in suitable climates such as Australia and the Middle East, solar cells. Such systems operate

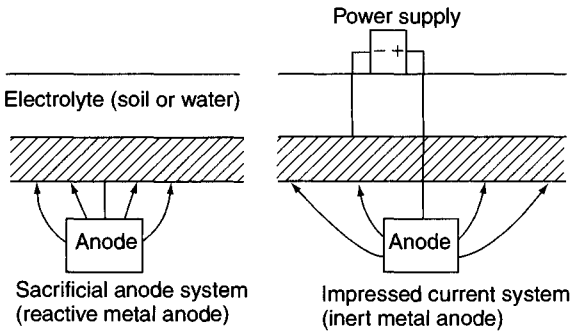


Figure 33.9 Cathodic protection

by 'impressed current' and suitable anodes are platinized titanium or niobium wire, cast iron, and graphite. They are not consumed, but can be damaged by the chlorine generated in sea water CP systems. Reinforcing steel in concrete jetties, bridge and carpark decks and some offshore structures are generally protected by means of impressed current systems.

Sacrificial anode systems operate without external power source. The anodes are reactive metals such as magnesium and zinc or aluminium alloys. The energy for the process is derived from the anode material. Careful design is required to match the output and lifetime of the anodes with the polarization and life-expectancy requirements of the plant. Sacrificial anode CP is used for offshore platforms, subsea pipelines and the inside of ballast tanks on tanker ships.

Correct design is necessary to achieve full protection without overprotection and to minimize wastage of power or anode materials. Overprotection is undesirable because alkali is generated at the cathode (this degrades many plant systems) and hydrogen can be evolved. Hydrogen is deleterious to some mechanical properties of steels and pipelines have failed through this mechanism. Steel is also susceptible to cracking in carbonate-containing environments in certain potential ranges. A reduction in the power requirements of a CP system can usually be achieved by coating the protected structure.

Stainless steel pipes (buried in the ground) and the interiors of stainless steel heat exchangers have been successfully cathodically protected, but CP is rarely used for materials other than steel. The protection potential usually adopted for steel is −850 mV to the saturated calomel reference electrode. This varies with temperature and the presence of other aggressive species in the environment.

33.7.3 Anodic protection

Anodic protection is possible only for material-environment combinations that exhibit fairly wide passive regions. Examples include type 304 stainless steel in phosphoric acid and titanium in sulphuric acid, steel and stainless steels in 98% sulphuric acid. The effect of the anodic polarization is to shift the steel into a region of passivity. This promotes the formation of a protective film on the steel surface, preventing general corrosion. Inadequate or over-polarization creates corrosion and hydrogen evolution problems. As with CP, only wetted surfaces can be protected; this excludes condensed films or droplets on vessel roofs and walls above the liquid line. Such areas are subject to rapid corrosion attack.

33.7.4 Corrosion inhibitors

The use of cheap constructional materials such as steel can be tolerated in certain instances where corrosion inhibition is possible:

1. *Boilers and steam systems*: Steel steam lines can be inhibited by the use of a volatile amine-based inhibitor such as ammonia, morpholine or cyclohexylamine introduced with the feedwater. It passes through the boiler and into the steam system, where it neutralizes the acidic conditions in pipework. The inhibitor is chemically consumed and lost by physical means. Film-forming inhibitors such as heterocyclic amines and alkyl sulphonates must be present at levels sufficient to cover the entire steel surface, otherwise localized corrosion will occur on the bare steel. Inhibitor selection must take into account the presence of other materials in the system. Some amine products cause corrosion of copper. If copper is present and at risk of corrosion it can be inhibited by the addition of benzotriazole or tolutriazole at a level appropriate to the system. All aspects of boiler water treatment are covered in BS 2486 (see also Section 33.3.2).
2. *Cooling waters*: Once-through cooling systems cannot usually be inhibited because of the expense of the chemicals required and the problems of the disposal of the treated water. Open recirculating systems lose water by evaporation from the tower and pick up atmospheric dust and other detritus. Inhibition of such a water is part of the overall water treatment in which scaling tendency and other factors are also controlled. Phosphates and phosphonates together with zinc ions are commonly used. Biocide additions are also required and algal growth control in the case of systems into which sunlight penetrates. Closed recirculating systems, including those in motor vehicles, can be treated with the most efficient inhibitors such as chromates. Disposal problems have restricted the use of these chemicals, but borates, benzoates and nitrites are used. If there is copper in the system, this must be inhibited also. If aluminium is in the system, nitrite poses a pitting problem in certain pH ranges. Nitrite is also aggressive towards lead–tin soldered joints and is ineffective as an inhibitor for zinc and its alloys. Aluminium is only properly protected by benzoate in acidic solutions; in alkaline conditions it is not fully effective (borates are preferred). The compatibility of all materials, including stainless steel and galvanized steel, must be ascertained before any corrosion-inhibition system is employed.
3. *Heating systems*: Where they are virtually sealed except for a make-up tank (as in the case of domestic central heating) systems can be treated as for closed recirculating cooling systems, and benzoates, nitrites

and borates are used. In a correctly designed system such that oxygen ingress is minimal and little make-up is required the oxygen content diminishes as corrosion proceeds and the system can require no inhibitor treatment. The use of certain toxic corrosion inhibitors is not permitted in hospitals, food-manufacturing plant and breweries, where a leak could result in contamination of food or exposure of people to the chemical.

4. *Vapour phase inhibitors*: These are used for the temporary protection of new plant in transit or prior to commissioning. Volatile corrosion inhibitors such as cyclohexylamine derivatives are used. The plant must be sealed or contained to prevent rapid loss of the inhibitor. Sachets of these materials are placed in packing cases. Papers impregnated with them are available for wrapping steel items. These inhibitors are used primarily to protect steel. Further guidance is available in BS 1133(6). An alternative is the use of desiccants where adequate sealing can be achieved.

33.8 Corrosion monitoring

Once a plant is in operation it is important to monitor the progress of any corrosion which might be taking place. The four approaches described below vary in sophistication and cost. The most appropriate for any plant is determined by a number of factors, including the mechanisms of corrosion which are anticipated and the implications of catastrophic or unexpected failure. Key areas of the plant require closer monitoring than readily replaceable items. The measures described below do not replace the mandatory inspections of pressure vessels, etc. for insurance purposes. The overall philosophy of corrosion monitoring is to improve the economics of the plant's operation by allowing the use of cheaper materials and generally reducing the over-design that goes into plant to combat corrosion.

33.8.1 Physical examination

Full records of all constructional materials that are used in the plant should be maintained and updated when repairs are undertaken. The exteriors of all parts of the plant should be subjected to frequent visual examination and the results reported and stored for future reference. This maximizes the warning time before corrosion failures occur, since the majority of failure mechanisms cause leaks before bursting. Key items of plant, those in which some degree of corrosion is anticipated and those which might suffer catastrophic failure should be examined in greater detail. Internal visual inspection during shutdowns is sufficient to identify most corrosion effects. Cracking can usually be seen with the naked eye but where cracking is considered to be a possible mechanism an appropriate non-destructive test method should be employed. In items of plant which are shut down only infrequently (relative to the timescale of possible corrosion or cracking failure) external non-destructive testing is often possible.

Candidate non-destructive test methods include:

1. *Ultrasonic techniques*: Wall thickness can be measured to monitor the progress of general corrosion, cracks can be detected and hydrogen blisters identified. Certain construction materials such as cast iron cannot be examined by ultrasound. Skilled operators and specialist equipment is required. Plant can be examined *in situ* except when it is above 80°C.
2. *Magnetic particle inspection*: Surface emergent and some sub-surface cracking can be detected in ferromagnetic materials. The technique must be used on the side of the material in contact with the corrodent.
3. *Dye penetration inspection*: This is a simple technique, requiring a minimum of operator training. In the hands of a skilled operator it is capable of detecting fine cracks such as chloride stress corrosion cracks in austenitic stainless steels and fatigue cracks.

33.8.2 Exposure coupons and electrical resistance probes

If changes have been made to the process (e.g. if incoming water quality cannot be maintained or other uncertainties arise) concerning the corrosion behaviour of the construction materials it is possible to incorporate coupons or probes of the material into the plant and monitor their corrosion behaviour. This approach may be used to assist in the materials selection process for a replacement plant. Small coupons (typically, 25 × 50 mm) of any material may be suspended in the process stream and removed at intervals for weight loss determination and visual inspection for localized corrosion. Electrical resistance probes comprise short strands of the appropriate material electrically isolated from the item of plant. An electrical connection from each end of the probe is fed out of the plant to a control box. Instrumentation in the box senses the electrical resistance of the probe. The probe's resistance rises as its cross-sectional area is lost through corrosion.

The materials should be in the appropriate form, i.e. cast/wrought/welded, heat treatment and surface condition. Metal coupons should be electrically isolated from any other metallic material in the system. They should be securely attached to prevent their being dislodged and causing damage downstream. Simple coupons and probes cannot replicate the corrosion effects due to heat transfer but otherwise provide very useful information. It should be noted that any corrosion they have suffered represents the integrated corrosion rate over the exposure time. Corrosion rates often diminish with time as scaling or filming takes place, thus short-term exposures can give values higher than the true corrosion rate.

33.8.3 Electrochemical corrosion monitoring

A number of corrosion-monitoring techniques, based on electrochemical principles, are available. These give an indication of the instantaneous corrosion rate, which is of use when changing process conditions create a variety of corrosion effects at different times in a plant. Some techniques monitor continuously, others take a finite time to make a measurement.

1. *Polarization resistance*: The current-potential behaviour of a metal, externally polarized around its corrosion potential, provides a good indication of its

corrosion rate. The technique has the advantage of being well established and hence reliable when used within certain limitations. This technique can only be used for certain metals, to give general corrosion rate date in electrolytes. It cannot be employed to monitor localized corrosion such as pitting, crevice corrosion or stress corrosion cracking, nor used in low-conductivity environments such as concrete, timber, soil and poor electrolytes (e.g. clean water and non-ionic solvents). Equipment is available commercially but professional advice should be sought for system design and location of probes.

2. *Impedance spectroscopy*: This technique is essentially the extension of polarization resistance measurements into low-conductivity environments, including those listed above. The technique can also be used to monitor atmospheric corrosion, corrosion under thin films of condensed liquid and the breakdown of protective paint coatings. Additionally, the method provides mechanistic data concerning the corrosion processes which are taking place.
3. *Electrochemical noise*: A variety of related techniques are now available to monitor localized corrosion. No external polarization of the corroding metal is required, but the electrical noise on the corrosion potential of the metal is monitored and analysed. Signatures characteristic of pit initiation, crevice corrosion and some forms of stress corrosion cracking are obtained.

33.8.4 Thin-layer activation

This technique is based upon the detection of corrosion products, in the form of dissolved metal ions, in the process stream. A thin layer of radioactive material is created on the process side of an item of plant. As corrosion occurs, radioactive isotopes of the elements in the construction material of the plant pass into the process stream and are detected. The rate of metal loss is quantified and local rates of corrosion are inferred. This monitoring technique is not yet in widespread use but it has been proven in several industries.

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34

Paint coatings for the plant engineer

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34.1 Definition and function of coatings

The term 'paint' is normally used to describe the liquid material before application and 'coating' after it has been applied, dried and cured. Organic-based coatings form the largest use for protection and decoration, and these can vary widely in properties and characteristics, ranging in thickness from a few microns to several millimetres. The term 'coating' is not confined to thick films.

Metal coatings (e.g. zinc on steel) can also provide a useful and economic form of protection for steelwork and plant in the appropriate circumstances. Some metallic coatings (e.g. hot-dip galvanizing) act as a complete barrier to the environment, but most corrosion-protection metal coatings and all organic coatings are permeable to moisture and gases to some extent. The rate of permeability varies with different types of coating, but in all cases protection of the substrate is mainly afforded by adhesion. Good adhesion, which is largely a product of adequate surface preparation, prevents the lateral spread of moisture and contaminants which would undermine the coating and lead to disbondment or corrosion and eventual breakdown.

The thickness of the coating also affects permeability, and in general, there is a correlation between thickness and life. However, with relatively thick coatings as obtained with some modern materials such as epoxies the relationship is not so well established. There may be a limiting thickness above which either little additional protection is obtained or the increase in cohesive strength reduces its adhesive strength. Coatings should always be applied as closely as possible to the manufacturer's recommended thickness.

Coatings will also react with the environment over a period of time. Metal coatings corrode, albeit at a slower rate than steel. They have a finite life in a specific environment, depending on the thickness of the coating. Organic coatings react in a different way, and generally a type can be chosen which will have superior resistance to chemical attack. However, they also deteriorate in time, the main natural destructive influences being sunlight and moisture.

34.2 The constituents of paint

All paints consist of a binder (sometimes called a medium) and pigment. Materials consisting of binder only are called varnishes. Most paints and varnishes contain solvent in order to make the binder sufficiently liquid to be applied. The combination of binder and solvent is called the vehicle. Some paints are available without solvent (e.g. solventless epoxies) but these generally require special methods of application (e.g. application of heat) to reduce the viscosity.

34.2.1 Paint binders

Binders are the film formers. After application, they turn from liquids to solids. Different types of paint have, in some cases, radically different mechanisms for this process.

This gives important differences in properties between the paints made from different binders.

In all cases, however, binders are a vital constituent of paint and provide its main mechanical and physical properties.

34.2.2 Paint pigments

Pigments are the solid constituents added during paint manufacture. Their function is not solely to provide colour but also opacity. Since pigments are opaque they also help to protect the binder from the harmful ultraviolet content of sunlight. In general, varnishes are less durable than paints. Pigments also reduce permeability, particularly when they are in the lamellar form (e.g. micaceous iron oxide, aluminium and graphite), since they increase the moisture path through the film.

Some pigments exert an inhibitive effect on the corrosion of metal. Many of the effective corrosion inhibitive pigments, such as those based on lead or chromate, are now banned or discouraged due to their toxicity. The problem particularly arises during surface preparation for maintenance painting. Powdered zinc metal or zinc phosphate are now the most widely used pigments for corrosion inhibitive primers.

Most pigments can be used in any type of binder, therefore paints cannot be identified by pigment type alone. For example, micaceous iron oxide pigment is traditionally in an oil-based binder but is being increasingly used in epoxies, etc. In the paint coating film the pigment content may vary from 15% to 60%. In the special case of zinc-rich primers it is over 90%.

The proportions of pigment to binder are a critical factor in paint formulation not only in providing the optimum strength and impermeability but also in the finished appearance (e.g. high pigmentation can give a matt surface, low pigmentation a high gloss).

34.2.3 Other constituents

Extenders

These are similar to colour pigments but are generally inorganic. Although often considered as cheap fillers, they can form a useful function as a reinforcement to the coating film.

Diluent

This is a volatile liquid which, while not a solvent for the binder, can be used in conjunction with the true solvent to reduce cost without precipitation of the binder.

Anti-skinning agent

This is added to reduce or prevent skin formation in partially filled containers.

34.2.4 Solvents

Solvents are used to reduce the viscosity of a paint so that it is suitable for application. They play no direct part

in the protective value of the coating and are lost to the atmosphere. Amounts are kept as low as possible (usually 5–40% by weight).

The type of solvent used depends on the binder. There is normally more than one type of solvent in a paint, particularly for spray application. Highly volatile solvents are needed to reduce the viscosity during atomization and then disperse as quickly as possible, but lower volatile solvents are necessary to remain momentarily to ensure that there is sufficient flow to form a continuous film.

Organic solvents are a toxic, fire and explosive hazard to varying degrees, depending on type. Legislation is now in place under the Environmental Protection Act 1990 (PGG/23/97 Coating of metal and plastics) which details controls to minimize and eventually eliminate volatile organic compounds (VOC) In paint coatings this means of course, organic solvents. There is also new legislation regarding health and safety (COSHH). This has already brought great changes to paint technology to make products compliant. A compliant coating is one which contains less VOC than the Maximum Amount Prescribed. This legislation and its requirements are regularly reviewed and amended.

Current methods of reducing VOC emissions are:

a. Less percentage solvent in the liquid paint (i.e., higher volume solids)
b. Water based coatings
c. Powder coatings
d. Radiation curing

Only the first two are suitable for site application and currently because of climate in the U.K., manufacturers are tending to adopt the high solids approach rather than water based.

The general terminology regarding solvent content is as follows:

a. Solvent based means containing organic solvents.
b. High solids or VOC compliant typically means over 70% volume solids for primers and undercoats and 60% for top coats.
c. Water-based or waterborne, means the main solvent is water, but can still contain some organic solvents.
d. Solventless coatings are essentially with less solvent, typically 90% or more volume solids.
e. Solvent free should be 100% solids, but often 98% volume solids may be called solvent free.

34.3 Types of coating and their uses

A convenient method of classifying paint coatings is by their curing mechanism. The process by which the wet film turns into a solid one has a significant effect on the properties of both application and durability. However, within a particular generic type the formulation can vary, and one manufacturer's product may be superior to another's. The general lack of standards and changes in the use of raw materials by manufacturers means that different products cannot be directly compared except by testing.

Given below are the main types of paint, their properties and some general guidance on their use. For any specific requirements it is always advisable to check with paint manufacturers.

34.3.1 Air-oxidizing coatings

Examples

Alkyds
Silicone alkyds
Urethane alkyds
Epoxy esters
Tung oil phenolic

General advantages

1. Relatively cheap
2. Easy to apply by brush or spray
3. Generally formulated with mild solvents, such as white spirit
4. Readily available in a wide range of colours
5. Reasonable gloss retention on exterior exposure
6. Resistant to mineral and vegetable oils
7. Available in high gloss

General disadvantages

1. Poor alkaline resistance (e.g. not suitable for application to concrete)
2. Not suitable for very wet, immersed or condensation conditions
3. Limited resistance to solvents
4. Relatively slow drying (e.g. touch-dry 4–6 h, dry to recoat 12 h (min.)
5. Possible problems of intercoat adhesion with unweathered high-gloss coats
6. Can only be applied at limited film thickness

Comparison of paints within this classification

Alkyds These are the most widely used of all air-oxidizing coatings and have the broadest use both industrially and domestically. They are usually classified according to the proportion of drying oil to synthetic resin (known as 'oil length'). The oil length influences all properties (e.g. chemical resistance, viscosity, flexibility and hardness).

Long oil-length alkyds (e.g. 60% and over, of oil) are the most suitable materials for site application on a wide range of surfaces under normal exterior or interior environments. They are not suitable for very wet conditions, immersion or condensation, or for application to alkaline surfaces such as concrete.

The shorter oil-length alkyds are quicker-drying, harder finishes which are most suitable for works application. The very short oil-length alkyds are used for stoving finishes on industrial and domestic equipment, etc.

Silicone alkyds These are alkyds modified with silicone resin. They have superior resistance to weathering (particularly gloss retention) than pure alkyds but are generally

significantly more expensive. They are useful for exterior use where appearance is important.

Urethane alkyds These are formed by the reaction of an isocyanate with alkyd, although the curing remains substantially through the oil-oxidation reaction. They have properties similar to alkyds although superior resistance to abrasion is claimed.

Epoxy ester Epoxy esters are a type of alkyd where a high molecular weight resin is reacted with alkyd resin. The curing mechanism remains primarily through the oil-oxidation reaction and their properties are in no way similar to the chemically reacted epoxies. They have similar properties to alkyds although with improved chemical resistance but inferior appearance and weathering properties. Their best use is as primers in an oil-based system.

Tung oil phenolic Tung oil is a natural, fast-drying material which, when combined with phenolic resins, forms an air-drying film of good film hardness, water resistance, flexibility and toughness. Prior to the development of more modern materials it was widely employed as a corrosion-resistant coating or varnish, particularly for marine use. It tends to yellow on ageing, so is not suitable for decorative use but when pigmented with micaceous iron oxide is still widely used for exterior structural steelwork painting. Its best use is for bridges, gantries, conveyor-belt steelwork, etc. where the relatively drab, matt appearance can be tolerated.

34.3.2 Solvent-dry coatings

Examples

Chlorinated rubber
Vinyls
Acrylated rubber
Modified chlorinated rubber
Bituminous
Vinyl tar

General advantages

1. Quick drying (typically touch-dry 2 h, dry to recoat 8 h)
2. Low water permeability, suitable for wet conditions and condensation
3. Good acid resistance
4. Good alkaline resistance, therefore suitable for application to concrete, etc.
5. Single-pack material
6. Very easy to recoat in both new and old condition
7. No danger of loss of adhesion between coats
8. Can be used for water immersion (e.g. swimming pools) but its thinner film generally makes it less durable than two-pack, chemically reacted materials (e.g. epoxies)
9. With the exception of bitumen, available in a limited range of colours, but light shades are generally more durable externally
10. Forms a solid film entirely by solvent evaporation and therefore does not rely on temperature, oxidation, etc. to cure. For internal, closed conditions adequate ventilation is the main requirement.

General disadvantages

1. They contain a high percentage of strong solvents typically 60–75%, so there will be a decrease in their use.
2. Limited temperature resistance (generally, maximum 60°C dry heat)
3. Sometimes called non-convertible types of paint since unlike all other types there is no chemical reaction during the drying and curing process and in the dry film they remain soluble in their own solvent. Therefore it tends to be 'lifted' or 'pickled' if overcoated with paints containing stronger solvents (e.g. two-pack epoxies or urethanes)
4. Thermoplastic material, so it moves with temperature and should not be overcoated with harder, thermoset materials such as alkyds, since these will eventually crack and craze
5. Relatively more difficult to apply than other types, particularly by brush. Since the paint always remains soluble in its solvent the brush tends to 'pick up' the previous coat.

Comparison of paints within this classification

Chlorinated rubber These materials are being phased out of production because of toxicity problems during their manufacture.

Vinyls Vinyl chloride co-polymer resins were developed in the USA in the late 1930s. They have better weather and slightly more chemical resistance than chlorinated rubber paints. They are generally resistant to crude oil but application is more critical. For example, they are particularly sensitive to moisture present on a surface during painting and this can lead to adhesion failure.

Acrylated rubber These are based on styrene butadiene. They are manufactured in several grades but most have the advantage over other materials in this class of being based on white spirit solvent rather than the stronger and more obnoxious xylol. In other respects they are similar to chlorinated rubber and cost approximately the same, although they are easier to airless spray and the dried film contains less pores. They are considered to have superior weather resistance to chlorinated rubber and vinyls but, as yet, long-term experience is lacking.

Bituminous This term is used for products obtained from both petroleum and coal-tar sources but the petroleum products are the more widely used. These materials are very resistant to moisture and tolerant to poor surface preparation. They are only available as black, dark brown or aluminium pigmented. The last has reasonable outdoor durability but, without the aluminium, the film will crack and craze under the influence of

sunlight. Normally they cannot be overcoated with any other type of paint, because not only will harder materials used for overcoating tend to crack or craze but there is also a possibility that the bitumen will 'bleed through' subsequent coats. The best use is as a cheap waterproofing for items buried or out of direct sunlight.

Acrylics A large group or resins closely related to vinyls which can be produced as both convertible and non-convertible types. The non-convertible, thermoplastic grade has similar properties to acrylated rubbers but are not widely used for steel protection, however, the convertible type reacted with isocyanates from acrylic urethanes form a very durable, two-pack, top-coat, currently used for off-shore oil platforms.

34.3.3 Chemically cured coatings

Examples

Two-pack epoxies
Coal tar epoxies
Two-pack urethanes
Moisture-cured urethanes
Polysiloxanes

General advantages

1. Very resistant to water, chemicals, solvents, oils and abrasion
2. Tough, hard films that can, if correctly formulated, be applied to almost any thickness.

General disadvantages

1. The majority are two-pack materials that must be mixed correctly before use
2. Their cure, overcoating properties, pot life (e.g. the time the mixed components are usable) are all temperature dependent. This means, for example, that an increase of 10°C can halve the reaction times
3. They are more difficult to overcoat then most types, and this can lead to problems of intercoat adhesion. Cured films require abrading before subsequent coats will adhere
4. As a rule, they cannot be applied over other types of paint
5. The high cohesive strength developed during the curing of these materials tends to place stress on their adhesive properties. Therefore unless they are specifically modified they require a higher standard of surface preparation than other types of paint.

Comparison of paints within this classification

Two-pack epoxies These were first patented in 1938 but were not in general production until 1947. They have been very widely used over the last decade. Produced from the by-products of the petroleum industry, the basic epoxy resins may be in the form of relatively low-viscosity liquid resins or they may be solid resins of increasing hardness. Both solid and liquid resins can then be reacted with a number of different curing agents. This means that almost any type of film and with any required properties can be made.

These materials are now widely used for coating both steel and concrete surfaces that are subject to a particularly aggressive environment (e.g. North Sea oil platforms). There is less validity for their use under normal atmospheric conditions since they are relatively expensive and tend to chalk on exposure to sunlight. However, their use as zinc phosphate, pretreatment or blast primers for blast-cleaned steel which is subsequently overcoated by any other paint system is an extremely valuable contribution to the painting of new steel work.

There are a number of curing agents that can be used with these materials and each gives different properties, the three most widely used are;

1. Polymides for general purpose.
2. Polymines for increased chemical resistance.
3. Isocyanate for low temperature curing.

Coal tar epoxies These are a combination of epoxy resins and selected coal tars. Properties can vary, depending on the coal tar-to-epoxy ratio. The ideal compromise appears to be approximately 50/50. Coal tar epoxies are only available in black or dark brown. They cost less than straight epoxies and generally have better wetting properties, so they can be used on slightly less than perfect surface preparation. Similar recoating problems as for the two-pack epoxies.

Their best use is for water immersion, particularly seawater tidal situations, but unfortunately this very useful material is being increasingly phased out because coal tar contains carcinogens.

Two-pack polyurethanes Also called urethanes, these materials are similar to two-pack epoxies in that they can be formulated to provide different properties. They can be made into foams or soft, rubbery materials, as well as very hard, tough, abrasion-resistant coatings.

In comparison with epoxies, the correctly formulated urethane can possess considerably superior gloss retention and flexibility. They also form a film so hard and solvent resistant that they can be used as an anti-graffiti coating. The graffiti can be removed with solvent without damaging the urethane. Since these materials give off toxic fumes in a fire it is preferable that they are not used in confined spaces.

The paint is sensitive to moisture during storage and application but then becomes exceptionally water resistant. Its best use is for exterior exposure in an aggressive environment but where the maximum gloss and colour retention is required. It is preferable to apply the urethane as a finishing coat over epoxy undercoating and priming. During application of all urethanes the spray mist is harmful and fresh air masks must be worn and care taken particularly under confined conditions.

Moisture-cured urethanes These are the only paints in this class of materials that are single pack. The curing is provided by moisture from the atmosphere. This has the advantage that the material can tolerate a degree of

dampness in the atmosphere and on the surface to be coated. Its disadvantage is that the film thickness per coat is limited and that, once opened, all the container must be used immediately. Conversely, if the humidity is very low the cure may be lengthened or stopped.

It is claimed that the cured film has similar properties and durability to the two-pack urethane. It also is used as an anti-graffiti finish.

Polysiloxanes These are a product of one of the few new resin technologies. Composed of complex silicone chemistry and using a very stable silicone-oxygen link, they can be formed into a wide variety of products.

To-date the most widely used in an epoxy-silicone hybrid. This is a two-pack material developed as a true weatherable epoxy and therefore as an alternative to polyurethane. It has outstanding gloss and colour retention with good all round chemical resistance. At the moment it is expensive but does offer very high volume solids compared to other top-coats.

Waterborne coatings

There are four main types; water reducibles, latex and emulsions.

For any waterborne coating, water evaporation is required before the products form a film. High humidity will decrease the rate of water evaporation and thus increase the drying time. Rain shortly after application may wash the coating from the surface. They will must be stored and applied above freezing temperatures.

1. Water Solubles

These include alkyds treated to be water soluble. They dry by water evaporation and cure by auto-oxidative polymerization. Examples include, household paints and electro-coats.

Advantages

a. Ease of application and clean-up.
b. Limited VOC (solvent mostly water)

Disadvantages

a. Low gloss.
b. For household paints, long water susceptibility after application.

2. Water reducibles

Dry by water and solvent evaporation. Two pack types cure by cross-linking polymerization. Includes epoxies where the water acts as a diluent and reduces the need for strong solvents but does not dissolve the resin. Example uses include structural steel coating.

Advantages

a. Reduced VOC.
b. Relatively high flash point.

Disadvantages

a. Long water sensitivity after application.
b. Epoxies will not cure at low temperatures, induction and pot life times important.
c. Strong solvents may still cause lifting of previously aged coatings.
d. Limited immersion service.

3. Latex

May be a copolymer blend of polyvinyl acetate, polyvinyl chloride and acrylics. A solid phase dispersed into a liquid base. Example uses include interior and exterior (acrylic only) "emulsion paints". They dry by water evaporation and cure by coalescing.

Advantages

a. Ease of application and clean-up
b. Shorter water sensitivity period.

Disadvantages

a. Porous films (may be advantageous if a breathable film is required for concrete or masonry)
b. Dirt retention.
c. Poor chemical resistance.
d. Not suitable for water immersion.

4. Emulsion coatings

True emulsions, consisting of an immiscible liquid phase dispersed into another liquid phase. Examples are epoxy emulsions used on structural steel and asphaltics.

Advantages

a. Frequently applied satisfactorily with limited or no subsequent inspection.
b. Generally applied as the sole coating on wood or concrete.

Disadvantages

a. Relative humidity and temperatures conditions important during application.
b. Most two pack emulsions will not cure below 10C.

34.3.4 Heat-condensation coatings

Examples
Phenolic coatings
Epoxy phenolic coatings

General advantages

1. These materials have exceptional chemical and solvent resistance;
2. In the fully cured form they are odourless, tasteless and non-toxic;

3. They have excellent resistance to boiling water, acids, salt solutions, hydrogen sulphide and various petroleum products.

General disadvantages

1. These materials can only be cured at relatively high temperatures (typically, 130–300°C). Therefore the process is normally carried out at works. With the use of special reactors it can be accomplished on-site but the operation is difficult. In all cases the application is critical, and variations in temperature and cure time will result in different film-forming properties. The application should always be left to specialists.
2. The resins need careful storage (possibly under refrigeration) before application.

Comparison of coatings within this classification

Phenolic coatings Phenolic is reacted with formaldehyde under heat to form a completely insoluble material. They are usually applied in an alcohol solution by spray, dip or roller. During their curing they release water which must be removed. They have maximum chemical and solvent resistance but poor alkaline resistance.

Epoxy phenolic coatings These materials are also cured at relatively high temperatures and are made by the reaction of the epoxy resin with the phenolic resin. They are slightly less critical in application requirements, are less sensitive to curing conditions and can be applied in thicker coats. The best use for both these materials is as tank linings used for the storage or food products, drinks, etc. or for process plant, evaporators, etc. that contain boiling water.

34.3.5 100% Solids coatings

Examples

Coal tar enamel
Asphalt
Unsaturated polyesters, glass flake and fibre reinforced
Powder epoxies
Powder polyesters
Hot-applied solventless epoxies
Hot-applied solventless urethanes

General advantages

1. In general, exceptionally thick films, very fast curing
2. Can provide exceptional water and chemical resistance
3. They contain no solvents to pollute the atmosphere.

General disadvantages

1. Generally require specialist, skilled application techniques
2. Materials and application costs can be high, but for large surfaces the quick, thick single-coat application can make them cost effective
3. Cannot be repaired or recoated easily on-site. In some instances solvent-based versions are needed for repair and maintenance.

Comparison of coatings within this classification

Coal tar enamel This is derived from the coking of coal and is further distilled to produce coal tar pitches. It is used for hot application on-site. It will crack and craze if exposed to sunlight but has been employed successfully for over 50 years for the protection of underground or immersed structures. The main use is now for the exteriors of buried or immersed pipelines. Different types of enamel are available to give various degrees of heat resistance. It is now generally used for pipelines below 155 mm diameter.

Asphalt Asphalt is a naturally occurring mineral or as the residue from the distillation of asphaltic petroleum. It is less brittle and has better resistance to sunlight and temperature changes than coal tar enamel. Its water resistance is good but less than for coal tar enamel. It is not resistant to solvents or oils. It may crack at low temperatures and age at elevated ones. Like coal tar enamels, it is primarily black in colour and difficult to overcoat with other materials. Its main use is for the *in-situ* coating of roofs or above-ground steel structures.

Unsaturated polyesters The formation of the coating occurs *in situ* by the reaction between polyester resin and styrene, activated by a catalyst such as organic peroxide. The main use as coatings is in the formation of glass fibre or glass flake, reinforced plastics.

It has good resistance to acid, oils and oxidizing materials but poor resistance to alkalis. Application is difficult and hazardous and is generally a specialist operation.

Shrinkage on curing means that a high standard of visual cleanliness and an exceptionally coarse surface-profile is required on blast-cleaned steel. Its main use is for tank linings.

Powder epoxies Applied as powder either by electrostatic gun or fluidized bed, these materials must be cured at 200–250°C. The coating cures within a few seconds and is normally water quenched to control cure time. They have good resistance to water but will tend to chalk on outdoor exposure.

Normally a specialist works application, these materials are useful protective coatings for such items as cable trays and switch boxes. They are also used for the externals of pipelines.

Powder polyesters These are similar to powder epoxies but with superior resistance to weathering and less chemical and corrosion resistance. They are used mainly for outdoor decorative use on equipment, etc.

Solventless epoxies These use heat rather than solvent to reduce viscosity, and are generally applied by airless spray, which requires specialist skills. The films cure very rapidly and can be built up in one coat to at least 1000 microns. They need a very high standard of

surface preparation. The films have exceptional water and abrasion resistance, and are usually only economic for use with large structures (e.g. the external and internal surfaces of the Thames Barrier gates).

Solventless urethanes These are similar to solventless epoxies but can be applied in even thicker films without adhesion problems. They are considered to have better water and abrasion resistance than the epoxy but cost more and application is even more critical. Their main use would be for large areas requiring abrasion resistance.

34.3.6 Non-oxidizing coatings

Examples

Grease paint
Wax anti-corrosive compounds

General advantages

1. Cheap;
2. Easy to apply, even with areas of difficult access;
3. Surface preparation not critical;
4. Can be applied in relatively thick films.

General disadvantage

The coating remains relatively soft and flexible, and is not suitable for areas where people may walk or touch the surface. The best use is for steelwork in enclosed areas or with difficult access where surface preparation and application are not easy.

34.3.7 Heat-resistant coatings

Examples

Modified oleo-resinous binder with aluminium pigment
Oleo-resinous binder with zinc dust and graphite pigments
Modified or pure silicone resin with aluminium
Zinc silicate

General requirements

In general, the requirements of heat resistance limit film thickness and therefore corrosion resistance. This is a particular problem when surfaces fluctuate between hot and cold. Coatings should be selected carefully, depending on the exact maximum temperature that will be experienced. Wherever possible, conventional materials should be used. The majority of air-oxidation coatings will be satisfactory up to 95°C and epoxies up to 175°C continuous dry heat.

Comparison of coatings within the classification

Modified oleo-resinous binder with aluminium pigment These materials are sometimes called general-purpose aluminium paint. They are suitable for use up to 200°C but, for corrosion resistance, needs to be applied over a corrosion-resistant primer such as zinc silicate.

Oleo-resinous binder with zinc dust and graphite pigments Generally called zinc dust graphite paint, this is a relatively cheap material that can resist temperatures in the range of 200–300°C, but regular maintenance repainting will be required.

Modified or pure silicone resin with aluminium These are silicone-based aluminium paints that can be used for temperatures between 260° and 540°C. They require a minimum temperature for curing (usually about 260°C) and in general have poor corrosion and weather resistance.

Zinc silicate This material has good corrosion resistance and can withstand temperatures up to 540°C, particularly when overcoated with silicone-based aluminium. The zinc silicate requires a high standard of surface preparation before application.

34.3.8 Coatings for concrete

Examples

Emulsion paints
Chlorinated rubber
Vinyls
Two-pack epoxy
Water-based epoxy

General requirements

Concrete may be coated for:

1. Decoration;
2. Waterproofing: correctly formed concrete will not transmit liquid water but will always remain permeable to moisture vapour;
3. Protection from freeze-thaw cycles: because concrete absorbs moisture it is very susceptible to damage by water freezing. The physical forces of the ice are greater than the concrete's strength and spalling and shattering occurs. Coatings can help to keep the concrete as dry as possible but they also must withstand the freeze-thaw conditions.
4. Protection for the reinforcing steel: high-performance coatings can help to prevent chloride ions, etc. permeating to the reinforcing steel. However, care must be taken that the use of relatively impermeable coatings does not trap water and make the situation worse. There is a growing tendency to coat the reinforcing bars themselves with powder epoxies.
5. Decontamination: since concrete is a porous material it can absorb oil, rusty water, etc. and coatings can reduce the absorption.

Comparison of coatings within the classification

Emulsion paints These materials are water based and cure by coalescence as the water evaporates. Films formed in this manner have sufficient porosity to allow water vapour to escape from the concrete but at the same time to retard the entry of water. The composition is

typically vinyl acrylic (e.g. a combination of vinyl and acrylic resin). The acrylic portion has superior weathering properties. Emulsions are mainly used for decoration.

Chlorinated rubber See Section 34.3.2. This is used for decoration but also provides a relatively impermeable coating. Its best use is for concrete surfaces that have to be kept clean by regular washing.

Vinyls Section 34.3.2. These have been used on concrete for a variety of situations. Thinned down, they have good penetration of the surface and provide a good base for subsequent applications of heavily bodied, thick viscous vinyl coatings. However, since they dry quickly but contain a high proportion of solvent, care must be taken to avoid solvent entrapment in the pores of the concrete.

Two-pack epoxy Section 34.3.3. These are widely used to give the maximum protection to concrete surfaces, floors and walls. They can be applied as relatively thin coatings by spray or as thick epoxy surfaces applied by trowel. In all cases the application must be preceded by adequate surface preparation (see Section 34.4.3). To allow maximum penetration into the concrete the first coat must have a low viscosity. Coal tar epoxies are used where protection is the main requirement.

Water-based epoxy These are sometimes referred to as acrylic epoxies. They are generally inferior to solvent-based epoxies in durability and resistance but have less toxic hazards and low solvent odour.

34.3.9 Coatings for concrete floors

Examples
Seals
Thin coating
Trowelled coatings
Self-levelling screeds

General requirements

An important requirement for all floor coatings is adequate surface preparation (see Section 34.4.3). In general, abrasion resistance is proportional to thickness and the thick single-colour epoxy screeds will give the maximum life before wear is obvious. Thin coatings will need regular maintenance but will be considerably cheaper, and this must be weighed against ease of access for any particular situation.

Anti-slip properties are generally required. Nearly all surfaces have poor slip resistance when wet. Self-levelling finishes tend to be glossier than other types, and this also has a psychological effect. Some surfaces with good initial slip resistance can become dangerous after heavy wear over a long period and should be inspected regularly. Surfaces with the highest slip resistance, particularly if this involves the incorporation of coarse aggregate, will also retain the most dirt and can be costly and difficult to clean.

Comparison of coatings within the classification
Seals Seals are normally transparent, quick-drying, highly penetrating materials that are used to stop cement dusting and contamination by oils, etc. The moisture-cured urethanes are particularly suitable, since they penetrate to produce a hard-wearing surface. However, if safety factors preclude their use there are also epoxy and even oleo-resinous products available.

Thin coatings These pigmented materials, commonly known as floor paints, are often based on chlorinated rubber (see Section 34.3.2) or epoxy ester (see Section 34.3.1). They have limited life in heavy traffic but are easy to apply.

Trowelled coatings There are a number of proprietary products available but the majority are based on epoxy resins and applied at thicknesses ranging from 0.5 to 5 mm, depending on exposure requirements.

Self-levelling These are generally based on solvent-free epoxy and there are a number of proprietary products available. Generally, they are 3–8 mm thick, but if the base floor is too rough it is advisable to first level this with a cement/resin screed.

34.3.10 Coatings for wood

Examples

Oleo-resinous primers plus alkyd finish
Aluminium-based primer plus alkyd finish
Emulsion-based primer plus alkyd finish
Wood stains

General requirements

Wood is painted in order to preserve from decay, to minimize changes in moisture content that lead to distortion, and for decoration. It is a waste of time and effort to apply expensive paints or stains to exterior wood not previously treated with preservative. Preservatives are designed to penetrate the timber to protect against microorganisms and insect attack. Modern preservatives can be overcoated with paint without problems.

Oleo-resinous primers plus alkyd finish These are normally used for soft wood and should be designed to be flexible and smooth for subsequent paint.

Aluminium-based primer plus alkyd finish The binder for these primers is normally oleo-resinous but the pigmentation is aluminium flake. This type is preferred for hardwoods and softwoods where knots or resinous areas predominate. They do not give such a smooth surface as primers without aluminium.

Emulsion-based primer plus alkyd finish These are based on acrylic resin dispersions and have the advantage of a rapid rate of drying. They generally have excellent

adhesion and flexibility but lack the sealing properties of aluminium primers.

Wood stains The problem with normal paint systems on wood is that if moisture penetration occurs (e.g. in the untreated end-grain) then the impermeability of the paint causes blistering, cracking and flaking. New developments with translucent finishes for wood incorporate pigments which deflect ultraviolet but do not obscure the wood grain. They are also designed to permit moisture movement but contain wax additives which shed surface water. They also degrade by gradual erosion rather than cracking and flaking. If the appearance is acceptable these form a useful, economic answer to wood protection.

34.3.11 Road and floor markings

Examples

Road paints
Thermoplastic road-marking materials

General requirements

Road markers require ease of application and very quick drying.

Road paints These are normally chlorinated rubber alkyds and are easy to apply but are inherently less durable than the thermoplastic materials.

Thermoplastic road-marking materials These require special application apparatus. Although they are thicker and last longer than the road paints their tendency to discolour may cancel this advantage.

34.3.12 Anti-condensation paints

General requirements

These materials are designed to reduce water from condensation dripping on equipment, etc. They often incorporate particles of cork so that water is absorbed. They are generally thick films to provide some insulation and have a rough textured surface finish to increase the surface area and encourage water evaporation. In general, physical methods of prevention such as adequate ventilation, etc. are more effective.

34.4 Surface preparation and priming

34.4.1 Structural steel (thickness greater than 5 mm)

Abrasive blasting Abrasive blasting is generally the most suitable and reliable method of obtaining a visually clean surface and a satisfactory surface profile. Dry abrasive blast cleaning should be used on new steelwork where the main contaminant is millscale. For heavily rusted and pitted steelwork, increased durability can be obtained by the use of wet abrasive blasting or ultra high pressure water jetting (the latter operating above 170 MPa) which should remove the invisible but potentially destructive and corrosive soluble iron corrosion products that form at the bottom of corrosion pits. Their removal will considerably increase long term durability of any coating system.

A wide range of International Standards and identical British Standards: "Preparation of steel substrates before application of paints and related products" now exists. The British Standard is BS7079 and is composed of six parts. Parts A are the visual standards of cleanliness. Parts B are the standards concerned with various tests to determine any chemical contamination, i.e. chlorides, ferrous salts etc on the visually clean surfaces, Part C give the methods of determining surface profile, Parts D are descriptions of the different methods of surface preparation, Parts E give detailed specifications for all types of metallic abrasive and Parts F for all types of non-metallic abrasive.

Hand or mechanical tool cleaning This method is generally not capable of achieving a uniform standard of cleanliness on structural steel. It is not effective in removing intact millscale or corrosion products from pitted surfaces. The durability of subsequent coats is therefore variable and unpredictable, and depends on the thoroughness of the operation and the exact nature of the contaminants left on the surface. The method should be confined to non-aggressive environments or where short-term durability is economically acceptable.

Acid pickling This is only suitable for works application and is only economically viable for repetitive cleaning of relatively small simply-shaped items, such as tank plate. The lower profile achieved by this method may not be suitable for high-performance coatings.

Priming Priming can be carried out before or after fabrication.

Before fabrication This has economic advantages and cleaning can be of a higher standard and before any destructive corrosion has occurred. Pre-fabrication primers need to be extremely quick drying (e.g. within minutes) to allow handling and ensure coverage of the blast profile peaks without attenuation.

Normally, the specifier will have to accept the type and make of primer used by a particular fabricator because, unless it is a major job, it is difficult and expensive to change primers on automatic plant. Many fabricators now use a zinc phosphate two-pack epoxy primer, which is a sound base for any subsequent paint system.

These primers are generally capable of being welded through, and although they are based on two-pack epoxy they are so formulated that the cure is delayed, and they remain overcoatable for at least one year.

After fabrication If a structure consists of a large area of welds it is inadvisable to carry out pre-fabrication blasting and then prepare the weld areas to a much lower standard on site. In those cases the structure should be blast cleaned after fabrication. This has the advantages that a thicker primer can be used and also that the entire

paint system can be completed without delay and possible contamination between primer and top coats.

34.4.2 Zinc metal coatings

Hot-dip galvanizing (new)

T-wash pretreatment This is an acid-mordant solution which turns the surface black when correctly treated. The majority of paint manufacturers can supply T-wash or their own similar proprietary product. It must be applied to zinc in a bright condition without corrosion products on its surface.

Sweep blast or abrading This is a suitable method before application of thick two-pack materials but care is required not to remove too much zinc coating.

Hot-dip galvanizing (weathered)

Weathered zinc surfaces that have lost their initial bright appearance and which are to be painted with thin paint systems need only to have dirt and zinc-corrosion products removed by brushing. For high-performance coatings it would be advisable to remove zinc-corrosion products by abrading or sweep blasting.

Sherardizing No special treatment is required other than the removal of any zinc-corrosion products, dirt or oil, etc.

Zinc or aluminium metal spray

Sprayed metal coatings are porous and should be sealed after application by applying a sealer coat (i.e. a thin penetrating coat).

Oil-based systems should not be used. Sealed metal spray coatings can have excellent durability without overcoating with paint.

34.4.3 Concrete

General requirements

Surface preparation of concrete consists mainly of removing laitence, form oils and air pockets. Laitence is the fine cement powder that floats to the surface of concrete when it is placed. Coatings applied over such a powdery, weak layer will lose adhesion. Form oils are used for the easy stripping of forms or shuttering. Their presence will also cause loss of adhesion of subsequent coatings. Forms should be coated with non-migratory hard coatings and the use of oils or waxes prohibited.

Air pockets or bubbles are left on the surface of all concrete. Good vibration and placing techniques will reduce their number but not eliminate them entirely. Many air pockets have a small opening on the surface in relation to their size. Paints will not penetrate into such holes, with the result that air or solvent is trapped and subsequent expansion will cause the coating to blister. In addition, some air pockets are covered with a thin layer of cement which also has no strength and will cause loss of adhesion.

The following alternative methods of surface preparation can be used for new concrete.

Dry abrasive cleaning This should be carried out using a finer abrasive, lower pressure and a faster movement across the surface with the blast nozzle further from the work than for blast cleaning steel. It provides a roughened, irregular surface with the laitence removed and all holes and voids opened up so they can be more easily sealed.

Wet abrasive cleaning As for dry abrasive cleaning, but with the advantage that there is reduced dust nuisance.

High-pressure water jetting This is an effective treatment on eroded and weak surfaces but will not open up the sub-surface voids or pockets or provide a surface profile on dense concrete.

Acid etching Hydrochloric acid (10–15%) is generally used. If applied correctly it will remove laitence and provide an adequate surface for adhesion. It will not open up air pockets and voids and is difficult and hazardous to handle and apply. It is most suitable for use on floors.

Hand or power tools These are generally more time consuming and costly than abrasive cleaning and can give variable results.

34.5 Specifications

The main functions of a painting specification, whether for new or maintenance work, are as follows:

1. To state the means by which the required life of the coating is to be achieved. This includes surface-preparation standards, paints and systems, application, storage, handling and transport, quality control;
2. To service as a basis for accurate costing;
3. To provide a basis for resolving disputes.

34.6 Economics

The greatest problem in making an economic assessment regarding coatings is the prediction of the coating life. With paint coatings this is particularly difficult, because there are many stages to completion of the coating process and many opportunities in practice for problems to arise. Furthermore, if there is poor workmanship at the outset and this is not detected, the potential life may fall short of expectations by a very wide margin.

However, some companies consider that they have sufficient experience of their requirements to use computer programs to provide economic assessments of candidate protective systems. The following summarizes typical steps to be taken.

1. Select suitable systems based on technical requirements.
2. Estimate life to first maintenance of each system.
3. Prepare sound specifications for each system.

4. Estimate maintenance costs at present values for each system (e.g. by using Net Present Value).
5. Select the most economic system if the difference in costs is greater than 10%. Otherwise, select the system for which the most experience is available.

If at the end of the exercise the cheapest system is beyond the budget available then either the budget must be increased or changes in the initial protection will be required. Whenever possible, the level of surface preparation should not be lowered, since if at a later date more money is available the protective coating can be built up but the surface cannot be re-prepared.

34.7 Painting inspection

The potential durability of a coating system can be realized only if it is applied to a suitably prepared surface, in the correct manner under correct conditions. Painting differs from any other industrial processes in that it is susceptible to operator abuse or adverse environmental influences throughout all stages of the work.

Furthermore, it is generally difficult to deduce from examination of the completed work what has occurred previously.

Many engineers appreciate that painting, which should be a minor part of an engineering project, can assume major proportions if there are problems or premature failures. For any painting work for which premature failure is economically or practically unacceptable it is advisable to use full-time, qualified paint inspection. Note that part-time inspection, or visit inspection, can in some ways be worse than no inspection at all.

The Institute of Corrosion has a scheme for the certification of painting inspectors. The following are their typical duties:

1. Measure, at regular intervals, the air temperature, steel temperature, relative humidity and dewpoint in the area where blast cleaning or painting is to take place.
2. Decide whether, in the light of these measurements, the ambient conditions are within the specification and therefore whether blast cleaning or painting can proceed.
3. In outdoor conditions assess the way in which the weather is likely to change and decide how this may affect the progress of the job.
4. Examine the abrasive to be used in the blasting process and record the name of the manufacturer and the type and grade of the abrasive.
5. Check that the abrasive is not contaminated with moisture, dirt, spent abrasive, etc., that the blasting equipment can deliver the abrasive at an adequate pressure and that the airlines are fitted with a water trap.
6. Check that the freshly blast-cleaned surface is of the specified standard (e.g. Sa2 ½, Sa3, etc.) at all points.
7. Measure the surface profile of the freshly blast-cleaned surface and ensure that it is within specification.
8. Check freshly blasted surface for steel imperfections, laminations, weld spatter, etc. and ensure that any necessary metal dressing is carried out.
9. Carry out chemical test on the visually clean surface to check for the presence of invisible corrosion salts etc.
10. Ensure that the newly blast-cleaned surface is primed within the specified overcoating time.
11. Record the name of the paint manufacturer, the manufacturer's description of each paint used in the system, the reference number and the batch number.
12. Ensure that the paints are applied in the correct sequence, by the correct method and that they are of the correct colour.
13. Ensure that, where possible, paint with the same batch number is used on any particularly identifiable unit of the total job.
14. Ensure that the correct overcoating times are observed.
15. Ensure that all paints, particularly two-pack, are thoroughly mixed in accordance with the manufacturer's instructions.
16. Ensure that the pot life and shelf life of paints are not exceeded.
17. Ensure that the applicator takes wet-film thicknesses for each coat applied and confirm that they are such as to yield the specified dry-film thicknesses.
18. Measure the dry-film thickness of each coat over a representative area and ensure that the specified film thickness has been attained.
19. Ensure that each coat has been evenly applied and is free from runs, sags, drips and other surface defects.
20. In the event of discovering any paint defects, mark them up and ensure that the necessary remedial steps are taken.
21. When required, perform adhesion tests, curing tests or tests for surface contamination.
22. Ensure that all blasting and painting operations are carried out without contravention of safety regulations.
23. Report on manning levels and time lost due to weather, mechanical breakdowns, labour disputes, etc.
24. Submit full inspection reports daily and/or weekly, as required.

34.8 Factors influencing the selection of coating systems

34.8.1 Environmental conditions

For aggressive conditions only highly resistant coatings can be considered; for milder environments, virtually the whole range of coatings can be used.

34.8.2 Access for maintenance

The cost of maintenance may be greatly influenced by the disruption caused by the access requirements. This involves not only direct costs such as scaffolding but indirect ones such as disruption of a process plant,

closure of roads, protection of plant and equipment in the vicinity, etc.

34.8.3 Maintenance requirements

With the correct surface preparation and application, many modern paint systems are now capable of maintenance free lives in excess of 15 years. A 1998 report from the Steel Construction Institute on the actual performance of protective coating systems for major bridge steelwork concluded that the majority of existing structures are now undergoing major maintenance at intervals in excess of twenty years.

34.8.4 Facilities for coating

Suitable skilled labour may not be available, at a particular site, to use complicated equipment (e.g. hot airless spray). On a foreign site or in remote areas even conventional equipment may be unfamiliar or unobtainable.

34.8.5 Handling, storage and transport

The choice of coating will be influenced by the need to avoid damage during handling. Where considerable handling is involved this may be a major factor.

34.8.6 Application properties

Many of the modern, high-performance coatings require a high degree of skill in application and are considerably less tolerant than older, conventional materials. Caution is required in choosing coatings when there is no record of sound work by contractors.

34.8.7 Experience of coating performance

New types of coating are regularly developed and marketed. Before selecting such coatings the specifier should be satisfied that the test results and practical experience is sound.

34.8.8 Special requirements

Sometimes the type of coating is determined by special requirements such as abrasion or heat resistance. The coating may have to withstand specific chemicals or solvents. All coatings have to be a compromise of properties. A gain in one may be a loss in another.

34.8.9 Importance of the structure

The importance of the structure in both technical and aesthetic aspects is an obvious factor to be taken into account.

For important structures there are now insurance backed guarantee schemes available in Europe and the U.K.

34.8.10 Costs

Cost is always a primary factor. However, the actual cost of paint is generally a small percentage of the total.

34.8.11 Other factors

Other factors may include: colour, toxicity and safety, temperature restrictions, ability to cure at service temperature, resistance to bacterial effects, shelf life and pot life of the paints.

34.8.12 Limited choice of coating systems

In practice, the selection of coatings is often the opposite to what might be expected. There are a multitude of proprietary materials but the choice of generic types is limited. Section 34.3 of this chapter is designed to illustrate the basic properties of these generic types as a preliminary guide to selection by the engineer. The specifier tends to examine the available materials to see if they will fit the requirements, rather than vice versa.

34.9 Sources of advice

The subject of paints and coatings is complicated, covers a large number of uses and conditions. There are few, if any, publications that cover all aspects. However, the subject of the protection of iron and steel structures is covered, for example in the new ISO Codes of Practice that replace BS 5493. ISO 12944 is in eight parts. Part 1 General Introduction, Part 2 Classification of Environments, Part 3 Design Considerations, Part 4 Types of Surface and Surface Preparation, Part 5 Protective Paint Systems, Part 6 Laboratory Performance Test Methods, Part 7 Execution and Supervision of Paint Work, Part 8 Development of Specifications for New Work and Maintenance.

The technical service departments of paint manufacturers are a valuable source of free information on their own products. For independent advice on new materials, specifications not tied to proprietary types and failure investigations, there are independent consultants and test laboratories that will generally assist on a fee-paying basis. Suitable names can be obtained from the Institute of Corrosion, 4 Leck House, Lake Street, Leighton Buzzard, Beds. LU7 8TQ.

34.10 Further reading

Bayliss, D.A. and Deacon, D.H., *Steelwork Corrosion Protection*, 2nd edn, Spon Press (2002)

Department of Trade and Industry, Committee on Corrosion Guides

No. 3: *Economics*
No. 6: *Temporary protection*
No. 12: *Paint for the protection of structural steelwork*
No. 13: *Surface preparation for painting*
No. 16: *Engineering coatings – their applications and properties*

Durability of steel structures, CONSTRADO

Painting steelwork, CIRIA Report 93

Steel Construction Institute. Technical report 241. Durability of Steel Bridges. A survey of the performance of protective coatings.

35 Maintenance

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35.1 Introduction

The implementation of a programme for the management of a company's assets has never been so important now that we are more involved with the European market and, indeed, will be an integral part from 1992. Chief engineers, group engineers, works engineers, building services managers, premises managers – the list is never ending with respect to job title and designation. While the individual's title may change, the responsibilities rarely alter, in that, it is from the person in those positions upon whom the employer depends so much. Building premises, factories, production equipment, facilities, service utilities and local services must be maintained in the most sound, safe and economical way to ensure that the client or user is provided with the appropriate goods, materials and working environment, as all these fall within the remit of the engineering maintenance department.

In a constantly changing work environment, with the introduction of new techniques, work practices and legislation the engineering department must ensure that they maintain an adequate level of continuous educational training. Major changes include the wide implementation in construction, installation and service fields of BS 5750, BS EN ISO 9000 Series Quality assurance, the introduction of more specific legislation, codes of practice, guidance notes for health and safety, and the standards being introduced by such bodies as the British Standards Institute. All are to improve the end product, service, etc., but they place an additional demand on existing resources that cannot be ignored. Therefore in an endeavor to minimize these demands, and in so doing to maximize the benefits from available resources, a 'planned' maintenance programme should be implemented.

35.2 A 'planned' maintenance programme

The development of any programme must take into consideration the maintenance tasks that need be carried out and the resources available, thereby ensuring that both product and safety standards are met. It follows that operational demands, whether they be from a service utility installation, a production line, a mainframe computer or an office environment, will play a major part in reaching the decision as to what type of maintenance programme requires implementation.

Plant and equipment that provide a service or is required to operate for 24 hours a day, 7 days a week, presents a different proposition to the maintenance programming requirements of, say a heating pump with a standby, which is required for a heating installation in an office with a set number of working hours from Monday to Friday. Alternative methods of maintenance programming may require the planner to allow for total replacement on plant failure or have available replacement units, so that when an item of plant or equipment fails, it is removed and a replacement installed.

The ideal method would be that all plant or equipment units have a duplicate standby, which on failure would automatically be brought into service. This is satisfactory when considering small, less expensive units, which are installed to ensure that the services they are providing are not disrupted (this could also include auxiliary items on major plant and equipment). However, due to the capital costs of the major unit itself, it would be difficult to establish adequate economic grounds to duplicate these items to the same degree (although this may be done in a computer environment due to the high costs involved in downtime).

'Planned' maintenance programmes are an essential weapon in a department's armoury to ensure that the services it is called on in meeting its responsibilities are fully met. The traditional method of working from pieces of paper or individuals' 'own' notebooks as to when maintenance is to be carried out or when the insurance representative is due to visit to carry out an inspection are no longer satisfactory. This is especially the case when the skilled resources necessary to carry out the work are more difficult to obtain.

It is therefore essential that a planned maintenance programme be established, which can encompass all (or elements of) the different maintenance methods of establishing the frequency and/or work to be carried out. This programming requires skills that, in most instances, can have only been gained by experience in the field of maintenance and operation. Operation must play an important part in the programming. If the planned maintenance programme is prepared without due consideration to the demands placed on the operation element the planned maintenance programme would probably collapse when the plant's equipment could not be released (i.e. switched off) when the maintenance technician arrived at the plant to carry out his duties indicated on his work docket.

Maintenance procedures that should be considered when preparing the planned maintenance programme include:

1. Carrying out repairs needed when plant or equipment breaks down;
2. Predicting, from a history of breakdowns, the life expectancy of parts, bearings, etc., the tasks to be carried out and the frequency to be established;
3. Checking the condition throughout the plant of equipment, its running hours, readings of different responses (e.g. vibration, temperatures, current, etc.);
4. Monitoring the operating cycle and, where appropriate, seasonal shutdowns of plant, equipment (e.g. production process, 24-hour duty, etc.).

35.2.1 Maintenance systems

The benefits to be accrued from the implementation of a programme of planned maintenance can be found in the efficient and economical operation of the plant and equipment and the utilization of resources (i.e. plant and equipment and manpower) while also maintaining a sound standard of safe working and environmental conditions for operators, other occupants and employees within the workplace. Maintenance systems vary, depending on the location of the plant and equipment and/or company policy. Systems can range from the complete maintenance of plant and equipment using all available methods to

their replacement on failure. To meet the company's requirements it is then necessary to decide on the maintenance system that provides the most satisfactory benefits overall.

The most commonly maintenance systems in use are: planned, preventive, scheduled, corrective and emergency.

Planned maintenance is work having benefited from information issued by manufacturers and suppliers, the experience and knowledge of the service department staff, and reports and records from previous service visits.

Preventive maintenance is work to be carried out at a specific frequency as indicated by potential failures or known reduction in efficiency of the plant and equipment, thereby avoiding failures or a decrease in performance.

Scheduled maintenance is work based on known information, such as number of operations, hours run, mileage, etc., and can therefore be carried out at a predetermined time interval.

Corrective maintenance is work carried out following the failure of the plant and equipment, and is so designed to return the component to its normal operating condition.

Emergency maintenance is that work which is required to be actioned without delay due to a failure of a component which, if not implemented, would lead to further failures or even permanent damage, resulting in the total loss of the plant and equipment. Plant and equipment in such a condition may also be dangerous to personnel.

As planned maintenance encompasses all types covered within the preventive or scheduled systems, this can be examined in more detail. In preparing a planned maintenance system all the available sources of information should be used. These include manufacturers' and suppliers' literature, trade associations, professional institutions, knowledge and experience from within the department and history and feedback from previous work for the specific type of equipment. Condition monitoring, life-cycle costing and predictive maintenance procedures should all be considered during the preparation of the planned maintenance system.

Planned maintenance systems should not be complicated. The simpler the system is to meet the requirements of the department and company, the more likelihood of it being used with satisfactory results. This aspect is of the greatest importance when, due to the size of the organization, engineers may be transferred from one department to another to gain a greater knowledge of the total company. This may cause the implemented planned maintenance system to fail or not be used to its full effect, due to the incoming engineer not understanding it fully.

In preparing a planned maintenance system the opportunity should be taken to involve the whole department. This can be achieved by using the operatives who will subsequently action the work to carry out the initial survey of plant and equipment.

35.3 A manual planned maintenance system

The planned maintenance programme forms the basis of a system whereby an in-house department may prepare and implement its own maintenance programme or introduce a trial system along similar lines. This would be prior to seeking the assistance of a consultant to provide guidance on the system that would satisfy the demands placed on the department by others and yet remain under the department's control. Irrespective of whether it is a manual or a computer system that is introduced, the elements of its composition vary little. Depending on the reports required from the implementation planned maintenance programme, the more satisfactory method of obtaining this result, both in quantity and quality of information, is by running the programme on a computer.

To assist engineers to implement a manual planned maintenance system that can be of benefit to the department it is important that a programme be set with respect to the system's implementation. Items that should be considered are:

1. Departments to be covered;
2. Plant and equipment to be included;
3. Technician and craftsmen trades available;
4. Person responsible for preparation and implementation of the system;
5. Time scale for preparation and implementation;
6. Administrative support.

It should be noted that initial interest in the preparation and implementation of planned maintenance systems can gradually decrease if only one person (preferably an experienced engineer) is given the responsibility to ensure that the proposal is carried out to its satisfactory conclusion. It is essential that the nominated person is given adequate support when necessary, to ensure that the planned maintenance system's introduction into the working operation of the department meets with success.

A suitable planned maintenance system, irrespective of the location or type of business, is complied from a number of standard elements (see the appendix at the end of this chapter):

1. Asset register;
2. Maintenance and repair record;
3. Technician and craftsmen guidance notes;
4. Planning schedule;
5. Week tasks;
6. Work dockets;
7. Year visual aid plan.

35.3.1 Asset register

Each item of plant and equipment is allocated a specific asset number. This number can be either for a complete boiler (with associated equipment) or a specific asset number for the boiler and individual asset numbers for the associated equipment. It is advisable to restrict this numbering sequence to a minimum while ensuring that it meets the specific needs of the company and location. Care must be exercised in determining the asset numbering during this manual phase if it is envisaged that, on completing a satisfactory trial period, the planned maintenance system will be transferred onto a computer.

To assist in the numbering of the assets, each type of plant and equipment can be given a predetermined plant

code reference number. In this case, the boiler and all its associated equipment are given the same asset number. The asset number is built up from certain elements, e.g.:

Location: Plant Code: Plant/equipment number

e.g.

Plant room 1: Boiler: No. 1 Boiler = PR1-01-01

Pump units, including valves, gauges, etc., are classified as individual assets. To enable the asset number to signify the different process that the pump is serving, the Plant Code 05 is suffixed, e.g.:

Roof Plant Room: Heating Circulating Pump: No. 1

= RPR-05/02-01

(02 indicates that the pump is installed in the heating system).

Items of equipment such as emergency lights may be grouped as one asset, supported by a checklist, which details the numbers, types and locations of the individual units in a predetermined area, e.g.:

First Floor: Emergency Lights = F1-34-01

(01 indicates it is No. 1 in the series of emergency lights assets). General area services such as lighting, heating, hot and cold water and air conditioning can be registered in a way similar to that of emergency lights.

In designing the asset register format for the specific location items such as manufacturer/supplier, purchase price and date, order no., cost code, function, parts/spares, guidance note reference and insurance inspections should be catered for. While carrying out the survey for the asset register, all the information found on plant and equipment nameplates should be recorded as, during their life, these tend to be lost or painted over.

To simplify this task it is an advantage if there is a set format prepared on the survey forms for specific types of plant and equipment. This enables the surveyor to enter the relevant information against the appropriate elements (e.g. manufacturer; volts; amps; bearings; etc.).

35.3.2 Maintenance and repair record

This is designed to record *all* work carried out and parts fitted on each asset item of plant and equipment. Service visits by contractors and insurance inspections are also entered. This record, which provides the history of the asset, may either be placed on the reverse of the asset record (thereby ensuring that all relevant information on a specific asset can be found in one place) or it may be an individual assets record form inserted within the asset register, next to the specific asset record.

To reduce the amount of information entered in the record, predetermined work of a planned maintenance nature can be entered in code form, while additional work or breakdowns may be more fully detailed.

As the maintenance and repair record indicates the cost of maintenance for the specific item of plant and equipment, a simple system may be used to provide recognition of the different methods by which the work has been carried out, e.g.

Planned maintenance work is entered in *black* pen.
Planned or corrective work is entered in *blue*.
Emergencies (i.e. breakdowns) are entered in *red*.

From this method of entry the engineer can observe at a glance if the planned maintenance programme is effective with respect to corrective work or emergencies. Further examination of the operation of the asset and its records are necessary in determining if the frequency of planned maintenance is correct or whether the plant and equipment should be replaced.

35.3.3 Guidance notes

The guidance notes can be produced either as a composite handbook containing task instructions for all types of plant and equipment for each trade group, or as specific task/advice notes for each asset of the service requirements of the plant equipment. When used, the handbook method provides the necessary work instructions for all similar types of plant and equipment throughout the location. This method of operation reduces the number of task/advice notes issued and therefore the system's work load, as well as the demands placed on the administration of the system. Either method eliminates the requirement of entering work instructions, etc. on the work docket/advice notes before they are issued.

The handbook can be prepared either for a specific trade or for all the trades involved in the maintenance of the plant and equipment. Its contents are as follows:

1. *Health and Safety*: Stresses the importance of carrying out the work in a safe and responsible manner.
2. *Introduction*: Details how the handbook contents and the individual's responsibility in the application of his skills are to be implemented.
3. *Plant Code, Frequency of Services and Work Tasks*: Details the work to be carried out, and at what frequency, as indicated by the instruction on the work docket.
4. *Plant Code*: Lists the plant codes for the plant and equipment covered by the handbook, prefixed by the appropriate trade reference (e.g. Mechanical Fitter = M).

The handbook is designed in an A5 loose-leaf format so that additional entries and amendments can be made as and when relevant.

To enable the maximum input and experience of the craftsmen to be introduced into the system the pages of the handbook should not be encapsulated thereby enabling the craftsman to enter additional information and comments that could increase the performance of the plant and equipment as well as amended instructions in the guidance notes. These amendments can then be issued to all staff in a similar trade.

35.3.4 Planning schedule

It is at this stage in the preparation of the planned maintenance that the engineer's knowledge and experience of maintenance is essential. In preparing the planned maintenance schedule it may be found that information on maintenance received from the manufacturer and supplier is no longer available. Technicians' and craftsmens' knowledge can play a major role in this planning stage.

Experience indicates that when preparing the planning schedule this should be carried out for each trade group. Prior to entering any asset detail on the planning schedule, items such as holiday periods and seasonal or shutdown programmes should be indicated. This can be done by the use of highlighter pens on the calendar weeks that require specific attention to loading of the relevant work tasks.

In scheduling the assets and work tasks to be carried out it is recommended that the plant room and department that require the greatest resources (i.e. man-hours) should be entered on the planning schedule first. The scheduling for each item of plant and equipment follows the same pattern in that the location (e.g. boiler-house) is entered as a heading, then the assets and their asset numbers are entered for each specified location.

Planning the frequency, work tasks and man-hours for each asset then follows. Choose the week in which the least-frequency service is to be undertaken (e.g. yearly; enter a 'Y/'). Other frequencies can then be entered (e.g. quarterly, 'Q/'; monthly, 'M/'). To complete the planning scheduled for the specific asset the hours required to carry out the work at the nominated frequencies are then entered (e.g. 'Y/12'; 'Q/4'; 'M/1', etc.). (*Note*: It is recommended that this scheduling be done in pencil so that amendments can be easily made.)

Plant and equipment that require a service on completion of a certain specified period of 'hours' may, through experience, be catered for on a fixed frequency basis. If employed, this method avoids the need to record running hours (or, in the case of transport, mileage) on a daily or weekly basis to schedule the relevant planned maintenance. If it is essential that the maintenance of the plant and equipment be carried out on the completion of a certain number of operating hours or mileage, then this must be allowed for in the allocated work hours of the relevant trade group.

Peaks and troughs in the man-hours allocated weekly for planned maintenance can be avoided if hours entered are added up for each week after a number of assets have been scheduled. Treating each plant room or department in this way provides the number of man-hours required for the respective plant room and/or department. All assets to be covered by the planned maintenance system are scheduled in the same format, thereby providing the engineer responsible for allocating the work tasks with total man-hours for each trade group.

There are two methods of entering man-hours:

1. The actual hours necessary to carry out the planned maintenance work task;
2. The 'total' hours to complete the planned maintenance work task (including non-productive hours). Non-productive hours would include such items as collecting spares, tea breaks, discussions, etc.

The planned maintenance system most commonly used is that indicated in (2), whereas the method of calculating the hours as in (1) is preferred if there is a productivity scheme in operation.

Service contractors' visits can also be indicated in the planning schedule (with 'C' for contractors or another symbol indicating a different contractor). To highlight different grades of service visits (e.g. yearly) 'Y/C' can be entered.

A major benefit of carrying out this planning schedule phase for all the plant and equipment is that the numbers of each trade required are known. Also, having carried out the exercise for all plant and equipment, if the decision is to be made as to which is to be covered by the scheme or contracted out, a complete picture of the total planned maintenance requirements for the department/company is available.

35.3.5 Week tasks

The information required to compile this form is obtained from the planning schedule. To minimize 'administrative' tasks in preparing the work dockets the information contained on the week task forms is presented in a format that enables that information to be easily transferred onto the work dockets, e.g.:

Location/Area: Plant/Equipment: Plant/Equipment No.:

Job Code: Check List

Week task forms are completed for each week. They may be designed as a separate form for each trade or as one covering all trades. The latter will, of course, depend on the number of tasks per week for the individual trades.

Tasks that are of a weekly nature (e.g. visual inspection) are entered onto a separate week task form. To avoid issuing work dockets for such inspections, the week task form may then be used as a work docket, a tick being placed against the tasks when they are completed.

Week task forms should only require amending when either additional plant and equipment is introduced or the frequency of planned maintenance tasks is being adjusted to meet revised operational or maintenance demands. Departments in which work is to be carried out may be issued a copy of their department's week tasks four weeks in advance. This then enables them to programme their operation, where necessary, so that the maintenance work can be carried out without disruption to the department's output. Alternatively, on receipt of this prior notice the departmental head can contact the engineer controlling the work to discuss departmental matters that may affect the proposed planned maintenance. This may, in some instances, require the engineer to reschedule the planned maintenance programmed for that department.

35.3.6 Work dockets

On examining the week task form for the forthcoming week the engineer will decide on the work dockets that

are to be prepared for issue. To enable the engineer to carry out this function satisfactorily, a knowledge of manpower resources and operational demands on the plant and equipment is essential.

It is at this stage that, having the information above, a decision can be made on which planned maintenance tasks are to be carried out and which may be postponed or cancelled. This may be due either to insufficient resources (e.g. man-hours or a forthcoming planned shutdown) or to planned maintenance that need not be carried out for another reason.

Recourse to the maintenance and repair records or a visual aid enables the engineer to establish if the planned maintenance tasks that are not to be carried out had been maintained either during the previous scheduled visit or, when next due, a planned maintenance visit. If not carried out as programmed, the engineer must ensure that the period over which no planned maintenance is proposed does not exceed any known maintenance/operational requirement.

The engineer or supervisor responsible for planned maintenance may issue the work dockets on an individual, daily or weekly basis. When issued on a weekly basis, the technician/craftsman responsible for a specific plant room or departmental area can then plan how the work should be programmed throughout the week, having gained experience in identifying which plant and equipment and also in which area planned maintenance can be actioned on or at specific periods of the week.

The work dockets would be normally issued on Fridays for the following week. This enables the technician/craftsman to plan his work for the forthcoming week. All completed work dockets should be returned to the engineer's office daily.

Work dockets partially completed (i.e. with the work task incomplete) should be discussed with the engineer. This then enables the engineer to make a decision on how or when the outstanding items on the work docket may be actioned.

Work dockets that have not been actioned should also be returned for the engineer's attention, with comments on why they have not been actioned. The engineer may then decide on whether the work need be rescheduled.

The engineer controlling the planned maintenance function within the department ensures that all work dockets are returned. Any comments entered on the work dockets are noted and, where further action is required, plans are prepared accordingly. (*Note*: A copy of the week tasks will suffice in maintaining a record of work dockets issued. If necessary, the technician/craftsman's initials can be entered on the week task form as a reminder to whom the work docket was issued.) Technicians/craftsmen should be advised of any matter that delays implementation of action required, as reported in the returned work docket, so that, if no corrective action has taken place on their next scheduled visit they understand why.

Further to the engineer's examination of the returned work dockets, purchase requisitions can be placed for parts, specialist contractors' attendance, etc. On completion of all the technical aspects of the process, the information regarding the service carried out on the plant and equipment can then be entered in the maintenance and repair record by the administration.

35.3.7 Year visual aid

Visual aids are developed from the planning schedule, in that assets and asset numbers are repeated and service visits indicated by a symbol. Hence the estimated man-hours for the specific task per frequency are not displayed for general view.

The benefit to be gained by the engineer and technician/craftsmen from the visual aid is that it provides them with a visual picture of the full year's programme, covering all the recorded assets and their associated work tasks. The format of this visual aid depends on the number of assets within the system, and each visual aid may cover approximately 100 assets.

If there is not a large number of assets a visual aid can be prepared for each trade, whereas when there is a greater number (e.g. 400+) a visual aid that covers all trades suffices. Indication markers on the aid in this instance would signify the least frequent service of the collective trades (e.g. mechanical: monthly visit and electrical: quarterly visit). The last would be indicated.

Visual aids can be purchased on which the information regarding assets and service visits would be affixed or, as in the examples shown in the Appendix, a negative (A1 size) can be drawn covering all the assets. Draft copies can then be printed for each trade's planning schedule.

The year visual aid visits indicated by colour spots relating to frequency is covered by a firm plastic sheet, so that the issue and return of work dockets can be indicated on the plastic by a china-graph pencil (e.g. '/': docket issued; 'X': work completed).

35.3.8 Comments

The above planned maintenance manual system provides a firm basis on which a computer-planned maintenance system may be developed. Having such knowledge and experience from working the manual system, the benefits that can be accrued from planned maintenance systems compared to the corrective or other non-planned methods previously used are numerous. It can be found that, due to the large amount of assets to be managed by the administration, it would be beneficial for the planned maintenance system to be transferred onto a computer system. A major non-technical weekly task is one of producing work dockets for issue and the subsequent entry into the maintenance records on completion of the work task.

Technical benefits are also obtained more readily from a computer system in that if sound identification of assets is established through their asset number, codes etc., similar assets can be examined in the event of a failure of any similar asset, and spares can be held in stock to cover the range of assets for which they are required, rather than for each individual asset. In preparing the asset register and respective work tasks these can also be more easily

duplicated with respect to similar assets than is possible with a manual system.

Scheduling of work tasks and therefore labour utilization can be carried out in a number of different methods on a computer, depending on the software system purchased. These methods can be similar to the manual system or they may take the form of automatic scheduling. That is, the work tasks are entered into the computer system with the appropriate hours and trades and the software program automatically schedules the hours evenly over the weeks of the year. In implementing such scheduling care has to be taken to ensure that such items as weekends, statutory holidays, annual leave, annual shutdown and seasonal requirements are all considered prior to loading the asset information onto the computer system.

Many engineering maintenance departments allocate more hours to new or extra works than they do to maintenance. Therefore the introduction of either type of planned maintenance system highlights this matter to both the department and the company generally when appropriate.

When considering a computer system, aspects that require attention are hardware and software (planned maintenance system). During the initial enquiry as to which hardware and software would best serve the company or department both must be considered.

If there is no restriction placed on the proposal by having to use the current in-house computer system, the choices of hardware/software packages are numerous. The software must be user friendly, complementary to existing systems to avoid duplication of asset registering, etc., and have the facility to expand (i.e. have other programs (modules) that enable greater use be made of the information held within the system). The program should also be compatible with any in-house computer system where possible.

The hardware should be dedicated to the maintenance department, as they then have access to the maintenance programmes as and when necessary. Systems are implemented whereby the software is loaded onto the company in-house hardware, which can lead to periods when access is limited by other demands on computer time (e.g. accounts departments). The ideal situation would be for the maintenance department to have their own computer, with the back-up facility provided by the in-house computer, thereby ensuring that copy is held.

It follows that if the planned maintenance system is to be shown as effective, the number of breakdowns reported must reduce, irrespective as to whether it be a manual or computer system. A satisfactorily installed system allows the engineer to plan his department's work and, when necessary, action emergency items or additional work, without their being detrimental to the department's overall performance.

The benefits from a planned maintenance system cannot be achieved without the commitment of the person responsible for its implementation. To ensure that the system operates to the satisfaction of operators and users, discussions should take place during the initial decision making and with the relevant departments when the planning schedules are being prepared.

35.4 Computer systems

Before committing the company or department to a system of planned maintenance it is essential that there is a complete overview of the total demand on plant, equipment and resources and the benefits from the implementation of such a system, manual or computerized. Varying systems and/or part systems exist in almost every engineering maintenance department, which are due to company policy, changes in departmental staff or workforce, commitment of persons responsible, or, as is the situation in a number of instances, a previous breakdown, which the planned system did not prevent. In this case the system is then often abandoned as unworkable.

On reaching the decision that there are benefits to be obtained from a planned system and that the system that will be most beneficial to the company generally is to be computer based, then the following aspects must be examined more fully:

1. Has the company or department the necessary knowledge of the computer system to prepare and implement a planned maintenance programme by this method? The benefits to be gained from the use of computers requires sufficient understanding of both computers and maintenance to foresee the advantages over those obtained from the manual system.
2. Has a budget cost been established on hardware and software?

Questions to be raised include:

1. Is the program to be run on the company's main computer or is the department to be given its own hardware? While assessing this, consideration must be given to which computer program is to be given priority (e.g. finance, purchasing, deliveries or maintenance). It is generally found that maintenance is given the lowest priority. The decision to 'go it alone' (i.e. purchase hardware specifically for the maintenance program) requires that the following details of the system's implementation be examined:
   (a) Will there be only one terminal and printer?
   (b) Due to the complexity of the company premises (e.g. dispersed locations, a number of large departments and operation and maintenance sections) it may be that although there is only one main computer source for information and records there are a number of terminals and printers distributed around the other demand areas. To ensure that records and information are not corrupted or destroyed it is normal practice for the remote terminals to have access only to information. This enables the information held within the program to be interrogated by authorized persons with respect to history, spare parts, inventory, etc. It could be considered good policy to implement the maintenance program with only one workstation (i.e. a central computer and printer) initially to gain experience of its operation before extending it into other departments. This method enables bugs to be ironed out before

the system becomes too large for any necessary modifications to be introduced.

2. Are there skills within the company or organization that can develop a cost-effective programme specifically for the respective department, or would it be more economical in terms of costs and the proposed timetable for implementation of the programme to purchase an 'off-the-shelf package'? Caution on which route should be taken must be exercised in that in-house staff may be available in the initial programming stages but as the system becomes more developed, they may not be free due to other priorities discussed above.
3. Who will prepare and then implement/operate the programme? What resources will be made available (e.g. facilities, resources, accommodation and administration assistance)? To implement the proposal the staff forming the steam will need to include a computer-literate operator (i.e. someone who can correct the faults that develop during the planning and programming stages), a person knowledgeable in the programming of the engineering tasks (e.g. an engineer) and also staff to inspect the plant and equipment and enter all the information into the computer's maintenance program. If there are not the skills available as mentioned above, it is imperative that the engineer responsible for the implementation of the computer program be given adequate training in the specific system to be purchased. If this is not done, substantial costs could be increased in continual recourse to the suppliers for assistance.
4. What assets, departments, etc. are to be included within the proposed program? This plays a major part in the decision to be reached on to what hardware and software is to be purchased. To support a system covering a number of areas and departments it will be necessary to consider network systems. Therefore the computer maintenance system to be purchased must accommodate such arrangements.
5. What details must be sought from the suppliers of both hardware and software packages? How can the computer best meet the department's current requirements and how can it be added to if and when necessary (e.g. increased demand from planned maintenance)? How can it be extended to cover other departments (network)? Energy consumption, input from condition monitoring, stores inventory, project work and possible interaction with space allocation must also be considered.

35.4.1 Computer system checklist

A checklist of items that may assist the intended purchaser of a computer system would include:

35.4.1.1 Costs

Computer and printer;
Maintenance package (i.e. number of modules required to provide a satisfactory system);
Modifications of maintenance package to meet user demands;
Modifications of computer so that it is compatible with the company's main computer;
Other possible add-on packages (list);
Network system, and installation costs (ensure compatibility with computer and maintenance package);
Stationery (include cost for modifying supplied material to meet user demands);
Maintenance agreement for computer;
Support from suppliers included in initial package;
Support from suppliers during operation;
Training;
Input of information into system;
Cover for staff involved in implementation of system;
Additional administration staff required for the system's operation.

35.4.1.2 Software package

Is it compatible with the company's main computer?
Is the total package user friendly or will it require a large amount of support?
Does it require modifications to meet the department's requirements?
Does it have the facility to copy information/details of similar assets, thereby reducing initial input of these?
Does it have the facility to copy information/details of common work tasks, thereby reducing initial input of these? (This would include labour requirement.)
Does it have the facility to search out similar assets (by manufacturer, duty, task etc.)?
To what extent is asset information held? Is there a limitation on the amount of information that can be stored in a readily usable format (e.g. history, costs, spare parts, etc.)?
Is there adequate help when entering information into the program (i.e. simple keyboard entries)?
When entering information, does it require to be entered in a number of different fields?
Is labour scheduling by a team or individual trades?
When loaded automatically, are work tasks scheduled to ensure an even weekly output?
How does the program cater for seasonal work (e.g. heating boilers, air condition)?
How does the program cater for seasonal work (e.g. plant shutdowns, holidays)?
How is scheduling of work tasks handled (e.g. different frequencies)?
Does the system only produce work dockets of the least frequent service (i.e. when yearly and quarterly service visits are due, will the quarterly visits also be printed)?
Is it easy to carry out simple corrections when incorrect information has been entered by mistake?
How is breakdown work handled? Is there a simple entry format so that a work docket can be issued without going through a lengthy keyboard process?
Is there a suitable format within the process to view pending work (e.g. job file) for a specific forthcoming period? Is it available in print?
Is there a facility for viewing the job file on the screen indicating docket status (e.g. work overdue, work due, work in progress, etc.)?

Is there a facility for viewing the job file on the screen indicating docket status (e.g. work overdue, work due, work in progress, etc.)?
Is the keyboard instructions simple with respect to the printing of work dockets and the entering of history relevant to these dockets on completion/part completion or cancellation of work?
Does the system require 'tidying' (e.g. transferring information from 'working file' to 'history file')?
Is there a facility to enter 'free format' information into e.g. history file, breakdown work dockets?
If purchasing a stores/spare parts module, does it have the facility to link similar parts for all assets to reduce stock holding? Does it automatically enter into the issue of these?
What reports can be produced (e.g. labour in trade groups and/or for specific assets, departmental, premises)?
Can a bonus system be incorporated into the labour element?
What facility is there for evaluation (e.g. life-cycle costing, capital write-off/replacement, design, reliability)?
Is the cost module compatible with the company's cost procedures?
Can the reports be produced in chart or table form?

If, after assessing the various computer and software packages, the decision is made to implement the proposed maintenance system on computer rather than by manual methods caution must be exercised. Irrespective of the above-mentioned benefits, the use of a computer does not increase work output but it does provide the department with a very sound method of improving the management of the company's assets and resources.

In establishing a sound maintenance programme, budget costs for both operation of the department and associated costs of the user department's assets will be readily obtained.

The proposed maintenance programme could be likened to a car. Both manual and automatic models can take one from A to B, and although the automatic may be easier to drive, both still require a driver (in the case of the maintenance programme, the engineer) to manage them.

35.4.3 Comment

Irrespective of the method of planned maintenance to be implemented, benefits to either will be accrued if all possible information/methods/systems, supported by the appropriate training, are also considered. Much will depend on the demands placed on the plant and equipment and what method is to be adopted in establishing the most economical means of maintaining their life. It is only when the specific plant and equipment is known that the appropriate maintenance programme can be implemented.

35.5 Life-cycle costing

This is the method of establishing the cost of the plant and equipment over its recognized life cycle. In maintenance situations the design and specification elements may be ignored, but those that must be considered in establishing the life-cycle cost of plant and equipment will include:

Purchase
Installation
Commissioning
Trials and tests
Operation
Maintenance
Replacement

For production plant and equipment life-cycle costs are important in that the revenue from a product must cover all aspects of expenditure. For plant and equipment such as boilers and air-conditioning units, establishing life-cycle costs can play a major part in assessing when these items should be replaced. For plant and equipment such as self-contained units (e.g. pumps with sealed bearings, etc.) life-cycle costing may be used to determine their replacement date.

The information on life-cycle costs gained through the use of certain items of plant and equipment need not be true for a similar item in another location, as specific details on operating hours and maintenance attendance can vary markedly. Also, it may be an auxiliary part (e.g. an electric motor) of a major component. Therefore it may have an entirely different set of parameters. An important element that must be examined in detail when establishing life-cycle costs of a specific item of plant and equipment is the demand placed on energy resources by them.

To establish costs with regards to a specific item of plant, sound feedback must be an element of the company's programme and subsequent records must be maintained. To be worthwhile these must include *all costs*: if not, the assumed life-cycle cost over a number of years could be misleading.

It follows that any maintenance programme introduced for specific plant and equipment must be designed so that all maintenance costs are recorded. This would then be taken into consideration when the life-cycle cost of the item is assessed, as it should be added to the loss of production if this has occurred due to any maintenance malfunction. Care must be taken when presenting the life-cycle cost to ensure that all elements within the cost cycle have been effective.

Life-cycle costing must be considered when purchasing or taking over new plant or equipment and include all aspects as listed above.

35.6 Condition monitoring

This is the method of establishing the condition of the respective plant and equipment, usually while it is in operation. Monitoring can be carried out continuously or at periodic intervals, depending on the plant or equipment being monitored. Plant and equipment that is required to run for a predetermined period over many weeks would require continuous monitoring, whereas periodic monitoring would suffice for, say, a heating pump/motor unit, fitted with sealed bearings and a mechanical seal on the pump element.

With continuing developments in the electronics field, care should be taken when considering which type of monitoring equipment is to be purchased. Another aspect to be examined is the equipment's compatibility with any installed building management or energy management systems.

To establish the condition of a certain item of plant or equipment, there are a variety of monitoring methods. The most common equipment in use is for temperature, vibration and oil condition, i.e.:

1. *Temperature meters:* Temperature meters are now available in the form of infrared cameras which enable the operative to take readings from a distance. This eliminates the need to gain access to the item of plant or equipment which may present a hazard due to its being in an operating mode, behind safety guards or at high/low level where access equipment would be necessary.
2. *Vibration monitors*: In most situations whereby the plant is a major source of energy or production, vibration monitors are built into the monitoring system controlling the item of plant. This provides an early warning of any deterioration in bearings, gear damage and wear, valve leaks, imbalance of rotating parts, misalignment or effects caused by incorrect displacement of fluids. Hand-held vibration monitors are also available. These are ideal for periodic checks on a wide variety of plant and equipment.
3. *Fluid condition monitors*: These units are designed to monitor the build-up of ferromagnetic wear debris in samples of lubrication and hydraulic oils. This method identifies whether there is any trace of wear from moving parts and, if found, enables the appropriate maintenance to be carried out.

With the high degree of accuracy available from such monitoring equipment the demand on skilled resources can be reduced. With suitable training and established control parameters for each monitor and item of plant or equipment an unskilled person can carry out this task. The information gathered (in some instances directly into the computer program of the more developed monitors) can then be transferred into the computer-planned maintenance programme so that the appropriate maintenance may be implemented. The readings could result in either the plant and equipment being brought out of service to avoid undue damage or the frequency of the service being amended (BS EN ISO 9000 series).

Other readings that assist in obtaining an overall view of the condition of an item of plant or equipment would include voltage, starting and running amperage and wattage. An individual's knowledge gained from working on such plant and equipment should also not be ignored.

35.7 Training

A major concern within maintenance departments and service contractors is the lack of experienced maintenance technicians and craftsmen. This has been allowed to occur through cutbacks in staffing levels accompanied by a reduction in training. Maintenance training is provided by a few companies, and it could be said that these are progressive in that they acknowledge that, by providing training for their workforce, they will not find themselves in the situation of searching for the limited skilled labour now available.

Planned maintenance can reduce the demand for highly experienced craftsmen in that, if the instructions issued in work docket and advice/guidance notes are adequate, a less-skilled person should be able to perform the work task correctly. It follows that adequate training must be provided to ensure that, irrespective of the degree of the operative's skills and experience, the work task given will be carried out to the required standard.

There are a number of suitable training establishments available, but for the specific plant and equipment within the organization, in-house training would provide a better result. Carrying out in-house training reduces costs and ensures that the subject matter is relevant. Support in this training can be complemented by the use of manufacturers, suppliers or specialists (e.g. control and/or service engineers). It will be found that such companies encourage this method, as it helps to reduce the demand on their own highly skilled staff. Trained operatives can carry out basic fault finding either alone or by telephone.

With the changing face of technology it is imperative that service departments keep up to date with the latest practices. Training should not be restricted to any specific individual but should include engineers, technicians, craftsmen and, where appropriate, semi-skilled staff.

35.8 Health and safety

No maintenance task can be issued without the person responsible for controlling workforce establishing that the work is to be carried out safely. Areas where this is essential would include boilers, pressure systems, electrical systems, confined spaces, hot work, deep sumps/shafts, tanks, and lone working.

To reduce the hazard from any of the above the risk to the individual must be assessed and, where necessary, a safe working system/procedure prepared and/or a permit to work issued. It follows that, whatever procedure is adopted, it can only be effective if closely monitored.

35.9 Information

Information on maintenance is available from a large number of sources. The initial one is that of the manufacturer/supplier for new plant and equipment. Where this plant and equipment forms a part of a process, the party responsible for the overall design must prepare the appropriate operation and maintenance and instructions. These should be supported by technical manuals, which should include spare parts lists, control measures and, where possible, fault-finding charts.

Problems arise in older plant and equipment, as there may have been no information supplied when the plant was first installed. Alternatively, the information may have been lost through the passage of time or by changes in department location and/or staff.

For an enquiring mind (which is an essential tool in the field of maintenance), sources of information outside the service department are available and include manufacturers, suppliers, trade associations, engineering institutions (e.g. plant, mechanical, electrical, etc.), consultants, suppliers of maintenance systems, libraries, technical journals. Standards are available from bodies such as the British Standards Institute. The Institution of Electrical Engineers. Health and Safety information is available from HMSO and the HSE.

35.10 Conclusion

This chapter should be sufficient to guide the engineer or manager through the initial stages of introducing a sound and effective planned maintenance system. However, as in any establishment – production, administration or (as in this case) engineering – without the commitment and endeavors of all those involved, the system will not produce the required results.

On setting out on the planned maintenance route, if the percentage of the work to be carried out under the plan is not sufficient (say, 80%), the department will continue to operate as before (i.e. fire-fighting) with the control of that department being in the hands of others. Any planned maintenance system is a *tool*. It cannot do the work itself but, employed correctly, the sound management results will prove that the efforts involved in setting up the system were worthwhile.

Appendix: Elements of a planned maintenance system

Plant codes

Plant code	*Plant/equipment*
01	Boilers
02	Heating systems
03	Domestic hot and cold water
05	Pumps
06	Water treatment
10	Ventilation
12	Chiller/refrigeration
13	Chilled water systems
15	Cooling water systems
31	Electrical distribution
33	Electrical lighting and power
34	Batteries/emergency lighting
41	Kitchen equipment
44	Fixed equipment
45	Portable equipment
46	Laundry equipment
70	Lifts

35.10.1 Guidance notes

35.10.1.1 Health and safety

Health and safety is everyone's responsibility.
Plant and equipment must be made safe before any work is carried out.
A permit to work may be required for certain work tasks.
Protective clothing/equipment should be used when necessary.
Defective tools or access equipment must not be used.
All safety rules and regulations must be adhered to.
On completion of a work task, the plant/equipment must be left in a safe and operable condition.
Safety guards, where fitted, must be replaced and secured.

35.10.1.2 Technicians'/craftsman's responsibility

The instructions given in these guidance notes do not cover every component part, but the technician/craftsmen is expected to carry out any necessary maintenance in accordance with their normal trade practice. Manufacturers' maintenance handbooks, when available, should be followed with respect to recommendations for work to be carried out and at which frequency.

35.10.1.3 Work tasks

Heating Systems Plant Code E02.
Half-yearly (H) Service.
5. Fan Assisted Heaters.
Blow out motor windings, lubricate as necessary.
Check insulation resistance and test earth continuity.
Examine apparatus for general mechanical condition, including guards and other safety devices.
Test mechanical action and polarity of equipment switch.
Clean and test switches, pilot lamps, thermostats and timing devices.
Ensure that writing and terminal connections are secure.
Test under normal running conditions.

Checklist

Emergency lights (E34) Floor/Zone.....

This service covers all emergency lights.
Indicate thus M: N: S/1: 2: 3, etc. for type of unit and duration of emergency light.
e.g. Maintained/3 hours: M/3.

Luminaire No.:	Type/Hour:	Comments/Report/Recommended action

Asset register

Asset: Description	No.
Location	G. N.
Description of plant and auxiliary equipment	Drg. No's
Manuf./supplier	Ord. No. Date
Schedule of plant and components/additional technical data/remarks	

Survey form

Asset: Description (e.g. Pump)	No.
Location	G. N.
Description of plant and auxiliary equipment	Drg. No's
Manuf./supplier	Ord. No. Date
Schedule of plant and components/additional technical data/remarks	
Unit model Size/Cap Head Brg. NDE DE Lubr't *Motor* Manuf. Mod/Type Frame V/A HP/W RPM Frame Rating Class Ins. Brg. NDE DE Lubr't. Isolator Starter Dist. Brd.	

Maintenance and repair record

Date	Report	Parts	Costs Labour	Total

Planning schedule

Appendix 9

Planning Schedule — MAINTENANCE PROGRAM

ASSET-LOCATION	ASSET NO.	JANUARY				FEBRUARY				MARCH				APRIL				MAY				JUNE	
		1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	17	18	19	20	21	22	23
PLANTROOM 1.																							
BOILER NO.1	PR1-01-01										Q/8												Y/20
AIR HANDLING UNIT 1.	PR1-10-01			M/1				M/1				Y/8				M/1				M/1			
																							gmp

Week tasks

Week One

Mechanical

Location/Area	Plant/Equipment	Plant/Equipment No.	Job Code	Check list
Plant Room 1	Boiler 1	PR1-01-01	M91/3,4	

Electrical

Location/Area	Plant/Equipment	Plant/Equipment No.	Job Code	Check list
Plant Room 1	Boiler 1	PR1-01-01	E01/3,4	

Week dockets

Location/Area	Plant/Equipment	Plant/Equipment No.	Job Code	Check list	Week

Work carried out:

Recommendation/Action:

Date: Time taken: Signature:

Visual aid

Appendix 12

Year "Visual Aid" Plan MAINTENANCE PROGRAM

ASSET-LOCATION	ASSET NO.	JANUARY				FEBRUARY				MARCH				APRIL				MAY				JUNE	
		1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	17	18	19	20	21	22	23
PLANTROOM 1.																							
BOILER NO.1	PR1-01-01										Ⓑ												Ⓡ
AIR HANDLING UNIT 1.	PR1-10-01				Ⓖ				Ⓖ				Ⓖ				Ⓖ				Ⓖ		

FREQUENCY INDICATION

GREEN FOR MONTHLY

BLUE FOR QUARTERLY

RED FOR YEARLY

36 Energy conservation

Eur Ing M G Burbage-Atter, BSc, CEng, FInstE, HonFSOE, HonFIPIantE, FCIBSE
Heaton Energy Services

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36.1 The need for energy conservation

Energy conservation has often been referred to as the 'Fifth Fuel', the other four being the so-called primary or 'fossil' fuels of coal (solid), oil (liquid), gas and nuclear/hydro-electricity. This emphasizes the importance of reducing the amount of energy used, not only nationally but also internationally.

The simple fact is that the world's reserves of fossil fuels will eventually run out, depending on the rate of use, and therefore, if the consumption of these forms of energy are reduced, the existing reserves will last longer. Research and experimentation could lead to those reserves currently available but uneconomic to recover and use being rendered economic, thus extending further the number of years before these non-renewable sources of energy do eventually run out.

The amount of worldwide energy reserves and life is variable according to the source of information used, but the position is of the order shown in Table 36.1.

The estimates of remaining reserves has been roughly the same over the last ten years despite the large increase in oil and gas extracted. This is due to new discoveries being made and new technology allowing the exploitation of previously unviable discoveries.

No mention is made of coal for which there are still vast amounts available, probably sufficient for some one thousand years, so that if oil and gas do become depleted then recourse to coal is a possible answer.

Oil and gas are the two non-renewable energy sources for which consumption has increased rapidly over the last ten years in the United Kingdom, as the mining of coal has declined from some 123.5 million tons in 1980 to 62.9 million tons in 1998.

According to the latest figures the energy consumptions for 1998 were:-

Gas	85.3 mtoe
Oil	74.8 mtoe
Coal	41.3 mtoe
Nuclear Electricity	25.2 mtoe
Total	228.9 mtoe!

(mtoe = million tons of oil equivalent)

Renewable energy sources are also being utilised, although the quantities provided are small compared to the original fossil fuels.

During 1998 some 2.655 million tons of oil equivalent was produced in the United Kingdom by Active solar heating, Onshore wind, Hydro electricity, Landfill gas, Sewage sludge, Wood, Straw, Municipal solid waste and other biofuels. Of these the largest sources were:-

Wood	0.713 mtoe.
Municipal solid waste	0.5677 mtoe.
Hydro electricity	0.4493 mtoe.
Landfill gas	0.4008 mtoe.

Table 36.1 World energy reserves

Oil	4,105 Million tonnes.
Gas	3,105 Billion cubic metres.

The major problem in energy conservation is, however, not the concept but the economics. Saving money by energy conservation is preferred to saving energy unless the energy saving occurs with the main effect required of cost savings. Hopefully, the energy manger will be able to persuade colleagues that both financial economy and energy reduction go together, hand in hand. He must take positive action within his organization at all levels from the board of directors to the shop floor to achieve the stated objectives.

36.2 Energy purchasing

The major energy cost-reduction exercise which can be undertaken prior to an energy audit is that of ensuring that energy is purchased at the most economical price. This is a relatively simple matter, and can be undertaken by the energy manager and his staff, if they have the expertise. However, with increasing competition amongst the energy suppliers, purchasing energy has become something of an art. The original gas suppliers will now provide electricity as well, independent of the area of the site and the same applies to the suppliers of electricity who also will provide gas.

Information on gas/electricity competition and prices is freely available from Ofgem as well as from the various gas and electricity suppliers. Energy consultants also offer a service of energy purchasing advice but in this case a fee will be payable which could amount to 50% of the annual savings over a five year period. When using consultants the energy manager should enquire around in order to find the practice which best suits his needs.

The use of coal for industrial purposes is now at a minimum. Most large users of such fuel having converted their plant to use either gas oil or natural gas. Indeed the use of heavy fuel oil has also declined over the last ten years so that most commercial/industrial energy users purchase only gas, gas oil and electricity.

Typical current prices for industrial/commercial use (1999)[2] are:-

	per tonne.	pence per kWh
Industrial coal	£35.16	0.477
Gas oil	£126.25	0.999
Heavy fuel oil	£76.31	0.636
Gas – interruptible	–	0.498
Gas – firm	–	0.633
Electricity – normal	–	3.667
Liquified petroleum gas	£151.33	1.103

36.2.1 Industrial coal

The majority of the United Kingdom coal consumption is now in the large power stations, 48.3 million tons in 1998. Industry only used 2.7 million tons in 1998 as compared to 7.9 million tons in 1980.[1]

Whilst the cost of coal per kWh is still lower than the other energy sources, higher maintainance and labour costs plus ash handling and disposal costs make the use of coal uneconomic in most cases.

The basic price of coal at the pit is based on the coal gross calorific value, with allowances then made for the ash, sulphur and chlorine contents. The haulage charges depend on the distance from the pit to the site and on the method of delivery. Tipper-vehicle deliveries are cheaper than conveyor vehicles which, in turn, are cheaper than the pneumatic (blower) vehicles. The method of delivery will obviously be decided by a combination of space and cleanliness factors. In the case of certain customers, special agreements may be available at special rates where the annual coal consumption is large and the supplier wishes to retain the market.

36.2.2 Oil

The type of oil used today is now virtually confined to gas oil. This type of oil is used mainly in the commercial and smaller public buildings sector and as the stand-by fuel for large industrial energy users using gas.

The prices charged can vary by up to 3.0 p per litre depending upon the current price of crude oil and the supplying companies.

OPEC have deliberately reduced the rate of crude oil production recently (Late 1999) in order to force the price up. Thus gas oil prices which were recently around 12.0 p per litre have increased considerably to 15.0 p per litre or more. Wide oil price fluctuations can now be considered normal.

The basic price of gas oil is also related to the price of natural gas and to site location, generally being lower around the coast or close to oil refineries.

36.2.2 Gas

Variations in contract gas prices are due to the availability of the fuel. Thus a non-interruptible supply costs more than an interruptible one by a quite significant margin.

The energy manager considering a change of fuel source to gas should maintain his options by installing dual-fuel plant rather than a single-fuel-fired plant in order to gain advantage from the fluctuating fuel price market.

36.2.4 Electricity

Each separate electricity company purchases its electricity from the Generating Companies and each area company has a large variety of tariffs and methods of pricing and payment available for the consumer.

These tariffs include:-

Monthly Maximum Demand with both day and night time variations and seasonal time and seasonal time of day variations.

Quarterly Business Tariffs with both day and night variations and weekend/evening variations.

Off-peak Tariffs – These are available to new customers but still in use there being sixteen variations.

Privately, agreements are negotiated by the very largest business consumers – mainly very large industrial concerns.

Finally, there are tariffs available for those organizations which generate their own electricity and export/import to/from the Distribution Grid system.

A typical example of the number of choices can be gained from the following example of a small company in the Yorkshire area using 100 000 units of electricity per annum (1989 tariffs)[3]:-

1. General Quarterly Tariff GQ

Daily fixed charge 14.25 p × 365	£52.01
Unit charge	
– Primary units 1000 × 4 × 6.87 p	£274.80
– Excess units 96 000 × 6.37 p	£6115.20
Total	£6442.01

2. Economy Seven Quarterly Tariff E7Q
   Night-time electricity usage = 12 500 units

Daily fixed charge 17.53 p × 365	£63.98
Unit charge	
– Night time 12 500 × 2.49 p	£311.25
– Primary units 1000 × 4 × 7.23 p	£289.20
– Excess units 83 500 × 6.74 p	£5627.90
Total	£6292.33

3. Weekend/Evening Quarterly Tariff WE
   Weekend and evening usage = 50 000 units

Daily fixed charge 17.53 p × 365	£63.98
Unit charge	
– Weekend/Evening 50 000 × 3.60 p	£1800.00
– Primary units 1000 × 4 × 9.18 p	£367.20
– Excess units 46 000 × 8.72 p	£4011.20
Total	£6242.38

4. Weekend/Evening Economy Seven Quarterly Tariff WE7

Daily fixed charge 19.73 p × 365	£72.01
Unit charge	
– Night time 12 500 × 2.49 p	£311.25
– Weekend 37 500 × 3.60 p	£1350.00
– Primary units 1000 × 4 × 9.18 p	£367.20
– Excess units 46 000 × 8.72 p	£4011.20
Total	£6111.66

5. Monthly Maximum Demand Tariff with Night Usage DM1
   Maximum Demand = 35 kVA

Monthly fixed charge 12 × £29.10	£349.20
Monthly availability charge 12 × 35 kVA × £1.31/kVA	£550.20

Maximum demand charges:-

March to October	Nil
Nov./Feb. 2 × 35 kVA × £2.40/kVA	£168.00
Dec./Jan. 2 × 35 kVA × £7.41/kVA	£518.70
Unit charge – Night time 12 500 × 2.35 p	£293.75
– Day time 87 500 × 5.17 p	£4523.75
Total	£6403.60

6. Monthly Maximum Demand Tariff with Night Usage DM2

This tariff can be used where the night time maximum demand is higher than that during the day, the availability and demand charges being related to the day time maximum demand not the seven hour night time period.

Day time Maximum Demand = 30 kVA

Monthly fixed charge 12 × £29.10	£349.20
Monthly availability charge 12 × 30 kVA × £1.31/kVA	£471.60

Maximum demand charges:-

March to October	Nil
Nov/Feb. 2 × 30 kVA × £2.40/kVA	£144.00
Dec/Jan. 2 × 30 kVA × £7.41/kVA	£444.60
Unit charge	
– Night time 12 500 × 2.58 p	£322.50
– Day time 87 500 × 5.17 p	£4523.75
Total	£6255.65

7. Monthly Maximum Demand Tariff without Night Usage DM3

Monthly fixed charge (as 5)	£349.20
Availability charge (as 5)	£550.20
Maximum demand charge (as 5)	£686.70
Unit charge – 100 000 × 5.15 p	£5150.00
Total	£6736.10

8. Seasonal Time of Day Tariff
   High rate usage = 2400 units/annum
   Medium rate usage = 6000 units/annum

Monthly fixed charge 12 × £29.10	£349.20
Availability charge 12 × 35 kVA × £1.31/kVA	£550.20

Unit charge:-

Night time 12500 × 2.35 p	£293.75
High rate – Nov/Feb. 2400 × 14.78 p	£354.72
– Dec/Jan. 2400 × 19.67 p	£472.08
Medium rate – Nov/Feb. 6000 × 6.59 p	£395.40
– Dec/Jan. 6000 × 7.00 p	£420.00
Other 70 700 × 4.69 p	£3315.83
Total	£6151.18

Comparing these prices with those of 1989 shows that electricity prices have risen by only some 5% during the last ten years. However, these prices are exclusive of VAT which has now been levied on fuel (and can vary from time to time).

On the basis of these costs, a selection of the Weekend/Evening Economy and Quarterly Tariffs would appear to offer the greatest savings. In most cases, however, it is expected that the Monthly Maximum Demand Tariffs with Night Usage to offer the greatest savings.

Regular meter reading are required to ascertain the breakdown of the total load and these will form a useful basis for the energy audit. Regular readings throughout the working week (say, at hourly or even half-hourly intervals for a week or fortnight around periods of peak energy consumption) along with details of the plant in use give an indication of the possibilities for peak lopping in order to reduce the maximum demand. Alternatively, suitable monitoring equipment with printout facilities would be of great benefit in many cases, especially where fluctuating loads are concerned. It should be remembered that the highest maximum demand incurred applies not only for the relevant monthly account but also for the availability charge for the next twelve months unless exceeded, when the new, higher, figure applies.

Maximum demand alarms are available for individual organizational use and these can be made to shut down non-essential plant in order to maintain a lower actual maximum demand. Where automatic shutdown is not in use alarms can be used to trigger a manual shutdown procedure.

36.3 The energy audit

Prior to carrying out an energy audit a simple walk round the site will give an indication of the scope of savings possible. On approaching a site, emissions into the air such as black smoke from a chimney indicate that all is not well.

The emission of steam from pipework, joints and valves also indicate a lack of maintainance and a high temperature upon entering a room indicates perhaps a lack of control especially if the windows have been opened to cool down the space.

The lack of insulation around pipes especially flanges and valves will also be readily apparent.

In certain processes the discharge of a hot effluent to drain also indicates a possible source of energy saving.

The basic energy facts must be established in an organization's energy conservation campaign. Any organization will purchase energy, even if this is limited solely to electricity. Thus, as a start, the actual energy accounts are available for use. These will have been employed already in determining the most economical purchase price (see Section 36.2). The accounts, however, only indicate the total site consumption, generally during the last three months, or monthly, depending on the plant size.

A better picture can be obtained if the energy accounts for twelve months or even better if two or three years are available.

However, in order to gain an accurate picture of site energy usage it is necessary to:-

1. Provide metering facilities for each energy source for each major cost area (e.g. the boiler house or a particular production process);
2. Read these metering facilities regularly. This can best be undertaken weekly and, at worst, monthly, but the frequency will depend on the load pattern and level of consumption.

On the basis of these regular readings, energy consumptions and costs can be allocated to particular cost centres, items of plant or process. The energy audit can be undertaken by using the organization's staff, such as the energy manager and his department. As an alternative, an energy consultant can be called in. It is suggested that costs and

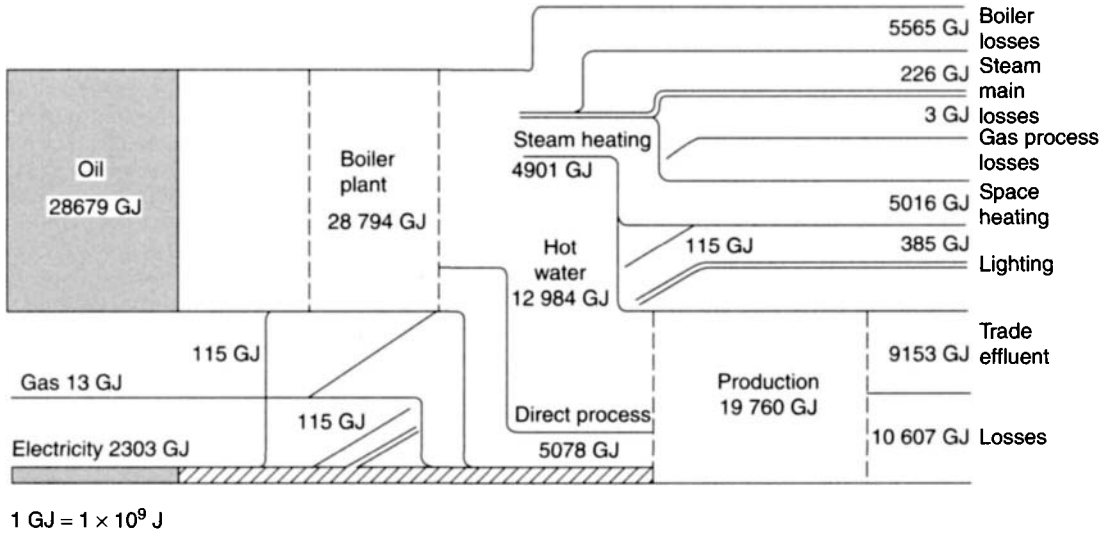


Figure 36.1 A typical Sankey diagram for a dyehouse

levels of consumptions should, where possible, be in some way related to production output, operating hours or process requirements.

The energy consultant may be better employed in investigating a specific cost centre, as detailed investigation could be required such as energy readings every hour, or half an hour or even every few minutes (e.g. a boiler test). As a result of an energy audit it should be possible to build up the pattern of energy usage of the whole site, or a particular cost centre. This can be expressed in energy terms in a Sankey diagram (Figure 36.1). The figure shows the uses made of the various energy sources purchased, and where this energy is eventually lost from the site to waste. It is essential to maintain a regular monitoring system, recording energy consumptions and costs. The use of computers provides a ready-made facility for this and software packages are available (see Section 36.5).

36.4 Energy management

Energy management will cost money whether the staff are employed by the organization or outside consultants are used. Large organizations, who already employ their own engineering staff, probably add energy management duties to an existing member of staff, or may appoint a specialist in such matters. Extra staff may be appointed, depending on the nature of the business.

In this case, there is an on-going cost, and this must be borne in mind when embarking on an energy-conservation campaign. Within a large organization with a large number of buildings, 80% of the energy consumption takes place in 20% of the buildings, and initially there are major savings to be made. However, when the initial and obvious energy-conservation schemes have been implemented then there only remains the effort to maintain the results achieved and to investigate any possible new schemes.

Within a large organization there may well be sufficient continuous work to keep a small team of energy-conservation engineers busy. However, in many cases, once the initial work has been completed then perhaps only one or, at most, two persons are required. If this is likely to be the case then the use of energy consultants may prove attractive for the investigation of individual areas of energy conservation, as there is no problem of long-term employment costs. In the case of small organizations, unless there is a very high energy consumption then full-time company employment cannot be justified.

It may be possible to employ a suitable engineer on a part-time basis, but perhaps the best alternative is to use either an energy consultant, as and when required, or a suitable student from a technical college, polytechnic or university during the vacations or during their year out of college on industrial placement. The advantage of the latter is that an eminently suitable student may then be offered full-time employment upon successful completion of his course, which could include further energy work.

The financial arrangements could be in the form of:

1. Energy consultant:
   An agreed hourly rate or day rate within a specified period;
   An annual retainer with a lower hourly or day rate;
   A percentage of the capital cost of the scheme involved;
   A percentage of any savings obtained.
2. A student:
   An agreed hourly or weekly rate for the specified period;
   An agreed salary.

Continuous energy management is required and the person so employed must have access to the organization's highest management or be a member of that team.

Many excellent energy-conservation schemes have failed or been altered by senior management due to inadequate representation from the energy-conservation staff concerned. The approach to energy conservation and energy management must be whole-hearted and enthusiastic. Only then can the best results be achieved.

36.5 Energy monitoring

Reference has been made earlier to the need for energy monitoring as part of the energy audit (Section 36.3). The monitoring system used can be as simple or as sophisticated as required. In its simplest form, energy monitoring consists of recording the billing details of the various energy suppliers and comparing these bills by reference to the previous bill or to the previous bill for the period twelve months earlier. Such comparisons are not the best basis for commenting on the performance of the plant concerned. Changes in plant and equipment, and the use of that plant and equipment, may give rise to large variations in energy consumptions, hence costs.

Thus for the best comparisons not only must the energy usage be monitored more frequently, but at weekly intervals (monthly at worst), with other parameters being recorded. These could include the following:

Plant/equipment

Period of time and times in use, each day of the week;
Load factor on that plant – goods produced;
Conditions of the plant – pressure, temperature, etc.;
The identity of the plant operator.

Buildings

Period of occupancy each day;
Internal environmental temperature and humidity;
Number of occupants;
Nature of the building construction;
Internal heat gains from lighting, machinery, etc.;
External heat gains from the sun;
Climatic conditions such as cloud cover, wind speed, external air temperature and humidity.

From this information it should be possible to ascertain the basic standing loads and the variable production loads which make up the total site load.

It is necessary to record much data, which is time consuming when undertaken by individual members of staff. Meters are available for the direct measurement of such energy sources as oil, gas and electricity and also for the measurement of water, steam and air flows. Steam can also be measured in the absence of any metering by diverting the condensate into a drum of water and weighing the drum prior to and after the test, noting the actual time for the test. Any steam system will have steam traps, and in order to check that these are working correctly, sight glasses should be provided after the trap. Solid fuel such as coal, coke and wood can best be measured by weighing the fuel on an appropriate system such as a belt weighing machine for large quantities of fuel down to a simple spring balance and small drum for small amounts.

Many of these parameters can be easily measured and recorded by modern devices, utilizing a minimum of manpower. A large variety of modern computer-based energy management systems will monitor, record and store the required data. Some will also control the required parameters within closely defined limits.

Energy management systems can vary in cost from low to high (£50 000–100 000) for the system itself. In addition, energy controls may have to be provided either to replace existing controls which are not compatible or which are not operating correctly or have never been provided in the past.

This additional cost to facilitate and implement the energy management system can vary from £100 000 to £300 000. In the long term, the centralization of energy monitoring can yield large financial savings, coupled with a considerable reduction in energy consumption.

With such systems it is possible to obtain individual room space heating and humidity control without the need to despatch an engineer to check every room in the building. Manpower costs can be reduced, with the staff being required for checking and maintenance purposes only. The cost of an energy management system can be recovered in a relatively short period of time (of the order of 2–3 years).

The cost of an energy management system at one site in the North of England was of the order of £500 000 and the payback period was just over 2 years. In view of the high cost of such systems it may be possible to obtain a system on a loan basis, the system being rented from the installer or by lease purchase. All options should be considered before entering into a contract.

A further advantage of an energy-management system is that the quantity of production can be included for process plant and a correlation made between the product and the energy required to produce it. Such a figure is useful in comparing similar processes within the same organization and in comparison with similar ones. It also allows the energy cost per unit of production to be calculated.

36.6 Energy targeting

Having initially ascertained the basic energy data, energy targeting is the next logical step. It is desirable to know if the energy consumption of a particular site or piece of equipment can be reduced without detriment to the product or personnel involved.

The easiest way is to alter the parameters downwards and note the effect, while monitoring the plant conditions and energy consumptions. The result of this is that eventually the product will become useless and/or the personnel aggrieved at the change in environmental conditions. This method is frequently used by making any downward adjustment small and monitoring the effect, adjusting downwards again after a short period of time.

It is possible to undertake theoretical calculations to ascertain the amount of energy required for the operation and to compare this with the actual consumptions. To do this requires the knowledge of a large number of

parameters but it can be undertaken, especially if an energy management system is installed.

The amount of energy required for space heating in a particular space can be estimated from the various parameters and compared with the actual energy consumption. The difference indicates the scope for further improvement. The following is a typical case of a warehouse used basically for the storage of goods only but with access by staff for goods movement:

Warehouse size – 91.5 m long by 61.0 m wide by an average height of 8.13 m, giving a total floor area of 5582 m^2 and a volume of 45 400 m^3.
Modern construction with a wall and roof U-value of 0.50 W/m^2C.
Internal environmental temperature required = 15°C.
External air temperature = −3°C.
Natural air infiltration rate = $\frac{1}{2}$ air change per hour = 22 700 m^3/h

Calculated heat losses
- Building fabric loss = 146 000 W
  Air infiltration loss = 152 000 W
  Total loss = 298 000 W

Type of heating in use – Thirteen downdraught-type steam unit heaters, controlled by an optimizer and internal air thermostats.
Hours of occupancy – Five days per week, 16 hours per day.
Calculated annual steam requirement = 692 000 kg (1 525 000 lb)
Calculated steam cost at £9.68 per 1000 kg = £6700.00.

In this case the actual annual steam consumption which was metered was 1 906 000 kg (4 202 000 lb).

In the case of a process, such a basic estimate is harder to achieve, but this can be undertaken. The heat requirement for most chemical reactions is known and this method can be used in most manufacturing processes to determine the energy requirement.

In a series of chemical process vessels where heating of each vessel takes place it may be possible to reduce this amount of heating by ensuring that the product from the first vessel is hot enough for the next. This can be achieved by alteration to the liquid boiling point by variation in the vessel pressure. A reduction in pressure reduces the boiling point. The rescheduling of production may also lead to economies.

The dyeing of cloth is a good example. The dye master of old always insisted that the dyeing process in all the required vessels be started at the same time. This process began with the boiling of large quantities of cold water in the dye vessels by the direct injection of steam through 50-mm diameter pipes, the steam load being extremely high. To meet this load it was customary to install a battery of boilers. After 30 minutes the steam load reduced to a minimum, as all the vessels were boiling. Fours hours later this same process would be repeated. The additional cost of the boiler capacity and of the fuel to keep the boilers alight between successive loads was excessive. A simple alteration to the production schedules by staggering this boiling of water and the introduction of steam accumulators reduced costs significantly.

Many computer software packages are available for energy-targeting purposes, but care should be taken in specifying the requirements and insisting on performance satisfaction and testing before final payment. Such software packages may be expensive and could require modifications for actual use.

There are many building space heating/humidity energy usage programmes available. A large number assume the building ventilation or wind speed rates. In most buildings, the major factor in any discrepancy between the theoretical and actual energy consumptions is due to the variation in wind speed. This is highlighted in the example of the warehouse above. The large discrepancy between the theoretical and actual steam consumptions was investigated in detail, and it was found that one of the large doors giving access into the warehouse was open for most of the time the warehouse was in use by the staff, and that this door was subject to the prevailing wind. In order to reduce the steam consumption a rapid-opening door was installed, with the result that the steam consumption was halved. The energy target set must be realistic and capable of achievement.

36.7 Major areas for energy conservation

For most organizations the major energy use is for building space heating, ventilation, air conditioning, domestic hot water purposes and lighting. Where energy is used for process, this may be secondary energy generated from a primary fuel (e.g. steam generated in a fossil fuel-fired boiler plant).

36.7.1 Boiler plant

Boiler plants are a major user of energy. The combustion efficiency of a boiler plant can easily be set at the optimum, and Table 36.2 suggests the parameters for this for various fossil fuels:

Exit flue gas temperature = 200°C
Ambient air temperature = 15°C

Close control of the amount of excess air is possible by the use of oxygen trim control equipment. Such equipment will control the flue gas oxygen content within the range of 2.0–3.0% as compared to the normal 3.0–5.0%. The

Table 36.2

	Coal	*Oil*	*Natural gas*
Excess air (%)	30	20	10
Dry flue gas CO_2 content (%)	12.0	13.3	10.5
Dry flue gas O_2 content (%)	7.5	3.5	2.3
Dry flue gas loss (%)	13.2	7.4	6.1
Moisture in the flue gas loss (%)	4.9	6.5	11.3
Unburnt/ash loss (%)	1.3	Nil	Nil
Radiation and other losses (%)	3.1	3.1	3.1
Total losses (%)	22.5	17.0	20.5
Inferred boiler plant efficiency (%)	77.5	83.0	79.5

improvement in boiler plant efficiency is of the order of 1.0–2.0%.

The combustion conditions suggested above should be achieved bearing in mind the fact that the lower the flue gas oxygen content, the greater the risk of incomplete combustion, while the higher the oxygen content, the greater the flue gas losses (see Figures 36.2–36.6). Poor

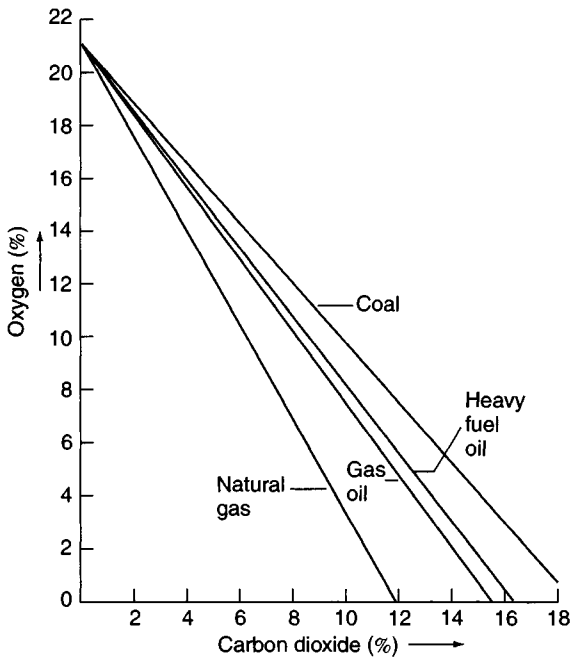


Figure 36.2 The relationship between oxygen and carbon dioxide in the products of combustion for various fuels

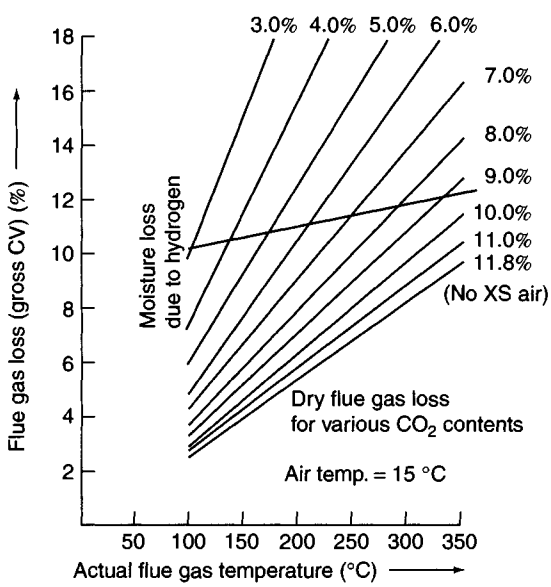


Figure 36.3 Flue gas losses – natural gas

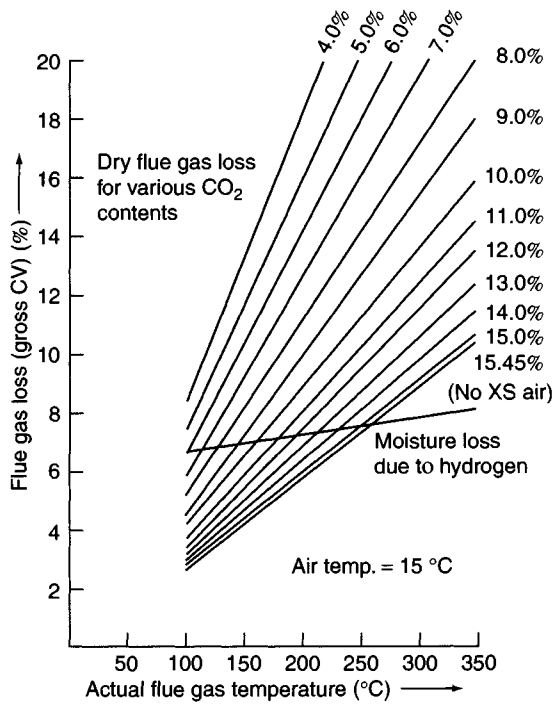


Figure 36.4 Flue gas losses – gas oil

overall boiler performance outside these parameters is due to the radiation and other loss factors.

The surface loss from a boiler is fixed once the physical size, insulation and boiler working conditions are known. The usual radiation loss figure provided is that for a boiler operating at least at 80% maximum continuous rating (MCR) or more. In this case, the surface loss is relatively low in percentage terms (around 3–5%). Experience of boiler loadings have indicated that very few boilers work at such high loads during their periods of use. Typical annual boiler load factors are only around 40%. As the boiler load factor decreases, the radiation loss becomes a much higher factor, and at 20% boiler load amounts to 25% and at 10% load factor to a loss of 50% (see Figure 36.7).

Many boilers do operate at low load factors and consequent poor annual efficiencies. This can be avoided by providing boiler plant with little or no margin over the actual required capacity and by installing multiboilers or two or three smaller boilers. Boilers of this modular type are available for low-pressure hot water (LPHW) purposes, but obviously cost more than a single boiler. This will also increase the maintenance, number of examinations and the labour costs. Such an increase should be more than offset by the reduction in fuel costs due to the much higher annual boiler plant efficiency, which should be of the order of 20–30%.

A further problem with heating boilers is that the boiler liquid temperature control thermostat (an immersion water thermostat in most cases) maintains the boiler liquid temperature at the set level, irrespective of the

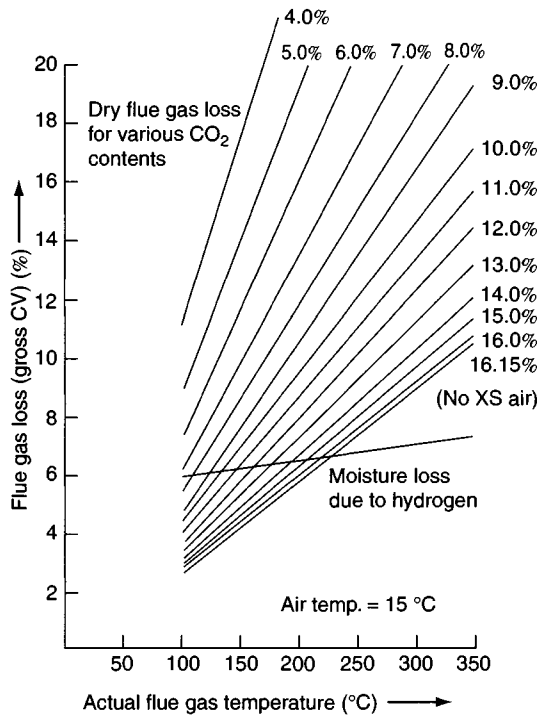


Figure 36.5 Flue gas losses – heavy fuel oil

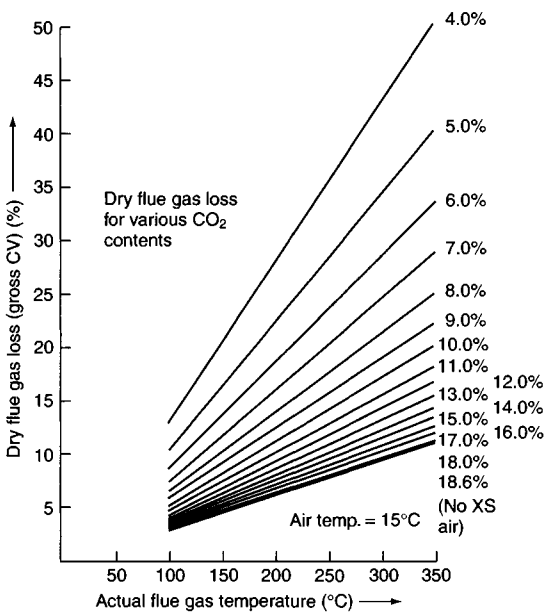


Figure 36.6 Flue gas losses – coal (Glasshoughton washed singles)

actual boiler load. The boiler, even though insulated, loses heat to the surrounding space through radiation and convection. The actual boiler load could reduce during the day such that the maintenance of the set

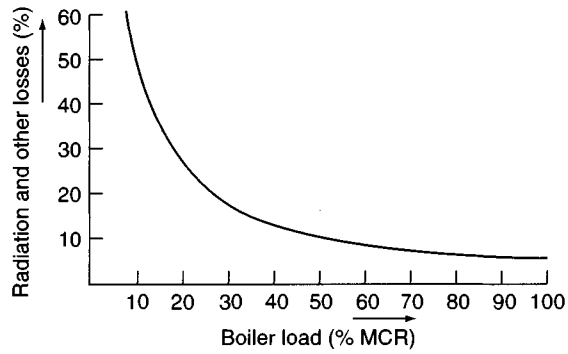


Figure 36.7 The variation in percentage radiation and other losses with the percentage boiler load factor

boiler liquid temperature is not required continuously. Thus the boiler liquid could be allowed to cool down with the consequent reduction in the radiation and convection losses (the standing loss). Boiler controls are now available to avoid maintaining the boiler liquid temperature at the thermostat control setting and consequently the unnecessary operation of the burner ('dry' cycling).

The cost of the supply and installation of such controls is of the order of £250–300. Energy reductions of 10–15% can be achieved, with a cost-recovery period of 3 years down to a few months, depending on the actual annual energy consumption.

Condensing boilers are now available for both gas- and oil-fired plant, the advantage of these being that the flue gases are further cooled down to below 100°C so that the latent heat available in the flue gas water vapour is recovered. The condensate has to be removed and the boiler capital cost is higher than for conventional plant. However, the boiler plant efficiency is increased to the order of 90%, based upon the fuel gross calorific value. Where the flue gas exit temperatures are in excess of 200°C a further economy can be obtained by the provision of a spray recuperator in the case of gas and flue gas economizers for oil and coal.

36.7.2 Furnaces

Furnaces are large users of energy, and in order to reduce costs, such equipment should be well insulated, used to maximum capacity and most of the waste heat in both the flue gases and product recovered. It should be possible to recover the waste heat in the flue gases down to at least 200°C. Specialist equipment for such waste heat recovery is available in the form of recuperators and regenerators.

36.7.3 Electric Motors

Electric motors are major users of electricity in industrial plant and commercial premises. Motive power accounts for almost half the total electrical energy used and for nearly two thirds of industrial electricity use.

A breakdown of consumption by industrial motors up to 300 kW in industry is as follows:-

Pumps	32%
Fans	23%
Process and Conveyors	15%
Other Compressors	14%
Air Compressors	8%
Other uses	8%

On an industrial site with an electricity bill of £150 000 per annum, an average of £100 000 per annum will be spent on running motors. The use of higher efficiency motors should give an annual saving of £3 000 and the fitting of variable speed drives should give an annual saving of £15 000 with further savings from paying attention to the transmission, the driven machinery and the system the machine is driving.

36.7.3.1 Energy saving checklist

1. Is the equipment still needed?
   Check that changing requirements have not eliminated the need for the equipment altogether.
2. Switching the motor off.
   Time the switching according to a fixed programme or schedule.
   Monitor system conditions, eg. high or low temperature, and switch off the motor when not needed.
   Sense the motor load so that the motor is switched off when idling.
3. Reducing the load on the motor.

There is no point in optimizing the drive if what the motor is driving is fundamentally inefficient.

   Is the system doing a useful and necessary job?
   Is the transmission between motor and driven equipment efficient?
   Is the drive machine efficient?
   Are maintainance programmes adequate?
   Have losses due to pipework, ductwork, insulation. etc. been minimized?
   Is the control system effective?

4. Minimizing motor losses.
   Always specify higher efficiency motors where feasible. These are now available without any cost premium.
   When a motor fails, ensure that proper care and attention is given in the repair process so as to minimize energy losses.
   Avoid using greatly oversized motors.
   Consider permanent reconnection in star as a no-cost way of reducing losses from lightly loaded motors.
   Check that voltage imbalance, low or high supply voltages, harmonic distortion or a poor power factor are not causing excessive losses.
5. Slowing down the load.

In pump or fan applications where the cube law applies, even a small reduction in speed can produce substantial energy savings.

Use variable speed drives (VSDs) where several discrete speeds or any infinite number of speeds are required.
Although often the most expensive option, the benefits and large energy savings from VSDs make them usual choice for speed control.
Use multiple speed motors (MSMs) where two and up to four distinct duties exist.
For belt drives only, a low-cost option is to change the pulley ratio.

Illustrations of possible economies are:-

36.7.3.2 Pumping

Select an efficient pump and operate it close to its rated design flow and head.
Install smaller impellers in consistently underloaded pumps.
Minimize the number of sharp bends in pipework.
Increase pump efficiency by the use of low friction coatings.

36.7.3.3 Fan Systems

Keep filters clean to minimize pressure drops.
Clean blades regularly.
Fit dampers to seal off the extract systems from unused machinery.
Install controls to switch fans on only when required.

36.7.3.4 Compressed Air Systems

Generate at the lowest acceptable pressure.
Check frequently for air leakage, as the loss of air is frequently masked by other production noises.
Zone the system and isolate pipework sections when not in use.
Remove or shut off permanently unused pipework.
Recover waste heat from the compressors for space or water heating.

36.7.3.5 Refrigeration Systems

Ensure the cooled space temperature is not lower than necessary. A 1'C increase in store temperature gives a 2–6% energy saving.
Minimize periods for which the cold store doors are open.
Repair damaged door seals and/or insulation.
Ensure free air circulation around condensers.

36.7.3.6 Conveyors

Use sensors to detect when the conveyor is unloaded and switch it off.
Consider zoning the conveyor so that sections not in use can be switched off.

36.7.4 Space heating

The provision of space heating, especially in large non-compartmented buildings, can be reduced by:

1. The installation of direct gas-fired units, where the products of combustion are discharged into the space

but are so diluted as to be harmless. The efficiency of these units is thus 95–100%, depending on the siting of the actual unit.

2. The provision of overhead radiant heating instead of convective heating. In this case the building heat requirements are some 15% lower for radiant heating than convective, with the consequent saving in both capital and running costs. It is also believed that the comfort conditions are improved with less draughts. Radiant heating is also beneficial in buildings which are sparsely occupied, such heating being provided only in the area of the occupants.
3. The provision of ceiling-mounted fans to recirculate the warm air at ceiling level to the ground. These fans can vary from the small three-bladed slow speed fan up to much larger units, recirculating large quantities of air. The operation of these fans can be thermostatically controlled and fuel savings of 10–15% are quoted.

36.7.5 Insulation

Buildings should be insulated to as high a standard as possible, as should any part of energy-using equipment. As a guide to buildings, the following overall heat transfer coefficients (or *U*-values) are suggested, which are currently of lower value than the requirements of the Building Regulations:

Roofs	0.20 W/m^2°C
Walls	0.30 W/m^2°C
Windows	2.90 W/m^2°C
Exposed floors	0.30 W/m^2°C

The current Building Regulations (1990) call for:

Roofs	0.25 W/m^2 K (Dwellings)
	0.45 W/m^2 K (Other buildings)
Walls	0.45 W/m^2 K (All buildings)
Ground floors	0.45 W/m^2 K (All buildings)

In order to improve the standards of existing building insulation the following methods are available.

36.7.5.1 Pitched roofs

Provide a blanket of 200 mm thickness of fibre glass or mineral wool insulation on top of the ceiling plaster.

36.7.5.2 Flat roofs

Provide a similar blanket of insulation on top of any suspended ceiling which is 300 mm below the flat roof or an external hot liquid spray-on type of insulation to the roof finish.

36.7.5.3 Cavity walls

Fill the existing wall cavity with a suitable insulant such as fibre glass, rock wool, polystyrene beads or foam. The greater the thickness of the cavity, the lower the *U*-value.

36.7.5.4 Solid walls

Solid walls can only be improved either by removing the internal plaster layer and providing suitable blanket insulation fixed to battens and then covering with the required new internal finish or by applying an external insulant to the wall and a new external finish.

36.7.5.5 Windows

Double or triple glazing may be provided in this case, the main criterion being that the cavity thickness between the layers of glass must be at least 20 mm.

36.7.5.6 Exposed floors

If access is available to the area below the floor, provide 50 mm of rigid insulation between the floor joists, leaving an air gap between the insulation and the underside of the floorboards.

36.7.5.7 Air infiltration

Provide good draughtproofing strip around the door and openable window frames, leaving sufficient fresh air ingress for any combustion appliances.

On completion of such measures, the use of thermography should be considered as a survey, undertaken when the building is in use and heated, will highlight hot spots. Any hot spots may be due to poor workmanship or unnoticed building faults and can then be rectified.

36.7.6 Controls

In order to achieve optimum energy usage (hence maximum energy conservation) it is essential to provide accurate controls designed to suit the application and for those controls to be correctly installed. It is no use providing insulation and highly efficient energy or heat generators if that energy or heat generated is simply lost in the system by providing better standards of comfort than those required. In the absence of such controls on space heating, the provision of building insulation simply increases the internal temperature conditions and results in windows and doors being opened to lose this heat.

Controls are expensive and quickly become outdated by the increase in technology. They are also the items which are omitted or their quality is reduced if the total project cost becomes excessive. The difference in the quality of the controls against cost can be determined and should be included as part of the project budget or application.

A typical example is the provision of a single room-air thermostat to provide whole building control of space heating. It will work, but far greater economy can be achieved by providing building zonal controls or, better still, individual room heating control. Zonal control is available in the form of either two- or three-port motorized valves which open or close in conjunction with an internal air thermostat. Individual room heating control is in the form of individual thermostatic radiator valves and in internal air thermostats controlling on/off or three-port motorized valves.

Individual room temperature control is difficult with warm air systems, as any temperature control damper is likely to pass air at all times. Air thermostats are not accurate detectors of temperatures and temperature overshoot occurs, with consequent increases in energy consumptions and costs. The typical limits of these thermostats is ±1°C, and as the air in the thermostat is not at the temperature of the air in the room because the thermostat is remotely sited (usually on an internal wall) the actual air temperature in the room can be 1.5–2.0°C above the desired temperature. Modern temperature detectors are accurate to ±0.5°C and give much closer and better control.

Steam flow to vessels can be controlled by motorized valves, allowing timed control of the valve. Such valves can also be made to modulate rather than on/off operation.

36.7.7 Heat recovery

All the heat used to supply heating in buildings (and much of that provided in any process) is ultimately lost from the building. Recovery of as much waste heat as possible reduces the need to purchase fresh energy from the suppliers. Much waste heat is produced in the form of contaminated hot moist air and in process liquids which require cooling.

There are many ways of recovering the waste heat from these sources and the following should be considered:

The heat wheel
The heat pipe
The run-round coil
The heat pump

The great benefit of the heat pump is the possibility of upgrading the heat as compared to the other methods, and is popular in swimming-pool applications, where the heat recovered from the exhaust air can be used to heat the incoming fresh air and the pool water and to provide hot water for showers and washing purposes.

36.7.8 Lighting

Artificial lighting is used throughout the UK and this can now be provided by energy-efficient lamps which give high lumens per watt. A new range of fluorescent lamps is available and similarly high-efficiency lamps have been developed to replace the conventional tungsten lamp.

The problem of lamps being left on when not required can be solved by provision of automatic switching, of which there are a number of systems available. These can be time-switch controlled with manual override at the point of use.

36.8 The justification for energy-conservation measures

In many cases, areas of obvious energy conservation are not considered simply because a process or some space heating has always been undertaken that way. In order to persuade the organization's management to embark on such energy-conservation measures overwhelming evidence is required that the theoretical results suggested can be achieved. However, most energy-conservation measures do offer large financial savings with very short payback periods and lead to increased organizational profitability. The cost of such schemes has to compete with others for new capital equipment and their success could depend on the effect of energy costs on the total organization costs.

It is obvious that a scheme to reduce energy costs by, say, 10% may fail if the total energy bill is only 3% or 4% of the organization's costs when compared to, say, a new production machine costing ten times as much but which reduces the organization's costs by 10%.

If an energy-conservation scheme is to succeed it must be well prepared and presented to senior management. In the project application and budgets the objectives of the scheme must be clearly defined and the capital costs fully detailed. This may involve preparing several budget costs from various equipment manufacturers and contractors. In such cases it is necessary to read and note the 'small print', as any comparison has to be on a similar basis. This is extremely difficult to achieve, as both manufacturers and contractors omit certain items which may be required to be added later. The estimated energy and cost savings have to be identified as accurately as possible, and this is very difficult in view of the large number of parameters involved.

In formulating these savings the parameters used should be clearly defined so that the estimates can be revised for any alterations. Indeed, in some cases a computer program can be utilized which allows such changes to be evaluated very quickly (e.g. the TAS package for buildings). In the end the submission will stand or fall on the overall impact on the organization, so that it is essential to get it right first time. That saving on the bottom line is the major item.

A further factor to be considered is that of the national energy situation. Fortunately, in the short term there are available sufficient reserves of gas, oil and coal to meet the national need, so supplies should not be a problem. However, the prices of these fuels are subject to international as well as national policies. Currently, there is a relationship between heavy fuel oil and coal and also between gas and gas oil (see Section 36.2). In the long term, as supplies of oil and gas are reduced it is likely that increases in the price of gas will outstrip those of oil.

36.9 The mathematics of the presentation

Any presentation to the organization's senior management, besides giving the technical details, should include a financial appraisal which could be on a simple payback basis. However, other methods are available, such as return on capital employed and discounted cash flow (DCF).

36.9.1 Simple payback

This method of comparing the initial capital cost against the annual energy/cost savings is relatively easy. Unfortunately, it does not take into account certain factors such as:

1. The life of the project;
2. Any benefits after the payback period.

Normally, as the required payback period is short (i.e. 2 or 3 years maximum) and the length of life of the equipment is much longer than this, on the simple payback basis there are usually large financial benefits in the long term.

Let us consider two projects both costing £20 000 with the following savings:

Project 1: Annual saving £10 000, life of equipment 10 years
Project 2: Annual saving £8000, life of equipment 15 years

In terms of simple payback, project 1 has an excellent payback of only 2.0 years, while project 2 has a payback of 2.5 years. Thus it is likely that project 1 will be selected. However, project 1 has a life of 8 years after the initial payback period, the financial saving being £80 000, the equipment then requiring replacement. Project 2 has a life of 12.5 years after the initial payback period, giving a total financial saving of £100 000. Thus project 2 is the better case in the long term.

36.9.2 Return on capital employed

This method compares the initial capital cost with the cash flow over the life of the project. Thus in this case an accurate estimate of the equipment life is required. When a project has a long life (considerably longer than the simple payback period) the results can be different.

There are four ways in which return on capital employed can be expressed:

1. Gross return on capital employed;
2. Net return on capital employed;
3. Average gross annual rate of return;
4. Average net annual rate of return.

In this method each year's savings need to take account of the fact that, as the equipment gets older, the cost of maintenance and repairs is likely to increase. The effect of inflation can also be allowed for in assuming the annual cash flows through the life of the equipment.

Using the two projects in Section 36.9.1 as an example, the returns shown in Table 36.3 are likely. Of the four methods, the net return is generally favoured to the gross return as the loss of capital is a major factor.

36.9.3 Discounted cash flow (DCF)

This method, which is favoured by many accountants today, takes into account the concept that money has a time value. This is based on the fact that £1000 in 10 years' time is not the same as £1000 now. Similarly, if a project earns £1000 in 10 years' time this is not the same as £1000 spent now to help finance the project. If, instead of spending this £1000, it had been invested at compound interest, then in 10 years' time it would have become a much larger amount than £1000, depending on the interest rates in the prevailing period. The way that this is taken into account is called 'discounting'. Trading income produced for each future year by the project is discounted after allowing for maintenance and repairs, giving present values for that income.

There are various ways of discounting, i.e. 'net present value' (NPV) or 'internal rate of return' (IRR). Discounting should ideally be carried out over the whole life of the project but generally, after 10 years, the discount factors are small and make little difference.

The selection of the discount factor depends on the financial policy of the business, but is usually 2–3% above the current interest rates. Use of discounting methods will determine whether the project cost will produce a better return than by simply investing the capital involved at the highest compound interest rate or, if the capital cost has to be borrowed, whether the rate of return is much higher than the cost of borrowing.

Table 36.3

Method	*Project 1*	*Project 1*	*Ratio*
Gross return on capital employed	$\frac{1000\,000 \times 10 \times 100}{20\,000}$ = 500%	$\frac{8000 \times 15 \times 100}{20\,000}$ = 600%	1:1.2
Net return on capital	$\frac{[(10\,000 \times 10)20\,000] \times 100}{20\,000}$ = 400%	$\frac{[(8000 \times 15) - 20\,000] \times 100}{20\,000}$ = 500%	1:1.25
Average gross annual return on capital employed	$\frac{(10\,000 \times 10) \times 100}{(10 \times 20\,000)}$ = 50%	$\frac{(8000 \times 15) \times 100}{(15 \times 20\,000)}$ = 40%	1:0.30
Average net annual return on capital employed	$\frac{[(10\,000 \times 10) - 20\,000] \times 100}{(10 \times 20\,000)}$ = 40%	$\frac{[(8000 \times 15) - 20\,000] \times 100}{(15 \times 20\,000)}$ = 33.3%	1:0.83

36.10 Third-party energy management and finance

As indicated in Section 36.7, energy-conservation measures cost money, and in spite of the likely results indicated by any of the methods available (simple payback, discounted cash flow, etc.) it is possible that the organization's funds are not available for such schemes. Alternatives that should be considered are:

1. Leasing;
2. Hire purchase.

Many organizations now have their energy requirements managed by a heat service company. In this case the company will provide and operate all the energy-producing equipment on the organization's site. This could include space heating, air conditioning, combined heat and power (CHP), steam boiler plant and other services.

The contractor will purchase all the fuel required and provide all labour, repairs and maintenance, thus relieving the organization of all responsibility. In return, the contractor will require a contract (generally of up to 10 years) with the fees charged comprising a monthly fixed standing charge and a monthly variable charge, depending on the amount of energy used. Such an arrangement is useful for obtaining new equipment when finance is not available within the organization itself.

A variation of the heat management service is to have contract energy management (CEM). In this case the energy contractor will generally survey the existing plant and equipment and take it over, running it for the organization. As equipment becomes due for replacement the contractor will undertake this part of the contract.

The contract is usually for a period ranging from 3 to 9 years, but in this case the amount payable to the contractor is the same or similar to the costs prior to contractor take-over. A further clause is added such that a proportion of the savings made by the contractor are returned to the client (perhaps 2–10% of the previous annual costs). It may also be possible for any further large saving to be shared in agreed proportions between the two parties involved.

It is essential to have any agreement properly drawn up in conjunction with the organization's legal section and to use reputable and busy heat service companies. It is important to lay down strict details of the period of the contract and of the services to be provided so that future legal difficulties can be avoided.

36.11 Motivation

Energy conservation will succeed if all the particles involved wish it to succeed. It only requires ill will on one person's behalf to negate all the positive efforts made.

Typical problems which can occur are:

1. The unauthorized alteration of internal air thermostats and time switches;
2. The use of supplementary heating (e.g. electric fires without permission).

The unauthorized alteration of set parameters is the most common problem and it is possible to install tamperproof equipment, albeit at additional cost. There is also the problem of the relationship with the existing management (e.g. the senior manager who views the growth and success of the energy management team as a threat to the supervisor or department manager).

There are a variety of methods to avoid this, and the more senior the management structure that takes an interest in energy matters, the greater the success. Ideally, this should start with the chairman, managing director or chief executive. Once they believe in it, then their staff will follow suit!

These people are extremely busy with the overall organization's objectives and time for energy matters may be very limited. They should therefore delegate this to a senior officer. Energy matters may be left to the works engineer as an additional duty. Consideration should be given to the appointment of an energy manager who is qualified for the post and provided with a suitable job description and objectives. Such a job description could be based on the following:

1. The energy manager will be responsible for the total energy function of the organization.
2. He will be responsible to the chief executive and will achieve the objectives laid down by senior management.
3. The duties consist of (a) the most economic purchase of all forms of energy – in conjunction with the purchasing section; (b) the optimum use of all forms of energy for both process and building environment use – in conjunction with the various departmental and engineering managers.
4. The energy manager needs to form a team – an energy committee – to help him and this could comprise the managers of each department, whether production or otherwise, and other suitable people. The team must be small to be effective (less than 10 persons). Each department could then have its own energy committee.

Hopefully, the enthusiasm for energy conservation will spread downwards to all employees. Their help can be obtained by the use of competitions and suggestions.

36.12 Training

Few senior staff, works engineers or even junior staff have had training in energy matters. When energy was cheap, this was a small company cost (say, 1%) so that any cost-reduction measures were directed at other areas. Universities and colleges now include energy management as part of the curriculum in engineering and related courses. Newly appointed staff will be energy orientated.

For those staff who have never had the benefit of education and training in energy matters there are courses both by part-time attendance at college

and by correspondence. Details of the courses can be obtained from the Secretary, the Institution of Plant Engineers. Throughout the UK there are a large number of energy management groups where the members (who are nearly all energy managers) meet regularly to discuss energy matters. Thus it is possible to obtain training at all levels required.

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37 Inspection of plant and equipment

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37.1 Historical background

It is important to understand how the relationship between inspection and insurance, which is available from the major engineering insurance offices, came about. From the outset the objectives have been toward a safe and efficient operation of all types of machinery and plant when used in industry and commerce.

The early 19th Century saw the beginning of factory production systems, particularly in the cotton mills of Lancashire and the woollen mills in Yorkshire. Accidents arising from the use or misuse of steam plant, particularly steam boilers, became common and led to not only damage and destruction of property but also to death and bodily injury to persons in or about the scene of the explosions.

In 1854 the Manchester Steam Users Association was formed to help with the prevention of explosions in steam boilers and also to find efficient methods for these boilers to be used. To achieve this, the Association employed the first boiler inspectors, whose services were then made available to the Association's members. Within a short space of time the members became convinced that insurance to cover the high cost of repairs or replacements of damaged boilers was desirable, and this resulted in the first insurance company to specialize in boiler insurance (The Steam Boiler Assurance Company) which was formed in 1858. The scope of the services for inspection and insurance were later extended to include pressure vessels, steam engines, cranes, lifts and electrical plant, the insurance protection in each case being supported by an inspection service carried out by qualified engineers.

The development of engineering insurance has been closely linked with legislation. The Boiler Explosions Act was passed in 1882 and this empowered the Board of Trade to hold enquiries into the causes of all boiler explosions and to charge the cost of that enquiry against any person held to have been responsible for causing that explosion. This provided a strong incentive to insure boilers, and in 1901 the passing of the Factory and Workshops Act made the regular inspection of steam boilers in factories compulsory. This was later extended by legislation to include steam boilers in mines and quarries.

37.2 The 'fundamental laws'

A simplistic overview of the above will show that many of the hazards associated with these plant classifications have arisen because of mans need to interfere with the fundamental laws of nature. Hence in seeking to create power from atmosphere the air itself is compressed into a container (an air receiver) for tapping as required. This is not the natural state of atmospheric air. Compression will obviously significantly raise the air's pressure, decrease its volume and modify its temperature. Release of this compressed medium will restore it to its natural state, but the rate of release is important, the velocity of escape is significant, the temperature gradients will be sharp and invisible suspensions in the air will become mechanically active. It follows that the design and condition of the container and its pressure regulation system are important if potentially explosive forces are to be safely stored. Replace the cold air receiver with a hot water boiler and the problems associated with seeking to profit from the interference with a fundamental law of nature can be seen.

Similar problems arise with lifting plant, where the interference with gravity must be safely controlled, and with power presses where the interference with the laws of motion (normally rotational in this case), require very careful control. And so with magnetism for electricity. To these traditional matters are now added, more stringently than originally written, controls of dust emission, noise and electromagnetic emission.

37.3 Evolution of legislation

From those early days a great deal of legislation was passed, essentially designed to protect the interests of those who worked in various 'sectors' of industry. It was recognized that as industries developed they produced various hazards which needed to be guarded against and therefore the sectoral Regulations were specific to the work carried on in that sector.

A major piece of legislation introduced to the UK was the Health & Safety at Work etc. Act 1974 which ran alongside the sectoral Regulations, but for the first time delineated precisely who had responsibility within the various sectors.

With the greater integration with Europe has come the need to rationalize safety legislation. This process has essentially been to remove the barriers to trade, harmonizing the rules which govern safety without hindering innovation. This has taken the form of 'Directives', promulgations from the Council of Ministers which are required to be enacted in every EU member country. Thus whilst member countries retain sovereignty and may choose to enact Directives within existing national parameters, the essential characteristic of Directives must remain identical to the original requirements. In the UK, European Directives are translated into Regulations exactly in accordance with the UK's traditional legal methods. Hence the adoption of the Directive method of legislation has seen the elimination of the sectoral indigenous type of legislation.

As legislation has grown and changed, so the role of the independent inspection authority has had to change itself to meet the demands and needs of industry and commerce. Legislation, particularly that relating to health and safety at work is something which never remains static. As new areas of potential hazard are identified and their implications are discussed to the point that new legislation is needed, the engineering insurers make their contribution to those discussions. Such matters as the Pressurized Systems Regulations and those Regulations related to the Control of Substances Hazardous to Health have long been implemented with the engineering inspection authorities having made their contribution.

To the Pressure Systems Safety Regulations and the Control of Substances Hazardous to Health (COSHH) Regulations, has latterly been added the Provision and Use of Work Equipment Regulations (which of course

arise from a European Directive, known as the Use of Work Directive (and its amendments), this being just one of a number of Regulations introduced to the UK in satisfaction of European requirements.

This raft of legislation has fully replaced the long established sectoral Acts and Regulations, which have been effectively repealed or revoked.

The thrust of European Regulations has been to introduce 'goal setting' objectives with 'risk assessment' being of major importance, in place of the 'prescriptive' requirements of the earlier sectoral legislation. The thinking behind these objectives has been to ensure that *all* plant and machinery is subject to 'statutory' control and that accountability is clearly placed.

The repealed or revoked Acts and Regulations included the Factories Act, the Shipbuilding and Ship Repair Regulations, the Mines and Quarries Regulations etc., all of which and others are now defunct. This does not mean that the requirements of those Regulations have been lost, indeed the Directives arising from European legislation have ensured that all the best parts of the old sectoral Regulations have been retained in some form or another. Of paramount importance in promoting safety has always been the requirement for independent thorough examination, by a competent person. This always was and remains supplemented by the need for interim inspection on behalf of the owner or user. Therefore the requirement to use competent persons to exercise their technical judgement and experience in relation to the safety of industrial plant by way of thorough examination has remained unchanged.

The current legislation of most importance to operations engineers in the UK is

The Health & Safety at Work etc. Act
PUWER (The Provision and Use of Work Equipment Regulations)
LOLER (The Lifting Operations and Lifting Equipment Regulations)
The Supply of Machinery (Safety) Regulations
The Pressure Systems Safety Regulations
The Pressure Equipment Regulations

37.4 The Health & Safety Executive

In the pursuit of industrial safety the government charges its specialist organization The Health & Safety Executive (HSE) with all matters of policy implementation and enforcement. The HSE is itself arranged to include several grades or levels of expertise and at all levels the role of the Engineer Surveyor in relationship to thorough examination is fully understood. This close association with the role is frequently used as the sole basis for them to exercise enforcement. Ideally all parties to safety should work in harmony. Adversarial situations arise because one or more of the parties fails to observe the Regulations and this is frequently found to be due to a failure to action the matters identified in an Engineer Surveyor's report, or beyond this, for a party to have otherwise failed to discharge other relevant responsibilities such as maintenance or suitable repair or renewal. If the latter matters were routinely actioned then many more Engineer Surveyor reports would be 'clear', than regrettably the current case. It is not and never was, the intention that a statutory thorough examination report be a substitute for maintenance or the adoption of safe procedures, based presently on 'risk assessment'.

37.5 Evolution of inspection authorities

Thorough examination or inspection by independent persons or bodies as mentioned above, directed at safety issues, goes back to the middle of the 19th Century, predating even the earliest mentioned Regulations above. At that time the focus of concern was merely the explosion of steam boilers, and that hazard was most prevalent in the textile industry. The Manchester Steam Users Association initiated the need for industrial surveillance. This body carried out boiler examinations and only later added insurance as an inducement for plant owners to use their service. By the turn of the century, steam and gas engines and electrical machines had been added, followed by lifting equipment and other mechanical plant. This reflected the rapid increase in the use of mechanized machinery in industry as the industrial revolution gathered pace.

Those persons engaged in the technical activity of thoroughly examining or inspecting plant eventually became employees of the much larger insurance companies and took on the title 'Engineer Surveyor', which is essentially the working title applied to those who are known as competent persons at law. Current legislation has not changed these requirements, and has, in line with the old sectoral requirements, permitted anybody to undertake this role providing he has the necessary skills, training and experience. Thus competent persons do not necessarily have to be employees of insurance companies, although those who choose to practise need to be able to demonstrate very clear independence from the organizations which use their services. Such demonstration, to the satisfaction of the Courts, is clearly a difficult objective to achieve.

The role which Engineer Surveyors discharge is commonly termed 'inspection' and has been fully referred to as such above, but the precise role demanded by the old sectoral Regulations and the new Regulations is 'thorough examination', a phrase which is otherwise not well defined. Current legislation, that which has been derived from Directives, continues to differentiate the role of thorough examination from that of inspection. It is generally understood that inspection is a lesser entity than thorough examination, but none the less of much importance in promoting and maintaining safety in relation to hazardous plant and its usage.

Owners and users of plant which can be or become hazardous to users or to others therefore have a statutory responsibility to ensure that it is thoroughly examined and inspected and of course maintained. All three entities should be applied simultaneously. Safety should be the first objective, but avoidance of unscheduled stoppages and objective assessments of plant condition aimed at timely replacements can also be powerful commercial inducements to users and owners.

Given the changes which have occurred with great rapidity in trade and industry in the UK the traditional names associated with thorough examination and inspection have begun to pass and following a succession of mergers and acquisitions new names are now in the market place. Most of these names are not in fact entirely new, being amalgamations of the very long established companies who have operated in this field, therefore the experience and professional expertise expected remains available to industry at large.

37.6 Trade associations

To maintain the technical integrity of the services provided by Engineer Surveyors to trade and industry, it was clear that trade bodies were required to ensure that the level of service offered to industry was suitable and satisfactory. Initially the major engineering insurers formed a body known as the 'Associated Offices Technical Committee' and at a later date those established members of the industry who were not members of AOTC formed a further body known as the 'Independent Engineering Insurers Committee' (IEIC) which followed similar aims. With the suggestion that the old sectoral rules should be dismantled to be replaced by more modern legislation, it was necessary for the industry to speak with government with one voice in the furtherance of its aim of continued employment in the pursuit of industrial safety. It was not satisfactory for more than one trade body to approach government and it was agreed that a single trade body be formulated which would speak with a united voice for the whole industry. Both AOTC and IEIC were disbanded in favour of a new organization named the 'Safety Assessment Federation' (SAFed) which is currently the major trade body for the thorough examination industry. This body is recognized by government and by industry as being the body which presents the united views of its members and which upholds its professional standards.

SAFed has a Secretariat which chairs the forums of its members and has to date published a number of documents which are accepted as being the authoritative judgments on the matters to which they refer.

37.7 The Engineer Surveyor

It is obvious that the Engineer Surveyor has responsibilities in many directions. He is of course an employee of the inspecting authority, usually but not necessarily an insurer of engineering perils, but he also has responsibilities with respect to the title 'competent person', which is enforceable at law. He also has responsibilities to his company's client whose plant he is routinely thoroughly examining and who need to rely upon the judgments which he makes, even though they may be commercially unattractive. Thus the legislative requirement for such a person to be independent of the plant and the user to permit him to speak without 'fear or favour'. His voice of course is carried in the statutory report of thorough examination which itself is a fully legal document.

Engineer Surveyors are selected according to their past experience and academic attainment. The traditional requirements have hardly varied for decades, it being recognized that the fully proficient Engineer Surveyor needs to be both practical and technical. It has been traditional to recruit Engineer Surveyors from the ranks of allied industry, therefore those specializing in the mechanical subjects are likely to have previous experience in medium to heavy engineering whilst those specializing in the pressurized aspects are more likely to have a seagoing or power station background. Similarly those engaged in electrical examinations and all its variants will have been specifically trained in that field. It is not regular or usual for Engineer Surveyors to practise in more than one field at the same time.

Academically the demands of the job are in excess of those normally found in workshop personnel, the job has a high degree of technical input and needs a thorough understanding of engineering principles and the technical solutions of problems. So whilst an Engineer Surveyor is not routinely expected to make calculations in relation to the plant which he examines, he does need to understand the origin of those calculations by how they are made and what the results signify.

Essentially the requirements are for maturity, thus Engineer Surveyors are seldom recruited below the age of 25. Evidence of early industrial training is needed such as a documented apprenticeship or cadetship and academic attainment to enable them to combine the other attributes and hence become Incorporated Engineers as recognized by the major engineering institutions. With the decline of heavy industry in the UK the pool of persons available for consideration for employment as Engineer Surveyors has become much reduced. Apprenticeships as traditionally understood are very few and far between, having been replaced by government initiatives most of which are of less duration than are required to fulfil the industry's requirements. There has been a dramatic increase in the numbers of persons attaining high academic qualifications, but given the changing nature of industry the actual technical content of these courses needs close examination. With the passing of the heavier industries such as ship-building, coal, mining etc., the pool from which Engineer Surveyors was traditionally selected has all but ceased.

37.8 Training the Engineer Surveyor

Recruitment of applicants for entry into service as Engineer Surveyors has become much more difficult which has resulted in the length of time required to train a successful applicant into the position being lengthened somewhat in order to ensure that the final product meets the required standard.

The period of training following engagement varies depending on previous experience, but is never less than 3 months and is frequently as much as 6 months. Trainees are not released until they fully satisfy the requirements for 'competency', the attainment of which is bestowed only after they have completed an intensive course of instruction followed by assessment. Trainees are streamed into their particular speciality, either mechanical.

37.9 The report

The Regulations which cover thorough examination include within them a requirement for a report to be issued. The Regulations also dictate the content of the forms to be used. Each report must contain the minimum requirements which are shown in the copy report specimen (Appendix A).

Of course the technical content is at the Engineer Surveyor's discretion, it is he who determines the actual condition of the examined plant, its compliance with Regulations and its likelihood of remaining in service without prejudice to the safety of persons. Because current Regulations are directed at 'safety of persons', the Engineer Surveyor's attention is directed principally to that matter. Defects which are revealed which are considered to be developing are adjudged in this context. The Regulations concerning thorough examination are not directed at other matters such as routine maintenance (although maintenance itself is a statutory requirement in its own right, and failure to maintain might result in hazards being presented to persons), nor at financial worth or process suitability. These are matters for the Operations Engineer to evaluate himself. It is incorrect therefore for reliance to be placed on the report for anything other than an indication of the items continued use with respect to its safety of persons. The report might indeed mention these other matters, but it is not its principal purpose.

Of paramount importance is the practicality of the arrangements for the thorough examination and their periodicity. Also of importance is the interpretation of the final report once received. The Regulations are specific on these points and the onus is clearly placed on the plant owner (normally referred to in the Regulations as the 'employer'). Many instances are known where employers have failed in the eyes of the Law to discharge their responsibilities satisfactorily.

So far as defects identified by the Engineer Surveyor as likely to cause imminent danger to persons (any person, not merely the operator or the driver) are concerned then the Regulations require the Enforcing Authorities to be notified of that defect. This notification is required to be against a specified time period for its correction which is either immediately or within a short period, normally up to 3 months from the date of the report. The Regulations also require the owner of the plant to be notified immediately of defects which fall into this serious category and Engineer Surveyors have agreed procedures for ensuring that this happens direct at site. The Authorities are empowered to 'enforce' either improvements or prohibition on continued usage and they may consider recourse to the Courts if appropriate. It follows that neglecting to afford safe and timely access to plant and machinery, or failing to act on the technical content of the resultant report can have very serious consequences. Those who have responsibilities for industrial plant should understand the gravity of failing to abide by the Regulations fully.

The report itself will be generated individually by the Engineer Surveyor whose home office will be fully equipped with modern computer systems for accessing necessary databases. He can compare his present findings with previous report entries to permit an additional dimension to be added to his decision making process.

The computer network is much greater than that needed for report generation. It allows for centralized costings to be applied, the compilation of customer schedules, for management information to be collated to promote effective control of the field force, and for the efforts of the field force to be focused as required. Regulations permit 'electronic signature' to be applied to reports, subject to stringent controls thereby endorsing the document at the appropriate legal level.

The controls which are applied are exercised by the Engineer Surveyor's Senior and Head Office support staff who 'audit' reports both on a rotational and a random basis to ensure that determined standards are consistently met. These standards are detailed in internal procedures which form a part of every responsible Inspection Company's 'quality' system which itself is subject to approval and periodic external audit by specialist assessors. Those who choose to apply thorough examinations from within their existing organization, as may be permitted by current Regulations subject to certain constraints, or from non accredited third parties, need to understand that Reports which subsequently arise are likely to be used by Courts in the event of disputes, and must therefore be properly 'impartial' and fully reflective of the needs of Regulations. For most, achievement of these matters is both technically and logistically extremely difficult.

37.10 Recognition of defects

The components which make up an item of industrial plant are subject to a variety of defects or deteriorations which need to be detected during thorough examination. The majority are not too difficult to find, the Engineer Surveyor's trained eye and experience will enable him to quickly ascertain the principles of operation of the whole machine and to accurately determine where deteriorations or defects are most likely to arise.

With a good knowledge of design he can readily identify which members in a structure are likely to be accepting the highest stress concentrations and what the nature of those stresses are likely to be. He will not otherwise be able to determine the exact magnitude of those stresses. Structural members under compressive stresses are more likely to fail due to buckling, if the cross sectional shape of the member is not adequately proportioned and disposed. Tensile stresses are usually less problematical, but the effects of bending stresses and torsional stress concentrations need careful consideration. Combinations of these stresses are likely to compound any deteriorations or defects which are developing.

The designer will have addressed these matters and ordered his design to suit, but in service the structure and its components will certainly suffer from the degrading effects of corrosion, vibration, fatigue, wear or combinations of them all. Many structures will suffer also from poor workmanship during construction. Misaligned members might have been forced into alignment, fastenings might have been under or over tightened, or

in some cases not fitted at all. Weldments are often poorly made, permitting eccentric stress transference or merely lacking sufficient penetration or fusion at joints to realize the designer's intentions. Serious consequences arise from simple misuse such as repeated over straining or uncontrolled motions, where adjacent structures or their individual components collide. These collisions, frequently unreported by operators, subject the assemblies to uncovenented impact loadings, often in areas where the designer had not thought it necessary to make compensation. Similar problems will arise from the mechanisms of machinery where gear degradation, shaft misalignment, coupling insecurity etc. will lead to increased wear or derangement of parts with consequent loss of operational control.

The Engineer Surveyor's prime responsibility is to determine the likely consequences to 'persons', he is not necessarily vigilant to 'maintenance' matters which if uncorrected will lead to downtime or lessening of efficiency. These are additional penalties that owners pay for failing to apply a satisfactory maintenance regime.

37.11 The examination

The nature of the examination is 'in-service' which means that the item to be examined is seen in its operational condition. The Engineer Surveyor will need to see it in converse conditions. If it is stopped, it will require to be started and vice versa, so that he can closely visually examine the individual components to his satisfaction and then see them demonstrated under loaded conditions. It is not necessary for him to see the item under maximum safe working load or pressure or at full speed, unless he so determines. He is the final arbiter. It is not necessary for him to have every concealed or hidden part fully or even partially exposed. He has recourse to clear technical guidance on these issues and interprets that guidance according to his opinions reached directly at site.

Where the Engineer Surveyor suspects a developing defect he might call for deeper strip down and arrange for this to be supplemented with non-destructive testing. He is trained to ensure that such services are provided by appropriately qualified personnel and that the results are interpreted professionally. Where adverse situations repeatedly arise, the Engineer Surveyor will ensure that not only is the matter corrected, but that his supporting office is fully advised so that necessary alerts can be put to the rest of his colleagues in the field force and to the manufacturer. It might be necessary to advise the HSE, over and above the routine statutory notification which is made on incidental defects which have been adjudged deleterious to the safety of persons.

Thus in making an examination of a regular item of machinery, let us suppose a mobile crane, the Engineer Surveyor must bring to bear his considerable knowledge of design, fabrication, machine shop practice, assembly procedures, hydraulics and wear criteria. He must also consider strength and stability characteristics for the individual item under examination. He must apply some or all of these considerations to individual components and also to the entire assembly. Thus his attention to the wire roping system on this particular crane must be as thorough as to the plate weldments on the chassis or indeed the integrity of the hydraulic system. A failure of any one of these aspects could lead to a catastrophic situation. He must overlay his considerations with detailed knowledge of Regulations and Standards for this type of crane and ascertain that any special requirements applicable are both fitted and working. Hence he needs to consider loading control devices which might protect the crane even if in pristine condition, from the effects of overloading or induced instability. There are of course many other similar considerations on just this type of item.

Just such a regime would be adopted if the examined item was an air receiver or a power press, although the Engineer surveyor accepting those responsibilities would have been selected, trained and authorized in those specific disciplines to ensure the maximum technical expertise was applied.

Engineer Surveyors must apply their knowledge of materials to their opinions, ensuring for example that they note the behaviour of dissimilar metals co-joined. The propensity for some materials to craze or crack locally when overheated must be considered and evaluated. Similarly, certain materials tend to extrude locally when subjected to high bearing pressures. Incorrect consideration of these and many other phenomena might cause unnecessary downtime and the expense of replacement of parts. On the other hand he may unwittingly be accepting a developing adverse situation.

Many failures are 'sudden', assumed to be instantaneous, when in fact a number of contributory factors might have been known to have been developing for some time. It is on these occasions that the true benefit of expert maintenance as opposed to post incident repair becomes evident. The Engineer Surveyor would have considerable experience of having consistently reported the existence of minor deteriorations to his customer which have eventually resulted in catastrophic failure, and for which no preventative maintenance had been periodically applied at all.

This category of deterioration can be as simple as an ineffective holding brake serving a fork truck. Despite repetitive report entries calling for rectification, it is frequently the case that no corrective action has ensued. The owner has considered the matter insignificant in relation to the greater demands from his process. In an emergency situation, supporting a full palletized load and needing to hold steady on an inclined ramp, the fork truck can inch forward trapping a person against a wall. The owner's defence of this matter becomes virtually impossible.

37.12 Repairs and renewals

Of much concern to an Engineer Surveyor is the determination of the worth of repairs. If he identifies a defect which requires to be corrected his report will say so, but it is beyond his remit to advise on how the repair shall be effected. Although he will have this knowledge, the subject must be dealt with via qualified repairers in consultation with owners, perhaps in direct liaison with the manufacturers or their agents. Frequently Engineer

Surveyors discover at subsequent examination visits following repair, that the execution of that repair has left the item in a lesser state than before that repair was attempted!

The Engineer Surveyor is assisted in his considerations by direct reference to his supporting office if he so desires, whose Senior Engineers can combine knowledge to advise him and his clients of current best practices and appropriate courses of action. His supporting office will be equipped with direct access to the numerous Standards, Codes of Practice and Guidance Notes, with reference to the particular situation in question. This information will be overlaid with specific knowledge of similar occurrences elsewhere, at home and abroad. Thus the Engineer Surveyor will be in early receipt of 'service alerts' from manufacturers or market knowledge of 'rogue' components or practices.

37.13 Plant classification

The particular classes of plant which needed inspection were decided by Government, arising from the perception of hazards which frequently materialized and often resulted in injury or worse. Traditionally these classes were:-

Pressurized plant
Lifting plant
Power Presses

Although these classes remain today as hazardous, despite many advances in design manufacture and maintenance and of course improved operating training, a number of other classes have been added. These include:-

Electrical plant
COSHH
Woodworking plant
Display screen equipment

Whilst Operations Engineers will understand the old 'statutory' provisions for the foregoing listings and also understand the newer requirements arising from the "6 pack," they need to remember that PUWER concerns all machinery supplied to workers as a tool for use at work. A list of typical items follows, with an indication of which is likely to be subject to LOLER and which to PUWER. Whilst of some detail, the listings are not fully comprehensive given the very wide range of industrial plant and processes covered by the said Regulations.

The listings give a recommendation for the frequency of inspection (for plant subject to PUWER) and thorough examination (for lifting plant subject to LOLER). Frequency of thorough examination of lifting plant as shown in LOLER and is essentially at 6 monthly intervals for a lifting machine which carries persons and for any item of lifting tackle. For the remainder of the items the recommendation is for 12 monthly thorough examination. Where dual frequencies are shown it is due to the fact that the item of plant might occasionally carry persons. LOLER does permit 'schemes of examination' to be used in place of set periodicies. LOLER also requires examination wherever an item of lifting plant has been subject to adverse situations (such as excessive loading). PUWER does not specify directly the frequencies of inspection. (Appendix B).

Engineer Surveyors are increasingly active in all of these fields, their employers offering a very comprehensive specialist service to industry for each.

37.14 Risk assessment

Modern regulations place onerous duties on 'employers' to 'risk assess' *all* of their activities at all levels of these activities. The dated concept of merely addressing those matters mentioned directly in regulations and largely ignoring much of the remainder, has passed. Those employers, often represented by their Operations Engineers, who questioned the need for maintenance, inspection and thorough examination simply on the basis of whether or not the plant activity was mentioned in regulations and therefore 'statutory', would not be satisfying the spirit of the intentions of modern 'goal based' regulations. The 'goal' is intended to be the achievement of safe working environments, initially addressed by the assessment of risk, the achievement of which cannot be wholly dependent on Government Regulations, which of necessity are somewhat remote from the actual workplace, the machinery within the workplace and its daily usage.

Of increasing concern with respect to risk assessment must be the tendency for employers to largely dispense with dedicated in-house operations personnel, those personnel with training, qualifications and experience gained over many years and in direct association with hazardous plant.

37.15 Specific aspects of regulations

37.15.1 Pressure

The Pressure Equipment Directive 97/23/EC (PED) covers pressure equipment and assemblies with a maximum allowable pressure above 0.5 bar. The intention of the legislation is to remove technical barriers to trade between community members by harmonizing national laws regarding the design, manufacture, marketing and conformity assessment of pressure equipment.

The range of equipment covered is wide and includes items such as reaction vessels, pressurized storage containers, heat exchangers, shell and water tube boilers, industrial pipework and safety devices. This Directive is transposed into UK law by the Pressure Equipment Regulations 1999 (PER), which is essentially concerned with the supply and putting into service of pressure equipment but not its in-service use.

Pressure systems in-service are covered by the Pressure Systems Safety Regulations 2000 (PSSR) but the scope of PER and that of PSSR are not exactly the same. For example, the scope of PER does not include any fluids at or below 0.5 bar but PSSR includes steam at any pressure.

PER divides pressure equipment into categories based on the degree of danger from the stored energy (on a quantitative basis) and the danger from the release of contained fluid (on a dangerous substances classification basis). PSSR however, is concerned primarily with the release of stored energy and the scalding effects of steam.

PSSR covers design and construction of pressure systems that is not within the scope of PER and also addresses duties placed on the users and owners of systems with regard to maintenance and continued safe operation. It also requires systems containing a relevant fluid to be assessed by a competent person to determine any need for a written scheme of examination for periodic examination of the system so as to detect conditions that might lead to failure.

Relevant fluids, which are defined in PSSR, include compressed gases and fluid mixtures with a vapour pressure above 0.5 bar, pressurized hot water above both its atmospheric boiling point and 0.5 bar and steam at any pressure.

Certain systems and parts are excepted from some or all of PSSR, based on the reduced risk from little stored energy or the particular use where they are covered by other more appropriate legislation. However, owners and users of pressure systems are still likely to have duties under the Health and Safety at Work etc. Act 1974 and the Provision and Use of Work Equipment Regulations 1998.

37.15.2 Lifting

Lifting plant is legislated for in the Lifting Operations and Lifting Equipment Regulations and is divided into two distinct types. These are either regular lifting plant or people lifting plant. The former can be classified generically as cranes and the latter generically as lifts, although there are numerous examples of the former being used, at least temporarily, as substitute for the latter. In such cases special rules apply to ensure that the safety of persons to be lifted by cranes and their varients is maintained.

Typical examples of lifting plant in these two classes include:-
Lifting tackle (ropes, slings, shackles etc.)
Lifting attachments (for fork trucks or for cranes)
Cranes (mobile, overhead)
Mechanical handling plant (fork trucks, excavators)
Lifting structures (jibs, towers, frameworks) and for Lifts
Passenger lifts
Tail lifts (lorry mounted)
Access equipment
Window cleaning equipment

and many varients, the list is virtually endless.

37.15.3 Electrical

Electrical plant is legislated for in the Electrical Regulations. Electrical plant includes generating equipment, rotating plant, fixed wiring installations and portable electrical appliances. The application of electricity is virtually total, hardly a machine operates which if not electrically driven is at least electrically controlled. Miniaturization has led to the development of electronics and especially computerization. These are all areas within an inspection company's competence and many services are offered in pursuit of electrical safety.

There are of course other types.

37.16 Consultancy services

A fully integrated inspection authority will have in addition to its regular periodic service covering thorough examination, a specialist department normally entitled Consultancy Services.

The Consultancy Services Department is staffed by specialist engineers and they provide a service to industry, very often existing clients but not exclusively, with respect to the exacting detail of all of the plant in question. This service can range from checking calculations and designs for accuracy and for compliance with recognized standards or can provide original calculations and designs to solve particular problems.

The service frequently requires the services of an Engineer Surveyor in the field who will make the necessary measurements and collate the information arising from many sources so that the head office based Consultancy Services Engineer can attend to his work with accuracy. For certain classes of plant it may require an Engineer Surveyor who frequently visits site to check progress and to ensure that the design intentions are realized.

The Consultancy Services Engineer has a very deep knowledge of all of the standards applicable and understands the minutae of the Regulations invoked.

For pressure plant the service can be divided into pre-commissioning services and post-commissioning services, both of which can be differentiated from the routine periodic work of an Engineer Surveyor. It is occasionally necessary for personnel to attend re-design meetings to discuss the best and most efficient service in coverance of the project and to determine the precise standards and objectives. Once a drawing or a design is approved, the work to the pressure plant will proceed and the Engineer Surveyor will liaise with the Consultancy Engineer with respect to the identification of materials, the quality of constructions, the adherence to weld procedures, operator performance qualifications etc. Once completed, the item will be tested prior to entering service and again the Engineer Surveyor will be instrumental in carrying out the wishes of the Consultancy Engineer.

For cranes, the service would be somewhat similar if the crane itself were being built, although the service most frequently centres around the testing of cranes, especially where that crane is likely to be working in arduous conditions. Unusual uses of cranes, such as for tandem or multiple lifting are also covered by Consultancy Services procedures, where it is recognized that additional technical advice is required. In service a number of cranes

are subjected to external forces causing derangement of parts or fractures of the structures and Consultancy Services Engineers frequently advise on the best technical solutions and assist in progressing these aspects.

A similar situation exists with lifts and a service is available to ensure that the appropriate designs are selected and that the resultant installation is likely to enter service with the minimum of problems. High speed passenger lifts are subjected to manufacturers' functional tests and dynamic tests and Consultancy Engineers often oversee or witness these tests and examine or scrutinize the resultant reports and certificates to ensure full compliance with regulations and standards.

These same Consultancy Services considerations can be applied to electrical installations where examination and witnessing of manufacturers' own tests can be undertaken independently and impartially.

An important aspect of the Consultancy Services Department is its attention to Non Destructive Testing and specialist engineers are retained with skills in this important industrial service. Increasingly their services are being called upon where repairs are made or defects are suspected. Sometimes the services are initiated by Engineer Surveyors who require support and additional advice, but increasingly industry recognizes these specialist skills and attainments and seeks the services independently. Often the services are applied to items of plant which are not subject to routine periodic examination, being specialist plant, but possibly high integrity or high value plant.

In association with non-destructive testing is the application of full metallurgical testing, frequently carried out at metallurgical laboratories. The purpose of this Consultancy Service is to offer interpretation of what might otherwise be very deep and technical reports arising from specialists in other fields of engineering. These services are not limited to the traditional pressure/lift/electrical work, but are increasingly being used by other design offices who need the verification and validation of designs for such things as bridges, structures, dams, dockside installations and numerous other types of industrial plant.

Appendix 1

Power Press, Guard or Protection Device Report

Provision & Use of Work Equipment Regulations 1998
Part IV

Thorough Examination

Name of User: Policy Number:

Location: Report Number:

---

1 Make, type and date of manufacture (if known)

a) Power Press
b) Protection Device(s)

2 Identification mark or number

a)	**Power Press**	Maker's	Occupier's
b)	**Protection Device(s)**	Maker's	Occupier's

3 Are the following parts of the press and protection device(s) in good working order?
If not, state what defects have been found and which require remedy

a) Power Press
i) Clutch mechanism
ii) Clutch operating controls
iii) Brake
iv) Flywheel bearing(s)
v) Other parts affecting safety at the tools

b) Protection Device(s)
i) Interlocking guard
ii) Automatic guard
iii) Fixed Fencing (inc. that associated with i), ii), and iv))
iv) Other type of protection device (e.g. photo electric)

c) Other

4 What Parts (if any) were inaccessible?

5 Repairs, renewals or alterations to the power press and protection device(s), to remedy defects, which are or may become a cause of danger to employed persons.

a) Before the press is again used
b) Within a specified time, as stated
c) Date when client was notified

6 Observations and recommendations

7 Repairs, renewals or alterations required in item 5 of this report, completed at the time of this thorough examination and test.

Competent Person

Date of completion of examination and tests

Date of Report

Engineer Surveyor

Lift Report

Lifting Operations & Lifting Equipment Regulations 1998
Provision & Use of Work Equipment Regulations 1998

Thorough Examination

Name of User:

Policy Number:

Location:

Report Number:

---

1 a) Description, unique identifier or number

b) Location of Lift

c) Date of last examination

d) Date of current examination

e) Latest date by which the next inspection should be carried out

f) Examination Scheme number

2 Defects which could cause a danger to persons. Particulars of any repairs, renewals or alterations to rectify those defects and the time within which those defects shall be rectified.

a) Enclosure of liftway.

b) Landing doors and car doors.

c) Interlocks on the landing doors and car gate(s).

d) Other door fastenings.

e) Car or platform and fittings, car guides, buffers, interior of the liftway.

f) Over-running devices.

g) Suspension ropes or chains, and their attachments.

h) Safety gear, i.e. arrangements for preventing fall of platform or car.

i) Brakes.

j) Worm, spur gears or jacks.

k) Other electrical equipment

l) Other parts.

3 What Parts (if any) were inaccessible?

4 Other Defects
Identification of any other part found to be deteriorating and which requires to be rectified.

5 Observations and Recommendations.

6 Safe Working Load.

Competent Person

Date of completion of examination and tests

Date of Report

Engineer Surveyor

Escalator or Passenger Conveyor Report

Workplace (Health, Safety and Welfare) Regulations 1992

Thorough Examination

Name of User: Policy Number:

Location: Report Number:

---

1 a) Type of installation and description, unique identifier or No

b) Location of Escalator/passenger conveyor

c) Date of construction or reconstruction (if ascertainable)

2 Defects which could cause a danger to persons. Particulars of any repairs, renewals or alterations to rectify those defects and the time within which those defects shall be rectified.

a) Balustrades (including gaps between the steps and skirting)

b) Treadway

c) Treadway interconnections

d) Combplates and terminal guides

e) Overspeed governor

f) Emergency stop switch(es)

g) Broken chain device

h) Broken drive device

i) Non reversal device

j) Brakes

k) Worm or spur gear

l) Chains

m) Other electrical equipment (including insulation etc.)

n) Balustrade skirting deflector devices

o) Other parts

3 What Parts (if any) were inaccessible?

4 Other Defects
Identification of any other part found to be deteriorating and which requires to be rectified.

5 Observations and Recommendations.

Competent Person

Date of completion of examination and tests

Date of Report

Engineer Surveyor

Report of a Pressure System or Part

Pressure Systems Safety Regulations 2000

Name of User: Policy Number:

Location: Report Number:

Written Scheme No.

Identification of System

Is the system subject to lease/hire arrangements? (i.e. Written agreement under Schedule 2)
Is any change advised in the scheme of examination?

Result of examination

Date beyond which the system may not be operated without further examination under the Written Scheme

1 Item Description
Plant Number
Serial Number
Manufacturer
Year of manufacture
Location on Site

2 Relevant History including tests and dates

3 State whether last report seen

4 Type of examination and test(s) undertaken

5 Parts covered but requiring periodic examination and date of last examination

6 Parts inaccessible (other than 5)

7 Condition of:
a. Internal parts
b. External Parts
c. Fittings

8 a. Safe Operating Limits
b. Are protective devices operating in order to maintain the system part(s) within the Safe Operating Limits?

9 a. Repairs or modifications, if any, and date to be completed
b. Are changes to the Safe Operating Limits required?
i Before the expiration of the period specified in 9a
ii After the expiration of such period if the required repairs have not been completed
iii After the completion of the required repairs

10 Other observations

Competent Person

Date of completion of examination and tests

Date of Report

Engineer Surveyor

Lifting Machines and Accessories Report

Lifting Operations & Lifting Equipment Regulations 1998
Provision & Use of Work Equipment Regulations 1998

Thorough Examination

Name of User:

Policy Number:

Location:

Report Number:

Competent Person

Date of completion of examination and tests

Date of Report

Engineer Surveyor

Appendix 2

Provision and Use of Work Equipment Regulations 1998 (PUWER 98) Guidance List of Work Equipment Requiring Inspection

Saws	T	12
Blow moulding machine	T	12
Conveyors, including passenger carrying	T/C	12
Coremaking machine	T	12
Die casting machine	T	12
Dock leveller	C	12
Drop hammer	T	12
Extruding Machine	T	12
Flying shear press	C	12
Hydraulic banding machine	T	12
Hydraulic paddle forming machine	C	12
Looms	T	12
Mixing machinery (industrial substances)	T/C	12
Piercing machine	C	12
Powder compaction machine	C	12
Process line machines (used in the mfg and prodn of items/substances)	T/C	12
Robotic systems	T/C	12
Rolling Mill Cooling Beds	T	12
Rotary tablet making machine	T	12
Sole moulding machine	C	12
Spot welding machine, c/w hydraulic clamping	T	12
Steel coil slitting lines	C	12
Steel sheet cut-to-length lines	C	12
Tyre moulding machine	T	12
Vacuum moulding machines	T	12
Press Type machines not covered by section IV of the PUWER 98		
Friction screw press	C	12
Horizontal extrusion press	C	12
Pneumatic/Hydraulic presses/press brake (moveable/fixed guarding)	C	6/12
Injection moulding machines	C	12
Isostatic press	C	12
Press type machines not listed in schedule 2 of PUWER 98	C	6/12
Manual press	C	12
Power press used for non metals (moveable/fixed guarding)	C	6/12
Spotting press	C	12
Waste and Scrap Industry		
Baling machine/press	T/C	12
Paper shredding machine	T	12
Shearing machine	C	12
Waste compactors	C	12
Waste disposal units	T	12
Waste skips (if not adopted under LOLER)	T	12
Woodworking Industry		
Saws for wood	T	12
Woodworking machinery	T/C	12

Lifting Operations and Lifting Equipment Regulations 1998 (LOLER) Guidance List of Lifting Equipment Requiring Examination

Main Item	Considered to Include	Examination Periodicity (Months)
Cranes	Jib Cranes, Static & Rail Mounted	12
	Container Cranes	12
	Crawler Cranes	12
	Derrick Cranes	12
	Dockside Cranes	12
	Goliath & Semi-Goliath Cranes	12
	Lorry Loaders	12
	Overhead Cranes	12
	Pillar Jib Cranes	12
	Portable Jib Cranes	12
	Portal Cranes	12
	Shipbuilding Cranes	12
	Tower Cranes	12
	Transporter Cranes	12
	Wall Jib Cranes	12
	Telpher Cranes	12
	Concrete Pumping Boom	12
	Pipe Laying Machine	12
	Excavator	12
Elevators	Bucket Elevator	12
	Elevator	12
	Elevator, Man Riding	6
Hoists and Lifts	Ash/Coke/Skip Hoist	12
	Builders Hoist, goods only	12
	Builders Hoist, passenger	6
	Passenger Hoist/Lift	6
	Goods only Hoist/Lift	12
	Passenger/Goods Hoist/Lift	6
	Inclined Material Hoist	12
	Service Lift	12
	Home Lift	6
	Paternoster Passenger Lift	6
	Paternoster goods only	12
	Scissor Lift	6
	Stair Lift	6
	Teagle Hoist	12
Patient Hoist	Patient Hoist	6
Winches	Winches, if used for lifting loads	6/12
	Capstans, if used for lifting loads	6/12
Sheer Legs	Sheer Legs with winch	6/12
Blocks	Rope	12
	Hoist	12
	Manual	12
	Powered	12
	Pulley	12
	Snatch	12
	Chain	12
	Ratchet	12
	Gin Wheels	12
	Hook Hoist	12

(*continued overleaf*)

(continued)

Main Item	Considered to Include	Examination Periodicity (Months)
Safety and Rescue Equipment for Supporting, Raising and Lowering Persons	Arborealists Equipment	6
	Bosuns Chair	6
	Mountain Rescue Sets	6
	Fall Arrestor/Retractable Lifeline	6
	Harness with Lanyard	6
	Safety Belts	6
Miscellaneous Items (Provided for the Support of Lifting Gantry Equipment)	Anchorage, Suspension Point	12
	Tracks	12
	"A"-Frame	12
	Overhead Gantry	12
	Davits	12
	Gantry	12
	Jib Arms	12
	Overhead Crane Bridges	12
	Runway Tracks & Beams	12
	Trolleys	12
Lifting Accessories	Eyebolts	6
	Cradle	6
	Fork Attachments	6
	Fork Lift Truck Attachments	6
	Girder Clips	6
	Grabs	6
	Hooks	6
	Lifting Beams/Frames	6
	Lifting Lug/Bar/Plate/Arm	6
	Magnets	6
Lifting Accessories (Continued)	Plate Clips	6
	Rigging Screws	6
	Running Out Block/Pole Carrier	6
	Shackles	6
	Slings	6
	Vacuum Lifting Devices	6
Access Equipment, Suspended	Suspended Access Equipment	6
	Window Cleaning Rig	6
Work Platforms	Work Platforms	6
	Mast Climbers	6
	Mast Hoists	6
	Bridge Maintenance Access Equipment–where lifting is involved	6
Platform Stacker	Platform Stacker	12
Car Parking Systems	Car Parking Systems	6/12
Vehicle Recovery Equipment	Vehicle Recovery Equipment	12
	"Spectacle" Frame	6
Tailboard Hoist/Lift	Tailboard Hoist/Lift	6/12
Jacks	Jacks, multistage	12
	Jacks, trolley	12
Vehicle Lifts	Motorcycle Lifts	12[6]
	Vehicle Lifts/Hoists	12[6]
Vehicle Skip Hoists	Vehicle Skip Hoists	12
Road Vehicle Wheel Lifter	Road Vehicle Wheel Lifter	12

(*continued*)

Main Item	Considered to Include	Examination Periodicity (Months)
Drum, Coil, Roll, Lifting Device	Drum, Coil, Roll, Lifting Devices, including where fitted to process plant	12
Fork Lift Truck	Fork Lift Truck	6/12 [6]
Pallet Trucks	Pallet (lift) Trucks, Manual and Powered	12
Order Pickers	Order Pickers, Inclined	6/12
	Order Pickers, Overhead	6/12
Pick & Place Robot	Pick & Place Robot	12
Loading Shovel	Loading Shovel	12
Straddle Carriers	Straddle Carriers	12
Telescopic Load Handler	Telescopic Load Handler	6/12
Lighting Mast	Aerial Mast	12
	Lighting Rigs where lifting is involved	12
	Articulated Lamp Post	12
Balancers	Tool Balancers	12
Cable Drum Raising System	Cable Drum Lifters	12
Stage Equipment Hoist	Stage Equipment Hoist, utilities, scenery, stages	6/12
	Camera Boom	6/12
Gymnasium Equipment	Gymnasium Equipment, if used at work	12
Palletizer	Palletizer, Electric, Hydraulic, Pneumatic	12
Piledriver	Piledriver	12
Drilling Rigs	Drilling Rig, where lifting is involved	12
Rail Tamping Machine	Rail Tamping Machine with Lifting Equipment	12
Wagon Tipler	Wagon Tipler	12
Miscellaneous Items	Drop Sections	12
	Gangways and Bridges	12
	Lock Gates	12
	Tidal Booms	12
	Service Gates	12
	Suspended Furnace/Process Plant Doors	12

38 Insurance: buildings and risks

Original by **Royal Insurance**
Revised by **Eur Ing Dennis A. Snow**
CEng, MIMechE,
HonFSOE, HonFIPIantE, HonFIIPE

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38.1 Insurance

It is very important to understand that an insurance policy is a legal document, and insurance negotiations should be approached on this basis. Insurance contracts have a detailed legal background of both case law and common law in the interpretation of their provisions. Professional insurance advice from a reputable source, whether an insurance company or an insurance broker, is essential if problems are to be avoided.

It is important to understand that insurers are separate commercial organizations in competition and each trying to make a profit. This affects the insurers' approach to loss prevention and it does mean that some insurers will have different priorities in individual cases.

Insurers trade in a competitive market – there are some 200 separate insurers in the market in the UK. Because insurance is such a competitive business, insurers do not have unlimited freedom to act. They occasionally have to accept less than the optimum in terms of safety. However, an individual insurer can always refuse the business if it is judged that the conditions are bad – and this is done from time to time.

There are occasions where somewhat less serious problems are encountered and the client refuses to take any action. In these circumstances statutory bodies like the Health and Safety Executive or the fire brigade can enforce their views through legislation. Insurers are not in that position. They can and do increase premiums for bad risks, but they also try to persuade managements by commonsense argument that changes should be made, even if this is not necessarily an economic proposition from the point of view of insurance cost.

Behind the insurance companies is the influence of the Association of British Insurers and the Loss Prevention Council, which includes the Fire Protection Association. Both these trade bodies carry out a range of functions, but the most relevant in this context is the literature that they produce. This is for guidance of insurers and their clients in combating fire problems and encouraging good standards of general fire protection. The various codes and standards are issued using the experience of insurers combined with industry, fire-protection equipment manufacturers, users and other interested parties with a contribution to make. A comprehensive list of these publications appears in Section 38.11.

38.2 Fire insurance

Fire is the major insurable risk to property on land. Each industry, trade or manufacturing process has its own fire problems. There are, in addition, causes of fire which are found in all occupancies (e.g. arson, smoking, misuse of electricity). With such a wide field it is only possible to touch lightly on the many important aspects of the subject.

The normal fire policy covers the fixed assets (buildings, machinery and stock) of the business against loss or damage by fire, lightning and explosion. Assets consumed by the fire damage caused as a direct result of fire (e.g. by smoke or water used to extinguish the fire) are included in the cover. Damage caused by equipment overheating or by something which is being fired but is burnt incorrectly is not covered by this type of policy. Lightning damage is self-explanatory.

Explosion damage cover means damage resulting from a wide variety of trade-related explosions (e.g. dust, vapour or uncontrolled chemical reactions). The explosion or collapse of boilers and pressure plant, in which internal pressure is due to steam or other fluids, is covered by engineering (not fire) policies.

It is the responsibility of the owner of the property to fix the figure for which the assets are insured. This must be a realistic assessment of the value, as insurers settle claims on the actual loss incurred and do not automatically pay the figure insured in the policy.

The policy cover may be extended to include damage to assets from extra perils if the necessary additional premium is paid. These include storm damage, floodwater, burst water pipes or tanks, aircraft, riot, malicious damage or impact by mechanical vehicles. It is also possible to include an item to cover architects', surveyors' and consultants' fees and legal fees all incurred in the reinstatement of the property insured, as well as a sum to cover the costs of removing debris from the site before rebuilding can start.

38.3 Business interruption insurance

Business interruption policies (also known as loss of profits or consequential loss) are designed to cover the trading loss due to the occurrence of the fire or other insured peril. This loss is normally identified either by a reduction in turnover as a result of the disruption caused to the business or by increased costs incurred to minimize the loss of turnover, or indeed a combination of the two. The cover under the policy does not last for an indefinite period after the loss but is restricted to a timescale expressed in the policy as the maximum indemnity period. This time limit is chosen by the management of the business, and is the time they think that they would need to recover the trading position of the company following the incident. With fire business interruption insurance there is a limit to the amount payable, which is the sum insured chosen by the management of the business.

38.4 Insurance surveys

It is normal practice in insurance for surveyors employed by the insurance company or the insurance broker to inspect premises that are to be insured and prepare reports for the underwriters. A major part of the survey report is an assessment of the quality of the fire protection relative to the level of hazard in the premises. Obviously, the business being carried on has a considerable influence on the risk of fire or explosion.

38.5 The legal requirement

Specific legislation governing fire safety, in the UK, includes the Fire Precautions Act 1971 (in Northern Ireland the Fire Services (Northern Ireland) Order 1984 (as

amended) the Health & Safety at Work etc Act 1974 and regulations made under that Act referred to collectively as the Fire Regulations.

The Fire Regulations and the Fire Precautions Act 1971 and the Northern Ireland equivalents are the responsibility of the Home Departments, and are mostly enforced by the Fire Authorities; although some aspects may fall with the remit of the Health and Safety Executive.

However, with Crown Occupied and Crown Owned premises, enforcement is carried out by the Fire Service Inspectorates of the Home Departments (In Northern Ireland) by the Department of Economic Development.

Fire Precaution legislation deals with general fire precautions, which include:

a. Detection and fire warnings,
b. Means of Escape
c. Means for Fire Fighting.
d. The Training of personnel in fire safety.

The Fire Regulations also include a requirement to undertake an assessment of fire risks. This covers the risk of fire occurring and my risks, that may be present, to people in the event of a fire occurring.

The Health & Safety at Work etc Act 1974 together with all the other Regulations made under them together with the references to the various 'Codes of Practice' for the various industries, and are designed to cover fire precautions associated with various processes, and are intended, to prevent the outbreak of a fire, or at least minimize the consequences should a fire occur.

Matters that fall under the scope of the Acts include such things as storage of flammable materials, control of flammable vapours, standards of good housekeeping, and the safe systems of working, the control of the sources of ignition and the provision of appropriate training of personnel involved in the industry concerned.

These precautions are enforced by inspectors from the Health and Safety Executive.

To summarize

What do the Fire Regulations and the Health & Safety at Work acts really boil down to in respect of your operations?

a. Carry out a risk assessment of your plant – you must consider all of your employees and everybody else who could be affected by a fire within your establishment, and you must make sufficient provision for any disabled people taking into account all their possible special needs who may be employed or may be visiting your plant or premises.
b. You must identify significant findings of the risk assessment and the details of the details of anyone who may be especially at risk in case of fire (these must be recorded if there are five or more people involved).
c. You must provide and maintain such fire precautions as are necessary to safeguard those who use your workplace.
d. You must also provide information, instruction and training to your employees about your fire precautions and within your establishment.

Your risk assessment will help you to decide the extent and the type of precautions you should take depending on your processes involved.

There are a number of legal duties that you are required to attend to:

1. Where it is necessary for you to safeguard the safety of your employees, you must nominate people to undertake any special roles which are required under your emergency plan; you as the plant engineer can nominate yourself if necessary or, if you may be otherwise involved, you can nominate a person or duty holder, who may be or should be present, at all times, with a suitable alternative in case of absence.
2. You should consult your employees or their elected representative, or Trade Union representative, about the nomination of people to carry out particular roles in connection with fire safety and about any proposals which may be under consideration for the improvement of the fire precautions.
3. You must inform other employers who may have plants within the same premises, in the case of multi-occupations, or any significant risks you found which may effect the safety of their employees and co-operate with them about the measures proposed to reduce or control those risks.
4. On the other hand, if you are not a direct employer, but you have control or authority over the premises, you still have a duty to make certain that all those involved within the premises, over which you have authority, are acquainted with the Fire Regulations and that they are complied with.
5. You must establish a suitable means of contacting the emergency services and you must ensure that they can be summoned easily.
6. The law also requires your employees to co-operate with you to ensure the workplace is safe from fire and its effects, and not to do anything which will place themselves or other people at risk.

In many places within the UK you may need to apply for a FIRE CERTIFICATE before you can operate your plant. It is your responsibility to make suitable enquiries from the Local Authorities, and the local Health & Safety Executive office, to see whether you will come under this directive.

However, it is advisable, in any case, for all plant planners or developers to seek formal advice from the local Fire Authority for fire precaution advice before attempting to plan an establishment. Compliance with their requirements, known in advance, can in the long run, be an economical solution to problems which may come to light at a later date, when alterations may become an expensive necessity. Time for compliance can, in some cases, if delays can result be even more expensive.

Fire Precautions & Means of Escape built in to the plant, in the first place, enable the engineer to be able to concentrate on the project without having to bother at a later date, especially if building works are necessary, or if major, a change in plant location may avoid unnecessary or extensive precautions having to be incorporated later as a retrofit.

38.6 Fire legislation

A very good synopsis of current Fire Safety Legislation is covered in the Publication: Fire Safety – an Employers guide. See also Chapter 8, Fire Safety.

38.7 Fire protection

Every year there are a number of fires in the UK costing £500 000 or more, but the greater part of the total annual loss is made up from a large number of smaller fires. Most fires are initially small, and if tackled manually or automatically at this early stage can be put out before any really serious damage is done. Rapid action can be taken either with portable firefighting equipment with hose reels or by fixed systems which are brought into operation automatically by the heat or smoke of a fire. The type and quantity of firefighting equipment necessary will vary greatly. Advice can be obtained from the fire brigade or the Health and Safety Executive.

In many cases insurers allow a discount from fire insurance premiums where equipment is installed providing the equipment complies with insurance standards. These may differ from those recommended for life safety under the Factories Act.

38.8 Extinguishers

The effectiveness of portable extinguishers is limited by the need to keep their weight, and therefore the amount of extinguishing agent they contain, within the limits necessary for quick and easy handling. The maximum discharge time which can be expected from any portable extinguisher is approximately 60–120 seconds.

For firefighting in occupied rooms with no exceptional fire risk, portable extinguishing equipment will normally suffice, provided that efficient appliances of the right type are properly positioned and will be handled by people trained to use them effectively. A fixed system will usually be necessary, on the other hand, to ensure adequate protection in factories where there is a real risk of fire breaking out after working hours, to ensure effective firefighting in workrooms where a fire is likely to spread too fast to be controlled by portable extinguishers, and in parts of buildings which have an appreciable fire risk but which are not normally occupied. Such a system should always be in addition to and not a substitution for portable extinguishers.

It is important to provide the right type of extinguisher for protection against a given risk. Some extinguishing agents which are outstandingly effective against fires involving certain substances may be useless or positively dangerous when applied to fires of another kind. Where more than one type of extinguisher is provided, the type of fire for which each is designed should be clearly indicated and staff instructed in the correct methods of use.

38.8.1 Water

Due to its cooling power, water is the most effective extinguishing agent for many types of fire. It is particularly suitable for fires in carbonaceous materials. Portable extinguishers provide a limited quantity of water using gas pressure. Extinguishers should have a nozzle fitted so that the direction of the jet can be properly controlled.

Hose reels connected to the public water supply have the advantage that their supply of water is unlimited, although the pressure may be less than that generated in a portable extinguisher. Very large hoses are difficult to handle and lengths should not normally exceed 35 m. Water should be immediately available when the control valve is opened.

38.8.2 Dry powder

A range of powders are available in portable extinguishers for fighting fires in flammable liquids and are also suitable for certain solid materials, including special metals. Discharge is by gas pressure and a hose is essential.

38.8.3 Gas

Carbon Dioxide Extinguishers have a specialized application for use on Electrical Equipment and Liquid fires but should not be used on metal fires.

38.8.4 Installation and maintenance

Equipment should be purchased from reputable manufacturers, preferable those registered to ISO 9000 (Quality systems). They should be located at clearly defined fire points. All equipment should be recharged after it has been used. Manufacturers' instructions for maintenance and recharging must be followed closely. Regular inspection and maintenance of all firefighting equipment is essential, otherwise it is liable to deteriorate and prove unserviceable when needed.

Staff who may require to use the extinguishers must be trained both in selecting the appropriate extinguisher and in handling it properly. There is no substitute for actual 'hands on' use of extinguishers, and fire brigades are usually very pleased to help.

38.9 Auto-sprinkler installations

Automatic sprinkler systems have the great advantage that they are comparatively simple in concept and operate automatically, whether or not there are people present on the premises. Water is supplied from the public mains or tanks and pumps into a network of distribution pipes at ceiling level, which covers the whole premises. Water is discharged through nozzles or heads sited at regular intervals in the pipework, which are normally sealed with a heat-sensitive device. These devices are actuated by the heat of the fire, therefore the system only discharges in the area of the fire. The sprinkler heads can be arranged to operate at suitable temperatures, taking into account ambient conditions. Where heating is not always available,

the pipework can be charged with air during the winter months. An audible alarm is given when the installation operates, and this can be relayed automatically to the fire brigade. As with all fire equipment, maintenance is essential, as it is not in regular use. See also the Chapter 9. Sprinkler systems where more detailed information can be evaluated. Obviously, specific regulations apply to usage.

38.10 Automatic fire alarms

Fire alarms are intended to give an early warning of the outbreak of fire. This may take the form of a local alarm or it may be signalled to the fire brigade. The disadvantage over, for example a sprinkler installation is that the system does not attack the fire, depending upon the human element for any firefighting to take place. Its advantages over a sprinkler installation is that it is more sensitive and detection is quicker. This is a particular advantage if quick action can be taken.

There are various types of detectors which recognize heat and/or smoke utilizing fused bimetallic strips, ionization chambers and the interruption of a light beam by smoke or other combustion products. It is important to select the most appropriate form of detector for the environment. Insurers give a modest discount from premiums if the alarm installation complies with the insurance rules, which are based on British Standards.

38.11 Trade hazards

The insurance survey referred to in Section 38.4 aims to identify plant, processes and storage of materials that are of significance in terms of fire hazard. Some examples include:

Drying
Dust hazards
Paint spraying and coating
Use of highly flammable liquids
Waste collection and disposal

Insurance companies are particularly interested in the standards to which the plant is operated and how the hazardous features are controlled.

38.11.1 Flammable liquids

Flammable liquids are widely used in many types of factories, and their misuse is responsible for many outbreaks of fire. The fire risks from the flammable liquids in common use such as petrol, paraffin, white spirit, cellulose solutions and thinners are well known, but these are only a few of the liquids which present hazards in industry. The variety of flammable liquids used in processes as solvents or carriers and for other purposes is constantly extending.

Processes involving coating, spreading and printing usually have a considerable area of exposure. If materials which include flammable liquids as solvents are sprayed, large quantities of vapour and fume are produced.

Many flammable liquids are used for a variety of purposes in bench work, either in semi-closed containers or in open trays. If spillage occurs due to breakage of apparatus or plant, or carelessness in handling, the liquid is distributed over a large area and considerable vapour is produced. Fires due to the ignition of vapours spread with extreme rapidity over the exposed surface of the liquid and the amount of flame and heat given off quickly increases.

38.11.2 Flammable gases

Many of the gases which are used for heating or in industry are easily ignitable, and there is grave risk of fire if the gas escapes because of leakage from a container or from piping. The only effective action against a gas fire is to stop the flow of the gas. If the fire is extinguished and the gas still allowed to flow, the escaping gas will form an explosive mixture with the surrounding air and produce conditions which are potentially far more dangerous than the fire. In addition, flammable gases are almost inevitably toxic, and hence a health hazard is produced.

Oxygen is not flammable, but leakages from oxygen supply pipes enrich the surrounding air and increase the ignitability of various materials within the enriched atmosphere. Some materials which would normally require a source of heat for ignition become pyrophoric. In the event of a fire the supplies of all flammable gases and oxygen should be cut off as quickly as possible.

38.11.3 Electrical equipment

In electrical equipment fires are caused by arcing or overheating, but continued combustion is usually due to insulation, oil or other combustible material associated with the installation. If the electrical apparatus remains alive, only extinguishing agents which are non-conductors of electricity should be used.

38.11.4 Management

Insurers are aware of the importance of a management that, at all levels, is fully conscious of the fire and other hazards within its premises and consequently acts in a highly responsible way. An opinion of the standard of management is an important part of the insurance surveyor's report referred to earlier, and is obtained by observation of conditions in the premises and a scrutiny of the organization and systems that are in operation.

38.12 Recommended references

38.12.1 Legislation

Fire Precautions Act 1971
Health and Safety at Work etc Act 1974
Fire Safety & Safety of Places of Sport Act 1987
The Management of Health & Safety at Work Regulations 1999.
The Fire Precautions (Workplace) Regulations 1997.
The Fire Precautions (Workplace) (Amendment) Regulations 1999.
The Highly Flammable Liquids and Liquified Petroleum Gases Regulations 1972 (see Chapter 8).

38.12.2 Loss Prevention Council

List of approved products and services covering: building products, fire detection and alarms, fire break doors and shutters, portable fire extinguishers, sprinkler and water spray systems.

38.12.3 Loss Prevention Council rules and recommendations

The rules give fundamental information related to loss prevention necessary for satisfactory property underwriting as follows:

Automatic fire alarm installations for the protection of property
Automatic sprinkler installations
Construction and installation of fire break doors and shutters
Provision of fire extinguishing appliances

Recommendations give practices which insurers expect to be adopted including:

Emergency power, heating and lighting
Builders' or contractors' operations
Protection of computer installations against fire
Liquefied petroleum gas
Welding and other hot work processes
Oil-fired installations
Installation and maintenance of grain dryers
Mobile power-driven appliances
Spraying and other painting processes involving flammable liquids
Portable and transportable space heaters
Deep fat frying equipment
Shrink wrapping
Warehouses and other storage places

Fire Safety – An Employer's Guide. ISBN 0 11 341229. Her Majesty's Stationery's Office

The Fire Protection Yearbook	FSB 8
Fire & Hazardous Substances	FSCD 2
Guide to Building Fire Protection	Vol. 3.
Vol. 4. Guide to Fire Safety Signs.	FSB 36.
Vol. 5. Fire Risk Management in the Workplace. A guide for employers 2nd. Edition.	FSB.22.
Vol. 6. Prevention and the control of Arson	FSB. 40.
Vol. 7. Fire Protection Equipment and Systems.	FSB.41.
Fire Safety Management.	LB.1.
Fire Risk Assessment: Log Book Record Sheets.	LB2.
Chubb's Fire Risk Assessment.	
A Guide to Fatal Fire Investigations	IFEFF1.
Safety at Scenes of Fire & Related Incidents	FSB.27.
Emergency Service.	
Disasters & Emergencies	Y171.
Risk Assessment for the Emergency Services.	IFERA.
Fire Fighting Manual of Trauma Care.	IFEMTC.
Essential Fire Safety:	
Fire Safety in Retail Premises	FSB.151.
Fire Safety in Offices	FSB. 201
Fire Safety in Village Halls & Community Halls	FSB.32.
Fire Safety in Hotels: requirements for Europe.	FSB.231.
Fire Safety Management in Hotels & Boarding Houses.	FSB.7.

Security:

An Introduction to Physical Security Techniques.	FSB.331
Guidance on the Acceptance of Electronic Locks To Doors required for Means of Escape.	IFLOC

Transport:

Airports & Aircraft Fire Protection, Firefighting and Rescue Techniques.	Y169.
Marine Fire Studies.	IFE.

Codes of Practice and Related Guidance:

The LPC Design Guide for the Fire Protection of Buildings 2000 (A code of Practice for the Protection of Business)	DG2k.
Fire Prevention on Construction Sites 5th. Edition.	FSB9.
Joint Code of Practice:	
Electrical Process Heating Fire Safety in the Metal Finishing Industry.	CPMF1.
Code of Practice for:	
The Safe Use of Chromium Compounds in Electrolytic Plating Processes.	CPCCEP.
Code of Practice for Occupational Fire Brigades 2nd. Ed.	CPOFB2.
Code of Practice for the Protection of Unoccupied Buildings.	CPPUB.

The IFSA Code: (The Intumescent Fire Seals Association).

Sealing Apertures & Service Penetrations to Maintain Fire Resistance.	IFSAC.
Code of Practice for Fire Safety in Houses in Multiple Occupation.	CHPMO
LPC Code of Practice for Fire Protection in the Food & Drink Industry.	CPFCF1.
Code of Practice for Fire Safety when Dealing with Waste Materials.	CPWM.
Code of Practice for Fire Safety in Warehouses & Storage Areas.	CPWARE
Guidelines for the Supply of Water to Automatic Sprinkler Systems.	GFSS.
LPC Rules for Automatic Sprinkler Installations (Building Services Journal).	

Building Materials & Operations:

Storage, use and filling of Liquefied Petroleum Gas in Containers	RC6.
Hot Work (Includes sample hot work permit)	RC7

Buildings & Building Services:

Emergency power, heating & Lighting.	RC1.
Fire protection of atrium buildings	RC2.

Electronic Data Processing Equipment:

Part 1: Fire Prevention.	RC3.
Part 2: Security protection.	RC3B.
Part 3: Protection of Data & Software.	RC3C.
Part 4: Small Office system Protection.	RC3D.
Part 6. Protection against electrical disturbances.	RC3F.

Equipment:

Cooking Equipment (other than fish & chip frying ranges)	RC16B.
Electrical equipment in flammable & explosive gaseous atmospheres.	RC30.
Fish & Chip frying ranges.	RC16A
Forklift trucks.	RC11.
Installation & maintenance of grain dryers.	RC10.
Oil fired installations.	RC9.
Organic thermal fluid heating systems.	RC26.
Portable & transportable space heaters.	RC15.
Space heaters burning waste fuel.	RC4.
Space heating: hazard classification.	RC27.
Spark detection & suppression systems on pneumatic conveying systems.	RC28.
Spark erosion machining.	RC29.

OCCUPATIONAL/STORAGE HAZARDS:

Fire safety in automotive refinishing and spraying processes.	RC31.
Fire protection of laboratories	RC5.
Prevention & control of dust explosions.	RC12.
Storage of aerosol products	RC19.
Fire safety in the storage and use of flammable liquids	
Part 1. General principles.	RC20A
Part 2. Storage of flammable liquids in drums, cans and other containers.	RC20B
Part 3. Storage of flammable liquids in external fixed tanks.	RC20C.

WEATHER PROTECTION:

Frost protection for new buildings.	WP1.
Assessment of roofs' resistance to wind damage.	WP3.
Protection of commercial buildings against water damage.	WP2.

FIRE ENGINEERING:

Gaseous Fire Protection Systems.	LPR16.
Halon alternatives.	LPR6.
Fire spread in Multi-Storey Buildings with Glazed Curtain Wall Facades.	LPR1.
Report on the State of the Art of Compartment Fire Modelling.	LPR1.

PROPERTY RISKS:

Cladding Systems for Building: Introductory Guide.	LPR2.
Property Subject to Structural Movement guidelines on the assessment of cracks.	LPR3.
Subsistence & Domestic Housing: Survey: analysis of results.	LPR4.
Geology & Building Subsidence.	LPR7.
Glossary of Wind Terms used in Construction.	LPR15.
Wind Damage to Buildings in the United Kingdom.	LPR8.

TECHNICAL BRIEFING NOTES:

Violence at work	TBN1.
Crime & Household Property	TBN2.
Legionella and Firefighting Systems.	TBN14.

Most of these publications can be obtained from:
The Fire Protection Association. Bastille Court. 2 Paris Gardens. London.
SE1 8ND. Tel: 020 7902 5300. Fax: 929 7902 5301

38.13 Security insurance

While a number of different classes of insurance cover relate to crime risks, the principal one which is sought by most businesses is known as 'theft' or 'burglary' insurance. The terms 'theft' and 'burglary' are defined in the Theft Act 1968, but while insurers use 'theft', the cover provided by this insurance is much narrower than the legal definition of that term in that it applies only in specified circumstances.

The basic theft policy covers the property insured against loss, destruction or damage by theft or attempted theft involving:

1. Entry to or exit from the premises by forcible and violent means; or
2. Actual or threatened assault or violence or use of force at the premises (this relates to the legal definition of 'robbery').

The theft policy extends to cover damage to premises caused in furtherance of theft or attempted theft, but malicious damage itself without theft is normally covered as an extension to the fire policy.

Theft by employees is another major exclusion from the theft policy, although the insurance market is prepared to cover this risk (subject to an excess to take care of petty pilfering) through a fidelity policy.

Theft insurance premiums vary from risk to risk. The principal factors which insurers take into account are:

1. The geographical location of the insured property (experience shows that metropolitan and urban areas have a crime incidence which is above average for the UK); and
2. The type and value of commodity insured (some items are particularly attractive and are always a major target for thieves).

In all cases, however, the theft insurance premium assumes that the security standards applied and put into operation are commensurate with the theft risk.

38.14 Theft insurance policy terms and conditions

Under most theft insurance policies the liability of the insurance company is conditional on the client's compliance with any policy terms and conditions. There is a Reasonable Precautions Condition under which the client is required to take reasonable precautions to safeguard the insured property and secure the premises, including the installation, use and maintenance of any security precautions stipulated or agreed with the insurance company.

In some instances special terms may be applied. For example, where the insurance company requires the installation of an intruder alarm, the protected premises must not be left unattended unless the alarm is put into full operation. In other cases, cover under the policy may apply only when the property insured is left within agreed and designated areas.

From these examples it will be seen that the client's obligations do not end with the mere provision of security hardware, etc. but extend to include procedures and routines which ensure that it is used effectively.

38.15 Risk assessment

Insurance companies employ staff who have been trained in crime-prevention techniques, and when theft insurance is provided/requested for commercial premises it is normal practice for the insurer to carry out a security survey of the premises to prepare a report for the underwriters. The report is based on the surveyor's assessment of the risk, which will consider the following main factors:

1. Type of property and values at risk;
2. Construction of premises;
3. Location/situation of the premises;
4. Extent and periods of unoccupancy;
5. Nature and degree of accessibility to thieves;
6. Existing protections:
   (a) Locks, bars, bolts, etc.;
   (b) Intruder alarms;
   (c) Safes and strongrooms;
   (d) Surveillance (e.g. security patrols, CCTV);
   (e) Site security (perimeter fencing, security lighting, etc.);
7. Previous theft history of the premises.

The assessment will establish whether or not the existing security arrangements equate to the standards normally looked for by the insurance company for the specific theft insurance exposure. If the security falls short of these standards, the insurance company will submit a list of security items requiring improvement. Pending satisfactory completion of these items, insurers may:

1. Withhold theft cover entirely; or
2. Provide provisional cover but usually subject to some restriction such as a significant excess or a percentage of self-insurance being carried by the client.

Refer to Chapter 8 – Fire Prevention, for further reading on Risk Assessment and associated procedures.

38.16 Planning for security

Like all forms of asset protection, security needs to be properly designed, planned and co-ordinated if it is to be both effective and cost beneficial. From previous comments in this chapter it will be noted that the insurance company's attention is largely focused on the security of movable assets (e.g. stock (both raw materials and finished goods), plant (including vehicles) equipment and tools) against the risk of theft. However, every industrial and commercial operation may have its own security vulnerability (e.g. arson bomb threats, fraud, information theft, industrial espionage, malicious contamination of products, etc.).

While the insurance company's security requirements against the risk of theft may go some way towards countering these other vulnerabilities, some of these issues present significantly different security problems and they may require separate assessment and control. This emphasizes the need for a total plan to cover all aspects of security. If planning is piecemeal, some aspect may be overlooked and the benefits (financial and operational) of a totally integrated approach will be lost.

Similarly, security should be a function of senior management, and it should rank alongside other management responsibilities. This will help to demonstrate that the company is committed to a security programme, that appropriate resources are allocated, and that protective systems and procedures are properly used and maintained.

38.17 Security objectives

The principal aims of security should be to forestall both organized and opportunist crime by cost-effective measures. While there is considerable variety in the type of criminal attack and skills involved, fortunately there is a tendency for them to act in a similar way, and this enables a common philosophy to be applied when determining countermeasures.

Based on the initial risk assessment, it will be obvious that as the exposure (commodity, value, location) increases so must the standard of security which is necessary for the risk. It is also the case, however, that items of comparatively low value will be stolen if they can be

easily reached and if their removal does not represent any undue risk to the thief.

Experience has shown that thieves are strongly influenced by a number of factors:

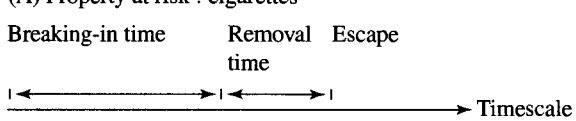
1. Thieves are mainly opportunists, so there is a greater likelihood that they will be deterred by more apparent security.
2. They wish to act quickly, so any delay will complicate matters for them and discourage or even frustrate them.
3. They wish to remain undetected while working.

An important principle is that security must be built in depth – otherwise known as 'defence in depth'. In this context, it may be helpful to think of security as a set of concentric rings, where the target is located at the centre. Each ring represents a level of physical protection (perimeter fence, building shell, security case) but the number of rings and security resistance will vary relative to the risk. The spaces between the rings may represent other defensive measures such as closed-circuit television (CCTV), security lighting, intruder alarm systems, etc.

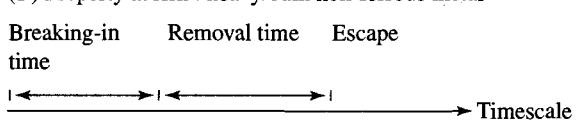
It will be apparent that delay (by physical features) and detection (by alarm, etc.) are entirely separate concepts. They should not be treated as being one and the same thing, nor should they be regarded as alternatives when arranging security. Delay, on its own, will have little security value unless it keeps the thief in a conspicuous place where there is a distinct likelihood of being seen (detection). Similarly, detection (by alarm) of the thief, where there are no obstacles to ensure subsequent delay, is unlikely to deter when it is known that the nature of property at risk may enable the removal of items of a high value in a short time. The message is that delay and detection, however achieved, should be used together and then with intelligence.

By using risk assessment techniques to determine the exposure of the property it is possible to determine the appropriate standard of security for a risk. The following simple example will clarify this point.

(A) Property at risk : cigarettes



(B) Property at risk : heavy/bulk non-ferrous metal



In example (A) the easy transportability of cigarettes requires a very high level of physical protection symbolized by the lengthy 'breaking-in time'. When considering the necessary complementary alarm protection it is obvious that this must occur at the earliest possible time to enable assistance to be summoned and to arrive while the intruders are still on the premises but before they have reached their target. To arrange for detection to coincide with the beginning of removal time is much too late.

In example (B) the exposure of the property to risk is rather less both by way of the value of the goods and the problems posed by their transportability. While, therefore, it is still desirable that detection should occur as early as possible, it will be seen that its concurrence with the beginning of the removal time would still prevent the intruders from being successful.

Security is intended to frustrate thinking people, and it will be obvious that its effectiveness will be determined by the strength of its weakest part. Care must always be taken to ensure that there is no known vulnerable point, since this will be exploited to the full, thereby nullifying the security equipment otherwise provided. Once the standard of security has been determined it must be uniformly and intelligently applied.

38.18 Location

The location of any premises has a considerable influence on the overall standard of security. With new building, and other things being equal, the site with a low level of local crime should be chosen. In most instances, however, location is a *fait accompli*, and the protection of the site should recognize the pattern of crime in the district. This information is normally available from the local crime prevention officer. It must be remembered that crime patterns are never constant, and it is important to keep abreast of local trends and, when necessary, be prepared to modify (usually improve) security standards.

38.19 Site perimeter security

38.19.1 Fences

The security of any premises may be enhanced by perimeter fencing. Not only does the fence present an obstacle for intruders to overcome but it establishes the principle of defensible space and constitutes a psychological barrier to access. A perimeter fence, when supplemented by gates, traffic barriers and gatehouses (manned by security personnel or some other system of access control), allows the site operator to have control and supervision over all vehicles and pedestrians entering and leaving the site.

There are three types of fencing suitable for security applications. In increasing order of security, these are:

1. Chain link: BS 1722: Part 10
2. Welded mesh: BS 1722; Part 14
3. Steel palisade: BS 1722: Part 12

The following features are necessary for any security application:

1. Total vertical height should not be less than 3 m;
2. Mesh size should not exceed 50 mm^2 to make footholds difficult;
3. Top edge of chain link and welded mesh should be barred and the fence topped by three strands of barbed

wire on cranked arms extending at 45° out from the external face of the face, where possible. Care should be taken to ensure that any barbed wire is not a danger to pedestrians. If barbed razor type is used, notices should be posted warning of the danger of serious injury if climbing the fence is attempted;
4. The bottom edge of the fencing material should be 'rooted' into a continuous-cast concrete sill set into the ground to prevent the material being bent up and burrowing;
5. Gates should be designed to provide the same barrier to intruders as the fence;
6. If a gross attack (using a vehicle to ram the fence) is envisaged, protection can be provided either by erecting a purpose-designed vehicle barrier or, where ground permits, digging a trench on the exposed side.

38.19.2 Security lighting

The purpose of security lighting is to deny the criminal the cover of darkness which he uses to conceal his activities. In addition, strategically designed lighting can considerably increase the security value of other measures, and it can also assist the detection capabilities of surveillance (manned or CCTV) systems.

Lighting need not be devoted to security, and indeed most lighting installations have a dual role. Where security is a required feature, the installation needs to be very carefully specified and designed to achieve optimum protection. Advice on lighting and the choice of equipment is discussed in the Electricity Council publication *The essentials of security lighting*.

38.20 Building fabric

38.20.1 Outer walls

The outer walls of a building should be commensurate with the security risk. The use of robust construction and materials (e.g. those resistant to manual attack and damage) is essential to the initial provision of security. Weaknesses in walls will be exploited by criminals. Where lightweight claddings are employed, security can be enhanced by a reinforcing lining such as welded steel mesh. Where the security risk is high it may be necessary to reinforce even brick/blockwork walls in a similar manner.

38.20.2 Roofs

Roofs are a common means of access to criminals. Where necessary, access can be minimized or deterred by:

1. Restricting access to the rooftop by physical barriers;
2. Applying anti-climb paint or spiked collars to access routes such as downpipes;
3. Use of strategic lighting of the roof area;
4. Fitting expanded metal or welded mesh below the roof covering, sandwiched between the skins of double-skinned roof coverings or within the roof space;
5. Roof openings, including rooflights and ventilation, should be treated, from a security point of view, in the same way as openings, located elsewhere in the building fabric.

38.21 Doors and shutters

External doors and shutters are often the focus of criminal attention. The range and construction of doors, shutters and their securing devices is too numerous to cover but the points which need to be considered are:

1. *Siting*: Wherever practicable, doors should be located where there is some element of surveillance;
2. *Numbers*: These should be kept to the minimum, consistent with operational requirements and any other requirements imposed under Building Regulations and fire/health and safety legislation;
3. *Construction*: Preference should be given to solid wood, steel or steel-faced doors. Glazing should be avoided but, where necessary, should be as small as practicable;
4. *Frames*: The frame should be of sound solid construction, with a substantial rebate and securely fixed into the building fabric;
5. *Condition*: All doors should be a good fit in the frame with no excessive gaps, and maintained in good condition;
6. *Hinges*: Outward-opening doors normally have exposed hinges which are vulnerable to attack. These should be supplemented by fitting hinge or dog bolts on the back edge of the door;
7. *Locks*: There is a wide variety of locks and security fittings, many with special applications. Advice from locksmiths or other security experts should be taken before deciding upon a type of lock, but, wherever practicable, only those locks which require a key to lock and unlock them should be chosen. BS 3621 establishes a useful minimum standard but is not applicable to all lock types;
8. *Emergency exits*: These doors should be identified and the local fire prevention officer consulted before any key-operated locks are fitted.

38.22 Windows

Accessible windows are a high security risk. Wherever practicable, storage areas in particular should have no windows. For a variety of reasons, this is not always feasible, and in these cases the following features should be considered:

1. Windows not required to be openable should be permanently fixed closed;
2. Where windows are required to open, fit limitations (e.g. stops or cradle bars) to restrict the extent to which the window may be opened;
3. Where there is a security risk, fit internal bars or grilles properly secured to the building fabric. Specifications for bars and grilles are available from the local crime prevention officer, the insurance company or from proprietary grille manufacturers.

38.23 Intruder alarms

In many cases it is necessary to complement physical security by the installation of an intruder alarm system in order to achieve the standard of security commensurate to the risk exposure. The scope of protection to be afforded by the alarm system depends on the security risk, but it may embrace fences, windows, doors, roofs, walls, internal areas, yards and external open areas, and vehicles inside and outside buildings. There is a comprehensive range of detection devices, but the choice of detector is critical to ensure that it provides the desired level of protection and is stable in the particular environment.

Intruder alarms are designed to give a warning of the presence of an intruder within, or attempting to enter, the protected area. Alarm systems may act as a deterrent to the casual or opportunist thief but they will do little or nothing to prevent a determined intrusion, and to be effective they must provoke an early response from the appropriate authority (in most cases the police). The warning may be a local audible device, but normally the alarm signal is transmitted by the telephone network to a central station operated by a security company on a 24-hour basis.

The alarm and telephone companies provide a comprehensive range of facilities for the transmission and receipt of alarm signals. The choice of signalling system will be determined by the security risk.

A number of alarm systems suffer from repeated false alarms. This may be due to the poor design and selection of detectors, inadequate standards of installation or preventative maintenance, and faulty operation of the system by key holders. Recurrent false calls will quickly discredit any system and will result in the withdrawal of police response to any alarm activation.

While alarm systems may be complex, false alarms can be minimized by the careful choice of installer, who should:

1. Be on the current List of Approved Installers maintained by the National Approval Council of Security Systems (NACOSS);
2. Be acceptable to the local police and appear on their list of recognized companies;
3. Install and maintain the system in full conformity with BS 4747 or, where the security risk is high, BS 7042.

38.24 Closed-circuit television (CCTV)

CCTV can make an important contribution to the security of a site, but it should be regarded as complementing and not replacing other security measures. Ideally, it should form part of an integrated system. In particular, CCTV allows greater flexibility in the deployment of security personnel by providing the facility whereby a single observer can remotely monitor several areas from one location. CCTV systems are not cheap, and need to be carefully designed by specialist CCTV engineers who will ensure that the necessary standard of reliability is obtained by proper planning and specification of the type, quality and installation of the equipment.

38.25 Access control

Although many access-control arrangements are designed to control access and egress during business hours they are an essential part of a total security programme. Leaving aside any arrangements previously discussed, access control is usually achieved by use of:

1. Security staff; or
2. Electronically operated entry/exit systems or a combination of both.

38.25.1 Security staff

The employment of full-time security staff either in-house personnel or contracted out to a professional guarding company (preferably one that is a member of the British Security Industry Association (BSIA) Manned Services Inspectorate) can make a significant contribution to overall security. Consideration should be given to the range of duties to be performed by security staff, their location, and how they will interface with other security measures and external agencies.

38.25.2 Electronically operated access/egress systems

These systems are used in conjunction with some form of physical barrier (e.g. door, gate, turnstile) and comprise:

1. Recognition equipment such as a token or card and appropriate reader;
2. Electrically activated release hardware; and
3. In some systems, central computerized control and monitoring equipment.

The choice of access-control technology depends upon the level of security to be achieved, number of users and traffic at peak periods, etc. Proper design of the system is critical to its performance (and user acceptance), and reliability and expert advice should be obtained from equipment manufacturers and system installers.

38.26 Recommended references

BS 1722: Fences
Part 10: Anti-intruder chain link fences
Part 12: Steel palisade fences
Part 14: Welded mesh fences (at draft stage)
BS 3621: Specification for thief resistant locks
BS 4737: Intruder alarm systems
Part 1:1986, Specification for installed systems with local audible and/or remote signalling
Part 4: Codes of Practice
Section 4.1: 1987, Planning and installation
Section 4.2: 1986, Maintenance and records
BS 5051: Security glazing
BS 5357: Code of Practice for installation of security glazing
BS 5544: Specification for anti-bandit glazing (glazing resistant to manual attack)

BS 5979: Specification for direct line signalling systems and remote centres for intruder alarm systems
BS 7042: Specification for high security intruder alarm systems in building
BS 8220: Guide for security of buildings against crime
Part 2: Offices and shops
Part 3: Warehouses and distribution units (at draft stage)

Building Regulations: 1985 (HMSO)
Code of Practice on noise for audible intruder alarms: Department of the Environment, HMSO (1982)
Essentials of security lighting (periodically updated) published by and available from the Electricity Council, 30 Millbank, London SW1P 4RD
Fire Precautions Act 1971 (HMSO)
Health and Safety at Work, etc. Act 1974 (HMSO)
List of Approved Installers (periodically updated): published by and available from The National Approval Council of Security Systems, Queensgate House, 14 Cookham Road, Maidenhead, Berks SL6 8AJ
Security Precautions: Security Data Sheets

SEC 3 – Fences, Gates and Barriers
SEC 4 – External Security Lighting
SEC 5 – Closed Circuit Television (CCTV)
SEC 6 – Doors
SEC 7 – Windows and Rooflights
SEC 9 – Locks

all published by and available from the Fire Protection Association Bastille Court. 2 Paris Gardens London SE1 8ND.

38.27 Liability and liability insurance

One of the basic requirements of society is to conduct ourselves so that we do not injure other people or damage their property. A business or any other undertaking is equally subject to this requirement.

For many years the social and legal climates have had a growing involvement in requiring and encouraging business undertakings to protect the welfare of persons and their property. As a result, a body of common law has developed and Acts of Parliament have been passed which impose a duty of care upon any business undertaking to conduct its activities responsibly in order to avoid causing injury to persons, or damage to their property.

A breach of duty under either common law or statute which causes injury or damage may result in those responsible having a legal liability to pay compensation (termed 'damages') to the aggrieved party.

38.28 Employer's liability

The liability of an employer to his or her employees in respect of injury arising out of or in the course of their employment usually falls for consideration under either common law (the law of tort) or statute.

38.28.1 Tort

The common law liability of an employer to an employee can arise, *inter alia*, as follows:

1. Acts of personal negligence;
2. Failure to exercise reasonable care in the selection of competent servants (including contractors);
3. Failure to take reasonable care that the place of work is safe;
4. Failure to take reasonable care to provide safe machinery, plant and appliances and to maintain them in a proper condition;
5. Failure to provide a safe system of working.

38.28.2 Breach of statutory duty

There is a wide range of legislation laying down standards of Safety Health and Welfare at Work the most important ones being as follows:

The Health & Safety at Work etc. Act 1974
The Management of Health & Safety at Work Regulations
The Provision & Use of Work Equipment Regulations.
The Lifting Operations & Lifting Equipment Regulations.
The Workplace (Health Safety & Welfare) Regulations.
The Personal Protective Equipment at Work Regulations.
The Health & Safety (Display Screen Equipment) Regulations.
The Manual Handling Operations Regulations.
The Control of Substances Hazardous to Health Regulations.
The Health & Safety (First Aid) Regulations.
The Reporting of Injuries, diseases & Dangerous Occurrences Regulations.

Although there are numerous other codes of Health & Safety Regulations, the above list encompasses the basic legal framework now in force throughout the United Kingdom.

It is important to note that breaches of the aforementioned can give rise to criminal sanctions by the enforcing authorities and also, (with few exceptions which are statue barred) give rise to civil action in the event of injury to an employee for 'breach of statutory duty'.

38.29 Third-party liability

Liabilities to third parties may arise from breach of contract or tort.

38.29.1 Breach of contract

A breach of contract is a violation of a right created by an agreement or promise, and an action for damages or other recompense can normally only be brought by the aggrieved party against the other party or parties to the agreement.

38.29.2 Tort

Tort (which is part of common law but may be modified by statute) always implies breach of duty. This may take various forms, the most common applicable to the engineering and production fields being as follows.

38.29.2.1 Negligence

This has been defined as 'the failure to do something a reasonable person would do, or to do something a reasonable person would not do'. For an action in liability to succeed in negligence the following conditions must be satisfied:

1. The defendant must have owed a duty of care to the plaintiff;
2. There was a breach of that duty;
3. The plaintiff sustained injury or damage as a result of that breach.

38.29.2.2 Nuisance

This has been defined as 'a wrong done to a man by unlawfully disturbing him in the enjoyment of his property or in the exercise of a common right'. Examples of this are the emission of toxic fumes from a factory affecting occupiers of surrounding property or of toxic effluents affecting adjacent watercourses.

38.30 Liability insurance

As previously stated, a business can be held legally liable to pay compensation (damages) for injury or damage caused by its activities, and a successful action against it may result in large financial demands upon the business. Liability insurance ensures that, subject to satisfactory compliance with specified conditions and procedures by the insured, funds are available for a business if it is held legally liable to pay damages (and associated legal costs) which are awarded following injury to persons or damage to property.

Under the Employers Liability (Compulsory Insurance) Act 1969 there is a legal requirement upon most employers to have in force employer's liability insurance covering injury to their employees. Public liability insurance, while not compulsory, is strongly recommended, both in terms of third-party liability (arising from the effects of corporate activities) and product liability (arising from the effects of corporate products.

38.31 The cover provided by liability insurance

The following provides a general summary of the cover provided by standard liability insurance policies.

38.31.1 Employer's liability

Indemnity for an employers' legal liability to his employees against damages awarded for injury or disease happening during the period of insurance and arising out of and during the course of their employment, excluding radioactive contamination. An employee is defined as any person under a contract of service or apprenticeship with the insured, or any person supplied to, or hired to or borrowed by the insured (includes labor-only sub-contractors).

Cover normally applies to employees in the UK, Northern Ireland, the Isle of Man and the Channel Islands or while persons normally resident in those territories are temporarily engaged in the business outside of these territories. Indemnity is unlimited in amount.

38.31.2 Public liability (third party)

Indemnity against legal liability to third parties against damages awarded for:

1. Injury or disease;
2. Loss of or damage to property or personal effects of visitors or employees

happening in connection with the business and during the period of the insurance. Limited indemnity is awarded for financial losses not flowing from injury or damage but which result from escape or discharge of substances from the insured's premises or from stoppage of or interference with pedestrian, vehicular, rail, air or waterborne traffic. Wide contractual liability cover excludes only

1. Liquidated damages, fines or penalties;
2. Injury or damage caused by products;
3. Financial loss

arising solely because of a contract.

Indemnity is awarded in respect of injury to third parties and damage to property arising out of or in connection with the exercise of professional engineering skill. The following are excluded:

1. Radioactive contamination;
2. War and kindred risks;
3. Liability arising solely because of a contract for:
   (a) Liquidated damages, fines or penalties;
   (b) Financial loss;
4. Cost of rectifying defective work;
5. Liability arising out of the use of or caused by craft or vehicles;
6. Deliberate acts or omissions;
7. Principal's professional risk.

Worldwide indemnity is normally provided for injury or damage resulting from:

1. Negligent acts in the UK, Northern Ireland, the Isle of Man or the Channel Islands;
2. Temporary work undertaken abroad.

The limit of indemnity is selected at the time of insurance or renewal thereof by the management of the insured. It applies to any claim or number of claims arising out of any one cause, and is unlimited in total in the period of insurance.

38.31.3 Public liability (products)

Products means goods (including containers and packaging) not in the custody or control of the insured, sold or supplied by the insured in connection with the business from any premises in the UK, Northern Ireland, the Isle of Man or the Channel Islands, including errors in the sale, supply or presentation of such goods. The cover provides indemnity against legal liability for injury or damage happening during the period of insurance and caused by products. This cover also applies in respect of injury or design arising from the design of or formula for products.

Exceptions to the cover are as for public liability (third party) policies plus:

1. Financial loss caused by products;
2. Aircraft products.

It should be noted that very few standard product liability policies provide cover for liability for the costs of repairing or replacing defective products or those which fail to perform as intended, nor for the costs of any necessary product recall. The insurer's liability in any one period of insurance for injury or damage caused by products during that period shall not exceed the selected limit of indemnity.

It cannot be sufficiently emphasized that individual liability policies do differ in detail from the general standard policy, and reference to the policy in force in any individual set of circumstances is most strongly recommended.

38.32 Points to be considered

As stated in previous sections of this chapter, there exists at all times a statutory and common law duty on all employers (which includes all engineers) to maintain a safe working environment for all their employees and the public at large. Additionally, it is contractual obligation on the insured under liability insurance policies to maintain the best reasonable standards of working procedures, equipment and the environment at all times. Consequently, there is a duty on all engineers to conduct their professional duties at all times in a manner which does not downgrade the safe environment of their sphere of influence.

While not exhaustive, the following points for consideration will go far towards optimizing the control of safety and liability standards within the engineer's sphere of influence.

38.33 Employee safety and employer's liability

38.33.1 Premises/buildings

38.33.1.1 Design

Suitability for purpose/occupation?
Best 'state of the art' design?

38.33.1.2 Construction

Suitability for identified operating conditions?
Adequate strength of roofs and control of access thereto?
No built-in accident traps?

38.33.1.3 Maintenance programme

Schedule of maintenance relevant to the needs for the operation?

38.33.1.4 Floors, aisles, stairs and floor openings

Evenness of floor surfaces?
Adequate provision and standards for handrails, toeboards and gates?
Adequate stairway capacity for number of persons likely to use them at one time?

38.33.1.5 Lighting, ventilation and heating

Adequate for identified conditions?
Compliance with statutory requirements?

38.33.1.6 Roadways, pavements, yards, car parks and open areas

Proper maintenance of surfaces?
Separation of pedestrian traffic from vehicular traffic (as far as possible)?
Speed limits (speed ramps, etc.)?
Adequacy of access?
Crane headroom (overhead wires), etc.?

38.33.2 Machinery and plant

38.33.2.1 Type and design

Adequate engineering design for the duty intended?
Hazard studies ('What if?') carried out?

38.33.2.2 Power sources and transmissions

Electrically safe (if applicable)?
Guarded (especially on rotating parts)?

38.33.2.3 Guarding/fencing

Compliance in all reports with Factories Act Statutory requirements?
No unguarded access to moving parts?
Safe provisions for maintenance, etc.?
Interlocking of guards with power supply?

38.33.2.4 Maintenance/adjustment procedure

Scheduled maintenance programme?
Appointment of machinery attendants?
Isolation procedures laid down?
Adequate oil containment?

38.33.2.5 'Permit to work' systems

Adequate specification for identified needs?
Responsibilities allocated for issue, receipt, etc. of 'permits to work'?

38.33.2.6 Access, scaffolds, ladders

Correct maintenance schedules and procedures?
Designated certification and test/inspection procedures?

38.33.3 Tools

38.33.3.1 Power tools

Correct specification/design for duty envisaged?
Adequate inspection/maintenance procedures?
Regular insulation testing?
Safe power supplies?
Power safety cut-out provisions?
Safe storage when not in use?

38.33.3.2 Hand tools

Correct specification of duty?
Adequate maintenance?
Safe storage when not in use?

38.33.4 Electrical installations

38.33.4.1 Type and design

Correct specification for duty envisaged?
Suitability for hazardous environment (if required)?

38.33.4.2 Maintenance

Schedule of maintenance and maintenance procedures specified?
Earth testing schedules?

38.33.4.3 Operating procedures

Adequacy of 'lock-off'/isolation systems?
Conformity with the Electrical Regulations?
'Permit to work' systems for maintenance?

38.33.4.4 Overhead power lines

Maintenance of adequate clearance with satisfactory signing of hazard?

38.33.4.5 Control of access

Adequate access control to areas of concentration of electrical equipment?

38.33.5 Pressure equipment

38.33.5.1 Type and design

Adequately engineered for duty envisaged?
Safe working practices clearly deployed and adhered to?
Possible abnormal fluctuations in pressure identified and allowed for in design?
Adequate design for safe relief of overpressure?

38.33.5.2 Inspection/maintenance

Inspection schedule in force in conformity with Pressure Vessel Regulations?

38.33.5.3 Gas cylinders

Correct storage facilities for full/empty cylinders?
Segregation of combustible from oxidizing gases?
Compliance with HFL (highly flammable liquids) Regulations where applicable?

38.33.6 Materials handling and storage

38.33.6.1 Cables, ropes, chains and slings

SWL (safe working load) marked thereon strictly adhered to?
Certification and retest procedures specified and implemented?
Adequate and suitable storage facilities?

38.33.6.2 Lifts and hoists

Statutory inspection schedule in force?
Safe barriers/chains, etc. on teagle openings?
Runway beams tested and SWL displayed?

38.33.6.3 Cranes

SWL schedule (including operating radius variations) displayed and adhered to?
Overload devices fitted?

38.33.6.4 Conveyors

Adequate guarding (if powered)?
Adequate tripwires/buttons?
'Hand-traps' eliminated

38.33.6.5 Power/hand trucks

Correct specification/design for duty?
Laid-down code of operation?
Full and correct training/retraining/licensing of operators?

38.33.6.6 Manual lifting/handling

Training in safe techniques of lifting/handling?

38.33.6.7 Storage/piling of materials and goods

Safe condition of pallets?
Observance of specified maximum stacking heights?
Safe conditions of stacks?

38.33.7 Hazardous materials

38.33.7.1 Flammable/explosive substances

Properties known and documented?
Compliance with Storage Regulations?
Quantities within licence/regulation limits?
Tank vents safe and adequately sized?
Compatibility of materials in storage acceptable?

38.33.7.2 Toxic substances

Properties known and documented?
Compliance with storage regulations?
Quantities within licence/regulation limits?
Compatibility with other materials in storage acceptable?
Adequate personal protective equipment available for handling and use of material specified?
Antidotes/emergency facilities available?

38.33.7.3 Corrosive materials

Properties known and documented?
Adequate emergency washing facilities available?

38.33.7.4 Disposal of hazardous waste

Regular removal?
Use of experienced/licensed removal contractors?
Conformity with Hazardous Waste Regulations?
Safe operation of site incinerators, settling lagoons, etc.?
Adequate containment of hazardous spillage?

38.33.8 Hazardous processes

38.33.8.1 General

Hazard studies carried out to identify normal and abnormal hazards and circumstances leading to such hazards?

38.33.9 Health hazards and their control

38.33.9.1 Dust and fume

Optimum suppression of dust/fume at point of origin?
Enclosure of dust/fume producing processes?
Superior ventilation at point of dust/fume origin?
Priority to cleaning methods (vacuum, etc.)?
Provision of adequate respiratory equipment and instructions on its correct use?
Correct (statutory) procedures for entry into enclosed areas which may contain fumes?

38.33.9.2 Noise

Minimization at source?
Regular monitoring of noise levels?
Enclosure of excessive noise sources?
Provision of personnel ear protection and instructions on its correct use?
Regular audiometry of employees at risk?

38.33.9.3 Skin disease (dermatitis)

Identification of potential causes?
Adequate hygiene in use of dermatitic substances?
Provision of protective equipment, barrier creams, etc. and instruction on their use?
Medical screening of employees at risk?

38.33.9.4 Carcinogenic materials

Identification of potential causes of cancer in the workforce?
Serious considerations of alternative materials?
Adequate containment of identified carcinogens?
Medical screening of employees at risk?

38.33.9.5 Radioactive materials and X-ray/ionizing radiation equipment

Minimization of exposure time?
Identification and maintenance of safe working distances between sources and employees?
Correct shielding of sources?
Adequate monitoring of exposure (film badges, dosimeters, etc.)?
Warning notices?

38.33.10 Personal protective equipment

38.33.10.1 Goggles/face screens, gloves/protective clothing, ear protection, barrier creams

Risks identified and the appropriate level of protective equipment determined?
Best available equipment specified for identified risks with instructions on correct use?
Effects of use of safety equipment assessed apposite possible creation of additional hazard (e.g. loss of ability to hear emergency signals while wearing ear protection)?

38.34 Safety of the public and public liability (third party)

In general, all points already listed under employer's liability apply equally in public liability (third party) situations. Additionally, the following should be considered.

38.34.1 Pollution

38.34.1.1 Solid wastes

Safe means of disposal, both on-site and at the disposal site, dump, etc. (long- and short – term effects)?
Safe and full incineration (if employed) with safe and full treatment of off-gases?
Correct pre-treatment of waste before disposal (if need identified)?

38.34.1.2 Liquid effluents

Correct design to optimize discharges?
Containment of spillages?

Bunding of tanks and storage devices
Discharges within consent levels?
Adequate effluent treatment plant (if need identified)?
Adequate monitoring of effluent streams with relevant recording?

38.34.1.3 Gaseous emissions

Correct design to optimize discharge within requirements of consent, Regulations, etc.?
Adequate monitoring of emission quality with relevant recording?

38.34.1.4 Noise

Adequate provision for limitation of noise levels (by distance or by reduction at source) at site boundary and beyond?

38.34.2 Visitors

38.34.2.1 Contractors

Adequate advice/training on-site, hazard site rules, etc.?
Competence assessed?
Liaison personnel appointed?

38.34.2.2 Invitees

Potential risks to visitors assessed?
Adequate advice on alarm systems, etc.?
System of escorts on-site implemented?

38.34.2.3 Trespassers

Optimization of site perimeter security and its maintenance in satisfactory condition?
Security patrols off-site?
Specified policy and means of dealing with trespassers found on premises?

38.34.3 Off-site work ('work away')

38.34.3.1 General

Adequate and competent supervision?
Adequate control of all operations involving the application of heat?
Adequate control of any operations (e.g. excavation) which may cause damage to or weaken third-party property?
Specific risk assessments

FURTHER READING

Chapter 8 Fire Prevention. And the list of publications associated.
There is a vast amount of advisory and guidance literature published on Health & Safety Legislation, the most notable source being the Health & Safety Executive & HSE Books, PO Box No: 1999. Sudbury, Suffolk. CO10 6FS.
Most of these publications are priced but many are free issue and a full list of all the publications is available on request.

39 Health and safety

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Support Services

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39.1 Introduction

The initial introduction of the Health and Safety at Work, etc. Act 1974 enabled provisions in the Act to supersede legislation contained in 31 relevant Acts and 500 subsidiary regulations in use at that time. The 1974 Act is the framework which, over the years, will enable the gradual improvement of existing health and safety requirements. This will be achieved by revising and updating current provisions in the form of regulations and approved codes of practice prepared in consultation with industry. These provisions will maintain or improve the health and safety standards established by existing legislation. The objective of the Act is not only that it be introduced to rationalize existing provisions but also to ensure that standards of health and safety are improved, thereby providing greater protection to persons at work and to the general public.

39.2 Legislation

Health and safety legislation is in four separate categories as follows.

39.2.1 Acts of Parliament

The Factories Act 1961 and the Health and Safety at Work, etc. Act 1974 are the result of Bills which, after being debated in Parliament, have received the Royal Assent and now form part of criminal law.

39.2.2 Regulations

The 1974 Act is all encompassing. It lays down only general duties and grants the appropriate minister the power to make detailed Regulations to cover relevant aspects referred to in general legislation. That is, the Act, being an up-to-date form of legislative control, differs from that found in previous formats of the Factories Act 1961.

The Control of Substances Hazardous to Health Regulations 1999 (**COSHH**), the Noise at Work Regulations 1989, and the Electricity at Work Regulations 1989 are examples of the Regulations introduced. For example, the Electricity at Work Regulations which came into effect from 1 April 1990 revoked the Electricity Regulations 1908 and the Electricity (Factories Act) Special Regulations 1944. Within the structure of Regulations provisions may be granted for exemptions from their requirements or application in some form, with respect to specific premises, processes or industries.

Current legislation July 2000 – Appendix A

39.2.3 Codes of Practice

Codes of Practice, where appropriate, are issued to supplement Regulations. These Codes, although having a special legal status, are not statutory requirements but may be used in criminal proceedings as evidence that statutory requirements have been contravened. Prior to replacing or amending existing Codes of Practice discussions are normally held with interested parties before the Health and Safety Commission approves them for use under the Health and Safety at Work, etc. Act 1974.

39.2.4 Guidance notes

Guidance notes relevant to sound health and safety practices are published from time to time by the Health and Safety Executive. They have no legal status nor a significance such as found in Codes of Practice. However, as their content is normally based on a wealth of practical experience, it would be expected by the enforcing authorities that employers would follow the advice contained in them.

39.3 Administration of the Health and Safety at Work etc Act

The bodies set up to ensure the satisfactory implementation and operation of the Health and Safety at Work, etc. Act 1974 (and the Employment Medical Advisory Service Act 1972) under Section 10 of the Act are the Health and Safety Commission and the Health and Safety Executive.

39.3.1 The Health and Safety Commission

This consists of a chairman appointed by the Secretary of State for Employment and a committee of not less than six and not more than nine members. The composition of the Commission is drawn from different groups: three members may be from employers' organizations and three from employees' organizations. The three remaining vacancies may be filled from such organizations as local authorities and professional bodies, as the Secretary of State considers appropriate.

39.3.2 The Health and Safety Executive

Whereas the Health and Safety Commission is responsible for the development of policies in the health and safety field, the Health and Safety Executive, being a separate statutory body appointed by the Commission, will work in accordance with directions and guidance given by the Commission. The Executive will provide advice on health and safety to both sides of industry and will also enforce legal requirements. The major inspectorates which normally worked within the structure of each relevant government department now report to the Executive.

39.3.3 Local authorities

Under the Commission's guidance these will enforce legislation in certain areas of employment. In general, theirs will not be industrial activities.

39.3.4 Fire authorities

The Health and Safety at Work, etc. Act 1974 gives the relevant fire authority the power to designate a place

of work as premises requiring a fire certificate. This certificate will indicate the measures to be taken with respect to means of escape in the event of a fire when the structural design of the premises is taken into consideration. The fire authority in most areas has the responsibility for enforcing the provisions of the Act, but the Health and Safety Executive are responsible for issuing fire certificates in certain classified premises (e.g. those used for storage, manufacture and use of highly flammable liquid).

39.4 General duties

Employers and others who now have duties under the 1974 Act will have had some form of responsibilities under previous legislation (e.g. the Factories Act 1961) to ensure the health and safety and welfare of people at work. However, a number of employers will be subject to such legislation for the first time.

Much of the previous legislation has been revoked by the introduction of E.C.Directives being adopted/implemented within the remit of the 1974 Act.

39.4.1 Duties of employers

It is the duty of employers, as far as is reasonably practicable, to safeguard the health, safety and welfare of the people who work for them and also others who may be affected. This applies in particular to the provision and maintenance of safe plant and equipment and methods of work, and covers all plant, equipment and substances used. Specific areas that require attention include:

1. Is the plant and equipment designed, installed and operated to the accepted standards?
2. Are there safe systems of work implemented during the operation and maintenance of the plant and equipment? (This may necessitate a permit to work to be issued by an authorized competent person.)
3. Is the work environment monitored, as required under the COSHH Regulations, to ensure that there is no hazard from, for example, toxic contaminants?
4. Has the monitoring of any control measure been implemented?
5. Is there a programme in place whereby all equipment and appliances found necessary to ensure the safety and health of those likely to be affected are regularly inspected?
6. Have the risks to health from the use, storage, handling or transport of articles or substances been kept to the minimum? (Expert advice should be sought in this area if there is no sufficient in-house knowledge).

39.4.2 Safety policies: organization and arrangements

It is a statutory requirement that an employer with five or more employees prepares a written statement of the company's general policy, organization and arrangements for health and safety at work. This policy statement should be revised at regular intervals and, where appropriate, amended.

39.4.3 Safety training and information

Employers have a duty under the 1974 Act to provide, as necessary, training and information to ensure that there is no risk to the health and safety of their employees. It may be found necessary to provide operators and maintenance employees with specific training to carry out certain processes or work tasks.

This duty has been further emphasized in all new legislation.

39.4.4 Duties to others

Employers must, as far as is reasonably practicable, have regard for the health and safety of contractors' employees or the self-employed who may be affected by the company's operations and for the health and safety of the general public. This covers, for example, the emission of noxious or offensive gases and dust into the atmosphere, or danger from plant and equipment to which the public or those not directly employed by the company have access.

39.4.5 Responsibilities of the self-employed

The self-employed have a similar duty to that of employers to ensure that there is no risk or danger to the health and safety of themselves or any other persons.

39.4.6 Duties of manufacturers and suppliers

Section 6 of the Act has been amended by the Consumer Protection Act 1987 and now imposes specific duties on manufacturers, importers, designers and suppliers to ensure that articles and substance supplied for use at work are safe and without risk to health.

To assist manufactures and suppliers attain the required level of health and safety, the Health and Safety Commission have approved standards laid down by such bodies as the British Standards Institution.

The Provision & Use of Work Equipment [PUWER] Regulations and The Construction (Design &) [CDM] Regulations have further enhanced the responsibilities/duties of manufacturers and designers.

39.4.7 Duties of employees

The Act and the new legislation also places a responsibility on the employees in that they must take reasonable care to avoid injury to themselves or to others by their work activities, and also cooperate with their employer and others in meeting all statutory requirements. The Act also requires that employees do not interfere with or misuse anything designed to protect their health, safety or welfare.

39.4.8 Enforcement

On finding that there has been a contravention of either an existing Act or Regulation, or of a provision of the Health and Safety at Work, etc. Act 1974, an inspector can:

1. Issue a prohibition notice, if there is a risk of serious personal injury, to stop the work or process giving rise to this risk until remedial action specified by the inspector in the notice has been undertaken. This notice can be served on the person carrying out the activity or in control of it at the time the notice is served.
2. Issue an improvement notice if there is a legal contravention of any statutory legislation relevant to the activity in that the activity cannot be continued until the remedial action specified in the notice is implemented. This notice can be served on the person who is deemed to be contravening the legal provision or who is responsible for the activity, whether they are an employer, employee or a supplier of equipment or materials.
3. Prosecute any person who may be contravening a relevant statutory provision instead of (or in addition to) serving a notice.

39.5 Safety policy

The safety policy for the company, although common in most parts with the safety policy for every company, may require to be prepared in greater detail. This would naturally cover any process, hazardous product or procedure specific to the organization. In preparing the policy it is essential to ensure that parts referred to in Section 2(3) of the 1974 Act are covered, i.e.:

1. The general policy statement;
2. The organization and arrangements for carrying out the policy.

In large companies these two aspects may be dealt with separately. In larger organizations it can be found that it is of greater benefit if the policy document is produced in two separate sections. These would include:

1. A concise statement of the company's general policy, organization and arrangements in a single document. It follows that this document can then be issued individually to all members of staff and contractors who work on the premises.
2. A more detailed document in the form of a health and safety manual. This manual would include the company's policy statement, company rules, safe working procedures, etc., and would normally be located in a nominated office. It is necessary in using this method that all staff are made aware of its contents and its location.

39.5.1 Policy statement

The company's general policy statement should be a declaration of the employer's intent to provide a safe and healthy workplace for all employees and should also include the request that the employees provide the necessary support towards achieving the company's aims.

39.5.2 Levels of responsibility

The policy statement should give the name, designation and office location of the nominated senior member of the company designated as the responsible person within the organization for ensuring that the company's policy statement is complied with. This nominated person should have high position within the company (e.g. director, senior manager, company secretary).

While the overall policy responsibility for health and safety rests with senior managers, all employees within the organization, irrespective of their duties, have some degree of responsibility for carrying out the policy. Where appropriate, nominated persons with specific responsibilities for health and safety should be named with a summary of their responsibilities defined. It follows that there should be a procedure established whereby deputies are available during the nominated person's absences.

Where specialist knowledge is required, the relevant aspects should be clearly established and the respective persons made aware of such. This expertise can be obtained, for example, from the company's safety officer, chemist, etc. Finally, the policy statement should make clear the level of responsibility of every employee.

39.5.3 Safety representatives and joint safety committees

Where health and safety consultation is in place (e.g. joint safety committees) the structure with regards to members' representation should be described.

39.5.4 Training and supervision

The policy statement should indicate how the company proposes to carry out training with respect to health and safety, but equally important is the responsibility placed on managers, supervisors, etc. to ensure that the individual who has been given the work task has the experience and knowledge to carry it out without risk to themselves or others. This task may be operating a piece of equipment on which all safety measures must be in order or carrying out a maintenance task where there is an acknowledged hazard. It is therefore equally important that managers and supervisors are suitably trained in both the technical and safety aspects of the work.

39.5.5 Hazard details

Many accidents occur because the operator or maintenance person does not understand the hazards involved or has not been instructed on the precautions to be taken. The policy document should identify the main hazards within the company with advice on which rules must be obeyed while carrying out a hazardous task. General rules should also be included to cover items such as untidy work areas, replacement of guards, the use of protective clothing/equipment where appropriate, safe working practices in handling goods and materials, etc. It is essential that on the introduction of new products, processes, operations or plant and equipment that any hazards

associated with these are brought to the attention of all concerned.

39.5.6 Reporting accidents

Procedures must be prepared to ensure that the reporting of accidents meets the requirements as set out in the Reporting of Injuries. Diseases and Dangerous Occurrences Regulations 1995. Accidents should also be recorded in the Company Accident Book. The procedure adopted should include a measure of recording and reporting of accidents, which should then form the basis of discussion by management and/or joint safety committees, with a view to identifying any hazard that gives rise for concern and introducing the appropriate corrective action where necessary. The number of accidents could be taken as a measure of how the organization is performing overall with respect to the health and safety of its workforce and others.

39.5.7 Policy review

The policy document should be reviewed at regular intervals, e.g. yearly, to ensure that any changes from the introduction of new legislation (i.e. regulations, codes of practice, guidance information concerning safe working procedures) are implemented.

39.6 Information

Health and safety information can be obtained from the following Health and Safety Executive [HSE] offices:

Info line: Tel. 0870 154 5500

HSE Books
PO Box 1999
Sudbury
Suffolk CO10 2WA
Tel. 01787 88116
Fax 01787 313995

Internet:
HSE home page on World Wide Web is at:
wwwopengov.uk
HSE online catalogue
http: www.hsebooks.co.uk

Additionally HSE documents, etc, can be acquired at e.g. Stationary Office [S.O] and certain Bookshops

Enquiries with respect to health and safety at the workplace should be directed to the local area office of the HSE or the local authority's Environmental Health Office [EHO]. The name of the authority responsible for the health and safety in the organization should be displayed prominently within the premises on the **poster 'Health and Safety Law'** [revised July 2000]. This poster gives a brief guide to health and safety law and specific details on key points must be obtained from the relevant legislative documents.

The revised "poster" in addition to the "enforcing authority" being displayed is so designed that (i) Appointed Person(s) with respect to the management of health & safety within the company and (ii) "safety representatives can also be displayed.

39.7 HSE inspectorates

HSE inspectors systematically visit and review a wide range of work activities, giving expert advice and guidance where necessary. The Inspectorates, within the HSE, which monitor or enforce standards and provide advice in specific sectors of industry or employment are as follows:

For National Interest Groups contact your local HSE offices

39.8 The employment medical advisory service (EMAS)

This is an organization of doctors and nurses based in area offices and forms the medical arm of the HSE. The EMAS provides advice, at the request of the employer, employee, self-employed, trade union representative or medical practitioner, on the effects of work on health.

39.9 HSE area offices

HSE Office addresses/telephone numbers for your locality will be found in local telephone directories.

The Health and Safety Executive operate from area offices as follows.

Wales & West Region
Regional Office: Cardiff [also EMAS office]
Brunel House, 2 Fitzalan Road, Cardiff CF2 1SH
Tel 01222 263000 Fax 01222 263120

Main Offices:
Inter City House, Mitchell Lane, Victoria Street, Bristol BS1 6AN
Tel. 0117988600 Fax 01179 262998
The Marches House, Midway, Newcastle-under-Lyme, Staffs ST5 1DT
Tel 01782 602300 Fax 01782 602400

Home Counties Region
Regional Office: Luton [also EMAS office]
14 Cardiff Road, Luton, Beds LU1 1PP
Tel. 01582 444200 Fax 01582 444320

Main Offices:
Priestley House, Priestley Road, Basingstoke, Hants, RG24 9NW
Tel. 01256 404000 Fax 01256 404100
39 Baddow Road, Chelmsford, Essex CM2 0HL
Tel. 01245 706200 Fax 01245 706222

London & South East Region
Regional Office
201–211 Borough High Street, London SE1 1JA
Tel 020 7566 2100 Fax 020 7566 2200

Main Office: [also EMAS office]
3 East Grinstead House, London Road, East Grinstead, West Sussex RH19 1 RR
Tel. 01342 334200 Fax 01342 334222

Midlands Region
Regional Office: Birmingham [also EMAS office]
McLaren Building, 35 Dale End, Birmingham, B4 7NP
Tel. 0121 607 6200 Fax 0121 607 6349

Main Offices:
5th Floor, Belgrave House, 1 Greyfriars, Northampton NN1 2BS
Tel. 01604 738300 Fax 01604 738333
1st Floor, The Pearson Building, 55 Upper Parliament Street,
Nottingham NG1 6AU
Tel. 01159 712800 Fax 01159 712802

Yorkshire & North East Region
Regional Office: Horsforth [also EMAS office]
Woodside House, 261 Low Lane, Horsforth, Leeds LS18 5TW
Tel 0113 283 4200 Fax 0113 283 4344

Main Offices:
8 St Pauls Street, Leeds LS1 2LE
Tel. 0113 283 4296 Fax 0113 283 4296
Sovereign House, 110 Queen Street, Sheffield S1 2ES
Tel. 0114 291 2300 Fax 0114 291 2379
Arden House, Regent Centre, Gosforth,
Newcastle NE3 3JN
Tel. 0191 202 6200 Fax 0191 202 6300

North West Region
Regional Office: Manchester [also EMAS office]
Quay House, Quay Street, Manchester M3 3JB
Tel. 0161 952 8200 Fax 0161 952 8222

Main Offices:
The Triad, Stanley Road, Bootle, Merseyside L20 3PG
Tel. 0151 479 2200 Fax 0151 479 2201
Victoria House, Ormskirk Road, Preston PR1 1HH
Tel. 01772 836200 Fax 01772 836222

Scotland
Head Office Edinburgh [also EMAS office]
Belford House, 59 Belford Road, Edinburgh EH4 3UE
Tel. 0131 247 2000 Fax 0131 247 2121

Other Offices:
375 West George Street, Glasgow G2 4LW
Tel. 0141 275 3000 Fax 0141 275 3100
Lord Cullen House, Fraser Place, Aberdeen AB9 1UB
Tel. 01224 252525 Fax 01224 252525

39.10 Health and safety procedures

Note that the following procedures only provide a framework in which specific health and safety procedures for the individual works or premises may be prepared. The foreword to a company's procedure should be written by a senior member of the company or the person nominated as responsible for health and safety in the organization. To emphasize its importance it should also include a part of the company's health and safety statement followed by an instruction such as 'You are required to read the following procedures carefully and comply with the sections relevant to your workplace'.

39.11 Fire and first-aid instructions

39.11.1 Fire

Fire bells are installed in works or premises:

1. To alert all staff in the event of a fire alarm;
2. To order complete evacuation of the works or premises (in a number of workplaces such evacuation may not be necessary).

On hearing the alarm all personnel should leave the building by the nearest safe fire exit. They should not use the lifts or re-enter the building until given permission by the person controlling the incident.

Staff should be aware of all fire-precaution notices and procedures (including the fire brigade's telephone number), fire call points, extinguishers, fire exits, escape routes and assembly points.

39.11.2 First aid/medical services

Staff should make themselves familiar with the first-aid procedures in the event of an accident and know the location of the nearest, occupational nurse, first aiders / appointed persons officers and the first-aid room (if there is one on the premises). They should also be aware of all first aid/medical notices and procedures and the telephone number to call for assistance during and outside normal hours. (These are likely to differ unless the works or premises operates 24 hours a day.)

39.12 Good housekeeping

Good housekeeping can play a major part in maintaining a safe and environmentally sound place of work. Many accidents are caused by tripping over material not tidied away. Another source of potential injury is in the lack of secure storage of cleaning equipment, tools, etc.

Liquids allowed to overflow and those not adequately cleaned off the floor also present potential hazards by persons slipping.

General hints on keeping the workplace clean are:

1. Use waste bins. Special containers may be required for specific hazardous waste material.
2. Return everything to its correct place.
3. Always tidy up after completing the task.
4. Keep passageways and footpaths clear at all times.
5. Store materials and equipment in a safe manner.
6. Store hazardous material in its correct location.
7. Encourage everyone to develop 'clean' habits.

39.13 Protective clothing and equipment

Protective equipment / clothing should comply with the Personal Protective Equipment at Work Regulations 1992

and meet standards as required with CE and British Standards.

1. Eye protection should comply with the relevant British Standard at time of purchase.
2. Safety helmets should comply with the relevant British Standards). If engaged in construction, the Construction (Head Protection) Regulations 1989 must be applied.
3. The Noise at Work Regulations 1989 has set action Levels which must be complied with:

   (a) Where employees are exposed to between 85 dB(A) 90 dB(A) they are
   (b) entitled to ask for ear protectors and the employer must provide them. There is no obligation on the employer to ensure that protectors are used or on the employee to use them.
   (c) At or above 90 dB(A) and the peak action level of 200 Pa or 140 dB re 20 μpa the employer must provide suitable ear protectors and enforce their use, and employees are under an obligation to use them. Hearing protectors should comply with British Standards.

   Where exposure is at or above 90 dB(A) the employer is required to reduce exposure to noise as far as is reasonably practicable by means other than ear protectors. As with other regulations, it is now a duty of the employer to assess the noise exposure and advise the employee as appropriate. In a noisy environment the employer may have to seek expertise from a competent person to carry out the necessary assessments and monitoring of the premises.
4. Safety footwear must be worn where applicable (moving heavy objects, working with hazardous materials (e.g. chemicals), working in wet conditions). Footwear should comply with the British Standards as appropriate:
5. Safety belts [harnesses] should comply with British Standards.
6. Protective clothing (including gloves) must be used where applicable (e.g. normal duties; welding/cutting; hot work; water treatment; application use of chemicals: during servicing of batteries; descaling/chemical cleaning). Clothing and gloves should comply with British Standards.
7. Respirators should comply with British Standards. (Refer to HSE publications for guidance on the type of respirators suitable for use against aerosols containing *Legionella.*)

When in doubt as to which standard of protection is necessary, consult the manufactures, suppliers, HSE, EMAS, or the Environmental Health Officer.

39.14 Safe working areas

It is essential when carrying out any operation or task that cannot be undertaken standing on a floor that an appropriate working platform is used. This can take many forms, but the methods that should be used fall within the following types: stepladders; trestles with suitable boards; towers (mobile); proprietary scaffolding or general-access scaffolding. Such access equipment should be to the relevant British Standard.

The use of access equipment should meet the acceptable standards as laid down in the Construction (Health, Safety & Welfare) Regulations 1966.

Items that should be checked on access equipment before use include:

1. General condition – is there any damaged section or parts?
2. Is it the correct access equipment to carry out the task safely? For example, is a ladder adequate or should a tower be used?
3. Is it positioned correctly (e.g. ladders at the correct ratio of 4:1; scaffold on a sound footing)?
4. Is the ladder or scaffold secured safely?
5. What is the condition of access equipment after inclement weather?
6. Is there any risk to its use in a specific area (e.g. close to overhead power lines)?
7. Does it have handrails and toeboards fitted? (Construction Regulations insists on these when working height is at 2 m to or more. This should not preclude taking the same measures at lower heights as the risk will be required to be assessed under the Management of Health & Safety at Work Regulations, Reg. 3.)
8. Does it provide a safe working area? If in doubt seek advice, as there are many injuries each year caused by falls or by material dropping from heights. The wearing of safety helmets is a secondary protection and should not be allowed to encourage carelessness.

39.15 Materials handling

Whenever possible, lifting of excessive weights should be by mechanical means and should only be done manually if there is no practicable method of obtaining access for mechanical equipment. It follows that material must only be moved manually if it is within the capability of the persons involved and that there is no risk of injury. Refer to Manual Handling Operations Regulations 1992.

39.15.1 Manual lifting

Correct manual lifting and handling of material prevents strains and injury and also reduces the effort required. Persistently incorrect lifting and handling may lead to the person suffering from permanent back strain or other health problems. Points to consider when preparing to lift material are:

1. Can you lift it yourself?
2. Does it have sharp corners or edges?
3. Is there any obstruction where you have to walk or place the material?

When lifting the material:

1. Stand with your feet apart, with one foot in the direction you intend to move.
2. Grip the object with the palms of your hands.

3. Keep a straight back and, bending slightly at the knees, use your thigh muscles to lift.
4. With elbows in and arms close to the body, slowly rise.
5. Keeping your chin in and raising your head, lift the object to the height required, adjusting the position of your feet to ensure that you maintain your balance.
6. Take care when a hazardous substance (e.g. acid is lifted).
7. Always wear the correct protective clothing.
8. Get help with heavy loads.

39.15.2 Mechanical lifting

In addition to the general rules of the Health & Safety at Work, etc. Act 1974 there are specific requirements set out in;

The Supply of Machinery (Safety) Regulations 1992 & Amendments

The Provision & Use of Work Equipment Regulations 1998 [PUWER] which covers all equipment, and more detailed requirements with respect to lifting in, The Lifting Operations and Lifting Equipment Regulations 1998 [LOLER]

39.16 Portable tools and equipment

1. Portable electrical hand tools and equipment shall be properly earthed and wound to operate on 110 V a.c. centre tapped to earth supply, and shall only be connected to the system by permanent joints or proper connections.
2. Portable lighting, when used in wet conditions or confined spaces, should operate at no more than 25 V a.c. single phase, and must be fitted with the correct guard.
3. Persons operating abrasive wheels (e.g. bench grinders, machine grinders, disc grinders) should be trained in their use. To dress or mount (change) a wheel or a disc, the operative must have attended a training course in compliance with PUWER, Regs 9 & 12.
4. It follows that with any tool or equipment that is potentially dangerous or operators who may suffer injury from its use must be protected. To meet this requirement, training must be provided.

39.17 Confined spaces

Some plant and equipment are immediately classified as confined spaces, but extreme caution is necessary in the assessment of other areas. Section 2 of the Health and Safety at Work, etc. Act 1974 requires employers to ensure the health and safety at work of their employees; this duty is 'so far as is reasonably practicable'. Therefore as work in confined spaces is potentially dangerous this Section of the Act clearly requires employers to ensure that there is no risk to their employees when working in such an area.

Where work is to be carried out in a confined space this must in accordance with the Confined Spaces Regulations 1997. No person must enter or be in a confined space unless he or she has been authorized to do so, and all the appropriate safety precautions have been strictly adhered to prior to entry and while within it. Points that must be checked prior to the issue of the appropriate permit to work should include the following:

1. Are there fumes present?
2. Is there an adequate supply of maintainable oxygen?
3. Will breathing apparatus be required? Has the operative had training in its use and is there adequate support?
4. Is there any hazardous residue in the 'space'?
5. Has the space been tested for being clean and gas free?
6. Is there a supporting person standing by in the event of an emergency?
7. Is there a safety harness and rope available for use when the work is to be carried out? The operative entering the space will wear a harness [where practicable] while the operative standing by the entrance will retain the free end of the rope attached to the safety harness.

39.18 Electricity

The Electricity at Work Regulations 1989 revoke, among others, the Electricity Regulations 1908 and the Electricity (Factories Act) Special Regulations 1944, which have been the most important electricity regulations for many years. These regulations, effective from 1 April 1990, place a responsibility on both employer and employee to comply as far as it is reasonable and practicable within their control. Major changes from the previous regulations are as follows.

Regulation 13: Precautions for work on equipment made dead

In order to prevent danger while work is carried out on or near electrical equipment which has been made dead, adequate precautions shall be taken to prevent it from becoming electrically charged during that work if danger may arise thereby.

Regulation 14: Work on or near live conductors

No person shall be engaged in any work activity on or near any live conductor (other than one suitably covered with insulating material) so that danger may arise unless:

1. It is unreasonable in all circumstances for it to be dead;
2. It is reasonable in all circumstances for the person to be at work on or near it while it is live; and
3. Suitable precautions (including, where necessary, the provision of suitable protective equipment) are taken to prevent injury.

Regulation 16: Persons to be competent to prevent danger and injury

No person shall be engaged in any work activity where technical knowledge or experience is necessary to prevent danger or, where appropriate, injury, unless he or she possesses such knowledge or experience, or is under such degree of supervision as may be appropriate having regard to the nature of the work.

Additional safety precautions

1. You must not work on or interfere with any electrical equipment unless you have been authorized to do so.

2. Do not use electrical equipment or switch rooms as a storage area.
3. Assume that all electrical distribution circuits are live.
4. Obtain the necessary authority/permit to work before commencing any work on electrical systems.
5. Do not improvise: electricity can kill.

39.19 Plant and equipment

39.19.1 Compressed air

Compressed air can be dangerous if used incorrectly:

1. Never use compressed air for cleaning. The pressure from nozzles may blow particles of dirt and dust into the eyes, ears or skin of the person using the nozzle for cleaning or of others in the vicinity.
2. Do not dust yourself down with the compressed air nozzle.
3. Indulging in horseplay with compressed air can have disastrous results.

Persons employed to use compressed air in carrying out a specific work task must be correctly equipped to prevent injury. The minimum requirement is to wear eye protectors which conforms to the relevant British Standard.

39.19.2 Steam boilers

Section 38 of the Factories Act 1961 defines a steam boiler as a 'any closed vessel in which for any purpose steam is generated under pressure greater than atmospheric pressure'.

The legislation covering boilers and pressure equipment / systems are,

The Pressure Equipment Regulations 1999 SI 1999 No.2001 The Pressure Systems Safety Regulations 2000 SI 2000 No. 128.

Boilers / pressure vessels examination will be carried out as per the Pressure Systems Safety Regulations by a competent person.

Entry into boilers / pressure vessels will be carried out under the Confined Spaces Regulations

39.19.3 Pressure systems

The Pressure Systems Safety Regulations 2000 SI 2000 No. 128 re-enact with amendments the Pressure Systems and Transportable Gas Regulations 1989.

1. The supply of information for new plant;
2. The proper installation of plant; and
3. The establishment of safe operating limits on existing plants.

The Regulations relating to gas cylinders apply to suppliers, importers, fillers and owners of cylinders from 1 January 1991 if:

1. The plant contains a compressed gas (such as compressed air or liquefied gas) at a pressure greater than 0.5 bar (about 7 psi) above atmospheric;
2. If steam systems with a pressure vessel are used at work, irrespective of the pressure;
3. The plant is used at work by employees and/or the self-employed.

For full details of the requirements reference should be made to the Pressure Systems Safety Regulations and the published Approved Code of Practices [A.C.O.P's] & HSE Guidance Notes.

39.19.4 Machinery

The requirement for safety precautions when operating or working on all types of machinery cannot be overstressed, in that the likelihood of an accident occurring on moving machinery is invariably high. It is essential that all these who work on such machines are adequately trained as to the operation and the safeguards fitted. The Provision & Use of Work Equipment [PUWER] Regulations must be complied with. Other information can be found in British Standards.

In premises in which there are, e.g. Woodworking Machinery and or Power Presses reference should be made to the appropriate A.C.O.P for detailed guidance.

General precautions to observe include:

1. Machines must not be used unless properly guarded (or operatives are trained). All damaged guards/security measures must be reported.
2. Never reach over operating machinery or wear loose clothing when working at or on machinery.
3. Never start up a machine until you are certain that no one can be injured by doing so.
4. Keep the floor area around the machine clean.
5. Do not clean the machine when it is in operation.
6. Wear appropriate protective clothing.

39.20 Safety signs and pipeline identification

39.20.1 Safety signs

The Health and Safety (Safety Signs & Signals) Regulations 1996 apply to signs which give a health and safety message to people at work by using certain shapes, colours and pictorial symbols. There are four basic types of safety signs which the Regulations require to conform to BS 5378: 1980, Safety signs and colours:

1. Solid blue circle: mandatory ('You must do');
2. Red circle with a red band across the diameter: prohibition ('Do not do');
3. Yellow triangle with black border: caution ('Warning of danger');
4. Solid green square: information ('Safe conditions').

Graphic symbols may be placed in the above shapes to give them more meaning and there may also be text affixed to them. In the case of Fire Exits there is a requirement to have a "running man" displayed on the sign.

Care must be exercised when adopting the hand signals shown in the guidance to the regulations in that they

differ in some instances to those found in the relevant British Standard. It is therefore imperative that when using hand signals that it is agreed with the signaler and the recipient of the signals that they are using those found in the guidance or the British Standards.

39.20.2 Pipeline identification

Pipelines should be marked clearly as to the contents as set out in the Health and Safety (Safety Signs & Signals) Regulations. This can be achieved by marking them in accordance with BS 1710, System (contents) and BS 4800, Colours (indicating contents).

39.21 Asbestos

In the 1987 Regulations, asbestos is defined as any of the following minerals; crocidolite, amosite, chrysotile, fibrous anthophyllite, fibrous actinolite, fibrous tremolite and any mixture containing any of these. Before carrying out work on any substance suspected of being asbestos a competent person must be called to advise on its possible composition. Such a person will advise on the measures that must be taken to avoid any hazard to the occupants or others likely to be affected. Companies with asbestos on their premises should hold the appropriate documents. Current Regulations include

Asbestos (Licensing) Regulations 1983, amended 1998
Asbestos (Prohibitions) Regulations 1992
Control of Asbestos at Work Regulations 1987

39.22 COSHH

The Control of Substances Hazardous to Health (COSHH) Regulations 1999 cover virtually all substances hazardous to health. Only asbestos, lead, materials producing ionizing radiations and substances below ground in mines (which all have their own legislation) are excluded. The Regulations set out measures that employers must implement. Failure to comply with COSHH, in addition to exposing employees and others to risk, constitutes an offence and is subject to penalties under the Health and Safety at Work Act, etc. 1974.

Substances that are hazardous to health include:

1. Those labelled as dangerous (i.e. very toxic, toxic, harmful, irritant or corrosive);
2. Agricultural pesticides and other chemicals used in farming;
3. Those with occupational exposure limits;
4. Harmful microorganisms;
5. Substantial quantities of dust;
6. Any material, mixture or compound used at work, or arising from work activities which can harm people's health.

In works, premises, factories, etc. there will be substances in use that come within the control of COSHH. Seek advice!

The following publications give detailed information on COSHH and its requirements:

1. Control of Substances Hazardous to Health Regulations 1999, Approved Code of Practice: Control of substances hazardous to health, Control of carcinogenic substances, Control of biological agents;
2. Occupational Exposure Limits: Guidance Note EH40 (revised and issued yearly)

39.23 Lead

The Control of Lead at Work Regulations 1998 apply to work which exposes persons; (both employees; and others) to lead as defined in Regulation 2 (i.e. to the metal and its alloys to compound; of lead, which will include both organic and inorganic compounds, and to lead as a constituent of any substance or material) when lead is in a form in which it is liable to be inhaled, ingested or otherwise absorbed by persons. Relevant publications are:

1. Control of lead at work: Approved Code of Practice, Regulations and Guidance

39.24 Other information

Whilst Regulations are issued by Government through the Stationery Office [SO] most are supported by HSE publications which contain the regulations and either an ACOP or Guidance and in some instance both of the latter. Numerous leaflets can be obtained from the local offices of the Health and Safety Executive or HSE Information Points. Remember, if you have any doubts about the health and safety risks involved with respect to any substance you may consider using, or any work you are planning to undertake, seek advice. This information may be obtained from your company safety officer, consultants, manufacturer/supplier or equipment/material/substance, HSE or local Environmental Health Officer. Use their expertise and knowledge. Do not be a statistic.

39.25 Assessment of potential hazards

39.25.1 Purpose

An assessment of potential hazards (APH) [Refer to The Management of Health & Safety at Work Regulations 1999 – Regulation 3 – Risk Assessment] shall be carried out prior to work tasks being issued to determine:

1. Physical hazards;
2. Access/exit;
3. Potentially unsafe practices likely to be implemented in carrying out the work;
4. Safe working procedures;
5. Whether a permit to work is required.

39.25.2 Working practices

An assessment of each element of the programme of work is carried out using the Assessment of Potential Hazards

Form APH1 (see below), which is to be completed by the person responsible for the task to be carried out. This may include 'hot' work; cutting/grinding; work on electrical systems; working alone; use of hazardous materials (e.g. chemicals, solvents, etc.); confined spaces or any other work which may be of a hazardous nature.

In establishing potential hazards in carrying out specific tasks, other sources may have to be consulted (e.g. manufacturer, supplier, HSE, environmental health officer, consultants, etc.) and protective clothing and equipment must be considered.

Prior to implementing any APH within the Method Statement for the task the APH and Method Statement must first be approved by the responsible person's senior and/or the manager of the department responsible for the plant and equipment. The approved APH and Method Statements will be brought to the attention of all persons called upon to carry out the specific task. Copies of the APHs will be issued to:

The department responsible for the person carrying out work;
The department in which work is being done: Health and safety/security departments.

APHs will be reviewed annually to ensure compliance with current plant and equipment, procedures and changes in health and safety recommendations.

In the event of accidents, an investigation should include examination of all aspects of the APH.

Assessment of Potential Hazards-Analysis Form APH1
Job Description/Classification Department Date

Task Elements	Hazards

Completed by: ..... Department .....
Approved by: ..... Department .....

39.26 Alternative method of assessing hazards

An alternative method of assessing the hazards of a specific work task may be as follows. The work task envisaged, to be carried out by a contractor, is that of connecting an additional outlet to fuel oil tanks situated within an oil tank room, which is located below ground level.

39.26.1 Work on fuel oil tanks

Relevant information:
Guidance Note CS15: The gas-freeing and cleaning of tanks containing flammable residues (HSE)
ACOP-L101 Safe work in cofined spaces

39.26.2 Procedures: 1

1. Identify the work task.
2. Examine alternative methods for carrying out the task.
3. Select the appropriate method.
4. Plan how the work will be carried out.
5. Who is to carry out the work task and when?
6. Carry out the work task.
7. Continually monitor the work task and the safety measures taken.
8. Review the procedures.

39.26.3 Procedures: 2

1. Identify the work task. Can an alternative method be suggested to the client, hence eliminating potential hazards from the work task?
   (a) Task 1: Ensure that there is no hazard from tanks, etc. that have to be worked on or from the locality of work (i.e. tanks have been emptied, degreased and gas-freed and checked and tested);
   (b) Task 2: As per client's instructions (client provides Method of Work Statement).
2. Examine alternative methods for carrying out the task.
   (a) Can the work be carried out without the use of heat (i.e. welding, burning, electrical equipment (arcing), cutting causing heat or sparks, assembled externally and flanged rather than welded?
   (b) Will the work be carried out in stages, i.e. will some of the adjacent tanks remain charged?
3. Select the appropriate method.
4. Plan how the work will be carried out.
5. Discuss with the client:
   (a) The period during which work can be carried out;
   (b) Their involvement and responsibility with respect to fire precautions, extinguishers, permit to work, liaison with fire brigade, fire officer attendance;
   (c) Who is responsible for emptying the fuel tanks;
   (d) Cleaning, degreasing and gas freeing the tanks;
   (e) Testing for explosions or oxygen deficiency.
6. Nominate a person to be in charge.
7. Prepare a programme of work.
8. Is training required on use of respirators, entry into confined spaces, fire prevention and use of extinguishers?
9. Who is to carry out the work task and when?
   Task 1:
   (a) Contractor;
   (b) Nominated specialist contractor;
   (c) Client;
   Task 2:
   (a) Contractor;
   (b) Nominated specialist contractor.
10. Carry out the work task only when a permit to work has been issued which states that the work area is safe for working and details the safety checks that have been made and precautions to be taken.
11. Continually monitor the work task and the safety measures taken.

(a) Ensure that Task 1 has been carried out satisfactorily and check report/record;
(b) Continually monitor working environment for explosion or fire risk and/or oxygen deficiency.

12. Review the procedures.
(a) Ensure that the company's safety officer checks the procedures;
(b) Have the procedures been effective or should they be amended? If so, why?

If specialist contractors are to be engaged a Method Statement should first be requested from them on how they plan to carry out the work.

39.27 Permits to work

Where there is a risk to the employee carrying out work, in addition to a Method Statement a permit to work should be used. A permit to work is a formal written means of making sure that potentially dangerous jobs are examined first, before authorizing the work to commence. Its task is twofold: it ensures that the person making the system safe and the person who is to carry out the work have both checked that it is safe to carry out the work task. Permits to work cannot be transferred to other parties. If any circumstances change from the issue of the original permit to work, it must be cancelled and a new one prepared.

Permits to work can be of differing formats. Therefore it is essential that when a permit to work has been issued it should be read carefully and understood and all possible measures taken to reduce or eliminate the known danger. Permits can be issued for a variety of work tasks (e.g. work on high-voltage electrical systems, steam boilers, hot work, confined spaces, etc.). The permit below is an example of differing types of work tasks.

39.27.1 Permission to Work on Electrical Systems Certificate (not exceeding 1000 V)

This certificate must always be raised by the authorized person and sections 1 to 3 inclusive completed before any work is allowed to be carried out. A consecutive serial number must be entered on the certificate.

Where the authorized person is to carry out the work, he must complete section as the person responsible for work being carried out and retain the top copy on him throughout the period the work is being carried out. The bottom control copy must remain in the register.

Where a competent person is to carry out the work he must complete section 3 as the certificate holder. The authorized person then issues him the top copy which he must retain on him throughout the period the work is being carried out. The bottom copy is retained in the register.

On completion or suspension of the work the responsible person must return the top copy to the register, so that the authorized person ensures that sections 7 and 8 are completed on both top and bottom copies of the certificate. The bottom copy must always be retained in the register for record purposes. Before any suspended work is allowed to be restarted, a new certificate must be raised and processed by the authorized person as above.

Examples of tasks that will require the issuing of the Permission to Work on Electrical Systems Certificate are indicated in Method Statements for Work on Electrical Systems.

Note

1. Authorized and competent persons are nominated by the company after they have been given the appropriate training in both the tasks to be carried out and their responsibility as nominated persons.
2. The electrical engineer would normally stipulate the tasks that require the use of Method Statements for Work on Electrical Systems and would also prepare the Method Statements.
3. A similar format of certificate would suffice as a permit to work for high-voltage systems (i.e. exceeding 1000 V).

An example of this certificate as well as a Hot Work Permit are given below.

39.28 Working alone

39.28.1 Company and contractor's responsibilities for the lone worker

Manager's responsible for services within works, offices or premises have an additional task in that when engaging service contractors they then have joint responsibility under the Health and Safety at Work, etc. Act 1974 and The Management of Health & Safety at Work Regulations for the health and safety of the contractor's employees while on their premises. When engaging contractors to carry out work within the premises, systems must be implemented by which the contractor's employee works in a safe manner and does not create a hazard to the premise's occupants or staff while carrying out this work. This responsibility is greater when there is an employee or service contractor working alone, as in most instances the premises' communications do not allow for such circumstances (e.g. the lone employee may be working in remote areas such as plant rooms).

To enable both company and contractor to comply with their specific responsibilities under the Health and Safety at Work, etc. Act 1974, a Lone Workers' policy, supported by a method of assessment of potential hazards [Risk Assessment] relating to the work to be carried out, should be prepared. Such a system would prove beneficial when, for any reason, the regular lone worker cannot be found.

39.29 Safety policy for lone workers

In the Health and Safety at Work, etc. Act 1974 the following Sections apply:

Section 2: General duties of employers to their employees
Section 4: General duties of persons concerned with premises to persons other than their employees
In the Management of Health & Safety at Work [MHSW] Regulations, the following Regulations apply;
Regulation 3 – Risk Assessment

Company..... **Serial No**.....

PERMISSION TO WORK ON ELECTRICAL SYSTEMS CERTIFICATE (not exceeding 1000 V)

1. This Certificate is issued for the following Authorized Work. No other work may be carried out. Entrance to work area is limited to those authorized. Tools/access equipment etc. must be approved by authorized person prior to them being taken into the work area.

2. **Work Details/Job No./Method Statement Ref. No**

3. **Work Location:**

4. **Method of Isolation:**.....
The equipment on which the work is to be carried out has been proven dead after isolation at:.....

Care must be exercised as the equipment is still live at:.....

Safety screening has been applied at:.....
Lock-Off Key Nos..... Danger Notices Posted: Y/N
Warning Signs Displayed: Y/N Safety Barriers Erected: Y/N

5. **Authorized Person issuing Certificate:**
Designation.....
Date Time..... Signature.....

6. **Person Responsible for Work being carried out:**
Company/Dept Name.....
Designation..... Signature.....

7. **Work Completed/Suspended:** Date Time.....
Person Responsible for Work being carried out:
Company, Dept..... Name.....
Signature.....

8. **Cancellation of Certificate by Authorized Person:**
Receipt of Certificate indicating work is Complete/Suspended:
Name..... Signature.....
Designation..... Date Time.....

On cancellation of this certificate, no other work must be carried out on the plant/equipment without a further certificate being issued.

Company..... **Serial No**.....

AUTHORIZATION TO WORK ON ELECTRICAL/MECHANICAL APPARATUS CERTIFICATE

1. This Certificate is issued for the following Authorized Work. *No other work other than that detailed must be carried out.*

Work Details:

Work Location:

Method of Isolation/Making Safe:

Lock-Off Key Nos.....
Danger Noticed Posted: Yes/No.....
Warning Signs Displayed: Yes/No.....

Authorized Person issuing Certificate.....
Designation..... Date / Time.....

Person Responsible for Work being carried out:
Company..... Name..... Signature.....
Designation.....

2. **Work Completed: Date** Time.....
Person Responsible for Work carried out:
Company..... Name.....
Designation..... Signature.....

3. **Authorized Person:**
Receipt of Certificate indicating work is complete:
Designation.....Date.....
Name..... Signature.....

N.B. Copy of this Certificate to be issued to Person responsible for carrying out Work.
Signature of Receipt.....

HOT WORK PERMIT

Required when any of the following tasks are to be carried out: Cutting; Welding; Soldering, Brazing and also during the use of any equipment which can produce heat, naked flames or dust (i.e. dust likely to affect Detector Heads)

Period of Work:

Commence:..... hrs day month year
Completion /..... hrs day month year
Expiry

Location of Work:

Description of Work:

Precautions:

Department in which work is to be carried out has been advised
Cutting/Welding/Brazing/Hot Work Equipment is in good order
Fire Alarm: ON/OFF Halon System: ON/OFF Sprinkler System: ON/OFF
Fire Notices Posted: YES/NO Insurance Informed YES/NO
Fire Detectors are protected
Precautions within 35 ft (10 m) of work area:
Floors and areas clear of combustibles
Walls and floor openings covered with e.g. Fire Blanket
Combustibles if not moved protected by Fire Blanket
Fire Watch will be provided for at least minutes after work (incl. breaks)
Fire Watch is supplied with suitable extinguishers
Fire Watch is trained in use of extinguishers and method of raising alarm

I have examined the location of the work, checked that all precautions and preventive measures have been implemented.
Authorizing Signature..... Name.....
Designation..... hrs.....20.....

I hereby declare that no work other than that stated above will be carried out.
Signed by.....Name..... Design'n/Company.....

I hereby declare that the work has been completed and that the work and adjacent areas have been checked for fire # minutes after the completion of the work task. enter 30 / 60 / 90 / 120 minutes as appropriate

Signed by..... Name..... Design'n/Company.....
Authorizing Signature..... Name.....

Designation..... hrs..... 90.....

Regulation 12 – Persons working in host employers' or self-employed persons' undertakings

Working alone presents a specific health and safety problem and companies, department managers and contractors must ensure that there is a safe system whereby:

1. The person working alone is adequately trained for the work that is to be carried out;
2. Having carried out an assessment of potential hazards (APH) or Risk Assessment, a Method Statement (including advice on whether a permit to work is required) is prepared;
3. The correct tools, equipment and manufacturers instructions are available;
4. Contact is maintained by: (a) Means of telephone at regular intervals; (b) Visits by others at regular intervals; (c) Persons passing through a 'Lone Worker' area are made aware of the lone worker's presence; (d) The intervals between contact being made should not exceed one hour.

A lone worker must:

1. Comply with any Method Statement / Assessment or safe system introduced for his or her health & safety;
2. Work safely at all times, and not take risks;
3. Understand the hazards-risks associated with the work to be carried out;
4. Understand the hazards/risks when *working alone*;
5. Ensure, where necessary, that a permit to work has been requested and issued.

39.30 Contractor's conditions and safe working practices

The use of contractors to carry out work that may in the past have been done by direct labour or during a normal sub-contract does not relieve the company from the responsibility of ensuring that all those working on their premises do carry out their work in a safe manner. The following contractor's conditions and safe working practices should form a part of the company's health and safety policy manual.

39.30.1 Introduction

These conditions and safe working practices form part of the contract and are to be read in conjunction with the general conditions of the contract form. The company reserves the right to make alterations or additions to those conditions and practices as and when necessary. Contractors, sub-contractors or their employees must not communicate to persons other than the company staff any information relating to the work being carried out by the contractor or sub-contractors. Information, drawings, etc. must not be removed from company premises without prior permission from the company contact, who is the responsible person for arranging the appropriate clearance relating to that information.

39.30.2 Contents

39.30.2.1 Local conditions

1. On arrival at company premises
2. Prior to commencement of work
3. Attendance at company premises for more than one day.

39.30.2.2 Safe morning practices and procedures

1. Health and safety
2. Emergency procedures

39.31 Safe working practices and procedures

39.31.1 Health and safety

1. Health and safety is each employer's responsibility with respect to their employees under the Health and Safety at Work, etc. Act 1974.
2. Contractors must comply with all statutory and site regulations.
3. It is the contractor's responsibility to ensure that all work is carried out safely and by competent persons.
4. Method statements / Risk Assessments as to how the work is to be carried out, clearly indicating matters relating to health and safety, must be passed for approval to the nominated company officer prior to the commencement of work.
5. The successful contractor is responsible for ensuring that all items above are brought to the attention of any contractors to whom work is sub-contracted.

39.31.2 Protective clothing and equipment

All clothing / protective equipment must comply with the Personal Protective Equipment Regulations and the current CE / British Standards

1. Eye protection.
2. Safety Helmets must comply with the Construction (Head Protection) Regulations in construction work.
3. Noise must comply with the Noise at Work Regulations.
4. Safety footwear *must* be worn where applicable (e.g. moving heavy objects; working with hazardous materials and in wet conditions).
5. Safety belts: Refer to HSE Roofwork HSG33 – Appendix 3.
6. Protective clothing (including gloves) *must* be used where applicable (e.g. normal duties; welding/cutting hot work; water treatment; application/use of chemicals; during servicing of batteries; descaling/chemical cleaning).
7. Respirators: Also refer to HSE publications for additional guidance.

When in doubt, consult with manufactures, suppliers, HSE, EMAS, the local authority or the environmental health officer.

39.31.3 Access equipment

All work equipment should be to the highest industrial standards

1. Stepladders,
2. Trestles,
3. Scaffolds.

Scaffold and other access equipment should comply with a standard as for the Construction (Health, Safety & Welfare) Regulations and HSE, HSG150 Health & Safety in Construction

39.31.4 Warning signs and good housekeeping

All appropriate warning signs must comply with the Health & Safety (Safety Signs and Signals) Regulations and must be displayed prior to commencement and for the duration of the work to be carried out. Workplaces must be kept safe and tidy and all access/exit areas clear of obstruction. Additional information is available from HSE publications.

39.31.5 Tools and equipment

The contractor will be responsible for the supply of all tools and equipment, unless otherwise agreed by company representatives:

1. Portable electrical hand tools and equipment shall be properly earthed and wound to operate on 110 V a.c. centre tapped to earth supply, and shall only be connected to the system by permanent joints or proper connections.
2. Portable lighting must operate at no more than 25 V a.c. single phase, and must be fitted with the correct guard.
3. Equipment issued by the company is so provided on the understanding that it will be properly used by competent workers under adequate supervision, and that the contractor shall be solely responsible for and indemnify the company against loss or damage to such equipment and all or any loss, injury, death of any person or damage to any property whatsoever arising out of the use of such equipment.

39.31.6 Materials/parts/spares

1. Materials used must be of the highest standard, complying as necessary with the appropriate British Standard.
2. Materials supplied by the company must only be used.

39.32 Emergency procedures

39.32.1 Fire

When arriving at the Company premises and being shown their work area the contractor's employees must:

1. Check the location of the nearest fire exit.
2. Make themselves familiar with fire alarm procedures.
3. Ensure that means of escape are kept clear at all times.

39.32.2 First aid

The contractor's employees must:

1. Make themselves familiar with the first aid procedures in the event of an accident.
2. Check the location of the nearest first aid persons and the first aid room if there is one on the premises.

39.33 Contractor's Guide

This is to be issued to an individual on arrival at a company's premises. All contractors' employees must adhere to the following procedures.

39.33.1 On arrival at company premises

1. Report to reception
2. Advise reception/office of:
   (a) Company contact who requested attendance;
   (b) Work to be carried out, stating department location;
3. On being signed in/issued identity badge be advised of:
   (a) Whereabouts of work location; or
   (b) Be escorted to work location by member of staff; or
   (c) Be escorted by company contact;
4. Be issued with a copy of the *Contractor's Guide.*

RELEVANT-HEALTH & SAFETY LEGISLATION?

HASAW ACT 1974
FACTORIES ACT
OFFICE SHOPS & RAILWAY PREMISES ACT 1963
FIRE PRECAUTIONS ACT 1971
FOOD SAFETY ACT 1990
ENVIRONMENTAL PROTECTION ACT 1990
CONTROL OF POLLUTION ACT 1990
6 – PACK [E.C. DIRECTIVES 1992]
MANAGEMENT OF HEALTH & SAFETY AT WORK 99
MANUAL HANDLING OPERATIONS
PERSONAL PROTECTIVE EQUIPMENT
PROVISION & USE OF WORK EQUIPMENT [PUWER 98]
DISPLAY SCREEN EQUIPMENT
WORKPLACE
OTHER RELEVANT LEGISLATION
ASBESTOS (LICENSING) (AMENDMENT) 1998
ASBESTOS AT WORK 1987
CHEMICAL (HAZARD INFORMATION & PACKAGING FOR SUPPLY)
CARRIAGE OF DANGEROUS GOODS BY ROAD 1996
CARRIAGE OF DANGEROUS GOODS BY ROAD (DRIVER TRAINING)
CARRIAGE OF DANGEROUS GOODS – SAFETY ADVISOR 1999

CONTROLLED WASTE (REGISTRATION OF CARRIERS & SEIZURE OF VEHICLES) 1991
CONSTRUCTION (DESIGN & MANAGEMENT) 1994
CONSTRUCTION (HEALTH, SAFETY & WELFARE) 1996
CONSTRUCTION (HEAD PROTECTION) 1989
COSHH 1999
CONFINED SPACES 1997
CONSULTATION WITH EMPLOYEES 1996
ELECTRICITY AT WORK 1989
ELECTRICITY SUPPLY 1988
EMPLOYER LIABILITY (COMPULSORY INSURANCE) 1998
FIRST AID 1981
FIRE PRECAUTIONS (WORKPLACE) 1997 & AMENDMENT 1999
FIRE CERTIFICATES (SPECIAL PREMISES) 1976
GAS SAFETY (MANAGEMENT) 1996
GAS SAFETY (INSTALLATION & USE) 1998
HEALTH & SAFETY INFORMATION FOR EMPLOYEES 1989 [amended 1999]
HEALTH & SAFETY (ENFORCING AUTHORITY) 1998
HIGHLY FLAMMABLE LIQUIDS & LPG 1972
HEALTH & SAFETY (YOUNG PERSONS) 1997
HEALTH & SAFETY (SAFETY SIGNS & SIGNALS) 1996
IONIZING RADIATIONS 1999
IONIZING RADIATIONS (OUTSIDE WORKERS) 1993
LEAD 1998
LIFTING OPERATIONS & LIFTING EQUIPMENT [LOLER 98]
NOISE AT WORK 1989
NOTIFICATION OF COOLING TOWERS & EVAPORATIVE CONDENSERS 1992
PRESSURE SYSTEMS 2000
PRESSURE EQUIPMENT 1999
RIDDOR 1995 & ACCIDENT REPORTING / BI 510 ACCIDENT BOOK
SPECIAL WASTE 1996
SAFETY REPRESENTATIVES & SAFETY COMMITTEES 1977
SUPPLY OF MACHINERY (SAFETY) 1992
STREET WORKS (QUALIFICATIONS OF SUPERVISORS & OPERATIVES) 1992
WORK IN COMPRESSED AIR 1996
WORKING TIME 1998

39.33.2 Prior to commencement of work

The company contact/coordinator will:

1. Discuss items in the Contractor's Guide relevant to the work to be carried out;
2. Ensure that adequate notice has been issued to all other parties, e.g.:
   (a) Members of department, including deputy;
   (b) Others who may be carrying out work in that area;
   (c) Contact security; loss prevention coordinator for issue of permits to work, advice/instructions on health and safety, specific hazards relevant to work and work area and issue of fire extinguishers/fire blankets;
3. Give permission to commence work.

39.33.3 Security

If attendance at company premises is required on more than one day to complete the work the contractor's employees must:

1. Sign in/out at reception/security;
2. Collect/return:
   (a) Identity badge;
   (b) Permits to work (not to be removed from premises);
   (c) Keys (not to be removed from premises).
3. Report proposed absence from/return to premises:
   (a) Contact;
   (b) Security/Loss prevention co-ordinator if work requires a permit;
   (c) Facilities coordinator/department head if work involves general premises/site, facilities/services.

39.33.4 Welfare/canteen

1. These facilities may be used by contractors subject to approval by the company.

39.33.5 Useful contacts

1. These include the telephone numbers of contact, security, first aid, etc.

39.34 Health & Safety Information

Local Environmental Offices
Tel-local telephone directory

Local HSE Offices
Tel-local telephone directory

British Safety Council
Tel 020 8741 1231 Fax 020 8741 0835

RoSPA
Tel 0121 248 2000 Fax 0121 248 2001

HSE Infoline
Tel 0870 154 5500

HSE Books
Tel 01787 881165 Fax 01787 313995

HSE Videos
Tel 0845 741 9411 Fax 01937 541083

HSE Scottish RIDDOR Hotline
Tel 0845 2770277

HSE (Northern Ireland)
Tel 028 9024 3249 Fax 028 9023 5383

British Standards (BSI)
Tel 020 8996 9001 Fax 020 8996 7001

The Stationery Office
Tel 0870 600 5522 Fax 0870 600 5533

Fire Protection Association
Tel 020 7902 5300 Fax 020 7902 5301

Environmental Agency [England & Wales]
General enquiry: Tel 0845 933 311
Hotline for reporting environmental incidents
Tel 0800 807060

Scottish Environmental Protection Agency
General enquiry: Tel 01786 457700 Fax 01786 446885
Hotline for reporting environmental incidents
Tel 0800 807060

Department of Trade & Industry
Enquires Tel 020 7215 500 Fax 020 7222 2629
Publications Tel 020 7215 6024
CE Marking Helpline Tel 0202 7215 1487

CORGI
Tel 01256 372 00 Fax 01256 708144

Construction Industry Training Board
Tel 01485 577577 Fax 01485 577689

Asbestos Removal Contractors Association [ARCA]
Tel 01245 259744 Fax 01245 490722

Heating & Ventilating Contractors Association [HVCA]
Tel 020 7229 2488 Fax 020 7727 9268

Building Research Establishment
Tel 01923 664000 Fax 01923 664010

The Institution of Plant Engineers
Tel 020 7828 6401

The Fire Protection Association-Loss Prevention Council
Tel 020 8207 2345 Fax 020 8207 6305

40 Lubrication

Original by BP Oil UK Ltd
Revised by Eric Sloman
Consultant

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40.1 Introduction

This chapter examines the need for lubrication and the types of lubricant available. Various applications are considered, including engines gears, hydraulic equipment, machine tools, metal cutting and working fluids, compressors, turbines and electrical oils. The care of lubricants on-site, application of planned lubrication and inclusion within overall maintenance management are also examined.

The plant engineer's objective must be to ensure that plant operates at a profit. If overall efficiency of operation is to be achieved, and the working costs of plant kept within acceptable bounds, time must be set aside for the control and application of lubrication. The evolution of lubricants and their application, has continued ever since the beginning of the Industrial Revolution, and as the pattern of industry becomes increasingly more complex, the standard of performance of lubricants becomes progressively more important.

40.2 Lubrication – the added value

All machines depend for their accuracy on the strength of their component parts, their bearings and on the type and efficiency of their lubrication systems. Many machine bearings are subjected to extremely heavy shock loads, or intermittent loads, or exposure to unfavourable environmental conditions, yet in spite of this they must always maintain their setting accuracy.

Accuracy and reproducibility are of vital importance to industry. Quite apart from the effect of these factors on the final product, several plant items are frequently links in a continuous chain of production processes. A sizing error in one machine, for example, could overstress and damage the succeeding machinery. Similarly, an error in a press may increase stress on the tool and could necessitate an additional operation to remove excessive 'flash'. Wear in a material preparation unit could allow oversize material to be passed to a moulding machine, creating an overload situation with consequent damage.

The reduction of friction is only one of the functions of a lubricant. It must remove heat (often in large amounts), protect bearings from damage and preserve the working accuracy and alignment of the structure. It must also protect bearings, gears and other parts against corrosion, and must itself be non-corrosive. Sometimes it may be required to seal shafts and bearings against moisture and the ingress of contaminating particles. The lubricant must be of the correct viscosity for its application and may need additives to meet specification requirements. It must also be non-toxic, and both chemically and physically stable.

Lubrication plays a vital role in the operation of industrial plant. For example, in a heavy rolling mill the lubrication system, though mostly out of sight in the oil cellar, may have a capacity of many thousands of litres and exceed in bulk the mill itself. Lubrication systems of this size and complexity are usually fully automatic, with many interlocks and other safety features. Even with the smallest machines, automatic lubrication is becoming more popular. Where an automatic system would be impracticable or uneconomical, as with many older or less complex machines, it is nevertheless important that lubrication be carried out in accordance with a planned schedule.

It can be seen therefore that heavy demands are made on the plant concerned, and hence on the lubricants required for its efficient operation. The importance of the correct selection and application of lubricants, in the correct amount and at the right time, will be readily appreciated. The cost of providing high-quality lubrication is negligible compared with the material return it will bring in terms of longer working life, higher output of work and reduced maintenance costs.

40.3 Why a lubricant?

When the surfaces of two solid bodies are in contact a certain amount of force must be applied to one of them if relative motion is to occur. Taking a simple example, if a dry steel block is resting on a dry steel surface, relative sliding motion will not start until a force approximately equal to one fifth the weight of the steel block is applied. In general, the static friction between any two surfaces of similar materials is of this magnitude, and is expressed as a coefficient of friction of 0.2. As soon as the initial resistance is overcome, a very much smaller force will keep the slider moving at uniform velocity. This second frictional condition is called dynamic friction. In every bearing or sliding surface, in every type of machine, these two coefficients are of vital importance. Static friction sets the force required to start the machine and dynamic friction absorbs power which must be paid for in terms of fuel consumed. Also, friction resistance of unlubricated surfaces causes heating, rapid wear and even, under severe conditions, actual welding together of the two surfaces.

Lubrication, in the generally accepted sense of the word, means keeping moving surfaces completely separated by means of a layer of some liquid. When this is satisfactorily achieved the frictional resistance no longer depends on the solid surfaces but solely on the internal friction of the liquid which, in turn, is directly related to its viscosity. The more viscous the fluid, the greater the resistance, but this is never comparable with that existing between unlubricated surfaces.

40.3.1 Types of lubrication

Lubrication exists in one of three conditions:

1. Boundary lubrication
2. Elastohydrodynamic lubrication
3. Full fluid-film lubrication

Boundary lubrication is perhaps best defined as the lubrication of surfaces by fluid films so thin that the friction coefficient is affected by both the type of lubricant and the nature of the surface, and is largely independent of viscosity. A fluid lubricant introduced between two surfaces may spread to a microscopically thin film that reduces the sliding friction between the surfaces. The peaks of the high spots may touch, but interlocking occurs

only to a limited extent and frictional resistance will be relatively low.

A variety of chemical additives can be incorporated in lubricating oils to improve their properties under boundary lubrication conditions. Some of these additives react with the surfaces to product an extremely thin layer of solid lubricant, which helps to separate the surfaces and prevent seizure. Others improve the resistance of the oil film to the effect of pressure.

Elastohydrodynamic lubrication provides the answer to why many mechanisms operate under conditions which are beyond the limits forecast by theory. It was previously thought that increasing pressure reduced oil film thickness until the asperities broke through, causing metal-to-metal contact. Research has shown, however, that the effect on mineral oil of high contact pressure is a large increase in the viscosity of the lubricant. This viscosity increase combined with the elasticity of the metal causes the oil film to act like a thin solid film, thus preventing metal-to-metal contact.

Full fluid-film lubrication can be illustrated by reference to the conditions existing in a properly designed plain bearing. If the two bearing surfaces can be separated completely by a fluid film, frictional wear of the surface is virtually eliminated. Resistance to motion will be reduced to a level governed largely by the viscosity of the lubricating fluid.

To generate a lubricating film within a bearing, the opposed surfaces must be forced apart by pressure generated within the fluid film. One way is to introduce the fluid under sufficient pressure at the point of maximum loading, but this hydrostatic method, although equally effective at all speeds, needs considerable power and is consequently to be avoided whenever a satisfactory alternative exists.

Above a certain critical speed, which depends mainly on the size and loading of the bearing and the viscosity of the lubricant, hydrodynamic forces are set up that part the surfaces and permit full fluid-film lubrication. At rest, the fluid film has been squeezed from beneath the shaft, leaving only an absorbed film on the contacting surfaces. As the shaft starts to revolve, friction between the journal and the bearing bore causes the shaft to climb up the inside of the bearing until torque, together with the increased thickness of lubricant film, overcomes frictional resistance and the shaft starts to slip at the point of contact. The rotating shaft then takes up its equilibrium position, where it is supported on a fluid film drawn beneath it by viscous friction (see Figure 40.1).

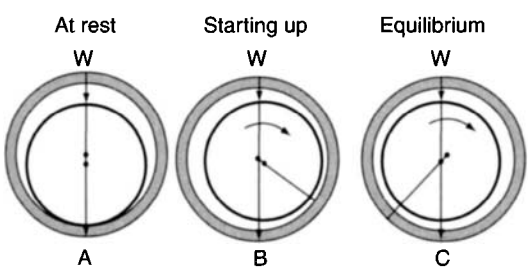


Figure 40.1 Journal positions during start-up while a hydrodynamic oil 'wedge' is being established

40.4 Physical characteristics of oils and greases

Reference will be made to the physical characteristics of lubricants as they affect their selection for various applications. These terms are well known to the lubricant supplier but are not always fully understood by the user. Brief descriptions of these characteristics are therefore given so that their significance may be appreciated.

40.4.1 Viscosity

This is the most important physical property of a lubricating oil; it is a measure of its internal friction or resistance to flow. In simple terms, it provides a measure of the thickness of a lubricating oil at a given temperature; the higher the viscosity, the thicker the oil. Accurate determination of viscosity involves measuring the rate of flow in capillary tubes, the unit of measurement being the centistoke (cSt). As oils become thinner on heating and thicker on cooling a viscosity figure must always be accompanied by the temperature at which it was determined.

The number of commercial viscosity systems can be confusing, and as kinematic viscometers are much more sensitive and consistent, there is a growing tendency to quote kinematic viscosities. The International Standards Organization (ISO) uses kinematic viscosity in its viscosity grade classification (Table 40.1). These ISO grade numbers are used by most oil companies in their industrial lubricant nomenclature. This provides the user with a simple verification of conformity regarding viscosity between plant manufacturer and oil supplier recommendations and also in the monitoring of correct oil usage on his plant.

Table 40.1 ISO viscosity grade chart

ISO viscosity grade	*Mid-point kinematic viscosity*	*Kinematic viscosity limits cSt at 40°C (104°F)*	
		min.	*max.*
2	2.2	1.98	2.42
3	3.2	2.88	3.52
5	4.6	4.14	5.06
7	6.8	6.12	7.48
10	10	9.00	11.0
15	15	13.5	16.5
22	22	19.8	24.2
32	32	28.8	35.2
46	46	41.4	50.6
68	68	61.2	74.8
100	100	90.0	110
150	150	135	165
220	220	198	242
320	320	288	352
460	460	414	506
680	680	612	748
1000	1000	900	1100
1500	1500	1350	1650

40.4.2 Viscosity Index (VI)

This is a way of expressing the rate of change of viscosity with temperature. All oils become less viscous as the temperature increases. The rate of change of viscosity varies with different oils and is mainly dependent on the type of crude from which the oil is derived and the refining method. The higher the VI figure, the lower is the variation in viscosity relative to temperature. The VI of an oil is an important property in applications where the operating temperature is subject to considerable change.

40.4.3 Pour point

This is a rough measure of a limiting viscosity. It is the temperature 2.5°C above that at which the oil ceases to flow when the vessel in which it has been cooled is held horizontally for 5 s. The pour point is a guide to behaviour and care should always be taken that operating temperatures are above the figure specified by the oil manufacturer as the pour point of a given oil.

40.4.4 Flash point

The flash point is an oil is the temperature at which it gives off, under specified conditions, sufficient vapour to form a flammable mixture with air. This is very different from the temperature of spontaneous combustion. The test is an empirical one and the result depends upon the instrument used and the prescribed conditions. For example, the flash point may be 'closed' or 'open', depending on whether the test apparatus has a lid or not. As far as lubricating oils are concerned, the test is of limited significance, although it can be indicative of contamination (for example, the dilution of crankcase oil by fuel).

40.4.5 Penetration of grease

The most important physical property of a lubricating grease is its consistency, which is analogous to the viscosity of a liquid. This is determined by an indentation test in which a weighted metal cone is allowed to sink into the grease for a specified time. The depth to which the cone penetrates, in tenths of a millimetre, is a measure of the consistency. There is a widely accepted scale, that of the American National Lubricating Grease Institute (NLGI), that relates penetration to a consistency number (Figure 40.2).

The penetration test is used mainly to control manufacture and to classify greases and is, within limits, a guide to selection. Penetrations are often qualified by the terms 'worked' and 'unworked'. As greases are thixotropic, that is, they soften as a result of shear but harden again after shearing has stopped, the worked penetration for a particular grease may be appreciably greater than the unworked penetration. The difference between these two figures may be a useful guide to the selection of greases for operating conditions that involve much churning – as small a difference as possible being desirable (see Table 40.2).



Figure 40.2 Grease penetrometer

Table 40.2 NLGI consistency classification for greases

NLGI number	*ASTM worked penetration at 77°F*
000	455–475
00	400–435
0	355–385
1	310–340
2	265–295
3	220–250
4	175–205
5	130–160
6	85–115

40.4.6 Drop point of grease

The drop point of a grease is an indication of change from a soft solid to a viscous fluid; its value depends completely on the conditions of test, particularly the rate of heating. The grease sample, which is held in a small metal cup with an orifice, is heated at a predetermined rate. The drop point is the temperature at which a drop of the sample falls from the cup.

The drop point is of limited significant as far as the user is concerned, for it gives no indication of the condition of the grease at lower temperatures, or of change in consistency or structure with heat. It is a very rough indication of a grease's resistance to heat and a guide to manufacture. The difference between the highest temperature at which a grease can be used and the drop point varies very much between types. It is at its maximum with some soda greases and much smaller with multi-purpose lithium products and modern complex greases.

40.5 Additives

Much highly stressed modern machinery runs under conditions in which a straight mineral oil is not adequate.

Even the highest quality mineral oil can be unsatisfactory in response of its resistance to oxidation and its behaviour under pure boundary conditions, but it is possible to improve these characteristics by the addition of relatively small amounts of complex chemicals. This use of additives resembles in many ways the modification of the properties of steel by the addition of small amounts of other chemicals. It will be of value to have some knowledge of the effect of each type of additive.

40.5.1 Anti-oxidants

When mixed with oxygen, lubricating oil undergoes chemical degradation resulting in the formation of acidic products and sludge. This reaction, which is affected by temperature, the presence of catalysts such as copper and the composition of the oil, can be delayed by the inclusion of suitable additives.

Anti-oxidants are the most extensively used additives and will be found in oils and greases which are expected to operate for considerable periods or under conditions which would promote oxidation. Typical examples are crankcase oils and bearing greases.

40.5.2 Anti-foam

The entrainment of air in lubricating oil can be brought about by operating conditions (for example, churning) and by bad design such as a return pipe which is not submerged. The air bubbles naturally rise to the surface, and if they do not burst quickly, a blanket of foam will form on the oil surface. Further air escape in thus prevented and the oil becomes aerated. Oil in this condition can have an adverse affect on the system which, in extreme cases, could lead to an adverse affect on the system which, in extreme cases, could lead to machine failure. The function of an anti-foam additive is to assist in the burst of air bubbles when they reach the surface of the oil.

40.5.3 Anti-corrosion

The products of oil oxidation will attack metals, and this can be prevented by keeping the system free from pro-oxidative impurities and by the use of anti-oxidants. These additives will not, however, prevent rusting of ferrous surfaces when air and water are present in the mineral oil. The presence of absorbed air and moisture is inevitable in lubricating systems and therefore the oil must be inhibited against rusting. These additives, which are homogeneously mixed with the oil, have an affinity for metal, and a strongly absorbed oil film is formed on the metal surface which prevents the access of air and moisture.

40.5.4 Anti-wear

The increasing demands being made on equipment by the requirement for increased output from smaller units create problems of lubrication, even in systems where full-fluid film conditions generally exist. For instance, at start-up, after a period of rest, boundary lubrication conditions can exist and the mechanical wear that takes place could lead to equipment failure. Anti-wear additives, by their polar nature, help the oil to form a strongly absorbed layer on the metal surface which resists displacement under pressure, thereby reducing friction under boundary conditions.

40.5.5 Extreme pressure

Where high loading and severe sliding speeds exist between two metal surfaces, any oil film present is likely to be squeezed out. Under these conditions very high instantaneous pressures and temperatures are generated. Without the presence of extreme pressure additives the asperities would be welded together and then torn apart. Extreme pressure additives react at these high temperatures with the metal or another oil component to form compounds which are more easily deformed and sheared than the metal itself, and so prevent welding. Oils containing extreme pressure additives are generally used in heavily loaded gearboxes which may also be subjected to shock loading.

40.5.6 Detergent/dispersant

The products of combustion formed in internal combustion engines, combined with water and unburnt fuel, will form undesirable sludge which can be deposited in the engine and so reduce its operation life and efficiency. Detergent/dispersant additives prevent the agglomeration of these products and their deposition in oilways by keeping the finely divided particles in suspension in the oil. They are used in engine-lubricating oils where, when combined with anti-oxidants, they prevent piston-ring sticking. They are essential for high-speed diesels, and also desirable for petrol engines.

40.5.7 Viscosity index improvers

When mineral oils are used over an extended temperature range it is frequently found that the natural viscosity/temperature relationship results in excessive thinning out in the higher-temperature region if the desired fluidity is to be maintained at the lower region. The addition of certain polymers will, within limits, correct this situation. They are of particular value in the preparation of lubricating oils for systems sensitive to changes in viscosity such as hydraulic controls. They are also used in multigrade engine oils.

40.6 Lubricating-oil applications

There is a constant effort by both the supplier and consumer of lubricants to reduce the number of grades in use. The various lubricant requirements of plant not only limit the extent of this rationalization but also create the continuing need for a large number of grades with different characteristics.

It is not possible to make lubricants directly from crude oil that will meet all these demands. Instead, the refinery produces a few basic oils and these are then blended in

varying proportions, together with additives when necessary, to produce an oil with the particular characteristics required. In some instances the continued increase in plant performance is creating demands on the lubricant which are at the limit of the inherent physical characteristics of mineral oil. Where the operational benefit justifies the cost, the use of synthetic base stocks is being developed.

Where these are considered for existing plant, seal and paint compatibility needs to be reviewed before such products are introduced. The problems which face the lubricant supplier can best be illustrated by looking at the requirements of certain important applications.

40.7 General machinery oils

These are lubricants for the bearings of most plant, where circulating systems are not involved. These are hand, ring, bottle or bath lubricated bearings of a very wide range of equipment; line shafting, electric motors, many gear sets and general oil-can duties. The viscosity of these oils will vary to suit the variations in speed, load and temperature.

While extreme or arduous usage conditions are not met within this category, the straight mineral oils which are prescribed must possess certain properties. The viscosity level should be chosen to provide an adequate lubricant film without undue fluid friction, though this may also be influenced by the method of application. For instance, a slightly higher viscosity might be advisable if intermittent hand oiling has to be relied upon. Although anti-oxidants are not generally required, such oils must have a reasonable degree of chemical stability (Figure 40.3).

40.8 Engine lubricants

The type of power or fuel supply available will influence the decision on prime mover to be used. This is often electric power, but many items of plant such as compressors, generators or works locomotives, will be powered by diesel engines, as will most of the heavy goods vehicles used in and outside the works.

The oils for these engines have several functions to perform while in use. They must provide a lubricant film between moving parts to reduce friction and wear, hold products of combustion in suspension, prevent the formation of sludges and assist in cooling the engine. Unless the lubricant chosen fulfils these conditions successfully, deposits and sludge will form with a consequent undesirable increase in wear rate and decrease in engine life.

40.8.1 Frictional wear

If the effects of friction are to be minimized, a lubricant film must be maintained continuously between the moving surfaces. Two types of motion are encountered in engines, rotary and linear. A full fluid-film between moving parts is the ideal form of lubrication, but in practice, even with rotary motion, this is not always achievable. At low engine speeds, for instance, bearing lubrication can be under boundary conditions.

The linear sliding motion between pistons, piston rings and cylinder walls creates lubrication problems which are some of the most difficult to overcome in an engine. The ring is exerting a force against the cylinder wall while at the same time the ring and piston are moving in the cylinder with a sliding action. Also, the direction of piston movement is reversed on each stroke. To maintain a full fluid oil film on the cylinder walls under these conditions is difficult and boundary lubrication can exist. Frictional wear will occur if a lubricant film is either absent or unable to withstand the pressures being exerted. The lubricant will then be contaminated with metal wear particles which will cause wear in other engine parts as they are carried round by the lubricant.

40.8.2 Chemical wear

Another major cause of wear is the chemical action associated with the inevitable acidic products of fuel combustion. This chemical wear of cylinder bores can be prevented by having an oil film which is strongly adherent to the metal surfaces involved, and which will rapidly heal when a tiny rupture occurs. This is achieved by the use of a chemical additive known as a corrosion inhibitor.

40.8.3 Products of combustion and fuel dilution

As it is not possible to maintain perfect combustion conditions at all times, contaminations of the oil by the products of combustion is inevitable. These contaminants can be either solid or liquid.

When an engine idles or runs with an over-rich mixture the combustion process is imperfect and soot will be formed. A quantity of this soot will pass harmlessly out

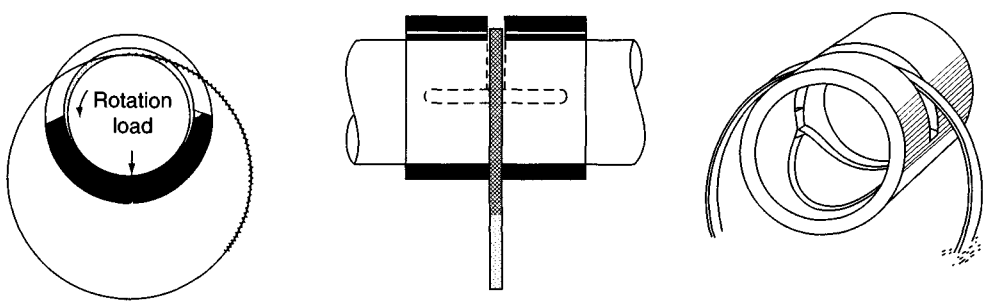


Figure 40.3 Ring oiled bearings

with the exhaust but some will contaminate the oil film on the pistons and cylinders and drain down into the crankcase. If there is any water present these solids will emulsify to form sludges which could then block the oilways. Filters are incorporated into the oil-circulation system to remove the solid contaminants together with any atmospheric dust which bypasses the air filters.

One of the liquid contaminants is water, the presence of which is brought about by the fact that when fuel is burnt it produces approximately its own weight in water. When the engine is warm this water is converted into steam, which passes harmlessly out of the exhaust. However, with cold running or start-up conditions this water is not converted and drains into the sump. Having dissolved some of the combustion gases, it will be acidic in nature and will form sludges.

Another liquid contaminant is unburnt fuel. A poor-quality fuel, for example, may contain high boiling point constituents which will not all burn off in the combustion process and will drain into the sump. The practice of adding kerosene to fuel to facilitate easy starting in very cold weather will eventually cause severe dilution of the lubricating oil. Excessive use of over-rich mixture in cold weather will mean that all the fuel is not burnt because of the lack of oxygen and again, some remains to drain into the sump.

Poor vaporization of the fuel will also produce oil dilution. Generally, this fuel will be driven off when the engine becomes warm and is running at optimum conditions. However, severe dilution of the oil by fuel could have serious results as the viscosity of the oil will be reduced to an unacceptable level.

40.8.4 Oxidation

The conditions of operation in an engine are conducive to oil oxidation, and this is another problem to be overcome by the lubricant. In the crankcase, the oil is sprayed from various components in the form of an oil mist which is in contact with a large quantity of air and at a fairly high temperature. Oxidation produces complex carbonaceous products and acidic material and these, combined with fuel contaminants, will form stable sludges. In the combustion chamber, where the temperatures are very much higher, the oil is scraped up the cylinder walls by the piston ascending at very high speeds and is again present in the form of an oil mist. A form of carbon deposit is produced by a combination of heat decomposition and oxidation. Some of this deposit will remain, but some will pass into the sump. The effect of oxidation adds to the problem of oil contamination by the products of combustion, resulting in the formation of a resin-like material on the pistons and hot metal parts known as 'laquer' and acidic material which will attack bearing metals such as copper-lead.

These problems of engine lubrication can be overcome by using a highly refined oil. The resistance to oxidation is further enhanced by the use of anti-oxidants. The addition of corrosion-inhibitors counters acidic materials produced by combustion at low engine temperatures.

Detergent–dispersant additives are incorporated so that the carbonaceous matter produced by imperfect combustion is retained in suspension in the oil, preventing it from being deposited on the engine surfaces. Such an oil is known as a fully detergent-type lubricant. All these additives are gradually consumed during operation and the rate of decline in their usefulness will determine the oil-change period. This rate is, in turn, influenced by the conditions of operation.

40.8.5 The SAE viscosity system

This classification was devised by the Society of Automotive Engineers (SAE) in America by dividing the viscosity span into four and giving each of the divisions a number – SAE 20, 30, 40 and 50. The thinnest (SAE 20), for example, covered the range 5.7–9.6 cSt specified at 210°F, which was considered to be a temperature typical of a hot engine. (The SAE originally specified temperatures in °F, because they was the convention. Today, temperatures are quoted in °C.)

Later, the SAE series was extended to include much thinner oils because of the growing demand for easier winter starting. The viscosities of the three new grades were specified at 0°F (typical of cold morning temperatures) and each was given the suffix W for Winter–SAE 5W, 10W and 20W. Later still, grades of 0W, 15W and 25W were added to satisfy the more precise requirements of modern engines (Table 40.3).

40.8.6 Multigrades

All oils become thinner when heated and thicker when cooled, but some are less sensitive than others to these viscosity/temperature effects. The degree of sensitivity is known as Viscosity Index (VI). An oil is said to have high VI if it displays a relatively small change of viscosity for a given change of temperature.

In the 1950s, development in additive technology led to the production of engine oils with unusually high VIs, known as multigrade oils. A multigrade oil's high resistance to temperature change is sufficient to give it the combined virtues of a thin grade at low (starting) temperatures and a thick one at running temperatures. An SAE 20W-40 multigrade, for example, is an thin at −20°C as a 20W oil, but as thick at 100°C as an SAE 40 oil. Thus the multigrade combines full lubrication protection at working temperatures with satisfactorily easy starting on frosty mornings. Figure 40.4 is a viscosity–temperature graph for six monograde oils and a 10W-40 multigrade, showing how the multigrade has the high-temperature properties of an SAE 40 oil and the low-temperature properties of an SAE 10W. Thus the multigrade is suitable for all-year-round use.

40.8.7 Performance ratings

The SAE numbering system refers purely to the viscosity of the oil, and is not intended to reflect lubricating performance (there is no such thing as an 'SAE quality' oil, for example). Engine oils are marketed in a range of performance levels, and need to be classified according to the severity of service conditions in which they are designed to operate. Accordingly, the American Petroleum Institute (API) has drawn up a coding system in which oils are subjected to a series of classifying bench-tests known as the 'Sequence' tests.

Table 40.3 Viscosity classification (engine oil viscosity classification–SAE J300 revised Dec. 1999)

SAE viscosity grade	*Low-temperature (°C) cranking viscosity (cP) max.*	*Low-temperature (°C) pumping viscosity (cP) max. with No yield stress*	*Low-shear-rate kinematic viscosity (cSt) at 100°C min.*	*Low-shear-rate kinematic viscosity (cSt) at 100°C max.*	*High-shear-rate viscosity (cP) at 150°C min.*
0W	6200 at −35	60 000 at −40	3.8	–	–
5W	6600 at −30	60 000 at −35	3.8	–	–
10W	7000 at −25	60 000 at −30	4.1	–	–
15W	7000 at −20	60 000 at −25	5.6	–	–
20W	9500 at −15	60 000 at −20	5.6	–	–
25W	13 000 at −10	60 000 at −15	9.3	–	–
20	–	–	5.6	<9.3	2.6
30	–	–	9.3	<12.5	2.9
40	–	–	12.5	<16.3	2.9[a]
40	–	–	12.5	<16.3	3.7[b]
50	–	–	16.3	<21.9	3.7
60	–	–	21.9	<26.1	3.7

[a](OW-40, 5W-40 and 10W-40).
[b](15W-40, 20W-40, 25W-40 and 40).

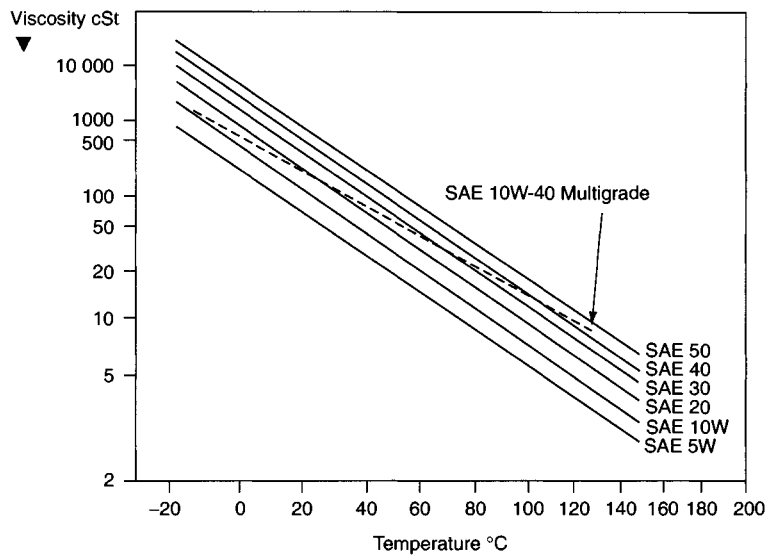


Figure 40.4 Multigrade chart

40.8.8 The API service classifications

In the API system the least demanding classification for a petrol engine was originally designated SA. The most demanding is, at present, SJ. (The S stands for Service Station.) Constant development of both engines and oils means that from time to time the highest ratings are superseded by even higher ratings. The API system also classifies diesel engine oils by their severity of service. Here the categories have the prefix C, which stands for Commercial.

40.8.8.1 Petrol engines

SA Service typical of engines operated under mild conditions. This classification has no performance requirements.

SB Service typical of engines operating in conditions such that only minimum protection of the type afforded by additives is desired. Oils designed for this service have been used since the 1930s; they provide only anti-scuff capability and resistance to oil oxidation and bearing corrosion.

SC Service typical of petrol engines in 1964–1967 cars and trucks. Oils designed for this service provide control of high- and low-temperature deposits, wear, rust and corrosion.

SD Service typical of 1967–1970 petrol engines in cars and some trucks; but it may apply to later models. Oils designed for this service provide more protection than SC against high- and low-temperature deposits, wear, rust and corrosion; and may be used where SC is recommended.

SE Service typical of petrol engines in cars and some trucks in 1972–1979. Oils designed for this service provide more protection against oxidation, high-temperature deposits, rust and corrosion than SD or SC, and may be used where those classifications are recommended.

SF Service typical of petrol engines in cars and some trucks from 1980. Oils developed for this service provide better oxidation stability and anti-wear performance than SE oils. They also provide protection against engine deposits, rust and corrosion. Oils meeting SF may be used wherever SE, SD or SC is recommended.

SG Service typical of petrol engines in cars, vans and light trucks during 1989 – 92. Oils developed for this service provide improved control of engine deposits, oil oxidation and engine wear relative to oils developed for previous categories. Oils meeting SG may be used wherever SF, SE, SF/CC or SE/CC are recommended.

SH Service typical of petrol engine warranty maintenance service in cars and vans during 1992 –1996. API SH oils cover the performance requirements of SG oils tested to the then latest CMA (Chemical Manufacturing Association-USA) protocol on engine testing, but define tighter manufacturing controls.

SJ Service typical of petrol engine warranty maintenance service for passenger cars and vans from 1996. API SJ oils cover the Engine test sequences as for SG, to the current CMA protocol, but with increased severity. SJ oils will provide better overall protection in terms of high and low temperature operation, lower volatility, improved foam control, fuel economy and catalyst compatibility.

40.8.8.2 Diesel engines

CA Service typical of diesel engines operated in mild to moderate duty with high-quality fuels. Occasionally this category has included petrol engines in mild service. Oils designed for this service were widely used in the late 1940s and 1950s; they provided protection from bearing corrosion and light-temperature deposits.

CB This category is basically the same as CA, but improved to cope with low-quality fuels. Oils designed for this service were introduced in 1949.

CC Service typical of lightly supercharged diesel engines operated in moderate to severe duty. Has included certain heavy-duty petrol engines. Oils designed for this service are used in many trucks and in industrial and construction equipment and farm tractors. These oils provide protection from high-temperature deposits in lightly supercharged diesels and also from rust, corrosion and low-temperature deposits in petrol engines.

CD Service typical of supercharged diesel engines in high-speed high-output duty requiring highly effective control of wear and deposits. Oils designed for this service provide protection from bearing corrosion and high-temperature deposits in supercharged diesel engines running on fuels of a wide quality range.

CDII Service typical of two-stroke cycle diesel engines requiring highly effective control over wear and deposits. Oils designed for this service also meet all the requirements of CD.

CE Service typical of certain turbocharged or supercharged heavy-duty diesel engines operating under both low speed-high load and high speed-low load conditions. Oils designed for this service must also meet the requirements specified for CC and CD classifications.

CF-4 Introduced 1990 for high speed, four stroke diesel engines. CF-4 specification provided improved oil control consumption and piston deposits over CE category.

CF Introduced in 1994 for service typical of indirect injected diesel engines which can be naturally aspirated, super or turbo-charged.

CF-2 Introduced 1994 for service typical of two-stroke diesel engines requiring highly effective control of wear and deposits. Essentially API CF plus Detroit Diesel 6V-92TA test. CF-2 is a direct replacement of CDII.

CG-4 Introduced 1995 for use in high speed four stroke diesel engines used in commercial vehicles with fuel sulphur content less than 0.05% wt and off-highway engines using fuel with sulphur content less than 0.5% wt. CG-4 specification oils, formulated for engines meeting the 1994 exhaust emission standards, could be used in engines requiring API CD, CE and CF-4 oils. CG-4 oils provided control over high temperature deposits, wear, corrosion, foam, oxidation stability and soot concentration.

CH-4 Introduced in 1998 for use in high speed, four stroke diesel engines designed to meet the 1998 exhaust emissions standards. Oils to this performance level are formulated for use with diesel fuels containing up to 0.5% sulphur by weight. CH-4 oils can be used in engines where CF-4 or CG-4 are quoted.

Before an oil can be allocated any given API performance level it must satisfy requirements laid down for various engine tests. In the SJ category, for example, the engine tests include the following:

Service IID measures the tendency of the oil to rust or corrode the valve train and to influence the value lifter operation.
Sequence IIIE measures high-temperature oil oxidation, sludge and varnish deposits, cam-and-tappet wear, cam and lifter scuffing and valve lifter sticking.
Sequence VE evaluates sludge deposits, varnish deposits, oil-ring clogging and sticking, oil-screen plugging and cam wear.
CRC L-38: the characteristics assessed are resistance to oxidation, bearing corrosion, tendency to formation of sludge and varnish, and change of viscosity.

In the CH-4 category the tests are:

Caterpillar 1K: the lubricant characteristics determined are ring sticking, ring and cylinder wear, and accumulation deposits under more severe test conditions than those for Caterpillar IH2.

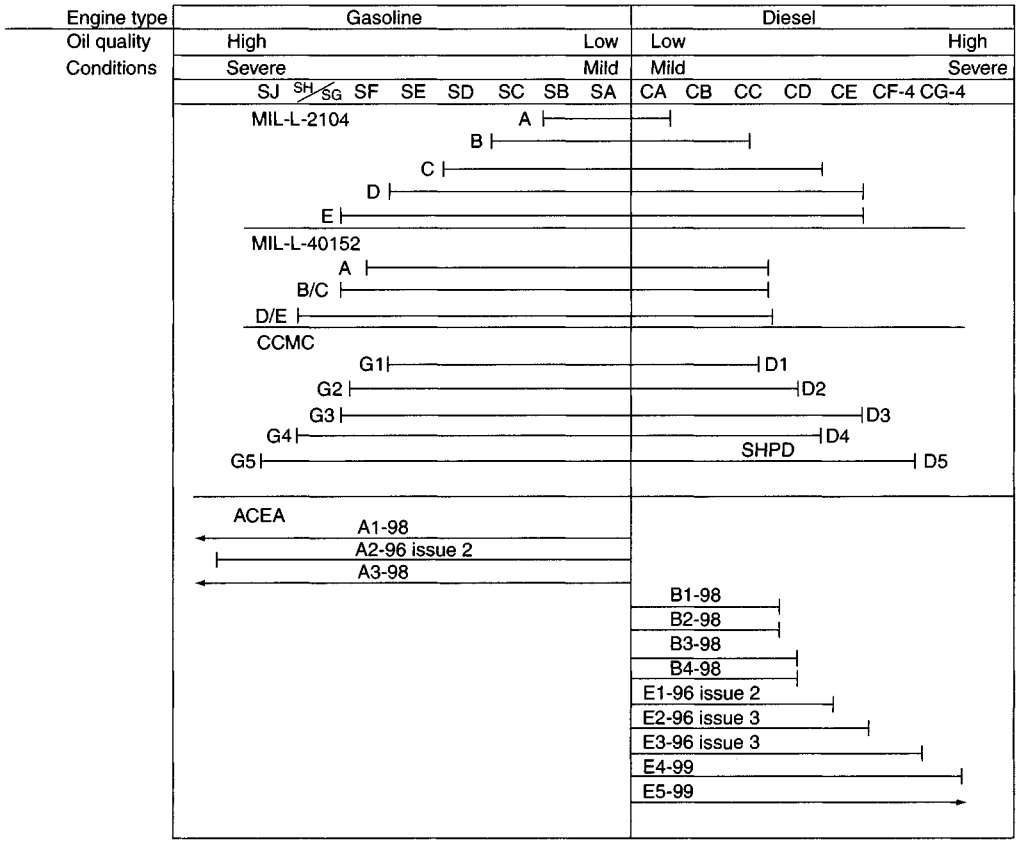


Figure 40.5 Approximate relationship between classifications and test procedures

Cummins M11 evaluates engine sludge crosshead wear and filter pressure.
Mack T8-E, evaluates oil thickening.
Mack T9 evaluates liner & piston ring wear

40.8.8.3 Other specifications

Various authorities and military bodies issue specifications relating to the service performance of engine oils. In some instances the ratings are almost identical with those of the API, but most of them are not precisely parallel because they cover performance factors encountered in particular engines and particular categories of service.

The most common of the other specifications are those with the prefix MIL, issued by the US military authorities. MIL-L-2104F approximates to the API CE rating for diesel lubricants, although it also relates to petrol engines that require API SE performance. MIL-L-46152D covers oils for both diesel and petrol engines, and approximates to API SG/CC (Figure 40.5).

40.9 Gear lubricants

There are few engineering applications in which gears do not play an essential part. They can be used to reduce or increase speed, transmit power and change the direction or position of a rotating axis. There are several types of gears to suit these varying operational conditions, such as spur, helical, plain and spiral bevels, hypoid, worm and wheel (Figure 40.6).

Extremely high pressures are developed between meshing teeth as, in theory, they only have point or line contact. Together with the sliding between mating surfaces which is always present it is clear that, if there is metal-to-metal contact, rapid wear will occur. The function of the lubricant is to provide and maintain a separating film under all the variations in speed, load and temperature. It must also act as a coolant and protect the gears against corrosion.

The lubrication of gears is not a simple matter, because of their shape and variability of motion. Fundamental factors which affect their lubrication are gear characteristics, materials, temperature, speed, loading, method of applying the lubricant and environment.

40.9.1 Gear characteristics

40.9.1.2 Spur, bevel, helical and spiral bevel gears

Providing the speed is sufficient and the load does not squeeze out the lubricant, the effect of rotating these gears is to produce a hydrodynamic wedge of a relatively

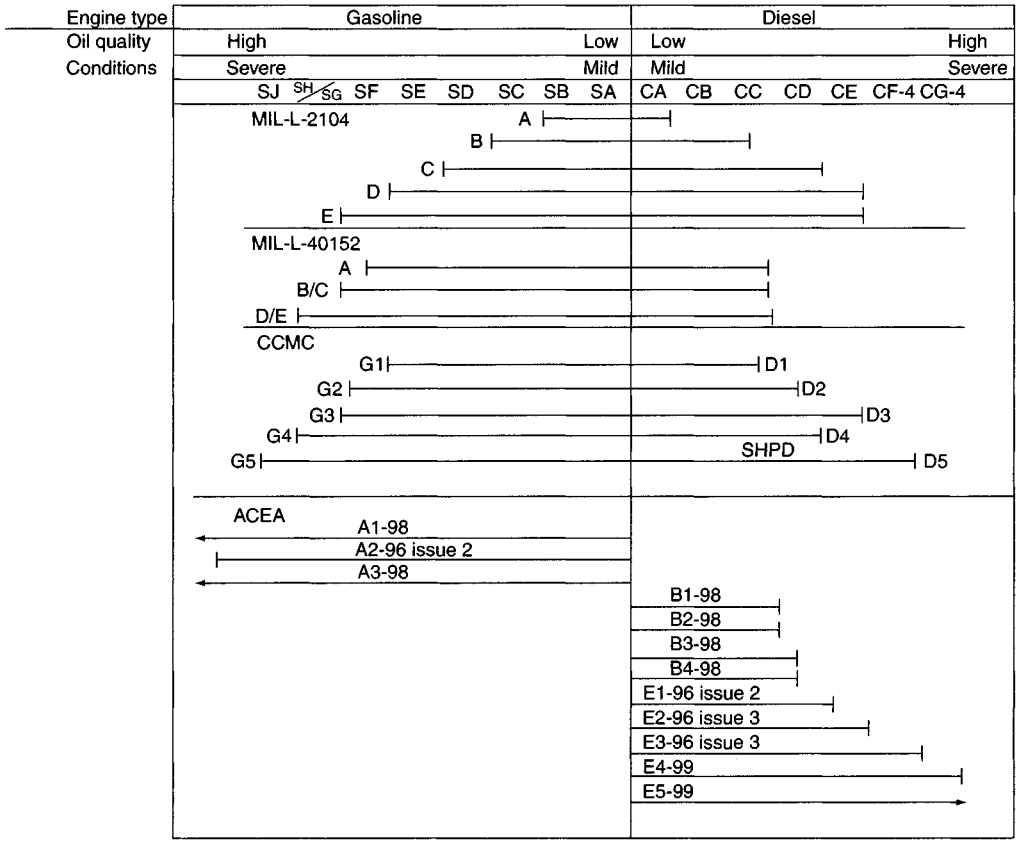


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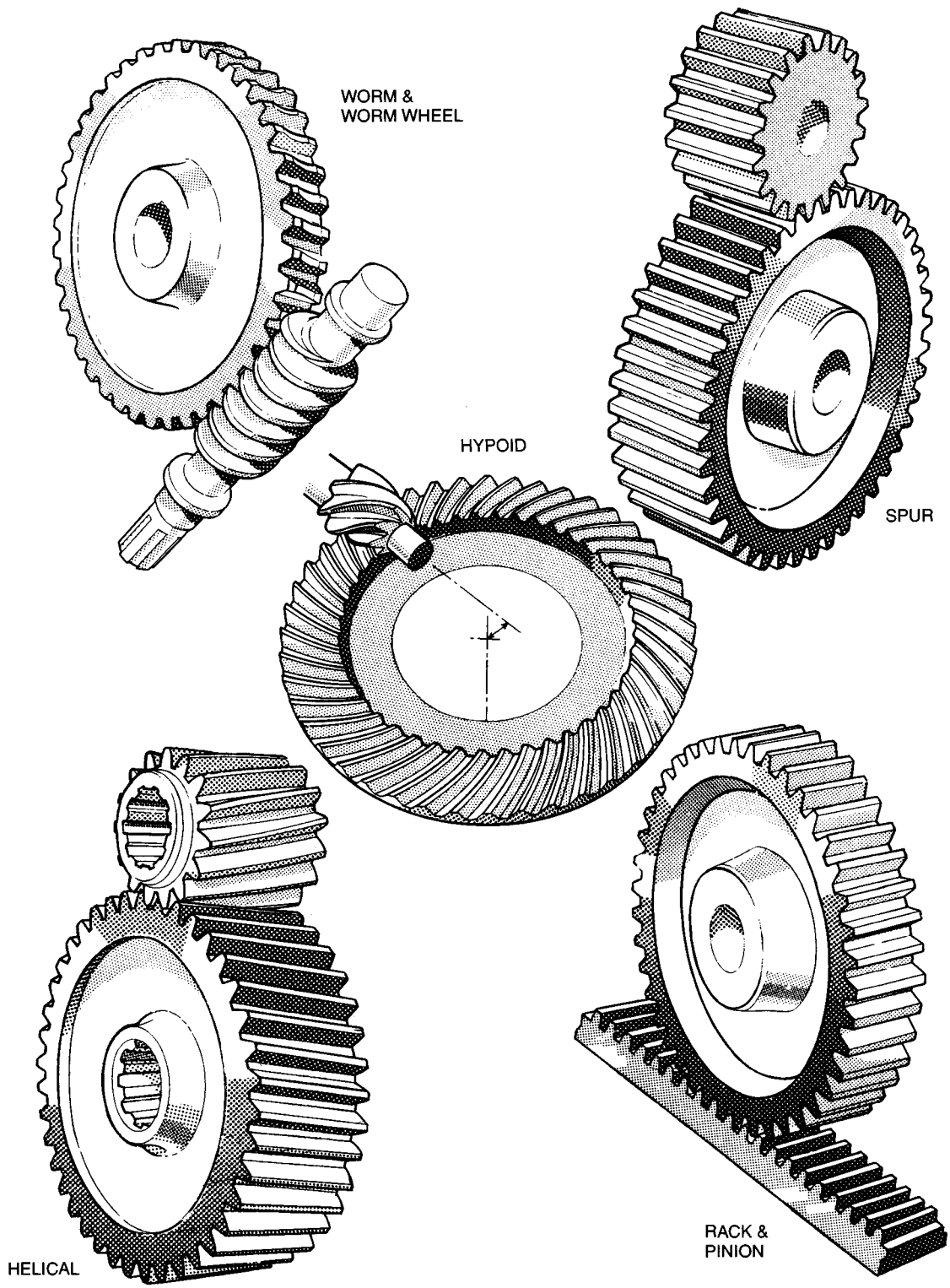


Figure 40.6 Gear types

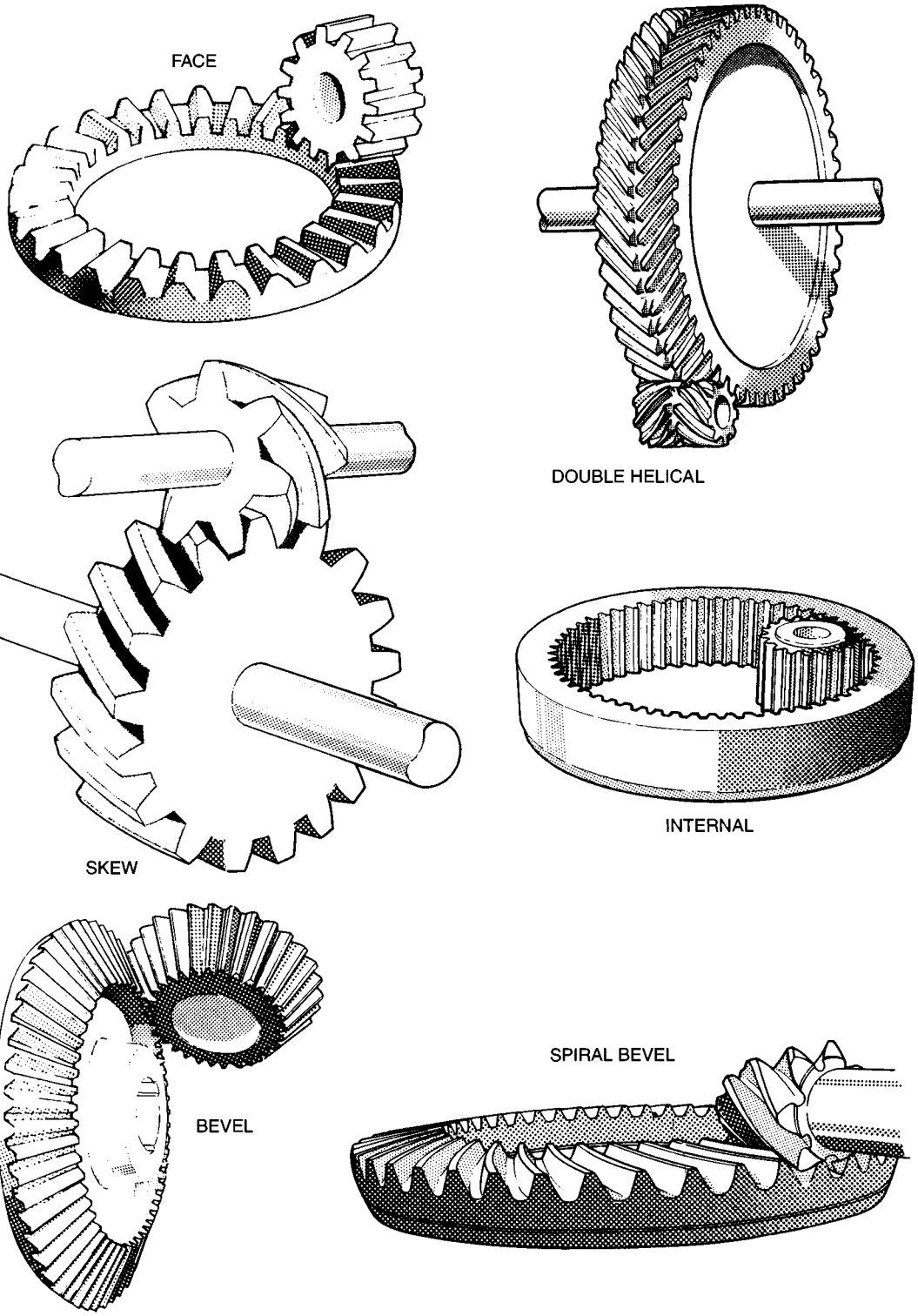


Figure 40.6 (*continued*)

thick lubricating film between the meshing surfaces. If the load is increased, the pressure within the contact zone increases, causing a reduction in film thickness until the high spots on meshing teeth begin to touch; wear will then occur.

At low speeds, when the high spots make contact due to load, the sliding velocities are not sufficient to generate the heat necessary to cause welding. The wear, which can be quite rapid, is caused by the abrasive action of the teeth on each other.

At medium speeds contact of the high spots will cause incipient melting and surface welding. The rise in surface temperature will encourage the breakdown of the lubricant film and the resultant scoring, which is distinctive, will cause rapid wear.

At high speeds, however, a position can be reached in which the load-carrying capacity increases with speed. The explanation is thought to be that when the teeth are in contact for such a short time, the oil film is not squeezed out and a separating film is therefore maintained.

40.9.2 Hypoid gears

The sliding and loading effect of these gears is such that they generally operate outside the limiting conditions for hydrodynamic lubrication. Additional protection against scoring is given by incorporating suitable extreme pressure additives into the lubricant. These react with the metal surfaces at or near scoring temperature, to provide a low-friction lubricant film. This delays the onset of scoring, although this film will eventually break down under much higher loads. Since these extreme pressure additives usually react with the gear surface they can cause corrosive wear, but this can be contained within reasonable limits by careful choice of oil and additives.

40.9.3 Worm gears

As worm gears tend to slide along their lines of contact it is virtually impossible to maintain a hydrodynamic oil wedge so boundary lubrication conditions nearly always exist. Correct meshing of worm gears is most important in preserving an oil film. Too small a contact area can result in a rupture of the film and consequent abrasive wear, whereas if the contact area extends to the entry edge of the worm wheel, lubricant can be scraped from the worm by the tooth edges.

An important point to remember with overslung worm gears is that they are not immersed in the lubricant and the oil must be fed to the point of contact. The viscosity of the oil is important here as it must not drain too quickly from the contact area. A mineral oil compounded with fatty oil is often preferred by manufacturers because of the particular lubrication problems involved with worm gears.

40.9.4 Gear materials

These have an important influence on both lubrication and wear. At the same speed, steel gears require a higher viscosity oil than cast iron or bronze, because they can carry higher loads. Where straight oils are concerned it is usually true to say that the harder the gear steel, the higher the viscosity needed.

40.9.5 Operating temperature

When selecting a lubricant, both the temperature at the contact area and the ambient temperature at important factors to be considered. To measure the peak contact temperature is very difficult, so, as a practical guide, the maximum rise in temperature of the oil leaving the gears and the maximum oil temperature, are specified for various types of gears. For spur, bevel, helical and spiral level gears, the temperature rise should not normally exceed 30°C with a maximum oil temperature of 70°C.

Worm and hypoid gears produce higher oil temperatures because they generate a greater amount of frictional heat. An oil temperature rise of 40°C and a maximum oil temperature of 95°C is acceptable. With EP oils it should not exceed 75°C.

40.9.6 Surface speed

It is generally true to say that, as speed increases, the oil viscosity decreases, that is, assuming that hydrodynamic conditions exist. A relatively low viscosity oil will allow the oil to spread rapidly over the tooth surfaces before meshing and, in the case of forced lubrication, ease circulation. In the case of bath lubrication it will eliminate the oil drag effect.

40.9.7 Loading

If a gear is subjected to shock loading, the high pressures which are rapidly applied may rupture the oil film. These peak pressures are of greater importance than average tooth loading. To prevent sudden wear of the teeth it is essential to maintain a lubricant film, and this is done by using extreme pressure additives. Continuous and severe overloading may cause the oil film to break down with disastrous results.

40.9.8 Specifications

The lubrication requirements of gears vary considerably and create the need for specifically formulated products. This, combined with the diversity of automotive and industrial gear types, has led to the introduction of several specifications for gear lubricants (see Figure 40.7).

40.9.9 Performance

In 1969 the API drew up a range of service designations to define the protective qualities of gear oils – the higher the number, the more strenuous the service conditions. API GL-1, GL-2 and GL-3 oils are specified by some manufacturers, but their use is dying out. At one time, manufacturers used GL-3 oils for factory-fill purposes only, to cover the running-in stage during which gears are not subjected to severe conditions. That practice is now

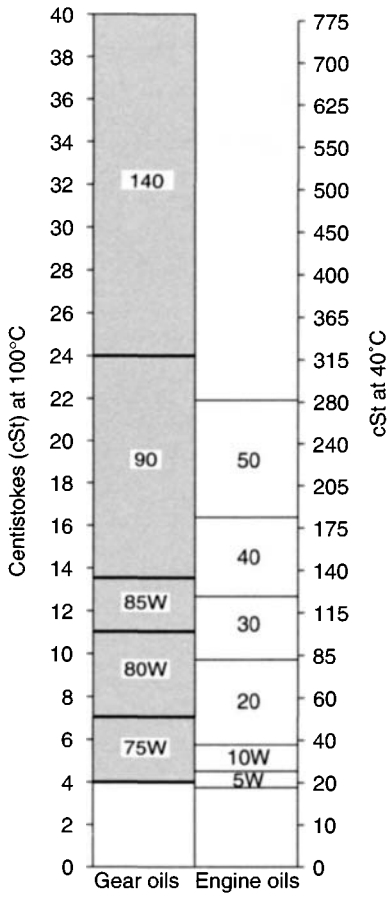


Figure 40.7 The SAE numbering systems for engine oils and gear oils are not related and must not be confused. This figure illustrates the differences

largely obsolete, and GL-4 oils are used almost universally for both factory fill and service refill.

GL-5 oils and formulated primarily for hypoid axles operating at high speeds and loads, and likely to suffer shock loads. The GL-6 classification was introduced to cover a Ford requirement for special hypoid gears operating in high-performance conditions at high speeds. In the event, however, the Lotus Elan was virtually the only European car to require this category. GL-6 is now regarded as obsolete, but oils meeting its requirements may still be used to overcome isolated service difficulties.

Manufacturers and other bodies have issued their own designations, which may be encountered occasionally. Most important is the US Military specification MIL-L-2105D (which replaced MIL-L-2105C) corresponding to API GL-5, and introduced approval for multigrade gear oils.

40.9.10 AGMA specifications

For industrial gears and circulating oils there is a specification published by the American Gear Manufacturers Association which expresses the viscosities corresponding to the AGMA Lubricant Numbers in Saybolt Universal Seconds only. The approximate viscosities in centistokes are provided in Table 40.4 for convenience. The recommendations in Table 40.5 and 40.6 are intended as a guide for lubricant selection.

Table 40.4 AGMA lubricant numbering system

Rust and oxidation inhibited oils	*EP lubricants*[a]	*Viscosity (40°C)*[b]
AGMA lubricant number	AGMA lubricant number	Kinematic cSt
1		41.4–50.6
2	2 EP	61.2–74.8
3	3 EP	90–110
4	4 EP	135–165
5	5 EP	198–242
6	6 EP	228–352
7 comp[c]	7 EP	414–506
8 comp	8 EP	612–748
8A comp		900–1100

[a]EP lubricants should be used only when recommended by the gear manufacturer.
[b]As per ASTM 2422 (also BS 4231).
[c]Oils marked 'comp' are compounds with 3–10% fatty or synthetic fatty oils.

40.9.11 Other specifications

Among other specifications that the plant user will encounter are those, for example, issued by David Brown Gears, the German DIN 51517, and individual suppliers' recommendations on the grades of oil to be used in their units.

40.9.12 Method of lubrication

The method of application, whether splash, spray, jet or mist, will have an effect on the lubricant. If an oil is atomized its surface area is increased and it is much more easily oxidized. The rate of oxidation will be increased by the frictional heat generated by the meshing teeth. The dissipation of the heat absorbed by the oil is important and this will be influenced by the lubrication system. The length of pipe run, the temperature and size of bearings, pumps, other surfaces with which the oil comes into contact, whether filters and oil coolers are fitted, all affect the heat content of the oil.

40.9.13 Splash lubrication

Some enclosed gears are lubricated by oil splashing at random within the casing. If the pitch-line speeds are low (say, less than 100 m/min), paddles and scrapers attached to the gear wheels may be needed to pick up the required amount of oil. If the speed is excessively high, however, the lubricant may be flung off the gears before it reaches the meshing zone, while that in the reservoir portion may be overheated by churning. The upper speed limit is usually about 800 m/min, but this can sometimes be exceeded where shields are close to gear peripheries.

Table 40.5 Lubrication of industrial enclosed gear drives. AGMA Lubricant Number recommendations for helical, herringbone, straight bevel, spiral bevel and spur[a]

Centre distances: main gear, low speed	*Ambient temperatures*[b] *(−40–78°C) Other lubricants*	*(−28.9 to −3.9°C)*	*(−9.4–15.6°C)*	*(10–51.7°C)*
			AGMA lubricant number[c,d]	
Parallel shaft (single reduction):	Automatic	Engine oil SAE		
Up to 8 in (200 mm)	transmission fluid	10W-30, or similar	2–3	3–4
Over 8 in (200 mm) and up to 20 in (510 mm)	or similar	product[e]	2–3	4–5
Over 20 in (510 mm)	product[e]		3–4	4–5
Parallel shaft (double reduction):				
Up to 8 in (200 mm)			2–3	3–4
Over 8 in (200 mm) and up to 20 in (510 mm)			3–4	4–5
Over 20 in (510 mm)			3–4	4–5
Parallel shaft (triple reduction):				
Up to 8 in (200 mm)			2–3	3–4
Over 8 in (200 mm) and up to 20 in (510 mm)			3–4	4–5
Over 20 in (510 mm)			4–5	5–6
Planetary gear units:				
Outside dia. of housing up to 16 in (410 mm)			2–3	3–4
Outside dia. of housing over 16 in (410 mm)			3–4	4–5
Spiral or straight bevel gear units:				
Cone distance up to 12 in (300 mm)			2–3	4–5
Cone distance over 12 in (300 mm)			3–4	5–6
Geared motors and shaft-mounted units			2–3	4–5

[a] Drives incorporating over-running clutches as backstopping devices should be referred to the clutch manufacturers, because certain types of lubricants may adversely affect clutch performance.
[b] The pour point of the lubricant should be at least 10°C lower than the expected minimum ambient starting temperature. If the ambient starting temperature approaches the pour point, sump heaters may be required to ease starting and ensure adequate lubrication.
[c] Viscosity ranges are provided to allow for variations such as surface finish, temperature rise, loading and speed.
[d] AGMA viscosity number recommendations listed above refer to R & O (rust and oxidation) inhibited gear oils, which are widely used for general bearing, turbine and gear lubrication systems. EP gear lubricants in the corresponding viscosity grades may be substituted, where they are deemed necessary by the gear drive manufacturer.
[e] Where they are available, good-quality industrial oils having similar properties are preferred to the automotive oils. The recommendation of automotive oils for use at ambient temperature below −10°C is intended only as a guide pending widespread development of satisfactory low-temperature industrial oils. It is advisable to consult the gear manufacturer.
High-speed units are those operating at speeds above 3600 rev/min or pitch line velocities above 1520 m/min. (Refer to Standard AGMA for High Speed Helical and Herringbone Gear Units for detailed lubrication recommendations.)

Table 40.6 Enclosed cylindrical and double enveloping worm-gear drives

Worm centre distance	*Worm speeds (rev/min) up to*	*Ambient temperatures* 15–60°F (−9.4–15.6°C)	50–125°F (10–51.7°C)	*Worms speeds (rev/min) up to*[b]	*Ambient temperatures* 15–60°F (−9.4–15.6°C)	50–125°F (10–51.7°C)
		AGMA lubricant no.			*AGMA lubricant no.*	
Up to and including 6 in (150 mm):						
Cylindrical worm	700	7 comp	8 comp	700	7 comp	8 comp
Double-enveloping worm	700	8 comp	8A comp	700	8 comp	8 comp
Over 6 in (150 mm) and up to 12 in (300 mm):						
Cylindrical worm	450	7 comp	8 comp	450	7 comp	7 comp
Double-enveloping worm	450	8 comp	8A comp	450	8 comp	8 comp
Over 12 in (300 mm) and up to 18 in (460 mm):						
Cylindrical worm	300	7 comp	8 comp	300	7 comp	7 comp
Double-enveloping worm	300	8 comp	8A comp	300	8 comp	8 comp
Over 18 in (460 mm) and up to 24 in (610 mm):						
Cylindrical worm	250	7 comp	8 comp	250	7 comp	7 comp
Double-enveloping worm	250	8 comp	8A comp	250	8 comp	8 comp
Over 24 in (610 mm):						
Cylindrical worm	200	7 comp	8 comp	200	7 comp	7 comp
Double-developing	200	8 comp	8A comp	200	8 comp	8 comp

[a] The pour of the oil used should be less than the minimum ambient temperature expected. Consult the gear manufacturer for recommendations regarding ambient temperatures below −10°C.
[b] Worm gears of either type operating at speeds above 2400 rev/min or 610 m/min rubbing speed may require force-feed lubrication. In general, a lubricant of lower viscosity than recommended in the above table may be used with a force-feed system.
Warning: Worm gear drives operate satisfactorily on R & O gear oils, sulfur phosphorus EP oils or lead naphthenate EP oils. These oils, however, should be used only with the approval of the gear manufacturer.

Although a gear train may comprise wheels of markedly different diameters, as in multiple-reduction sets, the degrees of immersion in the trough must be approximately constant. If not, the smallest or highest wheel may have adequate pick-up while the largest is over-immersed. The trough should therefore be stepped or the bearing-lubrication system extended to lubricate the smaller or higher gears.

Optimum depth of immersion depends on pitch-line speed. Deep immersion is permissible at low speeds because power losses from churning are low, but at moderate speeds the immersion depth should not be more than three times the tooth height. At the highest speeds, only the addenda of the teeth need be submerged (Figure 40.8).

When gears are rotating inside a casing some oil is being carried around by them and some is adhering to the walls, so the oil in the trough is lower than when at rest. The sight-glass or dipstick should therefore be calibrated when the gears are in motion. With bevel, hypoid and worm sets, the relative positions of the various elements can vary so much that the 'correct' oil level cannot always be accurately defined.

In splash lubrication the oil absorbs heat, which is transmitted to the casing. Gearbox designers sometimes augment the cooling effect by finning the casing to increase the area of metal exposed to atmosphere. In some designs a fan is mounted on the driving shaft, to force cooling air over the casing. At the installation stage the cooling of gear units can sometimes be facilitated by intelligent siting.

40.9.14 Forced circulation

Circulation by pumping is, of course, more expensive than simple splash lubrication, but the expense is usually justified. Some of the many advantages are as follows:

- Oil supplied to each meshing area can be metered to provide the optimum flow for lubrication and cooling.
- Heat exchangers can be installed to minimize changes of temperature. This means that the user can select viscosity solely on the grounds of conditions at the tooth face, and can virtually ignore other requirements. A thin oil, for example, can be cooled to prevent it becoming too thin during continuous circulation through meshing zones, or to prevent overheating; a thick oil can be heated to encourage rapid initial flow through feeder lines.
- Filtration units can be incorporated into circulation lines, thus ensuring that clean oil is fed to gears and bearings.
- Gear casings can be small, since their oil reservoirs can be sited remotely. In most rolling mills, for instance, an oil 'cellar' houses storage tanks, pumps, heat exchangers and filters.

Oil is fed to meshing zones by wide jets or sprayers, and uniform distribution across the tooth faces is necessary to avoid local distortion. Clearly, the rate of flow is important; the effects of too little oil are easily imagined. A sound practice is to position an extra jet on the 'exit' or disengagement side of a meshing zone, where the teeth are at their highest temperature. If gears run in either direction, sprayers must be installed on both sides.

Formulae exist for calculating the optimum rates of flow, based on considerations of the heat to be removed – which calls for more oil flow than does lubrication alone – but they are complex and require data that may not be available at the design stage. A reasonable estimate is 0.05–0.10 l/min for each millimetre of tooth width.

Heat from bearings is an important fraction of the total heat to be dissipated from a gear system, and must be taken into account in calculations of cooling requirements. Excessive churning of oil causes unnecessary loss of power, and the resultant combination of high temperature and atomization of the oil raises the rate of oxidation. Careful attention to the design and siting of sprayers minimizes these effects, keeps the oil cooler and prolongs its service life (Figure 40.9).

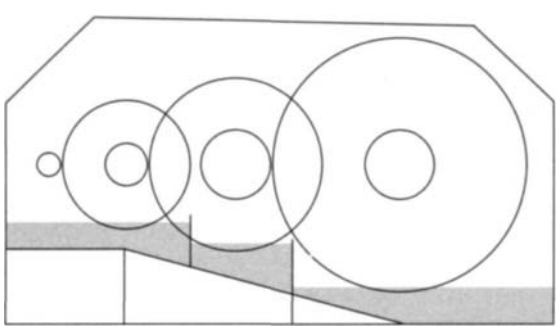


Figure 40.8 In a splash-fed gear the depth of immersion must be reasonably constant for all the gears, therefore the casing should incorporate stepped troughs for the oil

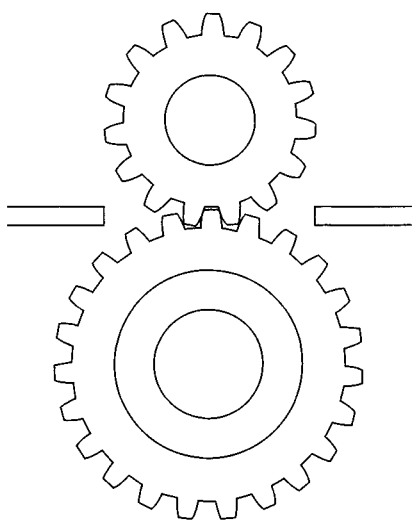


Figure 40.9 Oil is fed to some gears by jet or spray, so that the full benefits of lubrication and cooling are obtained precisely where they are needed. An extra jet at the 'exit' side of a meshing zone ensures that the teeth are cooled where the temperature is highest

40.9.15 Oil-mist lubrication

Although not widely used for gears, oil-mist lubrication is nevertheless worth mentioning here. It is a 'total loss' technique in which the oil is supplied in the form of fine droplets carried by compressed air. Two virtues are that the lubricant can be carried long distances through pipes without severe frictional losses, and that no oil pumps are needed since the motive power is provided by factory compressed-air lines. However, unless such systems are totally enclosed, the exhaust can create a build-up of oil-mist in the atmosphere. In order to maintain good standards of industrial hygiene, it is recommended that the concentration of oil-mist in the working environment should not exceed 5 mg/m^3.

40.9.16 Semi-fluid lubrication

Gear oils possess most of the attributes required in the lubricating function, but the need for an alternative lubricant is encountered in some industrial applications. One such need rises from the leakage caused by slight wear of oil-seals – which is inevitable in any gear unit. Oil escaping past seals seeps along input and output shafts, from where it is probably thrown onto adjacent walls, floors or machinery. Loss of lubricant is particularly undesirable in a geared motor, where leakage from the reduction-gear section may have rapid and disastrous effects on electrical components.

Industrial maintenance engineers are, unhappily, familiar with the problem of leaking gear units that have to run at a high factor of utilization, since interruptions or downtime for filling, checking and repair can seriously retard a production programme. Such checks are made necessary, of course, by the risk of drying up and gear failure. Leakage is annoying in units that operate in conventional 'horizontal' attitudes, but it can be of serious concern to maintenance staff if the gear units are operating in unusual orientations or are part of machinery that changes angular position during a work cycle.

In the past, greases have been used to eliminate leakage from a few small and lightly loaded gear units, but orthodox greases do not possess the full range of properties required in the more demanding applications. However, development has produced excellent semi-fluid gear lubricants, which are finding their way into an ever-widening range of applications. A gearbox lubricated by a modern special-purpose semi-fluid lubricant can operate for very long periods without the need of maintenance. The semi-fluid lubricants formulated for gear lubrication include a mineral based for spur, helical and bevel gears, and synthetic based for worm gears.

40.9.17 Spur, helical and bevel gears

The latest mineral-base grease is thickened, not by a metallic soap, but by a polymer, and its additives include an anti-oxidant and a modern EP agent of the sulphur/phosphorus type. Such a grease has flow characteristics that vary with shearing conditions. It is like a gear oil in the tooth-contact regions, where shearing is severe, but is more resistant to flow in regions of low shear – as in oil seals. Consequently, the grease resists leakage at the seals and joints, and the lubrication function is fulfilled, especially in heavily loaded steel gears. Another important virtue is that the product does not readily drain from metallic surfaces: dry starts are thus avoided (Figure 40.10).

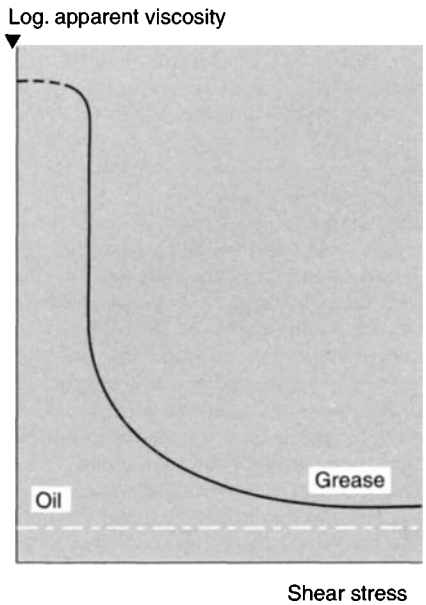


Figure 40.10 Comparison of the apparent viscosities of a gear oil and a gear grease. The grease flows readily in the tooth-contact region, where shear stress is high, but resists leakage at seals and joints

40.9.18 Worm gears

As already mentioned, the severe loading and sliding conditions at the tooth faces of worm gears generate a great deal of heat. EP or anti-weld additives are ineffective in these circumstances, and can even be harmful. Consequently the synthetic oils that have been developed specifically for worm gears are incorporated into semi-fluid grease formulations for applications in which leakage must be avoided. One of their primary requirements, of course, is high shear stability.

Several of the current synthetic semi-fluid lubricants for worm gears are based on a polyalkylene glycol – which possesses 'slipperiness'. Oxidation and rust-inhibitors are usually incorporated, and they are carefully selected to be compatible with both the polyalkylene and the grease-thickener system.

40.9.19 Oil or grease?

In summary, it can be said that the best choice of lubricant for a gearbox depends on the service conditions. If leakage is a problem, or if, during shutdown, the maintenance of a thick film of lubricant is necessary to inhibit corrosion and prevent 'dry-state' operation, greases show

to advantage. If generation of heat and consequent excessive temperatures are a problem, users will find it better to use liquid lubricants, which have the advantage of high rates of heat transfer.

40.9.20 Automatic transmissions

40.9.20.1 Frictional behaviour

Satisfactory gear-changing in an automatic transmission unit is a compromise between smooth slippage during take-up and firm grip during drive. The frictional properties of an ATF can be adjusted with friction-modifying additives during the formulation stages to ensure careful matching with the requirements of transmission manufactures. Two kinds of frictional behaviour have to be considered in combination:

1. Static friction, which exists when sliding motion starts from rest;
2. Dynamic friction, which comes into effect when the mating surfaces are in motion.

The transition stage from one to the other is critical, and is the point at which any problem of noise or chattering occurs. Some transmission designs have a take-up characteristic best suited by low static friction and some by a high static friction. On no account should the wrong ATF be employed when a transmission unit is being completely filled, but a limited degree of topping up with the wrong fluid is permissible in most cases. (The need for fluids of high static friction is receding now that related designs are being phased out.)

40.9.20.2 Automatic transmission fluids (ATFs)

An ATF has to satisfy several requirements. It must:

1. Lubricate the gears in the gearbox;
2. Fill the torque converter (or 'automatic clutch') and thus convey power from the engine to the gearbox;
3. Act as hydraulic medium by conveying signals from the valves in the control unit to the internal clutches/brakes that engage the gears;
4. Ensure smooth but rapid take-up of power between the friction faces of the oil-immersed clutches/brakes;
5. Remove frictional heat and cool the whole transmission unit.

An ATF requires high lubrication performance, high levels of oxidation stability to withstand the locally high operating temperatures, a degree of fluidity that ensures easy operation in cold weather, stable viscosity properties, closely controlled frictional behaviour to ensure quiet, consistent and chatter-free take-up of power in the internal brakes and clutches. It must preserve all these properties throughout its service life, so as to maintain consistent lubrication performance and gear-change characteristics.

Over the years, GM and Ford have progressively raised their levels of demand for oxidative/thermal stability, to cater for cars with higher power and thus greater likelihood of high transmission temperatures. GM's latest designation is Dexron III, and the latest Ford specification is Meocon v. The Daimler-Benz requirement is that a fluid should retain its frictional characteristics throughout its life (in other words, throughout the life of the car). Additive systems have been developed with properties acceptable to Daimler-Benz, however, and a 'universal' ATF can now be blended.

40.9.21 Open and shielded gears

In general, the lubricant for open or partly enclosed gears is used on a 'total loss' basis – it is neither recirculated nor recovered. Rates of application must be minimal, both for economy and because the accumulation of used lubricant creates problems. A distinguishing feature of this category is that separate provision must be made for lubricating the bearings – by grease cups, oil bottles or mechanical lubricators.

Open gears usually run at low pitch-line speeds, below, say, 150 m/min, and are not machined to high standards of accuracy. If their lubricant is to be applied intermittently by hand, the most satisfactory results are obtained with special high-viscosity 'residual' oils that have strong properties of adhesion. Very viscous and heavy lubricants may be heated and spread over the gear teeth, which must be clean and dry, with a brush or paddle. In this case, the oil must not be heated so that it becomes too fluid, for although it will then be easier to apply there will be considerable wastage. It is equally important not to use too much oil, for the excess will immediately be flung off when the gears are in motion. In addition, over-oiling can lead to the formation of hard pads of lubricant at the bottom of the teeth, which could stress or distort the shaft or cause wear in the shaft bushes. To make heating unnecessary, the lubricant may be supplied in a suitable solvent that evaporates after cold application to the gears.

Under better conditions, mechanical lubrication may be used. Force-feed lubricators can be installed that will provide a continuous and measured supply of oil to the meshing teeth or by spraying atomized lubricant onto the gears.

Some slow-running shielded gears, particularly those operating in relatively clean conditions, can be lubricated by thinner oils. In that case, the teeth of the largest wheel can dip into a 'slush pan' and carry oil to the rest of the gear train.

40.9.22 Environment

While a gear oil will protect the metal surfaces against corrosion appreciable amounts of corrosive contaminants will affect the properties of the lubricant. Water is particularly troublesome in this respect. Different oils, while quite suitable for gear lubrication under normal conditions, may react very differently when contaminated with water. With active extreme pressure type oils, water leads to severe corrosion problems.

All these factors have to be borne in mind when blending gear oils. The oil must have a viscosity capable of maintaining a hydrodynamic lubricating film under, as far as possible, all working conditions. Its viscosity index should be high enough to maintain the viscosity within

permitted limits at any operating temperature. It must be adhesive enough when on the gear teeth to resist removal by wiping or centrifugal force and not rupture under heavy or shock loads. The chemical stability of the oil must be such that it will not break down under the action of temperature, oxidizing agents and contaminants. It must provide protection against rusting and corrosion. It should not foam in service and should have the ability to separate from any water that may enter the system.

40.9.23 Gear wear and failure

A gearbox can be regarded as having four main components – gears, casing, bearings and lubricant – and failure can be caused by shortcomings in any one of them. Gear teeth that are inaccurate through design or manufacture can cause poor meshing, noisy running, overheating or surface failure due to overloading. Excessive flexing of the casing would allow misalignment of the gear shafts, which would also lead to surface failure due to overheating. Unsuitable or badly fitted bearings may fail because of their own surface damage, and this creates shaft misalignments and produces debris that can quickly damage the gear teeth. Lubrication failure can arise from unsuitable lubricant or from the inability (through bad design) of the lubricant to get where it is needed.

40.9.24 Manufacture

The makers of gear units have quite a choice of gear-cutting and gear-forming techniques at their disposal, including hobbing, shaping, grinding, broaching, milling and rolling. Every production process is inevitably a compromise between ease of machining, good surface finish, profile accuracy, speed of output and economic production. All metal-removal operations leave minute ridges and scratches, caused by tool shapes or by the motion of rotary cutters; 'perfect' profiles and finishes are not obtainable with normal industrial processes. Tooling marks and deep scratches act as stress raisers, which occasionally lead to fatigue failure and tooth breakage. Such a failure almost invariably starts in the fillet radius at the root of a tooth, and may be caused by the use of a cutting tool with too small a radius.

Most gears benefit from careful running-in under light load, since in this way the teeth acquire the surface finish needed for good lubrication and smooth running. In effect, they are given a final production operation, without which the process of surface failure might be initiated as soon as service operation begins.

The life of a gear can also be limited by poor assembly. If a pinion is clumsily pressed onto a shaft, for example, it is likely to operate in an overstressed condition and fail at an early stage, even through running well within its designated rating.

40.9.25 Materials

Gear failure is rarely attributable to the type of material selected. More often it is the result of defects such as cracks, casting inclusions and poor heat-treatment. A badly case-hardened steel might fail by the flaking of its hard outer layers and a through-hardened gear might have hard or soft patches. Distortions due to sub-standard hardening can modify tooth profiles to such an extent that load concentrations will break the ends of teeth.

The term 'failure' is relative, because severe operating conditions affect different materials in different ways. An example of this might be seen in a high-reduction gear unit whose pinion is very small and is therefore made of harder material, to avoid premature wear relative to the larger gear. In arduous running the two gears might not display the same kind of wear pattern.

40.9.26 Operation

The three most likely types of operational service misuse are overloading, incorrect lubrication and the presence of contaminants. Overloading is primarily due to the use of too small or too weak a gear unit, and this may be the result of false economy (installing an available unit for an application beyond its capacity) or failure to cater for the effects of shock loads in calculations of power rating.

Incorrect lubrication can take many forms. One example is the use of oil that is too thick or too thin, or is incompatible with the metal of the gears. Others include unsuitable methods of application, bad filtration, inadequate maintenance, filling to the wrong level, and poor standards of storage and handling.

Ideally, the lubricant should remain free from contaminants that might cause rust, abrasion or chemical attack; contamination may be caused by the presence of machining swarf, casting sand or even small items of rubbish left in the casing during manufacture. During service, dust and dirt can enter through the breathers, through neglected inspection covers or in additions of poorly maintained lubricant. Again, other contaminants have their origin inside the unit – rust particles, fine metal dust produced during the wearing process, and substances that result from the lubricant's gradual deterioration. Thick layers of sludge inside the casing can hinder the dissipation of heat, and thereby cause overheating; thick layers of dirt outside the casing can have exactly the same effect.

40.9.27 Surface damage

The types of wear and failure that occur in metallic gears are distinctive and have been subjected to close analysis over many years. The more common types of failure are abrasion, scuffing, pitting, corrosion, plastic yielding and fracture. Often the original cause, which may be misalignment, shock loading, faulty lubrication or one of numerous other possibilities, can be traced from the appearance of the gear teeth. It is important, also, that various kinds of wear may be combined in a single failure, making interpretation more difficult.

40.10 Hydraulic fluids

The wide application of hydraulic systems has undoubtedly been stimulated by the increasing use of fully automatic controls for sequences of operations where the

response to signals must be rapid and the controls themselves light and easily operated. These needs are met by hydraulic circuits which, in addition, provide infinitely variable speed control, reversal of high-speed parts without shock, full protection against damage from overhead and automatic lubrication.

Over the years the performance standards of hydraulic equipment have risen. Whereas a pressure of about 7000 kPa used to be adequate for industrial hydraulic systems, nowadays systems operating with pressures of 15 000–25 000 kPa are common. Pressures above 35 000 kPa are to be found in applications such as large presses for which suitable high-pressure pumps have been developed. Additionally, systems have to provide increased power densities, more accurate response, better reliability and increased safety. Their use in numerically controlled machine tools and other advanced control systems creates the need for enhanced filtration. Full flow filters as fine as 1–10 μm retention capability are now to be found in many hydraulic systems.

With the trend toward higher pressures in hydraulic systems the loads on unbalanced pump and motor components become greater and this, coupled with the need for closer fits to contain the higher pressures, can introduce acute lubrication problems. Pumps, one of the main centres of wear, can be made smaller if they can run at higher speeds or higher pressures, but this is only possible with adequate lubrication. For this reason, a fluid with good lubrication properties is used so that 'hydraulics' is now almost synonymous 'oil hydraulics' in general industrial applications. Mineral oils are inexpensive and readily obtainable while their viscosity can be matched to a particular job.

The hydraulic oil must provide adequate lubrication in the diverse operating conditions associated with the components of the various systems. It must function over an extended temperature range and sometimes under boundary conditions. It will be expected to provide a long, trouble-free service life; its chemical stability must therefore be high. Its wear-resisting properties must be capable of handling the high loads in hydraulic pumps. Additionally, the oil must protect metal surfaces from corrosion and it must both resist emulsification and rapidly release entrained air that, on circulation, would produce foam.

Mineral oil alone, no matter how high its quality, cannot adequately carry out all the duties outlined above and hence the majority of hydraulic oils have their natural properties enhanced by the incorporation of four different types of additives. These are: an anti-oxidant, an anti-wear agent, a foam-inhibitor and an anti-corrosion additive. For machines in which accurate control is paramount, or where the range of operating temperatures is wide – or both – oils will be formulated to include a VI improving additive as well.

40.10.1 Viscosity

Probably the most important single property of a hydraulic oil is its viscosity. The most suitable viscosity for a hydraulic system is determined by the needs of the pump and the circuit; too low a viscosity induces back-leakage and lowers the pumping efficiency, while too high a viscosity can cause overheating, pump starvation and possibly cavitation.

40.10.2 Viscosity Index

It is desirable that a fluid's viscosity stays within the pump manufacturer's stipulated viscosity limits, in order to accommodate the normal variations of operating temperature. An oil's viscosity falls as temperature rises; certain oils, however, are less sensitive than others to changes of temperatures, and these are said to have a higher VI. Hydraulic oils are formulated from base oils of inherently high VI, to minimize changes of viscosity in the period from start-up to steady running and while circulating between the cold and hot parts of a system.

40.10.3 Effects of pressure

Pressure has the effect of increasing an oil's viscosity. While in many industrial systems the working pressures are not high enough to cause problems in this respect, the trend towards higher pressures in equipment is requiring the effect to be accommodated at the design stage. Reactions to pressure are much the same as reactions to temperature, in that an oil of high VI is less effected than one of low VI. A typical hydraulic oil's viscosity is doubled when its pressure is raised from atmospheric to 35 000 kPa (Figure 40.11).

40.10.4 Air in the oil

In a system that is poorly designed or badly operated, air may become entrained in the oil and thus cause spongy and noisy operation. The reservoir provides an

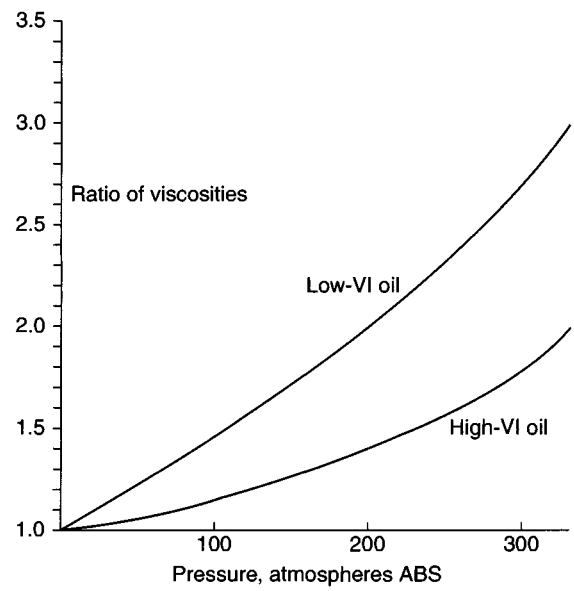


Figure 40.11

opportunity for air to be released from the oil instead of accumulating within the hydraulic system. Air comes to the surface as bubbles, and if the resultant foam were to become excessive it could escape through vents and cause loss of oil. In hydraulic oils, foaming is minimized by the incorporation of foam-breaking additives. The type and dosage of such agents must be carefully selected, because although they promote the collapse of surface foam they may tend to retard the rate of air release from the body of the oil.

40.10.5 Oxidation stability

Hydraulic oils need to be of the highest oxidation stability, particularly for high-temperature operations, because oxidation causes sludges and lacquer formation. In hydraulic oils, a high level of oxidation stability is ensured by the use of base oils of excellent quality, augmented by a very effective combination of oxidation inhibitors.

A very approximate guide to an oil's compatibility with rubbers commonly used for seals and hoses is given by the Aniline Point, which indicates the degree of swelling likely to arise; a high figure indicates a high level of compatibility. This system has been superseded by the more accurate Seal Compatibility Index (SCI), in which the percentage volume swell of a 'standard' nitrile rubber is determined after an immersion test in hot oil.

40.10.6 Fire-resistant fluids

Where fire is a hazard, or could be extremely damaging, fire-resistant hydraulic fluids are needed. They are referred to as 'fire resistant' (FR) so that users should be under no illusions about their properties. FR fluids do not extinguish fires: they resist combustion or prevent the spread of flame. They are not necessarily fireproof, since any fluid will eventually decompose if its temperature rises high enough. Nor are they high-temperature fluids, since in some instances their operating temperatures are lower than those of mineral oils. FR fluids are clearly essential in such applications as electric welding plants, furnace-door actuators, mining machinery, die-casters, forging plant, plastics machinery and theatrical equipment. When leakage occurs in the pressurized parts of a hydraulic system the fluid usually escapes in the form of a high-pressure spray. In the case of mineral oils this spray would catch fire if it were to reach a source of ignition, or would set up a rapid spread of existing flame. FR fluids are therefore formulated to resist the creation of flame from a source of ignition, and to prevent the spread of an existing fire.

Four main factors enter into the selection of a fire-resistant fluid:

1. The required degree of fire-resistance
2. Operational behaviour in hydraulic systems (lubrication performance, temperature range and seal compatibility, for example)
3. Consideration of hygiene (toxicological, dermatological and respiratory effects)
4. Cost

40.10.7 Types of fluid

The fluids available, cover a range of chemical constituents, physical characteristics and costs, so the user is able to choose the medium that offers the best compromise for operational satisfaction, fire-resistance and cost effectiveness. Four basic types of fluid are available and are shown in Table 40.7.

In a fully synthetic FR fluid the fire resistance is due to the chemical nature of the fluid; in the others it is afforded by the presence of water. The other main distinction between the two groups is that the fully synthetic fluids are generally better lubricants and are available for use at operating temperatures up to 150°C, but are less likely to be compatible with the conventional sealing materials and paints than are water-based products.

When a water-based fluid makes contact with a flame or a hot surface its water component evaporates and forms a steam blanket which displaces oxygen from around the hot area, and this obviates the risk of fire. Water-based products all contain at least 35% water. Because water can be lost by evaporation, they should not be subjected to operating temperatures above about 60°C. Table 40.8 shows a comparison of oil and FR fluids.

Table 40.7 CETOP classifications of fire-resistant hydraulic fluids

Class	*Description*
HF-A	Oil-in-water emulsions containing a maximum of 20% combustible. These usually contain 95% water
HF-B	Water-in-oil emulsions containing a maximum of 60% combustible material. These usually contain 40–45% water
HF-C	Water – glycol solutions. These usually contain at least 35% water
HF-D	Water-free fluids. These usually refer to fluids containing phosphate esters, other organic esters or synthesized hydrocarbon fluids

CETOP: Comité European des Transmissions Oleohydrauliques et Pneumatiques.

Table 40.8 Comparison of oil and FR fluids

	Mineral oil	*Water-in-oil emulsion*	*Water-glycol*	*Phosphate ester*
Fire resistance	Poor	Fair	Excellent	Good
Relative density	0.87	0.94	1.08	1.14
Viscosity Index	High	High	High	Low
Vapour pressure	Low	High	High	Low
Special seals	No	Partly	Partly	Yes
Special paints	No	No	Yes	Yes
Rust protection	Very good	Good	Fair	Fair

40.10.8 High water-based hydraulic fluids

For a number of years HF-A oil-in-water emulsions have been used as a fire-resistant hydraulic medium for pit props. Concern over maintenance costs and operational life has created interest in a better anti-wear type fluid. Micro-emulsions are known to give better wear protection than the normal oil-in-water emulsions. At the same time the car industry, in attempts to reduce costs especially from leakages on production machinery, has evaluated the potential for using HWBHF in hydraulic systems. As a result, in many parts of industry, not only those where fire-resistant hydraulic fluids are needed, there is a increasing interest in the use of HWBHF.

Such fluids, often referred to as 5/95 fluid (that being the ratio of oil to water), have essentially the same properties as water with the exception of the corrosion characteristics and the boundary lubrication properties which are improved by the oil and other additives. The advantages of this type of fluid are fire resistance, lower fluid cost, no warm-up time, lower power consumption and operating temperatures, reduced spoilage of coolant, less dependence on oil together with reduced transport, storage, handling and disposal costs, and environmental benefits.

In considering these benefits the user should not overlook the constraints in using such fluids. They can be summarized as limited wear and corrosion protection (especially with certain metals), increased leakage due to its low viscosity, limited operating temperature range and the need for additional mixing and in-service monitoring facilities.

Because systems are normally *not* designed for use with this type of fluid, certain aspects should be reviewed with the equipment and fluid suppliers before a decision to use such fluids can be taken. These are compatibility with filters, seals, gaskets, hoses, paints and any non-ferrous metals used in the equipment. Condensation corrosion effect on ferrous metals, fluid-mixing equipment needed, control of microbial infection together with overall maintaining and control of fluid dilution and the disposal of waste fluid must also be considered. Provided such attention is paid to these design and operating features, the cost reductions have proved very beneficial to the overall plant cost effectiveness.

40.10.9 Care of hydraulic oils and systems

Modern additive-treated oils are so stable that deposits and sludge formation in normal conditions have been almost eliminated. Consequently, the service life of the oils which is affected by oxidation thermal degradation and moisture is extended.

Solid impurities must be continuously removed because hydraulic systems are self-contaminating due to wear of hoses, seals and metal parts. Efforts should be made to exclude all solid contaminants from the system altogether. Dirt is introduced with air, the amount of airborne impurities varying with the environment. The air breather must filter to at least the same degree as the oil filters.

It is impossible to generalize about types of filter to be used. Selection depends on the system, the rate of contamination build-up and the space available. However, a common arrangement is to have a full-flow filter unit before the pump with a bypass filter at some other convenient part of the system. Many industrial systems working below 13 500 kPa can tolerate particles in the order of 25–50 μm with no serious effects on either valves or pumps.

Provided that the system is initially clean and fitted with efficient air filters, metal edge-strainers of 0.127 mm spacing appear to be adequate, although clearances of vane pumps may be below 0.025 mm. It should be remembered that an excessive pressure drop, due to a clogged full-flow fine filter, can do more harm to pumps by cavitation than dirty oil.

If flushing is used to clean a new system or after overhaul it should be done with the hydraulic oil itself or one of lighter viscosity and the same quality. As the flushing charge circulates it should pass through an edge-type paper filter of large capacity. It is generally preferable to use a special pump rather than the hydraulic pump system, and the temperature of the oil should be maintained at about 40°C without local overheating.

40.11 Machine tools

Lubricants are the lifeblood of a machine tool. Without adequate lubrication, spindles would seise, slides could not slide and gears would rapidly disintegrate. However, the reduction of bearing friction, vital though it is, is by no means the only purpose of machine-tool lubrication. Many machines are operated by hydraulic power, and one oil may be required to serve as both lubricant and hydraulic fluid. The lubricant must be of correct viscosity for its application, must protect bearings, gears and other moving parts against corrosion, and, where appropriate, must remove heat to preserve working accuracies and alignments. It may additionally serve to seal the bearings against moisture and contaminating particles. In some machine tools the lubricant also serves the functions of a cutting oil, or perhaps needs to be compatible with the cutting oil. In other tools an important property of the lubricant is its ability to separate rapidly and completely from the cutting fluid. Compatibility with the metals, plastics, sealing elements and tube connections used in the machine construction is an important consideration.

In machine-tool operations, as in all others, the wisest course for the user is to employ reputable lubricants in the manner recommended by the machine-tool manufacturer and the oil company supplying the product. This policy simplifies the selection and application of machine-tool lubricants. The user can rest assured that all the considerations outlined above have been taken into account by both authorities.

The important factors from the point of view of lubrication are the type of component and the conditions under which it operates, rather than the type of machine into which it is incorporated. This explains the essential similarity of lubricating systems in widely differing machines.

40.11.1 Bearings

As in almost every type of machine, bearings play an important role in the efficient functioning of machine tools.

40.11.2 Roller bearings

There is friction even in the most highly finished ball or roller bearing. This is due to the slight deformation under load of both the raceway and the rolling components, the presence of the restraining cage, and the 'slip' caused by trying to make parts of different diameter rotate at the same speed. In machine tools the majority of rolling bearings are grease-packed for life, or for very long periods, but other means of lubrication are also used (the bearings may be connected to a centralized pressure-oil-feed system, for instance). In other cases, oil-mist lubrication may be employed both for spindle bearings and for quill movement. In headstocks and gearboxes, ball and roller bearings may be lubricated by splash or oil jets.

40.11.3 Plain journal bearings

Plain bearings are often preferred for relatively low-speed spindles operating under fairly constant loads, and for the spindles of high-speed grinding wheels. These bearings ride on a dynamic 'wedge' of lubricating oil. Precision plain bearings are generally operated with very low clearances and therefore require low-viscosity oil to control the rise of temperature. Efficient lubrication is vital if the oil temperature is to be kept within reasonable limits, and some form of automatic circulation system is almost always employed.

40.11.4 Multi-wedge bearings

The main drawback of the traditional plain bearing is its reliance on a single hydrodynamic wedge of oil, which under certain conditions tends to be unstable. Multiwedge bearings make use of a number of fixed or rocking pads, spaced at intervals around the journal to create a series of opposed oil wedges. These produce strong radial, stabilizing forces that hold the spindle centrally within the bearing. With the best of these, developed especially for machine tools, deviation of the spindle under maximum load can be held within a few millionths of a centrimetre.

40.11.5 Hydrostatic bearings

To avoid the instabilities of wedge-shaped oils films, a lubricating film can be maintained by the application of pressurized oil (or, occasionally, air) to the bearing. The hydrostatic bearing maintains a continuous film of oil even at zero speed, and induces a strong stabilizing force towards the centre which counteracts any displacement of the shaft or spindle. Disadvantages include the power required to pressurize the oil and the necessary increase in the size of the filter and circulatory system.

40.11.6 Slideways

Spindles may be the most difficult machine-tool components to design, but slideways are frequently the most troublesome to lubricate. In a slideway the wedge-type of film lubrication cannot form since, to achieve this, the slideway would need to be tilted.

40.11.7 Plain slideways

Plain slideways are preferred in the majority of applications. Only a thin film of lubricant is present, so its properties – especially its viscosity, adhesion and extreme-pressure characteristics – are of vital importance. If lubrication breaks down intermittently, a condition is created known as 'stick-slip' which affects surface finish, causes vibration and chatter and makes close limits difficult to hold. Special adhesive additives are incorporated into the lubricant to provide good bonding of the oil film to the sliding surfaces which helps to overcome the problems of table and slideway lubrication. On long traverses, oil may be fed through grooves in the underside of the slideway.

40.11.8 Hydrostatic slideways

The use of hydrostatic slideways – in which pressurized oil or air is employed – completely eliminates stick-slip and reduces friction to very low values; but there are disadvantages in the form of higher costs and greater complication.

40.11.9 Ball and roller slideways

These are expensive but, in precision applications, they offer the low friction and lack of play that are characteristic of the more usual rolling journal bearings. Lubrication is usually effected by grease or an adhesive oil.

40.11.10 Leadscrews and nuts

The lubrication of leadscrews is similar in essence to that of slideways, but in some instances may be more critical. This is especially so when pre-load is applied to eliminate play and improve machining accuracy, since it also tends to squeeze out the lubricant. Leadscrews and slideways often utilize the same lubricants. If the screw is to operate under high unit stresses – due to pre-load or actual working loads – an extreme-pressure oil should be used.

40.11.11 Recirculating-ball leadscrews

This type was developed to avoid stick-slip is heavily loaded leadscrews. It employs a screw and nut of special form, with bearing balls running between them. When the balls run off one end of the nut they return through an external channel to the other end. Such bearings are usually grease-packed for life.

40.11.12 Gears

The meshing teeth of spur, bevel, helical and similar involute gears are separated by a relatively thick hydrodynamic wedge of lubricating oil, provided that the rotational speed is high enough and the load light enough so as not to squeeze out the lubricant. With high loads or at low speeds, wear takes place if the oil is not able to maintain a lubricating film under extreme conditions.

Machine-tool gears can be lubricated by oil-spray, mist, splash or cascade. Sealed oil baths are commonly used, or the gears may be lubricated by part of a larger circulatory system.

40.11.13 Hydraulics

The use of hydraulic systems for the setting, operation and control of machine tools has increased significantly. Hydraulic mechanisms being interlinked with electronic controls and/or feedbacks control systems. In machine tools, hydraulic systems have the advantage of providing stepless and vibrationless transfer of power. They are particularly suitable for the linear movement of tables and slideways, to which a hydraulic piston may be directly coupled.

One of the most important features for hydraulic oil is a viscosity/temperature relationship that gives the best compromise of low viscosity (for easy cold starting) and minimum loss of viscosity at high temperatures (to avoid back-leakage and pumping losses). A high degree of oxidation stability is required to withstand high temperatures and aeration in hydraulic systems. An oil needs excellent anti-wear characteristics to combat the effects of high rubbing speeds and loads that occur in hydraulic pumps, especially in those of the vane type. In the reservoir, the oil must release entrained air readily without causing excessive foaming, which can lead to oil starvation.

40.11.14 Tramp oil

'Tramp oil' is caused when heat slideway, gear, hydraulic and spindle lubricants leak into water-based cutting fluids and can cause problems such as:

- Machine deposits
- Reduced bacterial resistance of cutting fluids and subsequent reduction in the fluid life
- Reduced surface finish quality of work pieces
- Corrosion of machine surfaces

All these problems directly affect production efficiency. Recent developments have led to the introduction of synthetic lubricants that are fully compatible with all types of water-based cutting fluids, so helping the user to achieve maximum machine output.

40.11.15 Lubrication and lubricants

The components of a hydraulic system are continuously lubricated by the hydraulic fluid, which must, of course, be suitable for this purpose. Many ball and roller bearings are grease-packed for life, or need attention at lengthy intervals. Most lubrication points, however, need regular replenishment if the machine is to function satisfactorily. This is particularly true of parts subjected to high temperatures.

With the large machines, the number of lubricating points or the quantities of lubricants involved make any manual lubrication system impracticable or completely uneconomic. Consequently, automatic lubrication systems are often employed.

Automatic lubrication systems may be divided broadly into two types: circulatory and 'one-shot' total-loss. These cover, respectively, those components using relatively large amounts of oil, which can be cooled, purified and recirculating, and those in which oil or grease is used once only and then lost. Both arrangements may be used for different parts of the same machine or installation.

40.11.16 Circulatory lubrication systems

The circulatory systems used in association with machine tools are generally conventional in nature, although occasionally their exceptional size creates special problems. The normal installation comprises a storage tank or reservoir, a pump and filter, suitable sprays, jets or other distribution devices, and return piping. The most recent designs tend to eliminate wick feeds and siphon lubrication.

Although filtration is sometimes omitted with non-critical ball and roller bearings, it is essential for most gears and for precision bearings of every kind. Magnetic and gauze filters are often used together. To prevent wear of highly finished bearings surfaces the lubricant must contain no particle as large as the bearing clearance.

Circulatory systems are generally interlocked electrically or mechanically with the machine drive, so that the machine cannot be started until oil is flowing to the gears and main bearings. Interlocks also ensure that lubrication is maintained as long as the machine is running. Oil sight-glasses at key points in the system permit visual observations of oil flow.

40.11.17 Loss-lubrication systems

There are many kinds of loss-lubrication systems. Most types of linear bearings are necessarily lubricated by this means. An increasingly popular method of lubrication is by automatic or manually operated one-shot lubricators. With these devices a metered quantity of oil or grease is delivered to any number of points from a single reservoir. The operation may be carried out manually, using a hand-pump, or automatically, by means of an electric or hydraulic pump. Mechanical pumps are usually controlled by an electric timer, feeding lubricant at preset intervals, or are linked to a constantly moving part of the machine.

On some machines both hand-operated and electrically timed one-shot systems may be in use, the manual system being reserved for those components needing infrequent attention (once a day, for example) while the automatic systems feeds those parts that require lubrication at relatively brief intervals.

40.11.18 Manual lubrication

Many thousands of smaller or older machines are lubricated by hand, and even the largest need regular refills or topping up to lubricant reservoirs. In some shops the operator may be fully responsible for the lubrication of his own machine, but it is nearly always safer and more economical to make one individual responsible for all lubrication.

40.11.19 Rationalizing lubricants

To meet the requirements of each of the various components of a machine the manufacturer may need to recommend a number of lubricating oils and greases. It follows that, where there are many machines of varying origins, a large number of lubricants may seem to be needed. However, the needs of different machines are rarely so different that slight modification cannot be made to the specified lubricant schedule. It is this approach which forms the basis for BS 5063, from which the data in Table 40.9 have been extracted. This classification implies no quality evaluation of lubricants, but merely gives information as to the categories of lubricants likely to be suitable for particular applications.

A survey of the lubrication requirements, usually carried out by the lubricant supplier, can often be the means of significantly reducing the number of oils and greases in a workshop or factory. The efficiency of lubrication may well be increased, and the economies effected are likely to be substantial.

40.12 Cutting fluids

New machining techniques are constantly being introduced. Conventional workpiece materials have improved progressively through close control of manufacturer and heat treatment, and new materials have been fostered by the aeronautic and space industries. The results have been ever-improving output, dimensional control and surface finish. The continuous development of cutting fluids has enabled these increasingly severe conditions to be accommodated.

40.12.1 Functions of a cutting fluid

The two main functions of a cutting fluid are to cool and to lubricate. During a machining operation the cutting tool induces a continuous wave of dislocations, which travel ahead of the cutting edge, deforming and shearing the workpiece metal into continuous swarf or broken chips. The energy required for this deformation is converted into heat, and simultaneously frictional heat is created at the points where the tool rubs against the newly exposed surface of the workpiece and the chip rubs against the top face of the advancing tool.

These combined effects raise the temperature of the tool, workpiece and chip to a level that would be unacceptable in most operations if it were not for the presence of cutting fluid. Since the cooling effect is the greatest benefit, cutting fluids are widely known as 'coolants', In practice, the coolant cannot penetrate to the extreme tip

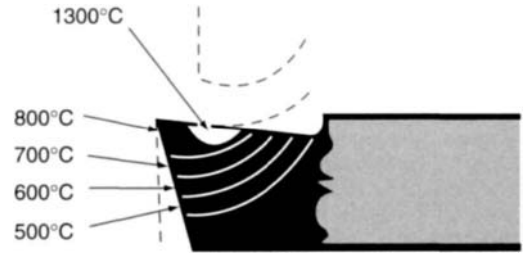


Figure 40.12 Heat is generated both by deformation of workpiece material and by the friction of the chip across the tool tip. A cutting fluid acts as a lubricant to reduce frictional heat and simultaneously cools the whole cutting zone

of the tool, of course, because the tip is so well shrouded by the metal being cut from the workpiece. Nevertheless, the coolant performs its function successfully because it enters a zone some way back from the tip, where the chip is passing over the tool at high rubbing velocity and where most of the frictional heat arises (Figure 40.12).

40.12.2 Benefits of a coolant

Cutting fluids provide benefits such as extended tool life, dimensional accuracy and good surface finish, all of which contribute to high rates of production. Almost invariably, the coolant that adheres to workpieces is relied on to protect ferrous components against corrosion while they are awaiting further machining or assembly operations.

The benefits to be obtained by the correct selection and application of coolant are considerable. The cost is hardly a major factor in production operations, however, because, on average, the price of coolant amounts to about 1% of the finished cost of a machined component.

40.12.3 Types of coolant

40.12.3.1 Water-based emulsions

Water, of course, is the cheapest cooling medium generally available. Its high specific heat makes it particularly effective as a coolant and its low viscosity allows high rates of flow through the coolant system and so enables it to penetrate the cutting zone and make contact with hot metal surfaces. Unfortunately, it corrodes most of the ferrous and some of the non-ferrous metals (a process hastened by high temperatures), and therefore is unsuitable in most machining.

However, its cooling properties can be utilized when other materials are added to improve machining performance. One of the most common water-based cutting fluids is the so-called 'soluble' oil which, in fact, is not a true solution but an oil-in-water emulsion in which very fine droplets of oil are suspended in water. Such a fluid has very effective cooling power and its lubricating and protective properties are provided by the petroleum oil and its additives. The proportion of oil may be as low as 2%, but is normally between 5% and 10%.

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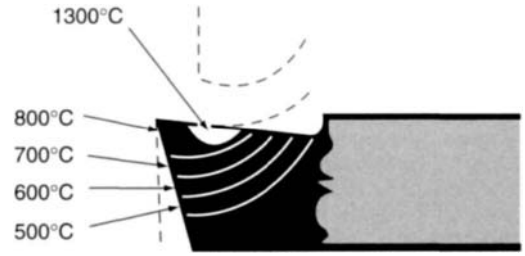


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Table 40.9 Classification of lubricants

Class	*Types of lubricant*	*Viscosity grade no. (BS 4231)*	*Typical application*	*Detailed application*	*Remarks*
AN	Refined mineral oils	68	General lubrication	Total-loss lubrication	May be replaced by CB 68
CB	Highly refined mineral oils (straight or inhibited) with good anti-oxidation performance	32 68	Enclosed gears – general lubrication	Pressure and bath lubrication of enclosed gears and allied bearings of headstocks, feed boxes, carriages, etc. when loads are moderate; gears can be of any type, other than worm and hypoid	CB 32 and CB 68 may be used for flood-lubricated mechanically controlled clutches; CB 32 and CB 68 may be replaced by HM 32 and HM 68
CC	Highly refined mineral oils with improved loading-carrying ability	150 320	Heavily loaded gears and worms gears	Pressure and bath lubrication of enclosed gears of any type, other than hypoid gears, and allied bearings when loads are high, provided that operating temperature is not above 70°C	May also be used for manual or centralized lubrication of lead and feed screws
FX	Heavily refined mineral oils with superior anti-corrosion anti-oxidation performance	10 22	Spindles	Pressure and bath lubrication of plain or rolling bearings rotating at high speed	May also be used for applications requiring particularly low-viscosity oils, such as fine mechanisms, hydraulic or hydro-pneumatic mechanisms electro-magnetic clutches, air line lubricators and hydrostatic bearings
G	Mineral oils with improved lubricity and tackiness performance, and which prevent stick-slip	68 220	Slideways	Lubrication of all types of machine tool plain-bearing slideways; particularly required at low traverse speeds to prevent a discontinuous or intermittent sliding of the table (stick-slip)	May also be used for the lubrication of all sliding parts – lead and feed screws, cams, ratchets and lightly loaded worm gears with intermittent service; if a lower viscosity is required HG 32 may be used.

Table 40.9 *(continued)*

Class	*Types of lubricant*	*Viscosity grade no. (BS 4231)*	*Typical application*	*Detailed application*	*Remarks*
HM	Highly refined mineral oils with superior anti-corrosion, anti-oxidation, and anti-wear performance	32 68	Hydraulic systems	Operation of general hydraulic systems	May also be used for the lubrication of plain or rolling bearings and all types of gears, normally loaded worm and hypoid gears excepted, HM 3X and HM 68 may replace CB 32 and CB 68, respectively
HG	Refined mineral oils of HM type with anti-stick-slip properties	32	Combined hydraulic and slideways systems	Specific application for machines with combined hydraulic and plain bearings, and lubrication systems where discontinuous or intermittent sliding (stick-slip) at low speed is to be prevented	May also be used for the lubrication of slideways, when an oil of this viscosity is required

Class	*Type of lubricant*	*Consistency number*	*Typical application*	*Detailed application*
XM	Premium quality multi-purpose greases with superior anti-oxidation and anti-corrosion properties	1 2 3	Plain and rolling bearings and general greasing of miscellaneous parts	XM 1: Centralized systems XM 2: Dispensed by cup or hand gun or in centralized systems XM 3: Normally used in prepacked applications such as electric motor bearings

Note: It is essential that lubricants are compatible with the materials used in the construction of machine tools, and particularly with sealing devices.
The grease X is sub-divided into consistency numbers, in accordance with the system proposed by the National Lubricating Grease Institute (NLGI) of the USA. These consistency numbers are related to the worked penetration ranges of the greases as follows:

Consistency number	*Worked penetration range*
1	310–340
2	265–295
3	220–250

Worked penetration is determined by the cone-penetration method described in BS 5296.

Water-based coolants, as diluted and used in service, are much cheaper than neat oils, and they offer remarkable economic benefits in the applications to which they are best suited. (Neat oils, however, are preferred for some machining processes – usually involving severe operations – where they give overall production economies and reduced machine-tool maintenance.)

Soluble oils are delivered, 'concentrated', to the user and contain an emulsifying agent to ensure that a stable emulsion forms when added to water. This additive does not mix readily with mineral oil, however, so to overcome this a 'coupling' agent is included in the formulation.

The performance of soluble oils is made possible not only by their high specific heat and thermal conductivity but also by their low viscosity, which permits good penetration into the very fine clearances around the cutting zone. Consequently, these fluids are used mainly where cooling is the primary requirement. Lubricating properties can be improved by polar additives, which are agents that enhance the 'oiliness' or anti-friction characteristics. Further improvements can be effected by EP (extreme-pressure) additives, which are usually compounds of sulphur or chlorine.

Some of the recently developed high-performance EP soluble oils have a cutting performance that almost matches that of additive-type neat oils, and they are particularly suitable for demanding operations in machine tools whose design allows the use of water-based fluids.

40.12.3.2 Water-based solutions

In recent years another kind of water-based coolant, the 'synthetic' or non-petroleum cutting fluid, has been used increasingly. Coolants of this kind contains agents that provide the necessary lubricating and anti-corrosion properties. They were originally introduced to satisfy the special demands of grinding operations, but now they have been developed to a state where they can cope with general machining requirements. Their use in CNC machines and flexible manufacturing systems is a significant result of this development.

Because the synthetic fluid is transparent, operators can see the cutting area at all times – a feature particularly useful for intricate machining and grinding operations. Workpieces, gauges and tools in the vicinity of the cutting zone do not become coated with an oily film, which is a pleasing feature for tool setters who have to handle spanners and precision tools in confined spaces. Occasionally a transparent dye is included in the formulation of a synthetic cutting fluid, both for identification and to give a pleasant appearance.

Synthetic cutting fluids are suitable for a wider range of uses than any other single cutting fluid, and can be employed in any machine designed for operation with water-based fluids. Applications include turning, milling, drilling and screw-cutting on all but the toughest materials; and also cylindrical, surface and centreless grinding. Most metals can be machined effectively; cast iron, which is prone to rusting when machined with conventional soluble oils, shows negligible signs of corrosion when the synthetic fluid is used. Copper-base alloys may display a slight degree of staining if work-pieces are not washed immediately after the machining operation.

40.12.3.3 Bacteria

Machine operators working with emulsions can become susceptible to skin infections because of the combination of the de-fatting effect of soluble-oil emulsifiers and the abrasive action of metallic swarf, but bacteria in cutting fluids are seldom the source of such infections. High standards of personal hygiene and the use of barrier creams should prevent such problems. A more difficult situation arises when a soluble-oil emulsion becomes infected with a bacteria capable of utilizing the emulsifier and mineral-oil components in the system. Even in clean conditions, untreated soluble-oil emulsions and solutions cannot remain completely sterile for any length of time.

The more common bacteria found in infected soluble oil systems can degrade the inhibitors, emulsifiers and mineral oil components. They they cause a loss of anti-corrosion properties, increase of acidity and deterioration of the emulsion. These bacteria thrive in well-aerated systems, and are termed aerobic.

When a system becomes infected with sulphate-reducing bacteria it develops the obnoxious smells associated with putrefaction. Bacteria of the species mainly responsible for such conditions thrive in the absence of oxygen, and are described as anaerobic. The foul smells of hydrogen sulphide are produced mainly in stagnant soluble-oil systems, particularly where the emulsion has a surface layer of oil that tends to exclude oxygen. The hydrogen sulphide arises from chemical reduction of either the inorganic sulphates that can give water its hardness or the petroleum sulphonate component of the soluble oil.

Bacterial examination could be used to confirm the presence of (and perhaps identify) the species. Where a soluble oil is being degraded, or where a noticeable loss of anti-corrosion properties has been detected, a check on the pH (alkalinity/acidity) of the system would be advantageous.

Cleanliness and good housekeeping in machine shops do much to avoid bacterial infection, and their importance cannot be overstressed. Various techniques such as heat treatment, centrifuging and filtration can be used to advantage, although economic considerations may restrict their use to systems containing large volumes of soluble oil. Chemical sterilization with bactericides can be more convenient.

Bactericides are substances that destroy bacteria, and they can be used in various ways. They may be incorporated into the soluble-oil concentrate, either at concentrations suitable to protect the oil in storage, or at levels sufficient to provide a persistent bactericidal effect on the emulsion in service. The cost of providing sufficient bactericide to cover the use of the soluble oil at a high dilution might prove prohibitive. Continued use of the same bactericide may produce resistant strains of bacteria.

Bactericides can be added to the soluble-oil system as a shock treatment when infection occurs, but the user must bear in mind that a badly infected and degraded emulsion

cannot later be reclaimed. The bactericidal treatment may have to be repeated periodically thereafter, and the effect of the bactericide must be monitored.

Studies of systems infected with bacteria show that a process of continued re-infection occurs from the residual oil left in the system whenever the fluid is changed. As far as possible, the system should be designed to avoid traps that might retain coolant. An effective treatment however, is the use of a bactericide in the form of a detergent sterilizing solution to cleanse the system. All traces of it must be removed from the system before a new charge of coolant is introduced, otherwise emulsion instability may develop in the fresh coolant. Thorough cleansing, combined with the use of a suitable bactericide in the fresh charge of soluble oil, should overcome most problems of bacterial infection.

40.12.3.4 Neat oils

Two factors militate against the universal use of water-based fluids. Very severe machining operations call for a lubrication performance that is beyond the capacity of such fluids, and the design of some machine tools means that water cannot be used because of the risk of cross-contamination with machine lubricants. In these instances, 'neat' cutting oil is the only fluid that can provide the required performance.

Neat oil is the name given to an orthodox petroleum cutting fluid, whether or not it contains additives, to enhance cutting properties. Oils of this sort are available in a very wide variety, and many combinations of workpiece material, machining characteristics and tooling requirement justify special formulations. The neat oils have lower specific heat than water, so they have to be fed to the cutting zone in copious amounts to provide the optimum cutting effect.

The viscosity of neat cutting oil is chosen to suit the machining application. Some operations need a very light oil, others a heavier viscosity because of its better load-carrying capacity. Oils are therefore available in a wide selection of viscosities. Most general-purpose cutting oils have viscosities of about 20 cSt at 40°C, but a lighter viscosity is used in operations such as broaching and deep-hole boring/drilling, when chips have to be flushed away from the confined areas around the tool. Whereas for machining – such as some milling, turning and gear cutting – heavier viscosities, up to 64 cSt at 40°C, are preferred.

40.12.3.5 Additives in neat oils

The increasing diversity of operations, new materials and processes and the constant demand for improved production efficiency can only be met by various additives and compounding agents being blended into the oil to enhance its performance. Additives tend to be expensive and the selection of enhanced cutting fluid is only justified by overall production economies.

40.12.3.6 Fatty oils

Small additions of fatty oils improve the 'oiliness' or anti-friction characteristics, and cutting oils reinforced in this way are known as compounded oils. Such oils are particularly useful in the machining of difficult yellow metals and aluminum alloys, giving excellent tool life and good finish without staining yellow metals.

40.12.3.7 EP oils

For the more difficult operations, neat oils containing EP (extreme-pressure) additives have to be used. The EP cutting oils usually contain additives based on sulfur or chlorine, or combinations of them.

The sulfur in EP oil can be present in two forms. In the inactive fluid, it is chemically combined with a fatty-oil additive, which is blended with mineral oil to produce sulfurised fatty oil. The active version, on the other hand, contains sulfur in elemental form, dissolved in mineral oil; the fluid is known as sulfurized mineral oil. Chlorine is usually present only as chlorinated paraffin, which is blended sometimes singly with mineral oils and sometimes in combination with fatty oils and sulfured additives.

40.12.3.8 Combinations of additives

Combinations of sulfur and chlorine additives are employed because the chlorine-based agents react at a lower temperature than do the sulfur-based ones, and in some applications, this progressive action is advantageous. Occasionally two kinds of additives, when used in combination, have a greater effect than the sum of their individual contributions. This phenomenon is known as a 'synergistic' effect, and it gives the lubricant technologist more scope for matching the properties of the cutting fluid to the requirements of the machining operation.

40.12.3.9 Electro discharge machining (EDM) oils

Electro discharge (spark erosion) techniques rely heavily on the ability of EDM oil to act as an electrical insulant, to dissipate heat from the electrode, and to flush away erosion debris from the workpiece. EDM oils also are suitable for all die-sinking spark erosion operations. They should have low aromatic levels, good filterability, low fuming, high dielectric strength, excellent oxidation resistance and low colour level.

A low-viscosity grade helps provide maximum flushing and cooling for delicate work and close tolerances. When rough and finishing machining is combined, a medium viscosity is recommended for the good flushing needed. In roughing operations, high-viscosity oil enables fast metal removal rates to be achieved.

40.12.4 Selection of cutting fluid

Selection of the correct fluid is essential if the maximum benefit is to be obtained for the user. In some machining operations and with some workpiece metals, of course,

the choice is fairly straightforward, but in the majority of cases, selection is inevitably a compromise in which several factors have to be weighed. The two most important considerations are the workpiece material and the type of machining operation (which, in turn, involves considerations of the tool material).

40.12.5 Workpiece material

A general guide to metals and their difficulty of machining, beginning with the most difficult, could be listed as:

1. Titanium
2. Nimonic alloys
3. Inconel
4. Nickel
5. Stainless steel
6. Monel metal
7. High-tensile steel
8. Wrought iron and cast alloys
9. High-tensile bronze
10. Copper
11. Medium- and low-carbon steels
12. Free-cutting mild steel
13. Aluminium alloys
14. Brass
15. Bronze
16. Zinc-based alloys
17. Free-cutting brass
18. Magnesium alloys

40.12.6 Machining operations

Operations vary in severity, but the following list gives a general indication of how they compare, starting with the most severe:

Broaching (internal and surface)
Gear-cutting and shaving
Deep-holeboring (Sandvick ejector drill or gun drilling)
Tapping and threading
Multi- and single-spindle automatics
Capstan lathes, central lathes
Milling and drilling
Sawing

40.12.7 Tool material

A third important factor in the economies of machining is the material of the cutting tool. This largely determines the rates of metal removal, the standards of surface finish and the frequency at which the tool needs to be reground – all of which are interrelated. These can be broadly grouped in three categories, each separated by a factor of 10 in terms of performance.

1. Ceramic-coated disposable inserts, including silicon nitride, boron nitride, titanium nitride (TIN), titanium carbide (TIC) and sintered synthetic diamond;
2. Tungsten carbide, usually in the form of tipped tooling;
3. High-speed steel.

40.12.8 Ancillary factors

Although the three sets of factors just given can be considered singly or in combination, and although a coolant-selection chart can be used as a guide, the most obvious choice of coolant is not always satisfactory from every aspect. Among other (and probably overriding) considerations are the economics of production, scope for reclaiming the coolant, health and safety requirements, and finally the suitability of the machine's design – because of possible incompatibility of the coolant and the machine's lubricant. In time, moreover, the performance of any chosen coolant can be seriously affected by variations of cutting speed, feed rate, tool-setting accuracy and even the condition of the machine. Incorrect tool geometry and inaccurate grinding may have their own adverse effects.

The chosen fluid, to be most effective, must be kept in good condition, supplied in the correct quantity and directed accurately towards the cutting area. If its pressure and rate of flow are too high, the resultant splattering causes wastage of coolant and untidy splashes around the machine and may well lead to overheating in the cutting zone because insufficient fluid is reaching it. The fluid must be applied where it is most effective – pointed either directly at the tip of the tool or flooding the complete cutting zone. Too often the flow is directed vaguely at the workpiece, only to be deflected by the workpiece itself or by ancillary parts of the machine.

Poor maintenance practices lead to dirty and degraded coolant, which affects tool life, surface finish and perhaps the welfare of the operator. Proper filtration is vital, and care must be taken that contamination from other coolants or machine lubricants is kept to a minimum.

40.12.9 Grinding

Although primarily regarded as a finishing process, grinding has also been developed for heavy stock removal. In effect, the grinding wheel is a multi-point machining tool because the metal is cut by many fragments of very hard material (the grit) embedded in a softer matrix (the bond). Each cutting edge requires a lubricant for clean cutting and a coolant for the dissipation of heat. Clearly, the cutting fluid must satisfy the requirements of both the workpiece material and the grinding wheel, and before a grinding fluid is selected a check must be made that the correct grade of wheel is being used for the operation.

The cutting fluid has to cool and lubricate without allowing grinding debris to clog (or load) the surface of the wheel. This could produce a burnished surface rather than a ground one – which might appear satisfactory but would be metallurgically unsound.

For many grinding operations, translucent soluble oils or synthetic solutions give the best results. Synthetic solutions are especially favoured for their very high clarity on intricate internal grinding. On the more complex and heavy-duty operations involving form-grinding, more importance is attached to lubricating properties, so EP neat oils are favoured. The level of EP activity required is determined by the severity of the form being ground.

40.12.10 Storage

Extremes of temperature should be avoided, particularly in the storage of coolants that contain water, because the balance of constituents can be upset. High temperatures lead to evaporation of water. Low temperatures can cause the separation of some of the components in additive oils; in particular, the natural fatty oils are susceptible to coagulation. Soluble oil, as supplied in concentrated form, usually contains a small amount of water for ensuring rapid dispersion during subsequent dilution. If this water freezes, it does not re-blend when the temperature rises again, and subsequently the oil proves very difficult to mix.

40.12.11 Water quality

Water from towns' main supplies is usually suitable for the preparation of water-based cutting fluids. That from factory boreholes is also generally suitable, although occasionally it contains excessive amounts of corrosive salts. Water from rivers, canals and ponds almost always contains undesirable contaminants, and should be tested before use. A good first test is to mix a small quantity of emulsion and allow it to stand for 24 h: in this time, no more than a trace of the oil should separate. If serious separation occurs, the water should be analysed to indicate the sort of remedial treatment required.

A laboratory check is normally desirable to assess the amounts of organic and mineral acids present, and a check on hardness is usually necessary in any case. Hardness in water is due to dissolved salts – mainly of calcium, magnesium and iron, and occasionally of aluminium. Softening may be required if the water is extremely hard, because the salts react with the emulsifier in the soluble oil to form an insoluble scum that floats on the surface of the emulsion. The scum may not in itself be harmful, but its formation uses up some of the emulsifier and causes the emulsion to be unstable.

40.12.12 Cutting fluids in service

40.12.12.1 Neat oils

During service, neat cutting oils suffer negligible deterioration of quality; their service life is almost indefinitely long, provided they are kept clean and free from contamination. They suffer very little depletion of their additives through cutting action, and quality is adequately maintained by additions of new oil to make up for 'drag-out' losses (those caused by oil adhering to both the swarf and the work). Serious leakage of hydraulic fluid or lubricating oil into the coolant system can have a diluting effect, which reduces additive concentration and hence the performance of the cutting oil.

40.12.12.2 Water-based fluids

As long as they are kept clean and maintained at the correct concentration, water-based fluids have a long service life. The concentration of an emulsion can be affected in two ways: by evaporation of water and by drag-out of the oil content. In many cases the effects counteract each other, so the top-up fluid is given the same concentration as the working fluid. Solutions, on the other hand, tend to become more concentrated during service because they suffer from evaporation of water but not from drag-out losses of the other constituents, so top-up solutions are generally weaker than working solutions.

It is advisable to monitor water-based fluids at frequent intervals so that their water content can be brought to within tolerance before the machining operation is affected. Maintenance of the correct concentration ensures that cutting performance and rust-preventive properties stay at the required level. A simple technique makes use of the fact that a fluid's density influences its refractive index. In this method a very small amount of the fluid is viewed in a pocket-size instrument called a refractometer, and the density is indicated by the edge of a dark shadow falling on a graduated line. The line gives a figure which, in some cases, is a direct reading of dilution, but in others it may have to be correlated with dilution on a graph drawn for the particular fluid.

The strength of a solution or emulsion is, of course, corrected by additions of stronger or weaker fluid. The percentage concentration of make-up fluid is calculated by the formula:

$$C = \frac{Q_e}{Q_r}(C_f - C_e) + C_f$$

where C_f = required final concentration,
C_e = existing concentration,
Q_e = existing quantity,
Q_r = quantity required of make-up fluid.

40.12.12.3 Cleaning procedures

Although some neat cutting fluids can be used almost indefinitely if well maintained, most fluids eventually reach the end of their useful life, so the system has to be drained and refilled with new fluid. On such occasions the system should be thoroughly cleaned out before the new charge is poured in. The nature of cleaning depends on the type of cutting fluid.

Normally a system containing net oil requires only manual cleaning because the debris contained is likely to be mainly metallic, but water-based fluids call for more searching treatment. Caustic-soda and proprietary solutions are available for the purpose of flushing away slimy deposits. If there is evidence of bacterial degradation, however, bactericides must be introduced. These tend to persist in remote pockets and in the more stagnant parts of a coolant system, and manual cleaning by itself is inadequate. The risk of persistence can be significantly minimized at the planning stage if the system is designed to be free of regions to trap stagnant fluid.

40.13 Compressors

Compressors fall into two basic categories: positive displacement types, in which air is compressed by the

'squashing' effect of moving components; and dynamic (turbo)-compressors, in which the high velocity of the moving air is converted into pressure. In some compressors the oil lubricates only the bearings, and does not come into contact with the air; in some it serves an important cooling function; in some it is in intimate contact with the oxidizing influence of hot air and with moisture condensed from the air. Clearly, there is no such thing as a typical all-purpose compressor oil: each type subjects the lubricant to a particular set of conditions. In some cases a good engine oil or a turbine-quality oil is suitable, but in others the lubricant must be special compressor oil (Figure 40.13).

40.13.1 Quality and safety

Over the years the progressive improvements in compressor lubricants have kept pace with developments in compressor technology, and modern oils make an impressive contribution to the performance and longevity of industrial compressors. More recently a high proportion of research has been directed towards greater safety, most notably in respect of fires and explosions within compressors. For a long time the causes of such accidents were a matter of surmise, but it was noticed that the trouble was almost invariably associated with high delivery temperatures and heavy carbon deposits in delivery pipes. Ignition is now thought to be caused by an exothermic (heat-releasing) oxidation reaction with the carbon deposit, which creates temperatures higher than the spontaneous ignition temperature of the absorbed oil.

Experience indicates that such deposits are considerably reduced by careful selection of base oils and anti-oxidation additives. Nevertheless, the use of a top-class oil is no guarantee against trouble if maintenance is neglected. For complete safety, both the oil and the compressor system must enjoy high standards of care.

40.13.2 Specifications

The recommendations of the International Standards Organization (ISO) covering mineral-oil lubricants for reciprocating compressors are set out in ISO DP 6521, under the ISO-L-DAA and ISO-L-DAB classifications. These

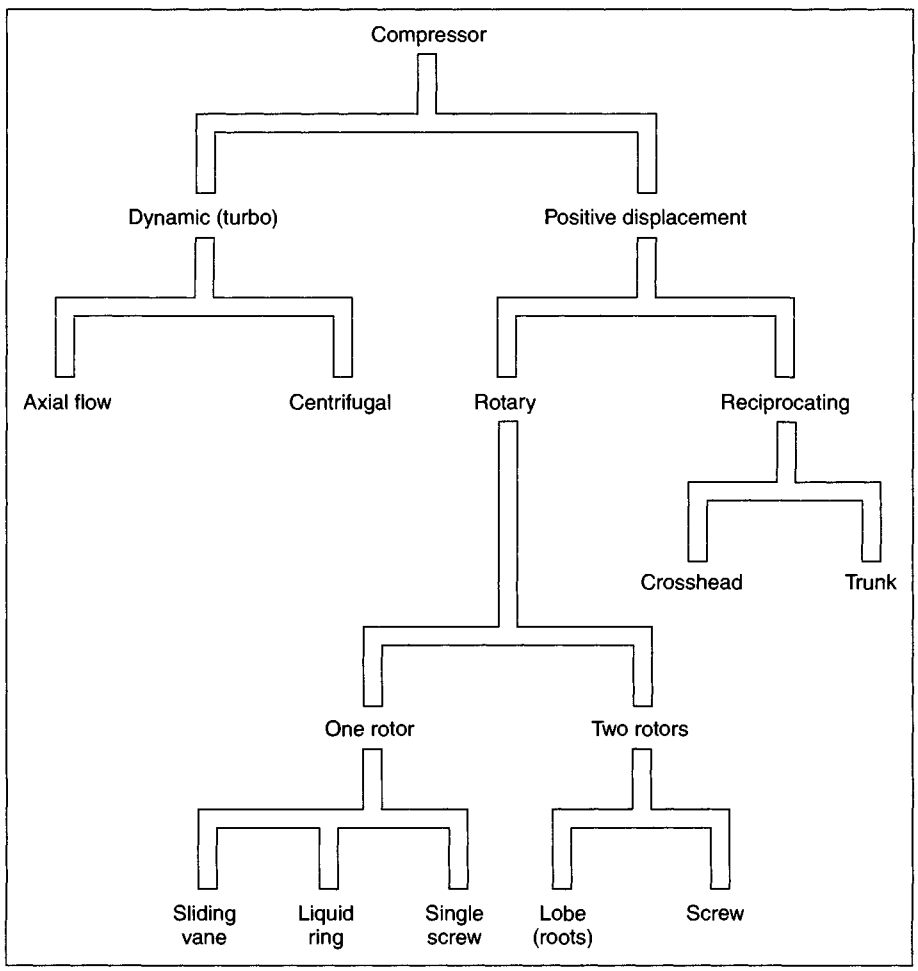


Figure 40.13 Compressor types

cover applications wherever air-discharge temperature are, respectively, below and above 160°C. For mineral-oil lubricants used in oil-flooded rotary-screw compressors the classifications ISO-L-DAG and DAH cover applications where temperatures are, respectively, below 100°C and in the 100–110°C range. For more severe applications, where synthetic lubricants might be used, the ISO-L-DAC and DAJ specifications cover both reciprocating and oil-flooded rotary-screw requirements.

For the general performance of compressor oils there is DIN 51506. This specification defines several levels of performance, of which the most severe – carrying the code letters VD-L – relates to oils for use at air-discharge temperatures of up to 220°C.

The stringent requirements covering oxidation stability are defined by the test method DIN 51352, Part 2, known as the Pneurop Oxidation Test (POT). This test simulates the oxidizing effects of high temperature, intimate exposure to air, and the presence of iron oxide which acts as catalyst – all factors highly conducive to the chemical breakdown of oil, and the consequent formation of deposits that can lead to fire and explosion.

Rotary-screw compressor mineral oils oxidation resistance is assessed in a modified Pneurop oxidation test using iron naphthenate catalyst at 120°C for 1000 h. This is known as the rotary-compressor oxidation test (ROCOT).

40.13.3 Oil characteristics

40.13.3.1 Reciprocating compressors

In piston-type compressors the oil serves three functions in addition to the main one of lubricating the bearings and cylinders. It helps to seal the fine clearances around piston rings, piston rods and valves, and thus minimizes blow-by of air (which reduces efficiency and can cause overheating). It contributes to cooling by dissipating heat to the walls of the crankcase and it prevents corrosion that would otherwise be caused by moisture condensing from the compressed air.

In small single-acting compressors the oil to bearings and cylinders is splash-fed by flingers, dippers or rings, but the larger and more complex machines have force-feed lubrication systems, some of them augmented by splash-feed. The cylinders of a double-acting compressor cannot be splash-lubricated, of course, because they are not open to the crankcase. Two lubricating systems are therefore necessary – one for the bearings and cross-head slides and one feeding oil directly into the cylinders. In some cases the same oil is used for both purposes, but the feed to the cylinders has to be carefully controlled, because under-lubrication leads to rapid wear and over-lubrication leads to a build-up of carbon deposits in cylinders and on valves. The number and position of cylinder-lubrication points varies according to the size and type of the compressor. Small cylinders may have a single point in the cylinder head, near the inlet valve; larger ones may have two or more. In each case the oil is spread by the sliding of the piston and the turbulence of the air.

In the piston-type compressor the very thin oil thin has to lubricate the cylinder while it is exposed to the heat of the compressed air. Such conditions are highly conducive to oxidation in poor-quality oils, and may result in the formation of gummy deposits that settle in and around the piston-ring grooves and cause the rings to stick, thereby allowing blow-by to develop.

40.13.3.2 Rotary compressors – vane type

The lubrication system of vane-type compressors varies according to the size and output of the unit. Compressors in the small and 'portable' group have neither external cooling nor intercooling, because to effect all the necessary cooling the oil is injected copiously into the incoming air stream or directly into the compressor chamber. This method is known as flood lubrication, and the oil is usually cooled before being recirculated. The oil is carried out of the compression chamber by the air, so it has to be separated from the air; the receiver contains baffles that 'knock out' the droplets of oil, and they fall to the bottom of the receiver. Condensed water is subsequently separated from the oil in a strainer before the oil goes back into circulation.

Vane-type pumps of higher-output are water-jacketed and intercooled: the lubricant has virtually no cooling function so it is employed in far smaller quantities. In some units the oil is fed only to the bearings, and the normal leakage lubricates the vanes and the casing. In others, it is fed through drillings in the rotor and perhaps directly into the casing. This, of course, is a total-loss lubrication technique, because the oil passes out with the discharged air.

As in reciprocating units, the oil has to lubricate while being subjected to the adverse influence of high temperature. The vanes impose severe demands on the oil's lubricating powers. At their tips, for example, high rubbing speeds are combined with heavy end-pressure against the casing.

Each time a vane is in the extended position (once per revolution) a severe bending load is being applied between it and the side of its slot. The oil must continue to lubricate between them, to allow the vane to slide freely. It must also resist formation of sticky deposits and varnish, which lead to restricted movement of the vanes and hence to blow-by and, in severe cases, to broken vanes.

40.13.3.3 Rotary compressors – screw type

The lubrication requirements for single-screw type compressors are not severe, but in oil-flooded rotary units the oxidizing conditions are extremely severe because fine droplets of oil are mixed intimately with hot compressed air. In some screw-type air compressors the rotors are gear driven and do not make contact. In others, one rotor drives the other. The heaviest contact loads occur where power is transmitted from the female to the male rotor: here the lubricant encounters physical conditions similar to those between mating gear teeth. This arduous combination of circumstances places a great demand on the chemical stability, and lubricating power, of the oil.

40.13.3.4 Other types

Of the remaining designs, only the liquid-piston type delivers pressures of the same order as those just mentioned. The lobe, centrifugal and axial-flow types, are more accurately termed 'blowers', since they deliver air in large volumes at lower pressures. In all four cases only the 'external' parts – bearings, gears or both – require lubrication. Therefore the oil is not called upon to withstand the severe service experienced in reciprocating and vane-type compressors. Where the compressor is coupled to a steam or gas turbine a common circulating oil system is employed. High standards of system cleanliness are necessary to avoid deposit formation in the compressor bearings.

40.13.3.5 Refrigeration compressors

The functions of a refrigerator compressor lubricant are the same as those of compressor lubricants in general. However, the close association between refrigerant and lubricant does impose certain additional demands on the oil. Oil is unavoidably carried into the circuit with refrigerant discharging from the compressor. In many installations provision is made for removal of this oil. However, several refrigerants, including most of the halogen refrigerants, are miscible with oil and it is difficult to separate the oil which enters the system which therefore circulates with the refrigerant. In either case the behaviour of the oil in cold parts of the systems is important, and suitable lubricants have to have low pour point and low wax-forming characteristics.

40.13.3.6 Effects of contamination

The conditions imposed on oils by compressors – particularly by the piston type – are remarkably similar to those imposed by internal combustion engines. One major difference is, of course, that in a compressor no fuel or products of combustion are present to find their way into the oil. Other contaminants are broadly similar. Among these are moisture, airborne dirt, carbon and the products of the oil's oxidation. Unless steps are taken to combat them, all these pollutants have the effect of shortening the life of both the oil and the compressor, and may even lead to fires and explosions.

40.13.3.7 Oxidation

High temperature and exposure to hot air are two influences that favour the oxidation and carbonization of mineral oil. In a compressor, the oil presents a large surface area to hot air because it is churned and sprayed in a fine mist, so the oxidizing influences are very strong – especially in the high temperatures of the compressor chamber. The degree of oxidation is dependent mainly on temperature and the ability of the oil to resist, so the problem can be minimized by the correct selection of lubricant and by controlling operating factors.

In oxidizing, an oil becomes thicker and it deposits carbon and gummy, resinous substances. These accumulate in the piston-ring grooves of reciprocating compressors and in the slots of vane-type units, and as a result they restrict free movement of components and allow air leakages to develop. The deposits also settle in and around the valves of piston-type compressors, and prevent proper sealing.

When leakage develops, the output of compressed air is reduced, and overheating occurs due to the recompression of hot air and the inefficient operation of the compressor. This leads to abnormally high discharge temperatures. Higher temperature leads to increased oxidation and hence increased formation of deposits, so adequate cooling of compressors is very important.

40.13.3.8 Airborne dirt

In the context of industrial compressors, dust is a major consideration. Such compressors have a very high throughput of air, and even in apparently 'clean' atmospheres, the quantity of airborne dirt is sufficient to cause trouble if the compressor is not fitted with an air-intake filter. Many of the airborne particles in an industrial atmosphere are abrasive, and they cause accelerated rates of wear in any compressor with sliding components in the compressor chamber. The dirt passes into the oil, where it may accumulate and contribute very seriously to the carbon deposits in valves and outlet pipes. Another consideration is that dirt in an oil is likely to act as a catalyst, thus encouraging oxidation.

40.13.3.9 Moisture

Condensation occurs in all compressors, and the effects are most prominent where cooling takes place – in intercoolers and air-receivers, which therefore have to be drained at frequent intervals. Normally the amount of moisture present in a compression chamber is not sufficient to affect lubrication, but relatively large quantities can have a serious effect on the lubrication of a compressor. Very wet conditions are likely to occur when the atmosphere is excessively humid, or compression pressures are high, or the compressor is being overcooled.

During periods when the compressor is standing idle the moisture condenses on cylinders walls and casings, and if the oil does not provide adequate protection this leads to rusting. Rust may not be serious at first sight, and it is quickly removed by wiping action when the compressor is started, but the rust particles act as abrasives, and if they enter the crankcase oil they may have a catalytic effect and promote oxidation. In single-acting piston-type compressors, the crankcase oil is contaminated by the moisture.

40.14 Turbines

40.14.1 Steam

Although the properties required of a steam-turbine lubricant are not extreme it is the very long periods of continuous operation that creates the need for high-grade oils to be used. The lubricating oil has to provide adequate and reliable lubrication, act as a coolant, protect against corrosion, as a hydraulic medium when used in governor and

control systems, and if used in a geared turbine provide satisfactory lubrication of the gearing. The lubricant will therefore need the following characteristics.

40.14.1.1 Viscosity

For a directly coupled turbine for power generation a typical viscosity would be in the range of 32–46cSt at 40°C. Geared units require a higher viscosity to withstand tooth loadings typically within the range of 68–100cSt at 40°C.

40.14.1.2 Oxidation resistance

The careful blending of turbine oils, using components which, by selective refining, have a reduced tendency to oxidize, produces the required long-term stability. The high temperatures and pressures of modern designs add to these demands, which are combated by the incorporation of suitable anti-oxidant additives.

40.14.1.3 Demulsibility

The ability of the lubricant to separate readily and completely from water, in either a centrifuge or a settling tank, is important in a turbine lubricant. Otherwise the retained water will react with products of oxidation and particle contaminants to form stable emulsions. These will increase the viscosity of the oil and form sludges which can result in a failure. Careful and selective refining ensures a good demulsibility characteristic. Inadequate storage and handling can seriously reduce this property.

40.14.1.4 Corrosion resistance

Although the equipment is designed to keep the water content at a minimum level, it is virtually impossible to eliminate it entirely. The problem of rusting is therefore overcome by using corrosion inhibitors in the lubricant formulation.

40.14.1.5 Foaming resistance

Turbine oils must be resistant to foaming, since oil-foam reduces the rate of heat transfer from the bearings, promotes oxidation by greatly extending the area of contact between air and oil. It is also an unsatisfactory medium for the hydraulic governor controls. Careful refining is the primary means of achieving good resistance to foaming. Use of an anti-foam additive may seem desirable but this should be approached with caution. If it is used in quantities higher than the optimum it can in fact assist air entrainment in the oil by retarding the release of air bubbles.

40.14.2 Gas

The lubricants generally specified for conventional gas turbines invariably fall within the same classification as those used for steam turbines and are often categorized as 'turbine oils'. In those cases where an aircraft type gas turbine has been adapted for industrial use the lubricant is vitally important to their correct operation. Specifications have been rigidly laid down after the most exhaustive tests, and it would be unwise, even foolhardy, to depart from the manufacturers' recommendations. No economic gain would result from the use of cheaper, but less efficient, lubricants.

40.14.3 Performance standards

In the UK there is BS 489:1983. In Europe there is DIN 51515 together with manufacturers' standards such as those set by Brown Boverie and Alsthom Atlantique. In the USA there are the ASTM standards and the well-known General Electric requirements.

The total useful life of a turbine oil is its most important characteristic. ASTM method D943 (IP 157) measures the life indirectly by assessing the useful life of the oxidation inhibitor contained in the formulation and is often referred to as the TOST 'life' of the oil. Rust prevention is generally assessed by the ASTM D665 (IP 135) method.

There are many other specifications designed by equipment builders, military and professional societies, as well as users. Care always needs to be taken when purchasing turbine oil to specification. The cheapest oil, albeit conforming to the specification, may not necessarily be the best within that specification for the particular purpose. For instance, the additive package is rarely (if ever) defined, so that unexpected reactions can occur between oils which could affect overall performance.

40.15 Transformers and switchgear

The main requirement for a power-transmission equipment oil is that it should have good dielectric properties. Oil used in transformers acts as a coolant for the windings; as an insulant to prevent arcing between parts of the transformer circuits; and prevents the ionization of minute bubbles of air and gas in the wire insulation by absorbing them and filling the voids between cable and wrapping. In switchgear and circuit breakers it has the added function of quenching sparks from any arc formed during equipment operation. Oils for use in power transmission equipment should have the following properties; high electric strength, low viscosity, high chemical stability and low carbon-forming characteristics under the conditions of electric arc.

40.15.1 Performance standards

The efficiency of transformer oils as dielectrics is measured by 'electric strength' tests. These give an indication of the voltage at which, under the test conditions, the oil will break down. Various national standards exist that all measure the same basic property of the oil. In the UK it is BS 148:1984. There is an international specification, IEC 296/1982, which may be quoted by equipment manufacturers in their oil recommendations.

40.15.2 Testing

How frequently the oil condition should be tested depends on operating and atmospheric conditions; after the commissioning sample, further samples should be taken at

three months and one year after the unit is first energized. After this, under normal conditions, testing should be carried out annually. In unfavourable operating conditions (damp or dust-laden atmospheres, or where space limitations reduce air circulation and heat transfer) testing should be carried out every six months.

Testing should include a dielectric strength test to confirm the oil's insulation capability and an acidity test, which indicates oil oxidation. While acid formation does not usually develop until the oil has been in service for some time when it does occur the process can be rapid. If acidity is below 0.5 mg KOH/g no action would seem necessary. Between 0.5 and 1 mg KOH/g, increased care and testing is essential. Above 1 the oil should be removed and either reconditioned or discarded. Before the unit is filled with a fresh charge of oil it should be flushed. These suggestions are contained in a British Standards Code of Practice.

Sludge observations will show if arcing is causing carbon deposits which, if allowed to build up will affect heat transfer and could influence the oil insulation. There is also a flash point test, in which any lowering of flash point is an indication that the oil has been subjected to excessive local heating or submerged arcing (due to overload or an internal electrical fault). A fall in flash point exceeding 16°C implies a fault, and the unit should be shut down for investigation of the cause. Lesser drops may be observed in the later stages of oil life, due to oxidation effects, but are not usually serious. A 'crackle' test is a simple way of detecting moisture in the oil. Where water is present the oil should be centrifuged.

40.16 Greases

Grease is a very important and useful lubricant when used correctly, its main advantage being that it tends to remain where it is applied. It is more likely to stay in contact with rubbing surfaces than oil, and is less affected by the forces of gravity, pressure and centrifugal action. Economical and effective lubrication is the natural result of this property and a reduction in the overall cost of lubrication, particularly in all-loss systems, is made possible.

Apart from this, grease has other advantages. It acts both as a lubricant and as a seal and is thus able, at the same time as it lubricates, to prevent the entry of contaminants such as water and abrasive dirt. Grease lubrication by eliminating the need for elaborate oil seals can simplify plant design.

Because a film of grease remains where it is applied for much longer than a film of oil it provides better protection to bearing and other surfaces that are exposed to shock loads or sudden changes of direction. A film of grease also helps to prevent the corrosion of machine parts that are idle for lengthy periods.

Bearings pre-packed with grease will function for extended periods without attention. Another advantage is the almost complete elimination of drip or splash, which can be a problem in certain applications. Grease is also able to operate effectively over a wider range of temperatures than any single oil.

There are certain disadvantages as well as advantages in using grease as a lubricant. Greases do not dissipate heat as well as fluid lubricants, and for low-torque operation tend to offer more resistance than oil.

40.16.1 Types of grease

The general method of classifying greases is by reference to the type of soap that is mixed with mineral oil to produce the grease, although this has rather less practical significance nowadays than it had in the past. One example of this is the multi-purpose grease that may replace two or three different types previously thought necessary to cover a particular field of application. Nevertheless, there are unique differences in behaviour between greases made with different metal soaps, and these differences are still important in many industrial uses, for technical and economic reasons.

40.16.1.1 Calcium-soap greases

The line-soap (calcium) greases have been known for many years but are still probably the most widely used. They have a characteristic smooth texture, thermal stability, good water resistance and are relatively inexpensive. The softer grades are easily applied, pump well and give low starting torque. Their application is limited by their relatively low drop points, which are around 100°C. This means that, in practice, the highest operating temperature is about 50°C.

Nevertheless, they are used widely for the lubrication of medium-duty rolling and plain bearings, centralized greasing systems, wheel bearings and general duties. The stiffer varieties are used in the form of blocks on the older-type brasses. Modifications of lime-base grease include the graphited varieties and those containing an extreme pressure additive. The latter are suitable for heavily loaded roller bearings such as in steel-mill applications.

40.16.1.2 Sodium-soap greases

The soda-soap (sodium) greases were, for some considerable time, the only high-melting-point greases available to industry. They have drop points in the region of 150°C and their operating maximum is about 80°C. These greases can be 'buttery', fibrous or spongy, are not particularly resistant to moisture and are not suitable for use in wet conditions. Plain bearings are very frequently lubricated with soda-based greases.

For rolling-contact bearings, a much smoother texture is required, and this is obtained by suitable manufacturing techniques. Modified grades may be used over the same temperature range as that of the unmodified grade and, when they are correctly formulated, have a good shear resistance and a slightly better resistance to water than the unmodified grades.

40.16.1.3 Lithium-soap greases

These products, unknown before the Second World War, were developed first as aircraft lubricants. Since then the field in which they have been used has been greatly

extended and they are now used in industry as multipurpose greases. They combine the smooth texture of the calcium-based greases with higher melting points than soda-soap greases, and are almost wholly manufactured in the medium and soft ranges. Combined with suitable additives, they are the first choice for all rolling-contact bearings, as they operate satisfactorily up to a temperature of 120°C and at even higher for intermittent use. Their water resistance is satisfactory and they may be applied by all conventional means, including centralized pressure systems.

40.16.1.4 Other metal-soap greases

Greases are also made from soaps of strontium, barium and aluminium. Of these, aluminium-based grease is the most widely used. It is insoluble in water and very adhesive to metal. Its widest application is in the lubrication of vehicle chassis. In industry it is used for rolling-mill applications and for the lubrication of cams and other equipment subject to violent oscillation and vibration, where its adhesiveness is an asset.

40.16.1.5 Non-soap thickened greases

These are generally reserved for specialist applications, and are in the main more costly than conventional soap-based greases. The most common substances used as non-soap thickeners are silicas and clays prepared in such a way that they form gels with mineral and synthetic oils. Other materials that have been used are carbon black, metal oxides and various organic compounds.

The characteristic of these non-soap greases which distinguishes them from conventional greases is that many of them have very high melting points; they will remain as greases up to temperatures in the region of 260°C. For this reason, the limiting upper usage temperature is determined by the thermal stability of the mineral oil or synthetic fluid of which they are composed. Applications such as those found in cement manufacturing, where high-temperature conditions have to be met, require a grease suitable for continuous use at, say, 204°C. Although it is difficult to generalize, the non-soap products have, on the whole, been found to be somewhat less effective than the soap-thickened greases as regards lubricating properties and protection against corrosion, particularly rusting. Additive treatment can improve non-soap grades in both these respects, but their unique structures renders them more susceptible to secondary and unwanted effects than is the case with the more conventional greases.

40.16.1.6 Filled greases

The crude types of axle and mill grease made in the early days frequently contained large amounts of chemically inert, inorganic powders. These additions gave 'body' to the grease and, possibly, helped to improve the adherence of the lubricating film. Greases are still 'filled' but in a selective manner with much-improved materials and under controlled conditions. Two materials often used for this purpose are graphite and molybdenum disulphide.

Small amounts (approximately 5%) of filler have little or no effect on grease structure, but large amounts increase the consistency. However, the materials mentioned are lubricants in themselves and are sometimes used as such. Consequently it is often claimed that when they are incorporated into the structure of the grease the lubricating properties of the grease are automatically improved. A difference of opinion exists as to the validity of this assumption, but it is true that both molybdenum disulphide and graphite are effective where shock loading or boundary conditions exist, or when the presence of chemicals would tend to remove conventional greases.

40.16.1.7 Mixing greases

The above comments on the properties of the various types of grease has shown that very real differences exist. Each one has its own particular type of structure, calls for individual manufacturing processes and has its own advantages and disadvantages. It is because of these distinct differences that the mixing of greases should never be encouraged. If greases of different types are mixed indiscriminately there is a risk that one or other of them will suffer, the resulting blend being less stable than either of the original components and the blend may even liquefy.

40.16.2 Selecting a grease

A few brief notes on the fundamental factors that influence a choice of grease may be found helpful. The first essential is to be absolutely clear about the limitations of the different types, and to compare them with the conditions they are to meet. Table 40.10 gives the characteristics of high-quality greases.

Greases with a mixed base are not shown in the table because, in general, they are characterized by the predominant base; for example, a soda-lime grease behaves like a soda grease. Temperature limits may be modified by the required length of service. Thus, if a soda grease requires to have only a short life, it could be used at temperatures up to 120°C.

When the type most suitable for a particular application has been chosen, the question of consistency must be considered. The general tendency over the last two decades has been towards a softer grease than formerly used. Two factors have probably contributed to this trend; the growth of automatic grease dispensing and the use of more viscous oils in grease making.

Table 40.10 Characteristics of high-quality greases

Grease (type of soap)	*Recommended maximum operating temperature (°C)*	*Water resistance*	*Mechanical stability*
Lime	50	Good	Good
Soda	80	Poor	Good
Lithium	120	Good	Good
Aluminium	50	Fair	Moderate

In practice, the range of grease consistency is quite limited. For most general industrial applications, a No. 2 consistency is satisfactory. Where suitability for pumping is concerned, a No. 1; for low temperatures, a No. 0; and for water pumps and similar equipment, a No. 3.

40.16.3 Grease application

In applying lubricating grease the most important aspect is how much to use. Naturally, the amount varies with the component being serviced, but some general rules can be laid down. All manufacturers agree that antifriction bearings should never be over-greased. This is particularly true of high-speed bearings, in which the churning of excess lubricant leads to overheating. The rise in temperature of a bearing as the amount of grease increases has been recorded. With the bearing housing one-third full, the temperature was 39°C; at two-thirds full the temperature rose to 42°C; and with a full charge of grease it went up to 58°C.

The general recommendations for grease packing are:

1. Fully charge the bearing itself with grease ensuring that it is worked around and between the rolling elements.
2. Charge the bearing housing one-half to two-thirds full of grease.

Churning, and its attendant high temperature, may change the structure of the grease permanently, in which event softening may result in leakage and stiffening in lubricant starvation. There is no fixed rule for the period between re-greasings, since this depends on the operating conditions. Most recommendations suggest inspection and possible replenishment every six or twelve months, though the general tendency as grease quality improves has been to extended this period. The higher the temperature of a machine, the more frequently it must be greased because of possible losses of softened lubricant or changes in its structure.

It is not always incorrect to over-grease. With a sleeve bearing, for instance, gun pressure may be maintained until old grease exudes from the ends of the bearing, and the same is true of spring shackles. For the sake of economy and cleanliness, however, this should never be overdone.

40.17 Corrosion prevention

Most plant has to work under adverse conditions, in all sorts of weather, and subject to contamination by various agents. However, as long as it is in use it can be reasonably sure of receiving at least a minimum amount of regular maintenance and attention, and this will reduce the likelihood of working parts being attacked by corrosion when plant is in service. However, when plant has to be laid up until required, no matter how carefully matters have been planned, corrosion is always a serious possibility. Modern machinery, with highly finished surfaces, is especially susceptible to atmospheric attack. The surfaces of components also require protection during transport and storage.

Even today, rusting of industrial plant and material is accepted by some as an inevitable operating expense. There is no necessity for this attitude, however, as the petroleum industry has evolved effective, easily applied temporary protectives against corrosion, where are well suited to the conditions met in practice.

40.17.1 Categories of temporary corrosion preventives

Temporary corrosion preventives are products designed for the short-term protection of metal surfaces. They are easily removable, if necessary, by petroleum solvents or by other means such as wiping or alkaline stripping. Some products for use in internal machine parts are miscible and compatible with the eventual service lubricant, and do not, therefore, need to be removed.

The major categories of temporary corrosion preventives are:

Soft-film protectives
Dewatering fluids giving soft/medium films
Non-dewatering fluids giving soft films
Hot-dip compounds
Greases

Hard-film protectives
Oil-type protectives
General-purpose
Engine protectives

The development of products in these categories has been guided by known market demands and many manufacturers have made use of established specifications for temporary protectives. In the UK, for example, British Standard 1133, Section 6 (covering all categories) and British Government Specifications CS 2060C (PX10 dewatering fluid) are frequently followed.

40.17.2 Selection of a corrosion preventive

Temporary corrosion preventives are in some cases required to give protection against rusting for periods of only a few days for inter-process waiting in factories. Where the protected components are not exposed to the weather, protection can be given for up to a year or more for stored components in internal storage conditions. On the other hand, components may require protection for a few days or even weeks under the most adverse weather conditions. Some components may have to be handled frequently during transit or storage. In general, therefore, the more adverse the conditions of storage, the longer the protective periods, and the more frequent the handling, the thicker or more durable the protective film must be.

Because of the wide variation in conditions of exposure it is not possible to define the length of protection period except in general terms. Solvent-deposited soft films will give protection from a few days to months indoors and some weeks outdoors; a solvent-deposited medium film will give long-term protection indoors and medium-term protection outdoors. Hot-dip compounds and cold-applied greases give films that can withstand

considerable handling and will give medium to long protection. Solvent-deposited hard-film protectives will give long-term protection but are fairly difficult to remove. Oil protectives give short- to medium-term protection of parts not subject to handling and are also much used for the preservation of internal working parts; they need not be removed and can in some instances serve as lubricating oils.

'Short term', 'medium term' and 'long term' are expressions that are not rigorously defined but are generally accepted as meaning of the order of up to 6 months, 12 months and 18 months, respectively, in temperate climates. Where local conditions are more severe (in hot, humid climates, for example) the protection periods are less. These protection periods are related to the preventive film alone, but where transit or storage conditions call for wrapping or packaging then longer protection periods can be obtained.

The distinction between a simple part and a complex assembly is an important factor in selecting a temporary protective. The solvent-containing protectives may not be suited to treating assemblies, because:

1. Assemblies may contain non-metallic parts (rubber, for example) that could be attacked by the solvent;
2. The solvent cannot evaporate from enclosed or shielded spaces and the intended film thickness will not be obtained;
3. Evaporated solvent could be trapped and could then leach away the protective film.

Hence the hot-dip compounds, or greases smeared cold, are better for assemblies with non-metallic parts masked if necessary. Solvent-containing protectives therefore find greater application in the protection of simple parts or components. The available means of application, the nature of any additional packaging and the economics and scale of the protective treatment are further factors that influence the choice of type of temporary corrosion preventive.

40.18 Spray lubricants

There are several applications where the lubrication requirement is specialized and very small, needing precise applications where access is limited because of equipment design or location. In these instances lubricant application by aerosol is the most suitable method. Extreme-pressure cutting flud for reaming and tapping, etc., conveyor and chain lubricant, anti-seize and weld anti-spatter agents, release agents, electrical component cleaner and degreasants are examples of the ever-widening range of products available in aerosol packs.

40.19 Degreasants

Often, before any maintenance work starts it is necessary (and desirable) to remove any oil, grease and dirt from the equipment concerned. It may also be necessary to clean replacement components before their installation. Solvents, emulsions and chemical solutions are three broad types of degreasants. The method of degreasing (direct onto the surface, by submersion, through degreasing equipment or by steam cleaners), component complexity and the degree of contamination will all have to be taken into account when selecting the type of product to be used.

40.20 Filtration

Some 70–85% of failures and wear problems in lubricated machines are caused by oil contamination. Clean oil extends machine and oil life and gives greater reliability, higher productivity and lower maintenance cost. Hence some type of filter is an essential part of virtually all lubrication systems.

Cleaning of oil in service may be accomplished quite simply or with relatively complex units, depending on the application and the design of the system. Thus for some operations it is enough to remove particles of ferrous metal from the oil with a magnetic system. In a closed circulatory system, such as that of a steam turbine, the nature of the solids and other contaminants is far more complex, and the treatment has therefore to be more elaborate. In an internal-combustion engine both air and fuel are filtered as well as crankcase oil.

The efficiency of filtration must be matched to the needs of the particular application, and, this is true both quantitatively (in relation the anticipated build-up of solids in the filters) and qualitatively (in relation to the composition of the contaminants and their size). Dirt build-up varies considerably, but it is probably at its maximum with civil engineering equipment. In this field, diesel engines in trucks will steadily accumulate something like 0.3 kg of solids in the crankcase oil within a month.

Particle size is naturally important. It is generally assumed that particles of less than 3 μm in diameter are relatively harmless. However, this is on the assumption that the oil film is itself of this, or greater, thickness; in other words, that full fluid-film hydrodynamic lubrication persists during the whole working cycle of the machine. This is seldom the case, for there are either critical areas or critical phases at or during which mixed or even wholly boundary conditions prevail – when, in fact, the oil film is less than 3 μm thick. The tendency of modern industrial equipment to operate at higher speeds and under greater pressures leads to higher wear rates. Increased pump capacity, as in hydraulic circuits, coupled with a decreased oil volume means a relatively greater amount of contamination. All in all, much more is demanded of the filter today, whatever the application, than at any time in the past.

40.20.1 Types of filter

The terms 'filter' and 'strainer' are in common use and may lubricant systems contain both. The word 'strainer' is often associated with the removal of large particles, and though it is true that in the majority of cases a strainer is in fact employed to remove coarse particles, the fundamental difference between it and a filter is not one of porosity but purely one of geometry. In a strainer the liquid passes

through in a straight line, but in a filter a far more devious route is followed.

Strainers are usually made from woven wire gauze, like a sieve, and though today the pre-size can be made very small indeed (BSI 300 mesh gauze separates particles of roughly 50 μm) they are mainly included for the exclusion of large particles. Filters deal with the removal of very much smaller particles.

Naturally from the above definition there is some unavoidable overlapping, and a really fine strainer of, say, stainless steel 'cloth' is regarded as a filter. There are five main types of filtering units as follows.

40.20.1.1 Surface films

These are usually constructed of woven metal gauze, paper or cloth. The paper filter may have the working surface enlarged by pleating and the paper impregnated and strengthened. As an example, one proprietary pleated model gives, from an element 11.5 cm long and 8.5 cm in external diameter, a filtering surface of some 3250 cm^2. This type, sometimes described as a radial-fin unit, has a good throughput and is easy to clean or replace. Filters in this class generally have porosities from 100 μm down to 10 or, in extreme cases, even down to 2 μm.

40.20.1.2 Edge filters

A typical unit comprises a pack of metal or paper discs with a washer between each, the gauge of the latter governing the degree of filtration. The oil flows from the outside and is discharged through a central channel. Some designs can be cleaned without dismantling or interrupting the flow.

An alternative method of manufacturing is to employ a coil of flat metal ribbon as the element, each turn spaced) from the next by small lateral protuberances. The principle of filtration is the same. Porosities of both types are identical and cover a wide range, usually from 100 μm down to 0.5 μm.

40.20.1.3 Depth filters (absorption-type filters)

1. *Chemically inactive*: These are made from a variety of materials that include wound yarn, felt, flannel, cotton waste, wood pump, mineral wool, asbestos and diatomaceous earths. The solid particles are trapped and retained within the medium. Certain types will remove water, as well as large and small particles of solids in a range down to 10 μm. Ceramics are sometimes employed for depth filtration, as also are special sintered metals.
2. *Chemically active*: These filters are similar in design to the non-active depth units but the filtering media used are so chosen that contaminants adhere by chemical attraction. Thus there is a dual action, mechanical and chemical. The materials used include various activated clays, Fuller's earth, charcoal and chemically treated paper. Their cleansing action is much more thorough than that of the purely mechanical devices, for they are capable of removing matter actually in solution in the oil.

40.20.1.4 Magnetic and combined magnetic filters

In its simplest form the magnetic filter comprises a non-magnetic outer casing with an inner permanent magnetic core round which the liquid flows. Because of the magnetic anisotropy of the field the ferrous particles are continuously diverted to the area of strongest attraction coinciding with the direction of flow. A more elaborate design of magnetic clarifier has its elements mounted in a rotating disc. The dirty fluid flows through the chamber in which the disc dips, and ferrous particles adhering to the magnetized areas are removed by the action of scrapers and collected in containers. The capacity of one such disc has been given as 2250 l/h with a range of sludge removal as high as 30 kg/h. Combined units may have the magnet located within a coil of wire that forms the permeable, mechanical filter.

For its specialized application (cleaning the coolants used for metal-machining operations such as grinding and honing) the magnetic filter is easily maintained and cleaned. It has a high throughput and will remove ferrous particles as small as 1 μm. Some of the non-magnetic material is associated with the ferrous particles suspended in the fluids and this is also removed with them.

40.20.1.5 The centrifugal filter

This is a specialized design and is, in effect, a true centrifuge of small size that operates on the reaction turbine principle, an oil-circulating pump providing the necessary power. One advantage claimed for this type is that it operates at a steady flow rate, whereas the flow rate through a felt or paper element diminishes as the bed of dirt is built up. The centrifugal filter has been successfully applied to diesel engines where the greater part of the dirt particles are under 2 μm in diameter.

40.21 Centrifuging

The centrifugal separation of solid impurities is adopted either as an alternative to filtration or combined with it. For example, a lubricant circulating system can be cleaned by having fixed-element filters that arrest larger particles, and a centrifuge system that removes the finer solids in suspension together with any water contained in the oil.

The centrifuge is a powerful tool. The magnitude of the available centrifugal force – the product of the mass of the particle and its acceleration – is easily appreciated when the speeds and dimensions of a commercial unit are considered. A vessel with a diameter of 25.4 cm spinning at 1700 rev/min gives an acceleration at the centrifuge wall of some 400 g. In terms of settling this means that centrifuging a crude oil for 30 s is at least equivalent to simple gravitational settling over a 24 h period.

The advantage of the modern continuous centrifuge is the rapidity with which it will separate both solids and immiscible liquids. Another stems from the larger volume of oil it can handle in a given time.

40.22 Shaft seals

Both physical and process-material considerations influence the choice and use of shaft seals in the industry. It is essential that the seal material is compatible with any process material and the operating variables.

40.22.1 Seal materials

Nitrile rubbers, including fibre-reinforced varieties, are used both as radial shaft-seal materials and as moulded packings for reciprocating shafts. They have excellent resistance to a considerable range of chemicals, with the exception of strong acids and alkalis, and are at the same time compatible with petroleum-based lubricants. Their working temperature range is from – 1°C to 107°C continuously and up to 150°C intermittently. When used on hard shafts with a surface finish of, at most, 0.00038 mm root mean square (RMS), they have an excellent resistance to abrasion.

Polyacrylic resins, which have similar chemical resistance to the nitriles, can be used for slightly higher temperature conditions, but because their abrasion resistance is not as good as that of the nitriles they need continuous lubrication.

Leather is a useful material in association with a whole range of organic liquids and oils. It retains its sealing properties very well over a temperature range of −45°C to 93°C. Its abrasion resistance is good and it will tolerate low speeds on 0.00076 mm RMS shafts with only intermittent lubrication.

Silicone rubber as a shaft seal and backing material has a number of special applications. It can be used over a temperature range of −60°C to 260°C in air or suitable fluids. Its abrasion resistance is good with hard shafts having a 0.000254 mm RMS surface finish. Commercial grades of silicone rubber are compatible with most industrial chemicals up to 260°C. In lubricating oils the limiting temperature is 120°C, but special types have been developed for use up to 200°C.

Face-seal materials can be chosen from filled, moulded or reinforced resins with which water, hydraulic fluids, mineral oils or synthetic oils are all compatible. Their maximum temperature in service depends on the brittle point of the resin but, generally, the range is from −50°C to 100°C. Abrasion resistance is generally good but, as far as possible, resins are not used in the presence of foreign solids.

Carbon is an excellent material, being unaffected by most industrial chemicals including corrosives, oils, solvents, water and steam. It has a temperature range of up to 260°C, coupled with a high resistance to abrasion in clean fluids.

Ceramics are highly resistant to wear, chemical attack and high temperatures and, consequently, have many applications. They are frequently bonded to metal in making seal components or applied as a coating for shafts where seal elements introduce wear.

Metal can cover many requirements in seal design; it may be used for faces and other parts such as rings and bellows. The specification of the metal depends on the degree of corrosion resistance necessary, the thermal expansion and the material of the mating face.

Rubber bellows casings and sealing rings are vulnerable to temperature and are thus limited to a range of between 0°C to 100°C. Rubber is compatible with most industrial chemicals and is particularly useful in the presence of solids.

Sealing rings that are inert to most chemical corrosives and solvents are usually manufactured from PTFE or one of the synthetic elastomers.

40.22.2 Packing materials

Nitrile and polyacrylic materials have temperature ranges of −34°C to 107°C and −34°C to 177°C, respectively. Both require continuous lubrication.

Silicone rubber is not recommended for use with hot organic materials. If, for specific reasons, its use is contemplated, the manufacturer should be consulted regarding its possible use for a particular application.

Neoprene, a well-proved packing material, has a temperature range of −60°C to 107°C but because it is unsuitable for use with many organic liquids it is normally used only with aqueous solutions. It possesses good resistance to abrasion, which makes it particularly useful with slurries or where there is abrasive contamination.

Metallic packings of aluminium, copper and lead cover a very wide temperature range up to 540°C. They should be matched to the shaft material, since shaft finish and tolerance are critical factors in overall efficiency. The great limiting factor in the use of metallic packings is the difficulty of ensuring corrosion resistance with all the likely process materials.

The textile fibres have a limited range of application. They may be used with hot or cold water, steam, oils and ammonia up to a maximum temperature of 100°C. Asbestos fibre is more versatile, can be be used as compression packing material with hot water, super-heated steam, hot oils and gases up to 310°C.

40.23 Centralized lubrication

Manual application of lubricants has the inherent risk of failure due to omission. With the increasing complexity of plant, the costs of lost production and of manpower to try to prevent such omissions are becoming unacceptable.

Mechanized methods of pumping oil and grease to bearings and other components are becoming increasingly

utilized. Some of these systems are fundamentally suited to either oil or grease, but others, including all those where continuous circulation is involved, are suitable only for oil.

Built-in mechanized grease lubrication is nearly always of the centralized 'one-shot' variety, in which a single pump stroke supplies grease simultaneously to a number of bearings. The amount supplied to each station is regulated by suitable valves or adjustable metering orifices. The pump may be manually operated or connected to a suitable machine component, whereby grease is fed only when the machine is actually running and at controlled temperatures. Pneumatic or electric pumps are also used, set in operation at regular intervals by an automatic timing device.

One-shot metered lubrication is eminently suited to oiling systems and can be employed either in an 'all-loss' arrangement or as part of a circulatory system. Sight-glasses or other indicators should be incorporated, since such lubricating mechanisms are nowadays so reliable that a blockage or other failure might not be suspected until too late.

Circulatory systems often use an intermediate header tank, from which the bearings are supplied by gravity. The complete system may comprise, in addition and according to the size of the installation, heat exchangers or coolers, filters, strainers, settling tanks, centrifuges and other purifying equipment.

Oil mist feeds are used less for plain bearings than for lubricating some other types of machine parts, but applications are increasing in number. A stream of dry compressed air is used both to generate the mist and to carry it to the bearing. The atomized oil droplets are released from air suspension at points of turbulence around bearings, gears and other moving components or in a special re-classifying fitting at the end of the supply line. Reclassifiers are generally employed when plain bearings are to be lubricated by oil mist, but the method is fundamentally unsuited for bearings requiring hydrodynamic thick-film lubrication.

Special precautions must be taken with oil-mist feeds to ensure that the compressed air, which greatly enhances the rate of heat dissipation, can escape from the housing. If vents or other outlets become blocked, the back pressure may stop the flow of lubricant.

40.24 Storage of lubricants

It cannot be emphasized too strongly that dirt and correct lubrication are incompatible. The lubricant manufacturer has a comprehensive system of classification, filtration and inspection of packages which ensures that all oils and greases leaving his plant are free from liquid and solid contaminants. It is in his own interests that the user should take the same care to ensure that the lubricant enters his machinery in as clean a condition as that in the bulk tank or barrel. The entry of abrasive dust, water and other undesirable matter into bearings and oilways may result if lubricants are handled carelessly.

The conditions in a plant are often far from ideal and usually storage facilities are limited. This, however, should serve as a constant reminder of the need for continual care, the adoption of suitable dispensing equipment, organized storekeeping and efficient distribution methods. Furthermore, the arrangements on any particular site will be governed by local organization and facilities. Technical personnel from lubricant suppliers are available to assist and advise plant management on the best methods for a particular site. The general recommendations given about the care of lubricants consist of elementary precautions which are mainly self-evident and yet, unfortunately, are often ignored.

The modern steel barrel is reasonably weatherproof in its original condition, but if stored out of doors and water is allowed to collect in the head, there may, in time, be seepage past the bung due to the breathing of the package. Exposure may also completely obliterate the grade name and identification numbers, as is evidenced by the frequent requests made to sample and test lubricants from full packages that have been neglected on-site because no other method of identification is possible. Unless it is absolutely unavoidable, packages should never be stored in the open and exposed to all weather. Even an elementary cover such as a sheet of corrugated iron or a tarpaulin may provide valuable protection.

However, rudimentary the oil stores, the first essential is cleanliness; the second is orderliness. These two essentials will be easily achieved if maximum possible use is made of bulk storage tanks. In the case of bulk storage of soluble oils the need for moderate temperatures is vital, and the tanks should be housed indoors to protect their contents against frost. There are several other benefits to be derived from the use of tanks, i.e. reduction in storage area, handling of packages and, possibly, bulk-buying economics. All barrels should be mounted on a stillage frame of suitable height, fitted with taps and the grade name clearly visible. The exterior surfaces of both tanks and barrels should be kept scrupulously clean and each container provided with its own drip tray or can.

The storage and handling of grease presents more problems than are encountered with fluid lubricants, as the nature of the material and design of the conventional packages make contamination easier. Lids of grease kegs must be kept completely free from dust and dirt, and should be replaced immediately after use. The most common way in which solids enter a grease package is by the user carelessly placing lid either on the ground or on some other unsuitable surface. Fortunately, there are available today a number of simple dispensing units which can entirely obviate this danger and which can be adapted to all types of packages.

Wherever manual distribution has to be adopted, containers should be reserved for the exclusive use of specific units and their operators and, as far as possible, for a particular grade. When not in use they must be stored away from all possible sources of contamination. To promote economy and reduce waste due to spillage, their shape and proportions must be suited to the application.

While it is impossible to describe a system of storekeeping and distribution suitable for every site there are certain essential principles which should be adhered to if cleanliness, order and economy are to be maintained.

How these principles should be applied is for individual managements to decide. The keynote, however, should be simplicity. Distribution should be controlled by a storekeeper familiar with both grades and needs. While the lubrication schedule for any particular unit is generally the concern of the operator, the storekeeper must equally be aware of it and have a comprehensive list of the different grades, their applications, quantities, daily and other periodic needs. On such a basis he will be able to requisition and store the necessary lubricants in the most convenient and economic quantities and packages, and ensure that supplies are used on a 'first in, first out' basis.

Care and good housekeeping at every stage from handling, stacking and storage, right through to dispensing and application will:

- Ensure that the correct product reaches the point of application and is free from contamination;
- Help towards maximum efficiency in the use of lubricants and the equipment in which they are employed;
- Avert accidents and fire hazards arising from mishandling;
- Prevent any adverse effects on people, equipment and the environment.

40.25 Reconditioning of oil

Reconditioning is the removal of contaminants and oxidation products (at least in part) but not previously incorporated additives. It may also involve the addition of new oil and/or additives to adjust the viscosity and/or performance level. This process is sometimes referred to as 'laundering' or 'reclamation'. The method treats used lubricating oil to render it suitable for further service, either in the original or a downgraded application. Two types of treatment are generally employed.

1. Filtration to remove contaminants, followed by the addition of new oil and/or additives to correct performance level;
2. A simple filtration process to remove contaminants.

In practice, treatment (1) usually involves a contractor collecting a segregated batch of oil, reconditioning and returning it for re-use. The simple filtration process can be carried out by a contractor, but is more usually done on-site. Re-refining is the removal of contaminants and oxidation products and previously incorporated additives to recover the lube base stock for new lubricant or other applications.

40.26 Planned lubrication and maintenance management

Having the correct lubricant in each application will only give the maximum benefit if and when it is applied at the correct frequency and quantity. With the increasing complexity of plant this is becoming more vital and, at the same time, more difficult to achieve. The solution to this problem is planned lubrication maintenance, which, in essence, is having the right lubricant in the right place at the right time in the right amount.

Most oil companies offer a planned lubrication maintenance (PLM) service that will meet these requirements with the minimum of effort on the part of the customer. These schemes provide logical routing for the lubrication operative, balanced work loads and clear instructions to those responsible for specific tasks associated with lubrication and fault-reporting facilities. Many schemes are now designed for computer operation which also accommodate plant and grade changes, operation costings and manpower planning. It is essential that any such scheme should be adaptable to individual requirements.

There are a few computerized PLM schemes which are dynamic systems and can be integrated into an overall maintenance management information system. These contain maintenance, inventory and purchase order modules and go far beyond 'just another work order system'. They provide the necessary information to control complex maintenance environments, thereby improving productivity and reducing operational costs.

40.27 Condition monitoring

Condition monitoring is an established technique which has been used by capital-intensive or high-risk industries to protect their investment. The concept has developed radically in recent years largely due to advances in computerizations which offer greater scope for sophisticated techniques. These fall into three types of monitoring: vibration, performance and wear debris. The last monitors particulate debris in a fluid such as lubricating oil, caused by the deterioration of a component.

Oil-related analysis encompasses a variety of physical and chemical tests such as viscosity, total acid number and particulate contamination. This is often extended to include the identification of wear debris, as an early warning of component failure, by either spectrographic analysis or ferrography or both. The former is commonly used in automotive and industrial application for debris up to 10 μm and the latter mainly for industry users covering wear particles over 10 μm. Ferrography is relatively expensive compared with many other techniques, but is justified in capital-intensive areas where the cost is readily offset by quantifiable benefits such as longer machinery life, reduced loss of production, less downtime, etc.

40.28 Health, safety and the environment

There are a wide variety of petroleum products for a large number of applications. The potential hazards and the recommended methods of handling differ from product to product. Consequently, advice on such hazards and on the appropriate precautions, use of protective clothing, first aid and other relevant information must be provided by the supplier.

Where there is risk of repeated contact with petroleum products (as with cutting fluids and some process oils) special working precautions are obviously necessary. The

aim is to minimize skin contact, not only because most petroleum products are natural skin-degreasing agents but also because with some of them prolonged and repeated contact in poor conditions of personal hygiene may result in various skin disorders.

40.28.1 Health

It is important that health factors are kept in proper perspective. What hazards there may be in the case of oil products are avoided or minimized by simple precautions. For work involving lubricants (including cutting fluids and process oils) the following general precautions are recommended:

- Employ working methods and equipment that minimize skin contact with oil;
- Fit effective and properly positioned splash guards;
- Avoid unnecessary handling of oily components;
- Use only *disposable* 'wipes';
- Use soluble oils or synthetic fluids at their recommended dilutions only, and avoid skin contact with their 'concentrates'.

In addition to overalls, adequate protective clothing should be provided. For example, a PVC apron may be appropriate for some machining operations. A cleaning service for overalls should be provided and overalls should be cleaned regularly and frequently. Normal laundering may not always be sufficient to remove all traces of oil residues from contaminated clothing. In some instances dry cleaning may be necessary. Where this applies to cotton overalls they should first be dry cleaned and then laundered and preferably starched, in order to restore the fabric's oil repellency and comfort. As a general rule, dry cleaning followed by laundering is always preferable to minimize the risk of residual contamination wherever heavy and frequent contamination occurs and when the type of fabric permits such cleaning.

Overalls or personal clothing that become contaminated with lubricants should be removed as soon as possible – immediately if oil soaked or at the end of the shift if contaminated to a lesser degree. They should then be washed thoroughly or dry cleaned before re-use.

Good washing facilities should be provided, together with hot and cold running water, soap, medically approved skin-cleansers, clean towels and, ideally, showers. In addition, reconditioning creams should be available. The provision of changing rooms, with lockers for working clothes, is recommended.

Workers in contact with lubricants should be kept fully informed by their management of the health aspects and the preventive measures outlined above. Any available government leaflets and/or posters should be prominently displayed and distributed to appropriate workers.

It should be made clear to people exposed to lubricants that good standards of personal hygiene are a most effective protection against potential health hazards. However, those individuals with a history of (or thought to be particularly predisposed to) eczema or industrial dermatitis should be excluded from work where, as in machine-tool operation, contact with lubricants is virtually unavoidable.

Some industrial machining operations generate a fine spray or mist of oil, which forms an aerosol – a suspension of colloidal (ultra-microscopic) particles of oil in air. Oil mist may accumulate in the workshop atmosphere, and discomfort may result if ventilation is inadequate. Inhalation of high concentrations of oil mist over prolonged periods may give rise to irritation of the respiratory tract, and in extreme cases to a conditions resembling pneumonia. It is recommended that the concentration of oil mist in the working environment (as averaged over an 8-h shift) be kept below the generally accepted hygiene standard of 5 mg/m^3. This standard does, however, vary in some countries.

40.28.2 Safety

In the event of accident or gross misuse of products various health hazards could arise. The data provided by the supplier should outline these potential hazards and the simple precautions that can be taken to minimize them. Guidance should be included on the remedial action that should be taken to deal with medical conditions that might arise. Advice should be obtained from the supplier before petroleum products are used in any way other than as directed.

40.28.3 Environment

Neat oils and water-based coolants eventually reach the end of their working lives, and then the user is faced with the problem of their correct disposal. Under *no* circumstances should neat oils and emulsions be discharged into streams or sewers. Some solutions can, however, be fed into the sewage system after further dilution – but only where permitted.

There are many companies offering a collection service for the disposal of waste lubricating oil. The three main methods employed are:

1. Collection in segregated batches of suitable quality for use by non-refiners
2. Blending into fuel oil
3. Dumping or incineration

If method (3) is used due regard must be paid to the statutory requirements that must be met when disposing of waste material. These are covered in two main items of legislation; namely, the Deposit of Poisonous Waste Act 1972 and the Control of Pollution Act 1974. It is the responsibility of the producer of waste oil to ensure that the waste is disposed of in the correct manner, to ensure that no offence is committed and that the contractor is properly qualified to execute the service.

Acknowledgements

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Further reading

BP publications

Industrial lubrication
Machine tools and metal cutting
Lubricants for heavy industry
Gear lubrication
Hydraulic fluids
Machine shop lubricants
Cutting fluids
Compressor lubrication
Greases
Temporary corrosion preventives
Degreasants
Storage and handling of lubricants
Aerosols
Health, safety and environmental data sheets

Further information on lubrication can be obtained from:

Booklets and leaflets published by most oil suppliers
Libraries of Institute of Plant Engineers
Institution of Production Engineers
Institute of Petroleum
Institution of Electrical Engineers
Institution of Mechanical Engineers
Literature published by additive companies
Literature published by the American Society of Lubrication Engineers
Libraries of universities
National Centre of Tribology

With such a wide and important subject it is not possible to provide a full list but the above will indicate some initial contact points. The author hopes that no offence is caused by any omission.

41 Heat pumps and their applications

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41.1 What is a heat pump?

Heat pumps are mechanical devices that extract low-grade heat from one source and transfer the heat to another. The advantage of a heat pump is that it up-grades the heat and delivers it at a higher temperature than the source from which the heat was extracted.

Heat pumps are usually based on refrigeration cycles. Unlike refrigerators the primary aim of heat pumps is to provide heating, although reverse cycle heat pumps can provide both heating and cooling.

Much of the technology used in heat pumps is identical to that used in refrigeration plant. The bias to heating, however, changes the emphasis of the design of the refrigeration circuit towards the condenser.

41.2 Types of heat pumps

Heat pumps are characterized by the mediums between which they transfer heat. There are three primary sources of energy, air, water and the ground. The heat extracted can be transferred to heat air or water, although it would also be possible in a cooling application to reject heat to the ground.

41.2.1.1 Air-to-air

In an air-to-air heat pump energy is extracted usually from ambient air and transferred to heat or cool a second air stream.

Ambient air is the most common energy source used by heat pumps. It should be remembered that air contains energy down to very low temperatures i.e. the point at which its constituents, Nitrogen and Oxygen, become liquids.

The energy in air comes from two sources, the sensible energy available from reducing the temperature of the air, and the latent energy available from the water content of the air. The water content of air varies with its condition but is approximately 1 per cent by volume.

41.2.1.2 Air-to-water

In an air-to-water heat pump energy is transferred from ambient air, as above, to a water heating circuit. See Figure 41.1.

41.2.1.3 Water-to-air

In a water-to-air heat pump heat is transferred from a water circuit to heat an air stream. This can be viewed as heating the air stream or alternatively, if the air is ambient, as cooling the water circuit.

41.2.1.4 Water-to-water

In a water-to-water heat pump energy is transferred from one water circuit to another at a higher temperature. This gives the heat pump an advantage over a passive heat recovery device, such as a plate heat exchanger, where the maximum temperature available is just below the source water temperature.

41.2.1.5 Geothermal or ground source

A geothermal or ground source heat pump is a variant on either a water-to-air or a water-to-water heat pump. In this case the energy source is from the ground, from a bore-hole, ground water or a ground loop.

A ground loop is a closed circuit of pipe that is buried 1–1.5 m below ground level. Water circulated through this loop of pipe will be returned at ground temperature (a constant 10–12°C in the UK) throughout the year. The length of pipe required and the area covered by the loop will depend on the amount of energy that is to be extracted.

A single bore-hole can be used in conjunction with a closed loop of pipe as above. Alternatively two can be drilled to exchange water with naturally occurring water bearing rock strata.

41.3 Coefficient of performance

The measurement of efficiency of a heat pump is known as the Coefficient of Performance or COP. This is defined as:-

$$\text{COP} = \frac{\text{Total energy given out}}{\text{Energy used to drive heat pump}}$$

The energy given out by a heat pump is equal to the energy recovered from the heat source plus the energy input from the driving force. The COP of a heat pump will therefore always be greater than 1, as the power input will always be added to the heat sink.

COPs of 2.5 to 3 are common, and in some situations can be as high as 5 or 6. The COP of a heat pump is seldom constant as it depends on the temperature of the heat source and the heat sink.

As a point of comparison, the COP of a boiler operating at 80 per cent efficiency would be 0.8 and of a heat exchanger with a heat transfer efficiency of 65 percent would be 0.65.

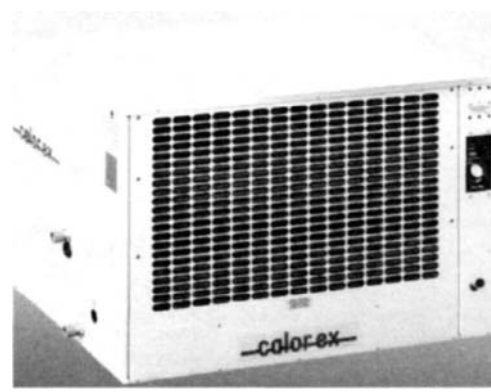


Figure 41.1 Small heat pump

41.4 Thermodynamic cycles

41.4.1 Mechanical vapour compression cycle

The majority of heat pumps use the vapour compression cycle, exactly the same as used in refrigeration. See Figure 41.2.

In this type of cycle a mechanical compressor provides the energy input into the cycle. The working fluid is termed the refrigerant. There are four stages to the cycle (refer to Figures 41.2 and 41.3):-

1. Heat is absorbed from the energy source into the evaporator. In the evaporator the refrigerant changes from a liquid to a gas at a constant pressure. The refrigerant is vaporized or evaporated.
2. The compressor raises the pressure and temperature of the refrigerant. The refrigerant goes from being a saturated gas/vapour to a super-heated vapour.
3. The heat absorbed by the refrigerant and the energy added by the compressor is released from the cycle as the refrigerant passes through the condenser. In the condenser as energy is rejected to the heat sink at constant pressure the refrigerant changes from a super-heated vapour back to a liquid. The gas condenses.
4. The high pressure, high temperature liquid passes through an expansion device, either a valve or a capillary. The pressure of the refrigerant is reduced back to the lower evaporating pressure. The temperature of the refrigerant also reduces during the expansion process. The refrigerant is now a mixture of liquid and vapour as it passes back into the evaporator.

It is common for the cycle to be reversed so that cooling becomes the priority, rather than the primary aim of heating.

There are many types of compressor used in this type of cycle, e.g. reciprocating, screw, rotary, vane, centrifugal, swing or scroll. They are usually driven by an electric motor.

The use of compression devices driven by other forms of energy is possible. The most common alternatives are the use of prime mover such as gas or diesel engines.

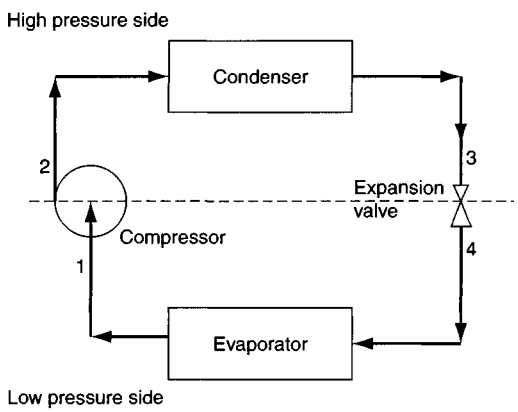


Figure 41.2 Vapour Compression Cycle

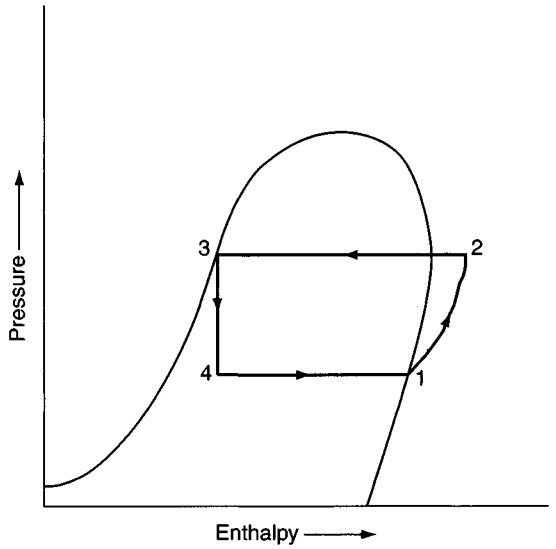


Figure 41.3 Pressure Enthalpy diagram of a vapour compression cycle

However, practical considerations often limit their use to larger applications.

41.4.1.1 Refrigerants

The most commonly used types of refrigerants are fluorinated hydrocarbon compounds. These are either hydrochlorofluorocarbons (HCFCs) such as R22 or hydrofluorocarbons (HFCs) such as R407c, R134a or R410a.

Hydrocarbons Butane and Propane are finding use in small appliances such as domestic dehumidifiers where their flammability is not a major concern due to the low quantities used. Ammonia has traditionally been used in large commercial and industrial applications, and systems using carbon dioxide are under development.

41.4.1.2 Legislation

Legislation on ozone depletion and global warming has forced the refrigeration industry to develop equipment to use alternative and new refrigerants.

The production of old CFC refrigerants, such as R12, has now been banned due to its effect on the ozone layer. It has an ozone depletion factor (ODF) of 1. The use of R12 for maintenance has been banned from 1 January 2001.

Although the production of HCFC R22 with an ODF of 0.1 is not due to be phased out until 2009, European equipment manufacturers will be forced to cease production of equipment using HCFCs before 1 January 2004 at the latest. For some countries and types of equipment earlier phase out dates apply. The use of recycled R22 for maintenance will be allowed until 2015.

41.4.2 Mechanical vapour recompression

Mechanical vapour recompression (MVR) heat pumps use the process fluid as the working fluid, usually in an open

or semi-open cycle. These systems often use water vapour or steam as the working fluid.

In an open cycle vapour from an industrial process is compressed to a higher pressure and consequently to a higher temperature. Once expanded through a nozzle or venturi the vapour is condensed in the same process giving off heat.

In a semi-open cycle the heat from the compressed vapour is transferred to the process via a heat exchanger.

Compared with the closed vapour compression cycle described above these systems eliminate the use of one or two heat exchangers, and as the temperature difference between heat source and heat sink is low the performance of MVR systems is high. Typically COP of 10–30 can be achieved. Current MVR systems operate with heat source temperatures of 70–80°C and deliver heat at between 110 and 150°C.

41.4.3 Absorption cycle

The operation of the absorption refrigeration cycle is similar to the above vapour compression cycle. The evaporator, condenser, and expansion device serve common purposes, but a heat-operated absorber and regenerator replace the compressor. A schematic of the absorption cycle is shown in Figure 41.4.

In the absorption cycle the refrigerant vapour is dissolved in a suitable liquid. The power required to pump the working fluid around the cycle is less than that required compressing a refrigerant vapour.

There are two common fluid pairings used. In smaller equipment the refrigerant used is ammonia and the absorbent used is water. In larger equipment the refrigerant is water and a solution of lithium bromide is used as the absorbent.

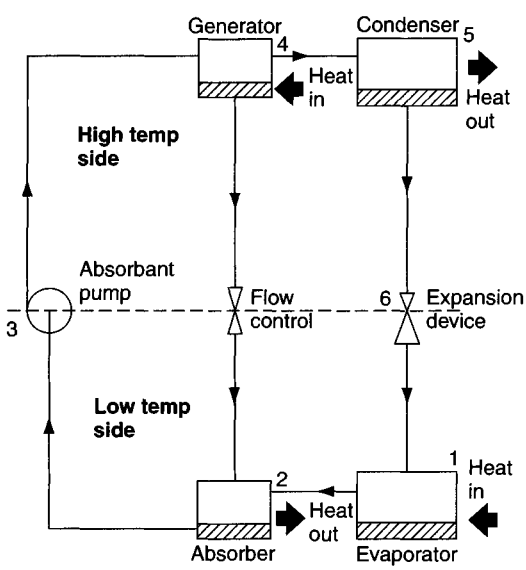


Figure 41.4 Absorption Cycle

The stages in the absorption process are:-

1. The evaporator absorbs heat from the energy source. The energy absorbed evaporates some of the refrigerant vapour from the liquid absorbent.
2. The vapour passes into the absorber where it is dissolved into the absorbent, releasing some energy and concentrating the solution. The heat sink fluid is usually passed through the absorber prior to the condenser in order to collect and remove this released energy.
3. Some of the solution is pumped to the generator, its pressure being raised to that of the condenser.
4. Heat is added to the generator to raise the temperature of the solution and evaporate the refrigerant vapour out of the solution. This reduces the concentration of the solution.
5. The weaker solution from the generator is then passed back to the absorber, via an expansion valve to equalize pressures. The solution in the absorber is diluted and so can continue to absorb vapour without becoming saturated.
6. The high temperature, high-pressure vapour from the generator passes into the condenser. Here the useful heat is rejected to the heat sink and the vapour is condensed back to a saturated liquid at constant pressure.
7. The refrigerant vapour returns to the evaporator via the expansion device, which reduces the pressure and temperature of the vapour. Prior to the collection of further heat from the energy source.

There are a number of practical drawbacks that limit the applicability of this refrigerant cycle.

1. Achievable COPs are low, typically 1.2 to 1.4.
2. Equipment sizes for lithium bromide/water systems are large.
3. Concentrations of fluids are critical for stable operation.
4. Practical systems are complex.
5. Operating ranges are restricted by fluid pairings. Lithium bromide/water systems cannot operate below freezing. Ammonia/water systems are restricted in top temperature due to high pressures.

However, these types of systems have found success where heat is available from a cheap source, or as waste heat from an existing process. Some smaller gas fired equipment has also been developed.

41.5 Climate change levy

The Climate Change Levy being introduced by the Government will oblige businesses to pay a levy on their energy bills. One of the aims of this legislation, alongside reducing CO_2 emissions, is to provide an incentive for businesses to reduce their total energy usage and to look at how efficiently they use energy.

Heat pumps can be beneficial in reducing energy usage in a number of applications, and so could be helpful in reducing the levy imposed.

41.6 Industrial applications

41.6.1 Heating

41.6.1.1 Buildings

General heating for buildings using heat pumps is more frequently used in Europe where district heating schemes are more common. Here the higher initial capital cost of a heat pump can be spread over a larger number of properties. These are water-to-water heat pumps, or air to water units often used in conjunction with low capacity back-up heating for the coldest periods of the year.

In the USA air-to-air and ground source water-to-air heat pumps are commonly used in domestic heating where air distribution heating systems are the norm. This usage occurs particularly in areas where higher average ambient temperatures allow higher heat pump COPs or where a ground source is available or a ground loop can be accomodated. These units are often reverse cycle to provide cooling in the summer.

Use in the UK is limited by the cost of available alternative energy sources e.g. low cost gas. Here gas fired boilers traditionally work in conjunction with a wet radiator system. Even allowing for the inefficiencies of boilers the COP of a heat pump would have to be in excess of 3 in order to give any running cost saving to fund the higher initial cost of a heat pump, based on the present differential between electrical and gas energy prices.

The COP of an air-to-water heat pump falls during cold weather just when the most heating is needed. A unit operating in air temperatures of 5°C and producing water at 55°C would have a COP of 2–2.5.

The increased use of under-floor heating operating at approx. 40°C has increased the consideration given to using ground source heat pumps. With a constant source temperature of 10–12°C the COP of the heat pump remains stable at around 3–3.5. In this scenario, particularly where gas is not available, the viability of heat pumps for heating looks a lot more favourable.

41.6.1.2 Hot water

Heating hot water using heat pumps suffers similar comparisons in the UK. In other areas of the world with higher ambient temperatures e.g. the Far East and Mediterranean countries, the use of air-to-water heat pumps to generate hot water for domestic and commercial/hotel use is common.

However, hot water production when waste process water is available as a heat source can be viable, see section 41.6.4 below.



Figure 41.5 Example of a dehumidified body panel storage area (Courtesy of Calorex Heat Pumps Ltd)

41.6.2 Cooling

The most common chillers providing chilled water to industrial processes are air-cooled water-to-air heat pumps or water-cooled water-to-water heat pumps. The cooling duty of these chillers is always larger than the energy input, the COP is greater than one.

The absorption cycle can be found used in industrial chillers, particularly those of high capacity that can be driven by a waste heat source, perhaps even linked to a CHP plant.

Gas fired vapour absorption chillers are becoming increasingly common. Small packaged units of 50 kW cooling capacity are available on the market.

41.6.3 Air conditioning

Reverse cycle split air conditioning units are called 'heat pumps', although the cooling only versions are also air-to-air heat pumps. These heating and cooling systems are a viable alternative to cooling only air conditioning, eliminating the need for a separate heating system. They are finding increasing use in commercial and industrial office buildings.

The 'Versatemp' type water based system is a unique concept that has been on the market for many years. In this system individual reverse cycle water-to-air heat pumps are located in each room in a building. They exchange heat with a two-pipe water circuit providing heating or cooling to the space as required. This water circuit is kept a constant temperature by a central heating and cooling plant, which could be a reverse cycle water-to-water, water-to-air or ground source heat pump. The system can simultaneously provide cooling on one side of a building exposed to solar gain and heating to the other side in shade.

41.6.4 Heat recovery

Heat recovery from industrial processes is perhaps the most under-used application for heat pumps.

Heat recovery can be from both air and water, with the most viable heat sink being water. Water can be heated to as high as 70°C lending itself to direct use in heating buildings or domestic hot water, or for preheating water for the same or another process.

There are many situations in which dynamic heat recovery using a heat pump is superior to a passive heat recovery device such as a plate heat exchanger or air-to-air cross-flow heat exchanger.

41.6.4.1 Recovery from water

An example would be where waste process water at a low temperature of 20–30°C is discharged to drain. A passive

device could only recover heat by heating an incoming water supply to 5–10°C below the discharge temperature. A water-to-water heat pump could recover this waste energy and up-grade it to a higher temperature, heating the second water circuit to 70°C, or more efficiently to a slightly lower level. This pre-heated water could be fed to a boiler to be boosted for use in another part of the process.

41.6.4.2 Recovery from air

It is similarly practical to recover heat from a ventilation exhaust air stream. The recovered energy can be directed towards the make-up air or to water, either to pre-heat process water or to heat domestic hot water.

The practicality of such a heat recovery scheme is limited by the proximity of the heat source and the heat sink. If long water or refrigeration pipework runs are required the installation cost and heat losses can outweigh the energy cost savings made by the installation of a heat pump.

There are examples where air-to-water heat pumps are being used to cool over heated plant room spaces. The recovered energy is used to pre-heat water for hot water calorifiers, and the cooling effect extends equipment life of plant installed in the space.

41.6.4.3 Practical limits

The operating conditions in which a heat pump can be used for heat recovery applications is limited first by the characteristics of the working fluid, and then by the mechanical components.

For example, an electrically driven mechanical vapour compression heat pump will be limited to an operating temperature range of −15°C to 70°C by the refrigerant gases used.

41.6.5 Dehumidification

A refrigerant cycle based dehumidifier is a type of air-to-air heat pump. The evaporator is designed to reduce the temperature of the air to below its dew point. The condensation that forms on the evaporator is collected and fed to a drain. The latent energy absorbed by the refrigerant is returned into the air stream passing through the dehumidifier as sensible heat. Typically a heat pump dehumidifier will return 3 times as much heat energy as is used by the compressor.

Dehumidifiers can be configured to have an extra water condenser to recover heat to water, if this was a more viable use for the recovered energy.

41.6.5.1 Storage

Many storage warehouses require, or can benefit from, a controlled humidity condition to protect the stored products. For instance paper and board products, hygroscopic materials as varied as cement and sugar, timber, textiles and steel. Dehumidifiers can limit the relative humidity in a building to below 70 per cent to prevent mould growth, to prevent dimensional change, or degradation of a product, and in the case of steel if the humidity is kept below 50 per cent RH corrosion can be reduced to negligible levels see Figure 41.5. The advantage of a package heat pump dehumidifier is that they can operate in an unheated warehouse, so eliminating the need to heat the space (except for human comfort) and providing a considerable running cost saving alongside the initial benefit of protecting the stored product. If dehumidification is planned from the start it can also eliminate the need for an insulated building to be constructed saving considerable capital cost. Figure 41.6 shows a range of refrigerant dehumidifiers with capacities from 30 litre/day to 600 litre/day at 20°C and 75% RH.

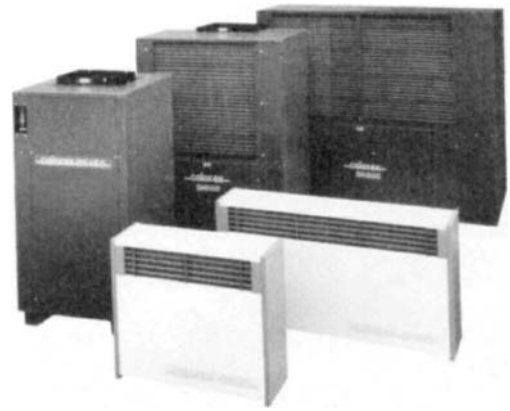


Figure 41.6 Typical refrigerant dehumidifiers (Courtesy of Calorex Heat Pumps Ltd)

41.6.5.2 Excess moisture

Many industrial processes produce moisture in enclosed spaces. Dehumidifiers can be an energy efficient way of removing the excess moisture from the space reducing condensation and similar damaging effects on buildings, equipment and products. They can replace the need for ventilation with high volumes of air that need to be heated to comfort levels before being dumped into the atmosphere along with the entrained moisture. The heat recovered by the dehumidifier can be used to assist in space heating or process water heating, providing a secondary energy saving to justify the capital outlay for a dehumidifier.

41.6.6 Swimming pools

41.6.6.1 Outdoor

Air-to-water heat pumps are commonly used for summer heating of swimming pool water, in both commercial and domestic situations.

These are usually electrically driven vapour compression heat pumps. With ambient air temperatures from 10°C to 30°C during a May to September swimming season and required water temperatures of 25–30°C, the coefficient of performance of a heat pump varies between 3.5 and 5.5. This gives favourable running costs even compared with gas fired boilers.

Initial capital costs can be comparable with conventional boilers in this application, as the installation of a

heat pump is simpler, with no requirement for flues, water pumps, fuel tanks and associated accessories.

41.6.6.2 Indoor

All indoor swimming pools require heating of both the pool hall air and pool water. They also require dehumidification to control the moisture that evaporates from the pool surface. Dehumidification is required to protect the building structure and to provide a comfortable environment for the users. A humidity level of 60 per cent RH is considered desirable.

The use of heat pumps for dehumidification and heat recovery for indoor swimming pools is a common and well recognized practice.

Conventional practice 20 years ago was to use large quantities of fresh air to sweep the moisture out of the pool hall. A ventilation rate of 10–15 litres/s per m^2 of pool surface and wetted surround was specified. This fresh air was heated to 28–30°C from winter ambient temperatures (typical design condition −3°C) and then exhausted. Meanwhile the water was being continuously heated to 26–28°C to counteract losses from evaporation. This used large quantities of energy to heat the air and further energy to maintain water temperatures.

If any heat recovery was achieved it usually involved a cross-plate heat exchanger between the two air streams. This allowed some sensible heat to be recovered from the exhaust air back into the incoming fresh air at an efficiency of approx. 50–75 per cent. Therefore the majority of latent energy available in the moisture evaporated from the pool, was exhausted to atmosphere and wasted.

A heat pump based dehumidification system can recover the sensible energy and also the majority of the latent energy. This energy can be transferred back into the pool water and also used to assist in heating the pool hall air. By re-circulating the pool hall air and limiting the fresh air input to that required for occupants and odour dilution the energy input could be further reduced.

At pool hall air conditions of 30°C and 60 per cent RH a heat pump dehumidification system will have a COP of 5. This gives rise to energy efficient maintenance of the pool hall environment, allowing operators to see a saving of up to 66 per cent in running costs compared to a 100 per cent fresh air system. Payback periods of less than 3 years are possible on refurbishment projects.

41.6.7 Process drying

The drying of products is an established application for using heat pumps. The heat pumps used are air-to-air heat pump dehumidifiers, so the process is often called dehumidification drying.

Drying is an important part of many industrial processes, and there are a number of different technologies available for drying. The drying method most applicable is dependent on a number of factors such as the throughput of product, the drying time available, the required moisture content, the nature of the product and how it can be handled.

Dehumidification drying is most applicable to batch production processes for products with a high initial moisture content, and where the time available for the drying process is a number of hours. Figure 41.7 shows an example of a drying chamber using a heat pump dehumidifier.

There is no reason why heat pump dehumidification drying cannot be applied to a continuous process. There would need to be sufficient dwell time in the drying oven for the moisture to be extracted. The total moisture extraction rate required will dictate the number and size of dehumidifier required. The greater the capacity required the larger the capital cost of the drying system, as a greater proportion will be spent on the heat pumps. A point will be reached at which the additional cost of the heat pump system compared to a conventional oven cannot be paid back in a realistic time frame by energy cost and other savings.

The products to be dried are usually loaded onto a series of racked trolleys and moved into a chamber, see Figure 41.8. Chambers are either large enough to accommodate a whole shifts production or a number of smaller chambers are used in rotation to give continuous production.

At the start of a cycle heat is introduced to speed up the release of moisture from the product. Air is re-circulated within the chamber to move the evaporated



Figure 41.7 Dehumidification drying chamber for cardboard tubes (Courtesy of Calorex Heat Pumps)

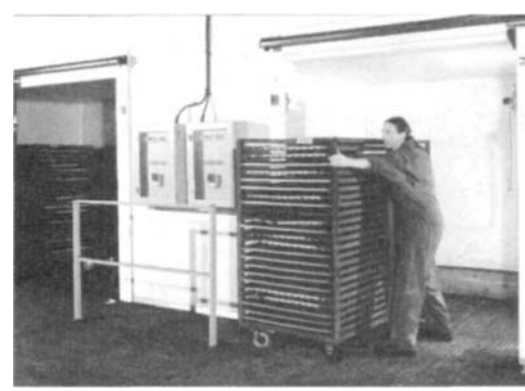


Figure 41.8 Example of racked trolley used in drying chamber (Courtesy of CHP Ltd)

moisture away from the drying products towards the dehumidifiers. The dehumidifiers then extract the moisture and recover the latent energy. This is then returned as sensible heat back into the chamber so maintaining the operating temperature. The warm dry air is then circulated backed past the drying products to extract more moisture.

The latent heat recovery of the air-to-air heat pump dehumidifier makes a dehumidification drying chamber highly energy efficient especially when compared with a conventional hot air drying oven.

The ability to be able to control both the temperature and humidity of the process allows a drying regime to be tailored to suit a particular product.

The depressed vapour pressure created by the dehumidifier sets up a high enough differential vapour pressure between the product and the air, for the process to operate effectively at much lower temperatures than a conventional drying oven. Typically a dehumidification drying chamber operates at 40–70°C compared with the typical 120–200°C for a gas fired oven. This can give positive benefits to the quality of the dried product and can allow sensitive products that would have been damaged in a conventional oven, to be dried more rapidly.

The energy efficiency of the process means that considerably less kWhrs are used in extracting a given amount of moisture, reducing both the running costs and the CO_2 emissions. Payback periods of 1–2 years have been calculated for capital investment in dehumidification drying chambers on running costs alone. Add to this the additional benefits of improved product quality, higher product throughput and reduced space required for drying and heat pump dehumidification drying becomes an attractive proposition.

A number of industries have a well proven track record of using heat pump dehumidification drying chambers:-

- Ceramic
- Textile
- Paper & board
- Food & confectionery
- Timber
- Brick & block producers

41.6.8 Evaporation and distillation

Evaporation and distillation are energy intensive processes and a number of heat pumps are installed in these processes in the chemical and food industries.

In evaporation processes it is the residue that is the product, whereas in distillation it is the vapour, or distillate, that is the product of the process. The advantage of using a heat pump is that heat is recycled within the process so reducing energy costs.

Most of the heat pumps used are MVR open or semi-open cycles. For instance they are used in distilleries for pot ale concentration.

41.7 Sources of further information

UK Heat Pump Network. Managed for the DETR by Building Services Research & Information Association (BSIRA). Contact: Dr Sandra Gomez, BSIRA, V wing, TRL, Old Wokingham Road, Crowthorne, Berks. RG45 6XA. 01344 750515.

Heat Pump Association (HPA). Contact Tony Bendall, c/o FETA, Henley Road, Medmenham Marlow, Bucks, SL7 2ER. Web-site: www.feta.co.uk.

International Energy Agency (IEA) Heat Pump Centre. Hosted by Novem the Dutch Energy and Environment Agency. Contact: Novem, PO Box 17, 6130 AA Sittard, The Netherlands. Web site: www.heatpumpcentre.org.

Energy Efficiency Best Practice Programme. Managed for the government by BRESCU (Building Research Establishment) for building applications, and ETSU for industrial applications. Contact: via free Environment and Energy Helpline on 0800 585794

International Ground Source Heat Pump Association (IGSHPA). 490 Cordell South, Stillwater, Oklahoma, 74078-8018, USA. Tel: 001-800-626-4747. Web site: www.igshpa.okstate.edu.

Geothermal Heat Pump Consortium, Inc. 701 Pennsylvania Avenue, NW. Third Floor, Washington DC, 20004-2696, USA. Tel: 001-202-508-550, Fax: 001-202-508-5222. Web site: www.ghpc.org.

The British National Committee for Electroheat (BNCE), Heat Pump Group, Millbank, London, SW1P 4RD. Tel: 0207 963 5709.

42

Solar water heating and the plant engineer

Tony Book
Riomay Ltd

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Introduction

Whenever the term Solar Water heating gets mentioned, one's mind immediately focuses on the domestic scene, as this is the area where, as an individual, the plant engineer gets attacked with junk post and evening telephone salespeople offering the earth and costing a price based on some well conceived payback calculation formulae.

In a commercial organization or plant, the provision of domestic washing or canteen water is one of those overlooked services which tends to get neglected, forgotten and probably, as a stand alone item, may remain a very expensive and neglected commodity, with electric water heaters, probably with incorrectly set thermostats, running all hours and costing a small fortune.

Some plant engineers may be able to take advantage of surplus heat from steam or condensate systems, process excesses, compressor cooling systems or some other form of heat recovery systems etc. in order to augment their hot water provision costs.

Over the past few years there have been great strides forward in the development of solar collecting devices which range in design, cost effectiveness and efficiency levels and overall developments.

Apart from the provision of the domestic requirements for hot or warm water there are many other requirements within commercial premises. Processes, which cover quite a wide range of activities, or lend themselves to at least, be considered for solar heating applications. Laundries, dye works process washing and cleansing plants, although initially provision by means of solar panels may not cover the whole application, there may be occasions where consideration may be given for joint systems, possibly incorporating water to water, air to water heat recovery, and the use of a heat pumps in order to reach the desired goal and or even part of the way.

Systems vary in complexity from a solar panel consisting of a simple set of pipes within a black glass-fronted box with a small pump coupled up for circulation purposes, to the latest versions where the panels can be of the flat type to cylindrical gas-filled units with special coatings used on the glass and the tubes to improve their heat collection and heat transfer.

The methods of installation and configurations have been developed further, the simplest are very much based on the original system, although the control systems have developed even further to take full advantage of what heat transfer is available.

The provision of heating and the use of solar applications cannot be considered in isolation as the whole aspect of heat and energy recovery, conservation and environmental acceptability.

In order to be able to give a full and sensible approach to Solar Heating it is imperative that the whole idea is approached from the basics, and once understood then appreciation will enable the various applications to be given their full consideration.

The whole concept is thus founded upon the effects and use of Solar Radiation.

42.1 Solar radiation and energy flows on earth

Solar radiation is the heat and light and other radiation given off by the Sun. Nuclear reactions in the interior of the Sun maintain a central temperature of 16 million °C, and a surface temperature of 5700°C. Like all hot objects, the Sun's surface radiates energy at a rate and a colour (wavelength range) which depends on its temperature. The Sun emits radiation at a rate of 3.8×10^{11} Watt, of which only two parts in a thousand million arrive at the Earth, with the rest disappearing into space or warming the other planets in our solar system.

At the outer edge of the Earth's atmosphere, the solar radiation on each square metre amounts to 1350 Watt, mainly of visible radiation and heat plus a little ultraviolet. Nearly one third of this is reflected back into space by clouds, water, ice etc. The rest of the solar radiation is absorbed and provides the energy for almost all the natural processes on Earth, as shown in Figure 42.1. The energy is shown in units of GigaWatt (GW) – about equal to the output of a large electricity generating station.

The average temperature of the Earth's surface (averaged over day and night and the seasons over the whole surface from equator to poles) has remained remarkably constant over the past few thousand million years. It has varied by only a few degrees from the mean of about 14°C or 287K. Any body at any temperature, including the human body, emits radiation. This is because it also absorbs energy from its environment (e.g. from the sun) and without emitting this energy back it would heat up infinitely. This emission is mainly long wavelength infrared (heat) radiation.

To maintain a constant temperature, the Earth's surface must emit the same amount of energy into space (in the form of heat radiation) as it receives from the Sun. Note that in Figure 42.1, the total input of 173 million GW is balanced by the 52 million GW reflected into space and the 121 million GW emitted as heat radiation by the Earth's surface. The temperature of the Earth's surface is determined by this balance of radiation. At night when there is no input, the surface temperature falls as some energy is radiated back into space. A cloudy sky reflects much of the heat radiation back to the ground, so clear nights are colder than cloudy ones. Some atmospheric gases such as carbon dioxide or methane can trap the long wavelength radiation. Since less energy is radiated away than is being absorbed from the Sun, then the temperature of the Earth will rise – this is the Greenhouse Effect.

42.2 Spectral distribution of solar radiation

Solar radiation extends over a wide range of wavelengths (colours) of light. The precise spectrum depends on the path length of the sunlight through the atmosphere, and the humidity, dust content etc., of the air. Figure 42.2 shows the spectrum of sunlight for the Sahara Desert when the sun is directly overhead, and for a typical British sunny summer's day. The dips in the solar spectrum are due to absorption of the sunlight on its way through the

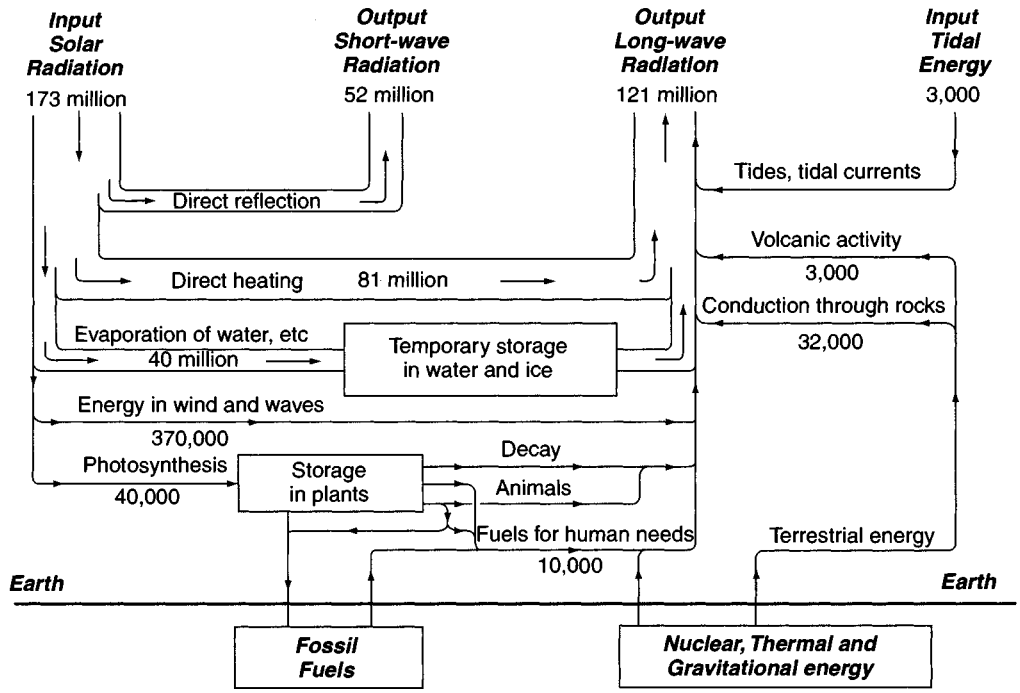


Figure 42.1 Energy Flows of the Planet Earth (units = gigawatts, GW)

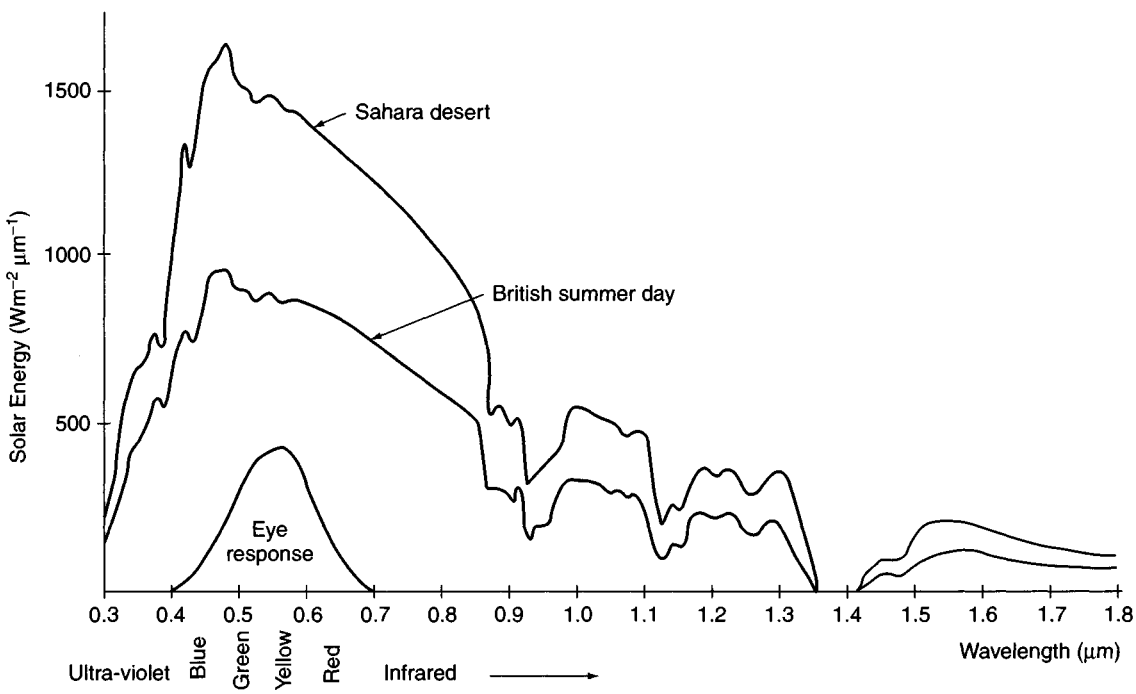


Figure 42.2 Spectral distribution of sunlight for the Sahara desert and a British summer's day

atmosphere, by ozone in the ultraviolet and by water vapour and carbon dioxide in the infrared. For comparison the spectrum of the long-wavelength radiation emitted by the Earth would be a broad curve with a peak at about 10 μm.

The response curve of the human eye is also shown in Figure 42.2 and it is interesting to see how closely human eyes (and those of many other animals) have adapted to have a maximum sensitivity where there is most energy in the sunlight.

42.3 Distribution of solar power around the world

Solar radiation is very variable. It varies from place to place, and from time to time. As we move from the poles towards the equator, the power of the sunlight increases. This is partly because the sun is more directly overhead, and therefore has a shorter path length through the atmosphere, and partly because there are more clouds at higher latitudes. There is in fact less solar energy at the equator than at the tropics because of the equatorial rain clouds. Figure 42.3 shows the average solar power around the world. These power data are obtained by measuring the average solar energy received in one year and dividing by the number of seconds in a year, so the averages include day and night. Note that in the UK we receive an average power of about 125 Wm^{-2} whilst the Sahara Desert gets 250–300 Wm^{-2} – a much smaller difference than most people would guess.

North of the equator, the highest radiation levels in the world are found in the Sahara desert, the Arabian Gulf area, and the deserts of California and New Mexico. South of the equator the Kalahari and Australian desert areas have the highest levels. These areas all average about 250–300 Wm^{-2}. Southern Europe has a radiation level of about 200 Wm^{-2}, as does most of the "sun belt" of the world, between latitudes 40°N and 40°S.

42.4 Seasonal variation in the UK

The amount of sunshine varies with the seasons, and the higher the latitude the greater the seasonal variation. Figure 42.4 shows the average energy received in the UK.

The variation between summer and winter is very large (a factor of over 10 in most places). Since we need more energy in winter because the temperature is lower and the nights much longer, the energy received directly from the sun does not match the UK energy demand at all well. Wind and wave energy are much more abundant in winter than in summer, and these indirect solar energy sources are a much better match to UK energy demands.

The daily energies shown in Figure 42.4 are averaged over the whole of the particular month. The sunshine in any month varies from year to year, particularly in island climates such as ours, and the data in Figure 42.4 are for typical months, i.e. averages over many years. For the sunniest months (which might happen 1 year in 10), the daily average energy received can be twice the value in Figure 42.4, whilst for the worst months (again occurring 1 year in 10), it can be as little as one fifth of these values.

The data in this figure refer to the energy received on a horizontal surface, such as flat farmland. For passive

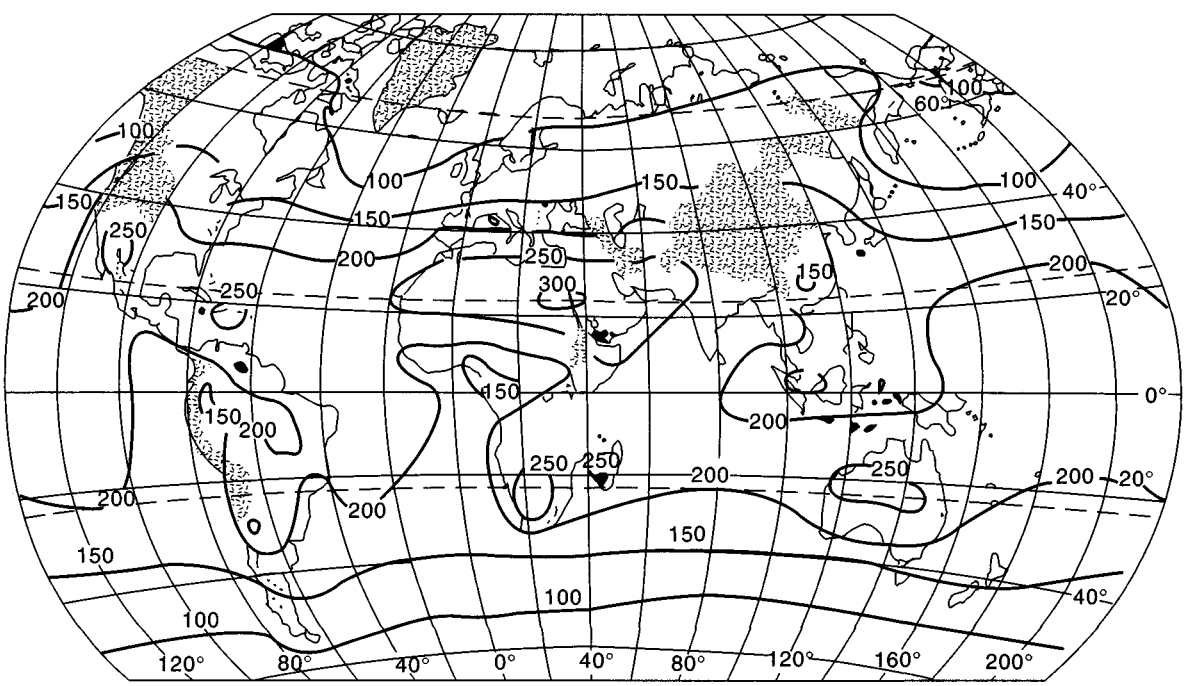


Figure 42.3 Average solar power around the World

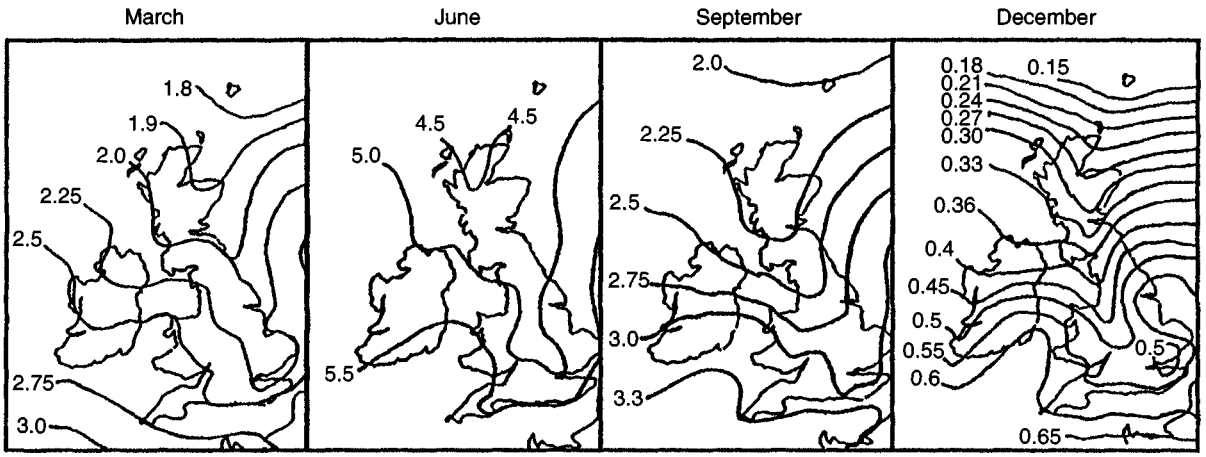
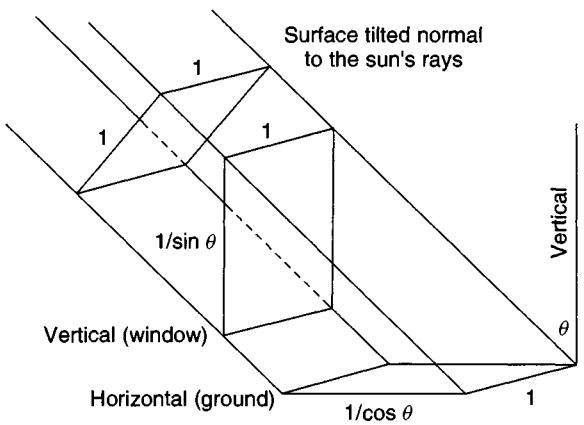


Figure 42.4 Daily average solar energy received in the UK ($kWhm^{-2}day^{-1}$)



	June	December
Sun angle θ at noon	30°	70°
Surface normal to the sun's rays	900 Wm^{-2}	700 Wm^{-2}
Vertical surface (window)	450 Wm^{-2}	660 Wm^{-2}
Horizontal surface (ground)	780 Wm^{-2}	240 Wm^{-2}

Figure 42.5 Effect of slanting of sunlight on power density on vertical and horizontal surfaces

solar architecture, we need to know the energy passing through vertical windows, whilst for solar heating or photovoltaics, the surfaces are tilted to be nearly normal to the sun's rays. Figure 42.5 shows the areas projected by a beam of sunlight on vertical and horizontal surfaces. Since these areas are bigger than the area of the beam, the power in the beam is spread over these larger surfaces and the power per unit area decreases. The power density for a bright sunny day in June and December at midday is shown in the table above. More power enters a window in December, even though the sunlight is weaker, but the power to warm the soil or grow the crops is less than 113 in December compared to June.

Units: The usual unit of energy is the Joule, equal to a power of 1 Watt applied for 1 second, 1 J = 1 Ws. Another unit of energy that is often used is the kiloWatthour (kWh). Since there are 3600 seconds in an hour, 1 kWh = (1000 × 3600) Joule = 3.6 MegaJoule (MJ). The average solar power at the Earth's surface, of 125 Wm^{-2} (Watt per square metre) translates to 3600 × 24 × 125 = 10.8 MJm^{-2} per day, equivalent to 10.8/3.6 = 3 $kWhm^{-2}day^{-1}$.

42.5 Background to basic collector circuits

In Britain each square metre of a south-facing roof receives around 1000 kWh of solar radiation during a year. This means that the roofs of many of our homes receive more energy from the sun in a year than we need to provide both the space heating and hot water; by using solar collectors it is possible to capture some of this solar radiation and reduce our consumption of fossil fuels like gas, coal and oil.

The sun is used to provide hot water for a house in many countries. In Britain it is possible to use the sun to provide most of an average families hot water requirements from about May to September and to obtain some 'pre-heating' of the cold water supply during the other months.

In principle it is possible to scale up the size of a solar water heater to provide under floor heating and a solar water heater can be used in a preheating arrangement if the produced hot water is not used elsewhere.

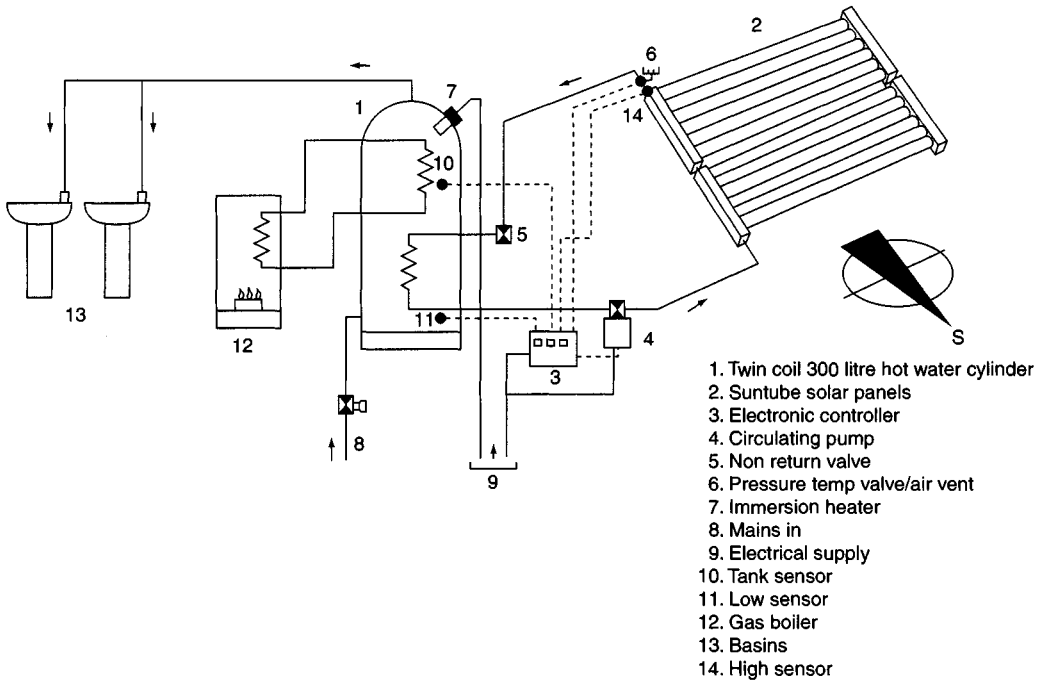


Figure 42.6 Typical plumbing arrangement

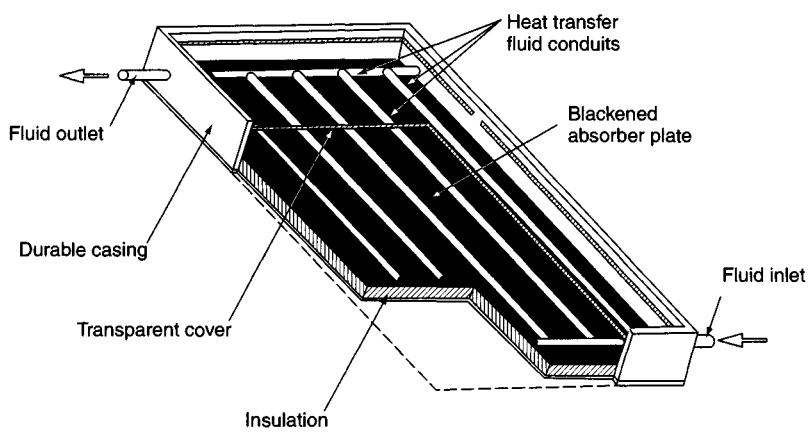


Figure 42.7 Illustration of a flat plate collector

Hot water is normally produced by heating the cold mains water to the required temperature with a gas or oil fired boiler or an immersion heater. By slightly modifying the conventional heating system, solar collectors may be introduced, as shown in Figure 42.6. The solar collectors are securely attached to some convenient part of the house so that they face south and are tilted from the horizontal around 30°C. A pitched roof which faces between E.S.E. and W.S.W. and is unshaded is usually the best location for the collectors.

A special water based anti-freeze solution is used in the solar circuit to transfer the heat from the solar collectors to a heat exchanger in the hot water cylinder. A controller switches on the circulating pump only when the collectors are hotter than the hot water cylinder, thus preventing the cylinder from being cooled at night or on dull days. All the pipe work as well as the hot water cylinder are well insulated to reduce heat losses.

42.6 The benefits of solar heating

Some people may install a solar water heating system to help conserve the world's supply of fossil fuels. Most people, however, will be more concerned with the money that the system will save them in the future.

The cost of a solar water heater consists of:

the cost of the components
the cost of paying the installer to fit it

These costs represent your initial investment in the system. The savings made each year in conventional heating fuels will repay your initial investment and the time taken to get your money back is often called the payback period. In the UK it is unlikely that the payback period will be less than ten years hence it is important to install a well made system.

A solar water heating system for a typical family of two adults and two children might have 3–4 m^2 of collector and a hot water tank capacity of 150 litres. For families with smaller or larger hot water needs these amounts can be adjusted accordingly. In typical UK conditions such a system will collect up to about 350 kWh/year per m^2 of installed collector depending on the amount of water used. Of course if you don't use much hot water, you can't save much energy, thus solar water heater are most economically in places with large hot water demands, such as schools and hospitals.

42.7 How a solar collector works

The majority of solar collectors used for heating domestic hot water are of the flat type with a transparent cover. These collectors often referred to as flat plate collectors consist of a black absorber (which is rather like a central heating radiator) contained in a weatherproof box, insulated at the back and glazed at the front.

Since the collectors are located outside the house and have to operate for many years, it is important that the materials used in their construction are durable and compatible with the rest of the plumbing. Since collectors can reach temperatures in excess of 200°C if they are left empty, all the materials in contact with the absorber must be able to resist this temperature without melting or distorting.

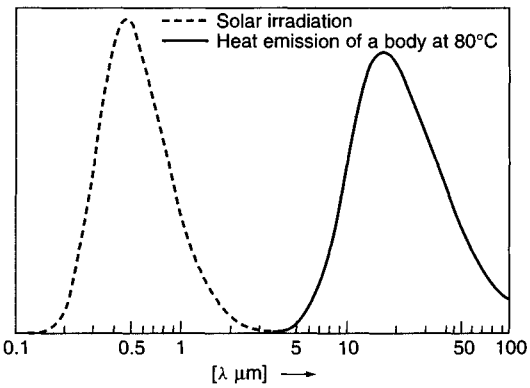


Figure 42.8 Comparison of solar and heat radiation

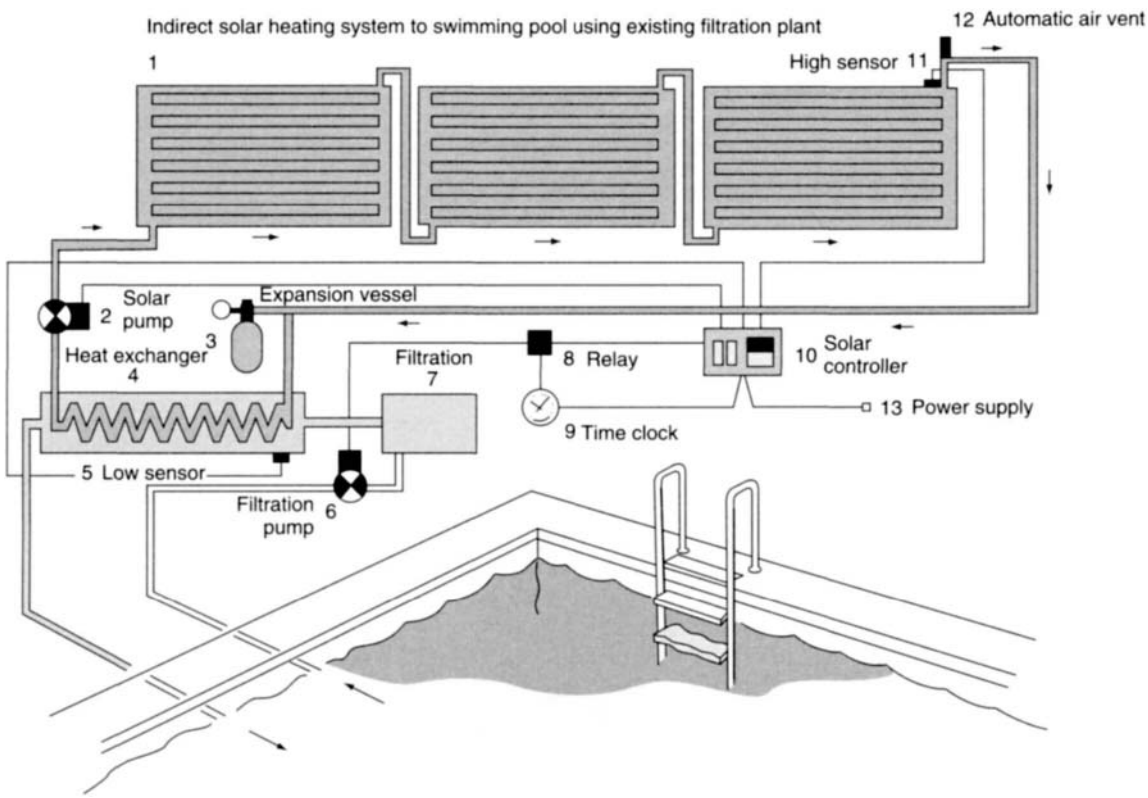


Figure 42.9 Illustration of a swimming pool system

A flat plate collector uses the well known 'greenhouse effect'. The energy from the sun reaching the earth is mainly in the invisible wavelengths. The glazing material (glass or plastic) does not absorb these wavelengths to any significant extent and therefore most of the incoming radiation is received by the blackened absorber. The absorber increases in temperature and the heat is conducted through the metal fins to the heat transfer fluid in the waterways.

Both the insulation below the absorber and the glazing at the front reduce heat losses due to convection. The heat radiation from the hot absorber plate is prevented from escaping directly back to the atmosphere by glazing which absorbs it.

When designing a collector, therefore, it is important that the glazing should have a high transmittance and the coating on the absorber plate, a high absorption for solar radiation.

In addition, the thermal performance of the collector may be improved by applying special coatings to the absorber place which have the effect of reducing the radiation given off by the plate. Figure 42.8 shows the difference in the spectrum of a hot body and solar irradiation.

The air conduction and convection losses may be reduced by creating a vacuum between the glazing and absorber plate like that of a thermos flask. However, the improvements in solar collection achieved by these techniques have to be weighed against the extra costs incurred.

42.8 Swimming pool or large volume water heating

Swimming pool heating presents an ideal application for solar heating since the peak usage, particularly for outdoor pools, coincides with the peak availability of sunshine.

Combining solar heating with air to air heat pumps can provide all year heating at very reasonable costs. (see chapter on Heat Pumps).

Unlike domestic hot water, where high temperatures of about 60°C are required, swimming pools need only be heated to temperatures which are a few degrees above the air temperature. See Figure 42.9.

Typically one evacuated tube array of $3\,m^2$ will be needed per 10 000 litres of pool volume, about one quarter of the surface area of the pool.

Since the major heat loss from a swimming pool is by evaporation from the surface, a pool cover should be laid on the surface whenever the pool is not in use. For the safety of the swimmers the cover should always be removed before swimming begins.

Circulation may be achieved by using the pump in the filtration circuit or by using a separate pump. In winter the solar circuit should be turned off and drained down to prevent the water in the collector from freezing and breaking the collectors.

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43 Solar electricity: photovoltaics

Mark Hammonds
BP Solar Ltd

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43.1 Solar electricity

As we know the sun is responsible for most of the earth's energy in one way or another. Plant photosynthesis provides the basis of our fossil fuels such as coal and oil. At the same time heat from the sun is again indirectly responsible for other common forms of renewable energy such as wind and wave power. Solar power in its accepted working definition, is the supply of energy directly from the sun. It is made up of two very distinct technologies, solar thermal and solar electricity. The first is based on the principle of using the sun's direct heat energy and is most commonly used for supplying hot water for houses and, swimming pools. It is solar electricity, with which this article concerns itself. This is a technology where the light from the sun is converted directly into electricity: this process is known as photovoltaics.

43.2 The past and present

Despite its rise to prominence in the 1970s and 1980s, this industry can trace its origins back 150 years. The actual photovoltaic effect was first noted over 150 years ago by Professor Becquerel. He observed a light dependent voltage between two electrodes immersed in an electrolyte. Albert Einstein united these threads with his theory of the photoelectric effect in 1905 which proposed the existence of the light photon (for which he received the Nobel Prize). Further practical application of this work had to wait until the acceleration of the space programme during the late 1950s. From there the industry has grown in leaps and bounds.

During the mid to late 'seventies, major improvements in material processing techniques resulted in cheaper, more efficient solar cells. This coupled with improvements i.e. reductions in power consumption in telecommunication devices provided the necessary spur for the adoption of solar as a viable energy source for terrestrial applications. This time also witnessed a dramatic rise in conventional fossil fuel prices and the realization that one day they were finite. This gave a fresh impetus to the research and technology being undertaken in this area.

As further improvements in cell processing continued throughout the late 1970s and early 1980s, resultant cost reductions have made solar power an economic proposition for an increasing range of applications.

43.3 How does it work

At its simplest, the solar cell works like a diode. Silicon is intensely refined to remove all the unwanted impurities. Half is then doped with boron which has excess positive electrons and half with phosphorous which has excess negative electrons. When light photons hit the cells, this results in the movement of electrons between the boron and phosphorous doped silicon (exactly as a P–N junction diode). This is then collected by a metal backplate and grid on the cell, as electricity.

The early work by Becquerel used Selenium and it wasn't until 1954 that the present dominance of silicon began as the major raw material for solar systems. Silicon (in its many forms) is the second most abundant element on earth, its most well known manifestation is sand. Availability combined with high light to electricity energy conversions made it the predominant industry raw material. Future work on reducing the price of solar energy concentrates on this area of solar cells. These being the most expensive component of a solar system, it holds the secret of increased energy conversion efficiency of sunlight into electricity and at the same time improving manufacturing costs.

To withstand the harsh environmental conditions that they operate under, the cells are laminated between a layer of special high transmission glass and weatherproof plastic, commonly tedlar polyester tedlar (tedlar is a Dupont trade mark). Silicon cells have an inherent potential of about 0.6 V DC so tend to be packaged as 32–36 cells into a solar module typically 1.2 m × 0.6 which can give nominally 12V DC and 75 watts under industry standard test conditions. These test conditions are 1000 W/m^2 insolation (light), temperature 25°C and air mass 1.5 (latter derates for the effect of light passing through the atmosphere)

The key material used by the photovoltaic industry today as it has been for the last twenty years is crystalline silicon solar cells. The starting material is the lower specification silicon produced by the semiconductor silicon industry. There are three current ways of utilizing this technology, monocrystalline, cast multi-crystalline silicon or ribbon multi-crystalline silicon. The first two are sliced into wafers of about 125 mm square and 350 μm thickness. This material has enabled relatively high stable conversion efficiencies typically 13–15%.

Work continues to go into this technology and it is estimated that there are still major volume cost reductions to be had here. Studies such as the MUSIC FM project under the EC Apas program have shown it is possible to reduce given increases in industry volume costs to 1/0.7 ECU per watt peak i.e. over 80% less than current costs.

43.4 The benefits

Enough of the present where is this technology going and how is it getting there? To understand this it is best to remember the benefits of photovoltaics.

Firstly as a renewable energy source it is environmentally benign. Once manufactured and producing electricity it does not put into the atmosphere gasses such as Carbon dioxide, the natural by-products from fossil fuel plants which lead to global warming.

Photovoltaics require no fuel and minimal maintenance (usually simply cleaning). As such a big use of this technology to date has been locations such as marine navigational aids, telecommunications repeater sites on mountains where it is very expensive and difficult to bring in fuel for alternative power supplies.

Solar produces no noise when operating and providing it has access to light will generate electricity. This enables it to be by far the most appropriate renewable technology to be used in the urban area.

43.5 Uses

To understand the technology and where it is going it is necessary to understand the uses.

The present Photovoltaic market is characterized by a fairly high and stable increase of over 15% per year. As at today the annual solar module production is estimated to be about 160 MW Still only very small in comparison to conventional power station output but growing fast in comparison.

Whilst costs have fallen seven fold since 1980's it still remains an expensive technology.

So how can the market be broken up and where is the growth coming from? There are several ways to look at market segments for solar but one of the more common ones is the five key areas – Telecommunications, Rural infrastructure, consumer, grid connect and specialist segments such as navigational aids, cathodic protection

Not only are all markets growing but there is increasing growth in the segment known as grid connect. Here solar acts as a complement to the standard grid and solar is utilized in central power station markets or on individual/company buildings to supplement power to the grid.

The key drivers for this at present are the reducing costs of large scale solar developments but above all the key environmental benefits of using a renewable energy which does not add to the greenhouse gas problem or create pollutants. There are large government programs in place in many countries to stimulate the take up of solar. Of note are Japan, the U.S.A., Germany, Japan, and Switzerland.

So what affect is this growth in the grid connect market having on the solar industry. Firstly companies are adapting to a different market. There is now a need to consider reduced installation costs and architectural choice in solar module design.

43.6 The future

The holy grail of the solar industry is lower cost and higher efficiency product to compete even further with conventional power sources. Market growth is important as it leads to increasing economies of scale. To get a "step" change in cost however needs above all technological development.

Traditionally the market has been dominated by the use of silicon as the base semi-conductor. 80% crystalline silicon, 20% amorphous. As the silicon used in solar cells makes up the bulk of the cost it is on alternatives to this that research is focused. As an indirect semiconductor, silicon has the disadvantage of absorbing parts of the solar spectrum rather weakly. Therefore the absorbing layer of the cell must be fairly thick (>200 μm) which leads to a large consumption of expensive high purity silicon material. It also depends furthermore on the processing of silicon wafers which complicates and therefore adds to the costs of module production.

Alternative solar cell materials and cell designs have been under development for a number of years in many laboratories. These are now beginning to be commercialized in volume

43.7 How can plant engineers make use of photovoltaics?

There are two basic approaches:

1. Grid connected systems.
2. Stand alone systems

43.1.1 Grid connected electricity

The first is where solar is connected to the normal grid. The expectation is that solar will not provide all the power but a fraction, and can be used as a means of peak-lopping, or as a base carrier.

Where these systems have mostly been taken up are: Germany/Switzerland/Japan/Austria (whilst they are growing in other countries such as the USA, Netherlands, Denmark, Belgium etc.).

The driving force for their use is the desire to use non-polluting, environmentally friendly, renewable electricity.

Here to overcome the cost barriers, there are subsidy schemes in place supplying up to 50% of the cost of the installation. The reason for these "subsidy" schemes, are to encourage take up of technology, allow suppliers a bigger market and ultimately speed cost reductions.

There are no such similar systems, in operation within the UK, at present, though is a European program which periodically offers in competitive bidding up to 35% funding for the right innovative projects, and there maybe further encouragement given within the European Community in due course.

At present, systems in the U.K. cannot provide electricity as cheap as the normal grid supplier. And could only provide a minute fraction of a plant electrical load. Why plants have considering using the technology even then is to act as the most visible statement of their environmental commitment. The world is growing more environmentally conscious, consumers, employees, regulators, and local councillors, demand greater private sector concern.

Solar photovoltaics offers the most visible way of demonstrating that fact even if the electricity generated cannot yet be a large cost effective part of supply. Dupont in 1999 for example committed to providing 10% of its energy from renewable sources. Whilst this can be from remote plants so called green electrons; a solar system can visibly demonstrate that commitment by being on site. Ford for example has solar on its engine plant in Bridgend.

These systems combine four key elements:

A number of solar modules
A mounting framework to mount the solar modules
An inverter or group of inverter, which connects to the main system,
Safety relay./metering set up/
Cabling, interconnecting and protection systems etc.
The key element, the solar module is a bit like a window in construction. It is usually 1.2 m × 0.6 m(4 feet ×

2 feet) weighing 8 kgs. Its front consists of toughened glass, its rear waterproof plastic. In between are laminated 36 125 mm pseudo-square solar cells which convert light into electricity. With grid connection as only part of the plant is being powered by solar, the issue on quantity tends to be space/budget. The solar modules simply feed into one or a number of inverters which feed into the main switch box.

43.1.2 Cost/performance

As a guide a square metre of solar in the UK costs £600.00 per or square metre all up including panels, inverters, installation and generates 0.4 kwh/day on average. Basically the more solar used the greater the proportion of output.

43.1.3 Stand alone

For small loads remote from electrical supply a complete self contained solar power system maybe the solution, Here the backup power is not the grid but batteries for poor weather/night-time. This may be cheaper and less disruptive than laying a cable to the installation or frequently replacing batteries. Thus at remote ends of plants it maybe cheaper than laying in cable. This is already used extensively in UK for telemetry/noise monitoring, rail degreasing systems.

To provide power during the times when the sunlight is insufficient either during the night or periods of poor weather e.g. heavy cloudcover requires an energy store. The most efficient medium for this is the battery. Whilst it is true almost any type of battery can be used, providing the electrical parameters are suitable, solar systems have some particular design requirements. These are effectively low maintenance i.e. infrequent battery top-up and long life i.e. able to withstand the heavy daily battery cycling required under these conditions. As such batteries have been specially developed for this particularly rigorous service The output from the solar modules varies considerably depending on prevailing sunlight and temperature conditions.

Whilst it is possible to connect directly to the batteries, in unattended situations this may result in considerable abuse of the battery leading to much reduced system life and greater water loss in the batteries. To counteract this therefore, electronic control units are supplied which regulate the output from the solar modules to charge the batteries. This is done to ensure the maximum energy efficient transfer coupled with the minimal battery water loss.

With stand alone systems the trick is working out how many of what type components are needed. At the heart of solar system design is the predicted performance and subsequent sizing at different locations throughout the world. This technique has been constantly refined. From a calculation method that could be done on a single sheet of paper the methodology has evolved to sophisticated computer programs involving weather pattern probability analysis. Only accurate sizings of the system will result in the benefits of solar being obtained by users. Demonstration systems such as the 30 KW solar plant (jointly funded by BP, the DTI and EEC) at Marchwood power station near Southampton have provided comprehensive data on system performance. Data such as this, again coupled with intense research means that this process enables users to receive their required energy with confidence.

43.8 The plant engineer – the user

There are many ways where full use has and can be made of the stand alone systems. Probably one of the most economical uses that have been made of these systems is in the marine industries. Namely in the lighting of navigational buoys used in not only coastal waters, but in the open seas.

The use has completely restructured the maintenance and inspection of these very important items of equipment.

Originally regular maintenance and routine visits had to be made to enable illumination to be maintained at all times, whether it be to replace gas cylinders or batteries etc sometimes making it necessary for the buoys having to be lifted from the water, incurring considerable costs.

The use of batteries, which are continuously charged by the use of the photovoltaic principle, the use of sealed miniature computerized controls, etc. has reduced the total programme and saved considerable expense and increased reliability, so much needed in these particular applications, and at the same time reduced a very expensive service to within reasonable limits.

How can this sort of application be applicable to the Land-based plant and have similar advantages?

Probably when setting up a new plant or even taking an overall view of an existing plant, it is well worth carrying out an audit similar to one that would be carried out when viewing the energy consumption account. One has only to give just a little consideration to the savings and stress reduction that has been brought about when the photocell was introduced to the pocket calculator, virtually eliminating the use of batteries altogether and the hassle that always went along with a battery failure.

How many illuminated signs, notices, isolated lighting, monitoring equipment requirements are there, which all will require, in the first place, the installation costs, which could be very expensive in very isolated situations, followed up by routing maintenance and repair or replacement visits etc.

The use of these systems should be more commonplace that they are an the moment, this is brought home when visiting some of the towns on the continent of Europe.

43.9 Conclusion

Photovoltaics continues to mirror all the classic signs of a start up industry. Costs are falling. New applications are leading to new innovations/new products. New lower cost technologies are rapidly being commercialized. With the issues of climate change and environment increasingly at

the forefront of the political agenda, the prospects for this technology are immense.

Solar above all is the renewable energy which can be utilized in urban areas on built up equipment. Whilst solar may not provide the huge amounts of energy that plants traditionally call for; using this power source as part of a well balanced power consumption system can have some very definite advantages.

43.10 The whole idea sounds good to me but how do I exploit it?

Some of the ideas mentioned, on the face of it look good but have I got the time and the enthusiasm to get down to carrying out an audit in my plant?

Time is the most important commodity in most engineer's life, so how can this be overcome?

The obvious hand to reach for is the consultant who is involved in the specialist application or direct to a company who have set themselves up either in the application investigation field or who have systems which they have developed in a specific field.

Likewise there are usually within easy reach of most installations, a University, or even more locally a Technical College, most of which have course leaders looking for project work for their students.

Some companies are developing close associations with local schools, which can be a very rewarding experience, although may not be as cost effective in time and attainment. But this will be up to the individual engineer to explore. A call to an appropriate engineering department Head will usually give access to students looking for project work.

This contact can be very beneficial to both the students and to the industry and employs a new view to your very familiar surroundings and possibly a wealth of enquiring knowledge waiting to be tapped which can have a rewarding return for a little co-operation with that institution.

Having said that this co-operation need not be restricted to the application of photovoltaics but to many other subjects within the scope of many courses.

Your help can pay dividends in the long run.

As time progresses and global warming is taken seriously internationally, there are increasing government grants and advice available. The project controller and energy manager should make every effort to find what is available.

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44

Wind energy and the plant engineer

Tony Book
Riomay Ltd

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44.1 Introduction

Initially the title of this chapter immediately makes one jump to the conclusion that where wind is concerned then there are problems associated with it; either the wind is causing problems with process equipment, lifting or support difficulties, strengthening and stiffening costs etc. as well as other problems with dust, gas or pollution distributions, efflux velocities as well as possible plant internal personnel problems by way of draughts, process temperature disruptions etc. This is without giving consideration to other possible difficulties associated with climatic changes.

Discounting the above-mentioned occurrences it is possible, in certain circumstances, that full advantage can be taken of the wind. Over the years there have been great strides made in harnessing the power that wind carries.

Depending on the location and the type of power requirements of a plant use can be made of electricity generation.

It is in areas where necessity is the driving factor that maximum advantage is gained, for instance, in the leisure boating industry where photovoltaics have become a general source of power for general purpose on-board electrics, so, in turn, wind generators have come into their own and great strides have been made in this particular area, although associated in the lower voltage DC range. These developments have usually been associated with back-up charging of batteries for the operation of electronic circuits for lighting, communications and monitoring.

Having said that, there is no reason why the Plant Engineer should not also use these techniques within the plant confines of the plant perimeter.

Whereas, in the chapter on photovoltaics, applications have been quoted covering their use, it is an obvious extension to cover the same ground using wind power for very similar situations.

However, one can more or less guarantee that daylight will follow darkness, it does not follow that wind will always be available for harnessing in everyday application.

Going to the other end of the spectrum – the higher voltage requirements and the higher loads, then, providing there are back-up supplies available, wind power for the generation of electricity is always a possibility. The more isolated the site, and the openness to uninterrupted wind direction, thought can be given to wind power generation. This can be a main source of a wind farm for major generation of electricity possibly by a generating supply company or for large individual plant use is suitably located.

Consideration is being given to off-shore wind farms where there is a fairly constant supply of uninterrupted wind, where noise would not be a major problem, which it does tend to be, with on-shore power plants.

Although these advantages are available there are also other major disadvantages, like the cost of the initial installations, maintenance, and weather which could affect accessibility.

There are quite a number of manufacturers who have gone into the development of wind turbines and who are carrying out installations. Further developments have been going on within the University research establishments in order to make advancements in this area as future generation of power must almost certainly be directed to wind generators.

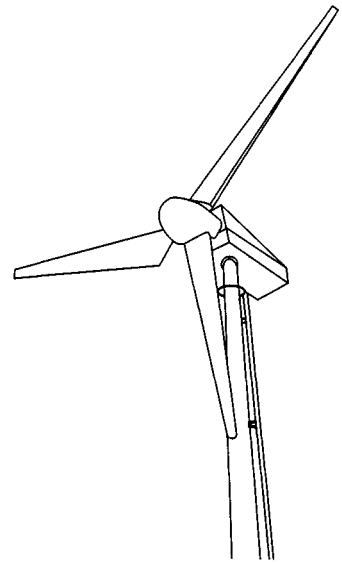


Figure 44.1 A basic wind turbine

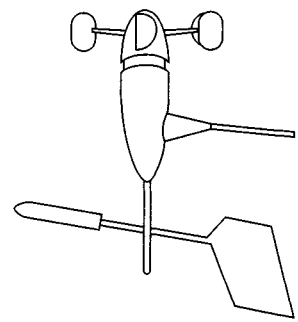


Figure 44.2 Anemometer and wind direction indicator

Great strides have been made in turbine developments and can fall into several categories:

Turbines with low rated power output in proportion to the rotor diameter and give an energy output at wind speeds of about 2.5 m/s, thus enabling a high yearly energy production. This type of turbine is probably far better for use where wind speeds are lower in that particular area.

Another type of turbine are equipped to give a higher rated output, in relation to the rotor diameter, than the previously mentioned type, giving energy outputs at wind speeds over 3.5–0.0 m/s and are probably better suited for the windier regions.

Many variables have to be taken into consideration when evaluating a situation during a feasibility study, to determine the optimal type for a particular application.

Factors like; site, wind situation, user's purpose and energy consumption and available alternative standby supplies. Also consideration must be given as to how the new system will integrate with existing supplies or how it can dovetail into a new situation, and how inter-connections and protections can be covered. If the new installation is going to be inter-active with the local grid, then full consultation must be effective from the moment any idea is envisaged.

44.2 Wind and wind turbine output

Wind, in the past, has always played an important part as a source of energy. Sailing vessels sailed from the East to the West, from the North to the South over all the oceans, making full use of the wind whether it was behind them or directly in front, but having the ability to adapt to use the wind to the very best advantage. Windmills ground corn and powered machinery. Now the wind is also coming into its own once again and will, in due course, be seen as a profitable source of energy especially as techniques in efficiency develop and the cost and restrictions on other sources of the energy increase and as scarcity plays a part.

Unfortunately wind is not a constant source of energy. Power and forces vary considerably with the wind speed. For windless periods, special arrangements have to be made. Also the energy output depends on the season of the year and the site concerned. Likewise the turbine has to be protected against overload.

To measure the windspeed, an anemometer is used, and to measure the direction of the wind, a wind direction indicator is required. The output power of the wind turbine is a function of the windspeed. The windspeed is given in m/s, km/hour, miles/hour or in wind-force according to the Beaufort scale.

Table 44.1 Windspeed

Beaufort Scale	*Description*	*Windspeed*		
		M/S	*Km/Hour*	*Miles/Hour*
1	light air	0.3–1.5	2–5	1–3
2	light breeze	1.6–3.3	6–11	4–7
3	gentle breeze	3.4–5.4	12–19	8–12
4	moderate breeze	5.5–7.9	20–28	13–18
5	fresh breeze	8.0–10.7	29–38	19–24
6	strong breeze	10.8–13.8	39–49	25–31
7	near gale	13.9–17.1	50–61	32–38
8	gale	17.2–20.7	62–74	39–46
9	strong gale	20.8–24.4	75–88	47–54
10	storm	24.5–28.4	89–102	55–63

44.3 Mean windspeed

Meteorological stations all over the world measure the windspeed at different heights. Close to the ground the windspeed is much lower than high into the sky. Trees, bushes, houses, hills or other obstacles affect the wind considerably. Wind duration curves are made from windspeed records supplied by meteorological stations. These curves show the number of hours the wind is blowing above a certain windspeed. Often the frequency distribution of the mean windspeed is used. Results are often known for a period of 10 years. An example (Dutch

Table 44.2 Terrain classification

Class terrain	*1 sea*	*2 flat*	*3 open*	*4 low crops*	*5 rough*	*6 very rough*	*7 forest*
U_{30}/U_n	1.24	1.21	1.19	1.17	1.14	1.12	1.09
U_{20}/U_n	1.19	1.06	1.12	1.08	1.05	1.01	0.96
U_{10}/U_n	1.12	1.06	1.00	0.94	0.88	0.82	–

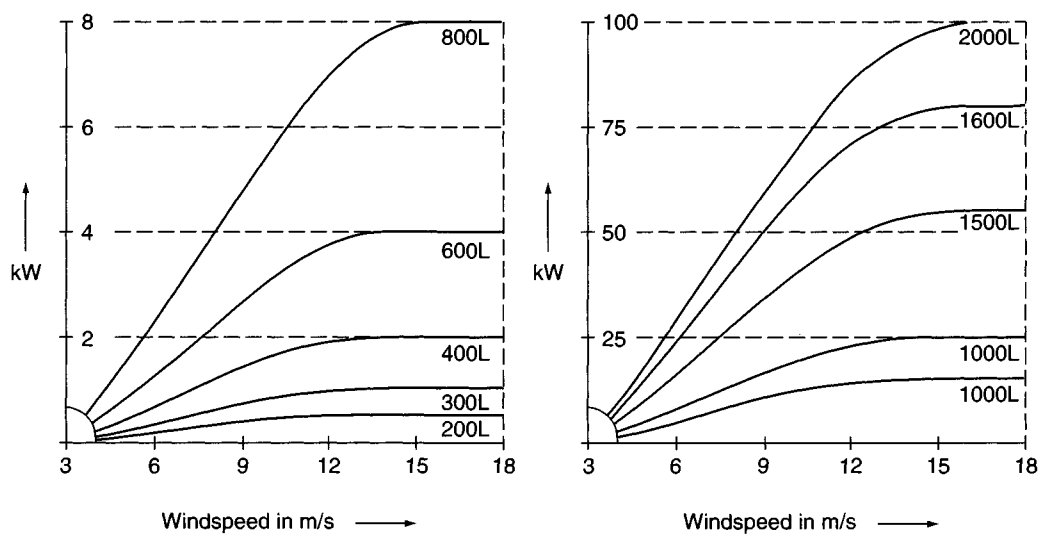


Figure 44.3

Table 44.3 Example: For different types of wind regions

Frequency distribution (in per cent) of the mean windspeed
Classes: 0 = 0.0–0.9 m/s; 1 = 1.0–1.9 m/s etc.

Class	*Amsterdam*	*Rotterdam*	*Lelystad*	*Eindhoven*
0	5.78	9.21	5.25	11.32
1	6.42	9.78	6.14	9.11
2	10.32	13.87	10.91	14.07
3	13.31	15.89	14.54	14.77
4	13.35	13.37	14.43	13.03
5	11.43	10.59	13.06	13.06
6	10.66	9.46	10.31	8.62
7	8.41	6.21	8.15	6.31
8	6.27	4.30	5.89	4.08
9	4.33	2.91	3.87	2.97
10	3.24	1.93	2.84	2.31
11	2.15	1.22	1.76	1.24
12	1.71	0.65	1.15	0.97
13	0.94	0.31	0.71	0.34
14	0.55	0.15	0.40	0.28
15	0.27	0.07	0.21	0.21
16	0.33	0.04	0.22	0.09
17	0.29	0.02	0.08	0.06
18	0.09	0.02	0.03	0.05
19	0.05	0.01	0.02	0.03
20	0.03	0.00	0.01	0.04

Table 44.4 General terrain classification

Terrain classification

Class	*Short terrain description*		
1	Open sea, fetch at least 5 km.		
2	Mud flats, snow, no vegetation, no obstacles.		
3	Open flat terrain; grass, few isolated obstacles.		
4	Low crops; occasional large obstacles: distance (x) times height (h)		between obstacles >20
5	High crops; scattered obstacles: 15 < x/h < 20	6	Parkland, bushes; numerous obstacles: x/h □ 10
7	Regular large obstacles coverage (suburb, forest)		
8	City-centre with high and low rise buildings		

source) is given in Table 44.2. As mentioned before, it is very important to know the influence of the surroundings. For modelling the surroundings, the terrain classification can be used.

44.4 Wind structure above terrain

U_{30} = mean windspeed 30 m. above terrain
U_{20} = mean windspeed 20 m. above terrain
U_{10} = mean windspeed 10 m. above terrain
U_n = mean windspeed 10 m. above terrain (measured by meteorological station)

Table 44.5 Data will vary depending on manufacturer

Rated power kW	*Rotor diameter m*	*Energy output/mean windspeed*		
		3–4 m/s	4–5 m/s	5–6 m/s
0.25	2	400	600	1000
1		900	150	2000
2–3	4	1500	2500	3500
2.4–5	6	3500	6000	8000
8		7200	10000	14000
7.5–15	10	8500	15000	20000
18.5–25	10	10000	19000	29000
25–45	15	20000	40000	65000
30–50	15	22000	45000	70000
55–95	16	32000	60000	90000
75–125	20	48000	100000	150000
125–165	23	90000	180000	290000

44.4.1 Power versus windspeed

These characteristics are global and should be adapted to local circumstances, to find the optimal installation for the user purposes.

44.4.2 Energy output

The combination of windspeed, terrain and turbine characteristics makes it possible to estimate the energy output of a windturbine at any particular site.

44.5 Technology

Our windturbines combine the most recent technology with excellent aerodynamic and aesthetical design. The turbines are sturdy, and of simple construction, giving a long life and less maintenance.

The construction is appropriated for stand-alone use. Special features are suitable for offshore use. For special projects the turbine should be purpose-built.

1. Rotor

- 2 blades or 3 blades laminated according to Rotor diameter, 2 to 20 m.

2. Main transmission

- Heavy main shaft with two bearing blocks and a double row of spherical roller bearings designed for long life
- The gearbox is constructed for a very long life and has 2 or 3 stages with a total ratio of 1:10 to 1:40 depending on site of erection and application
- The generator is generally driven via a flexible coupling

3. Generator

- Some types have no gearbox but a direct drive
- The generator is suitable for direct drive

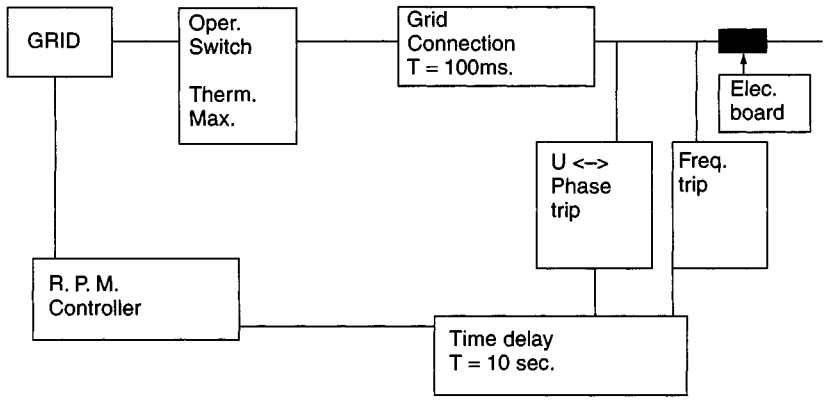


Figure 44.4 Principle of electronical diagram for connection to grid

- For special projects a synchronous generator can be used
- Instead of a generator other power generating systems can be installed

4. *Yaw control*

- The yaw control operates fully automatically via a windservo
- Operates as safety device; in case of too high windspeeds, the rotor of the turbine can be yawed out of the wind

5. *Nacelle*

- The heavily loaded parts are enclosed
- All machine components including the generator are fully enclosed and covered by a hood of glass fibre reinforced polyester
- A service platform is mounted, with an anti-slip surface

6. *Mast*

- The mast has a cylindrical or conical shape and is manufactured of high quality steel
- Flexible construction, natural frequency differs sufficiently from turbine frequencies
- A special ladder with safety cable is mounted; the system is approved by safety inspectors
- As standard the mast is hot dipped galvanized; additional coatings for special use are possible
- Minimum height as mentioned in table, heights up to 36 m.

7. *Foundation*

- Type of foundation depends on the erection site
- According to soil data (foundation) our technical department is able to design the optimal foundation specification

8. *Safety*

- The turbine has built-in safety devices for mechanical and electrical overload besides an aerodynamic safety system of blade pitching
- The aerodynamic safety system will yaw the rotor out of the wind and stop the turbine
- Manual stop will have the same effect

9. *Electrical switch and control cabinet*

- Connects generator at sufficiently high speed
- Disconnects generator as generator functions as motor

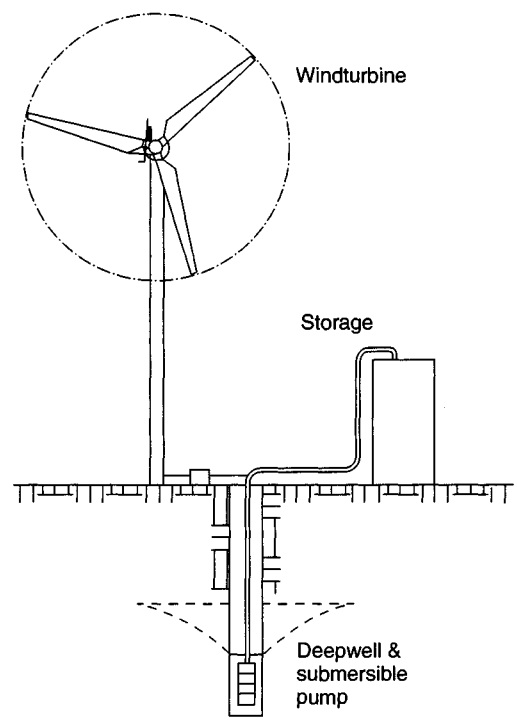
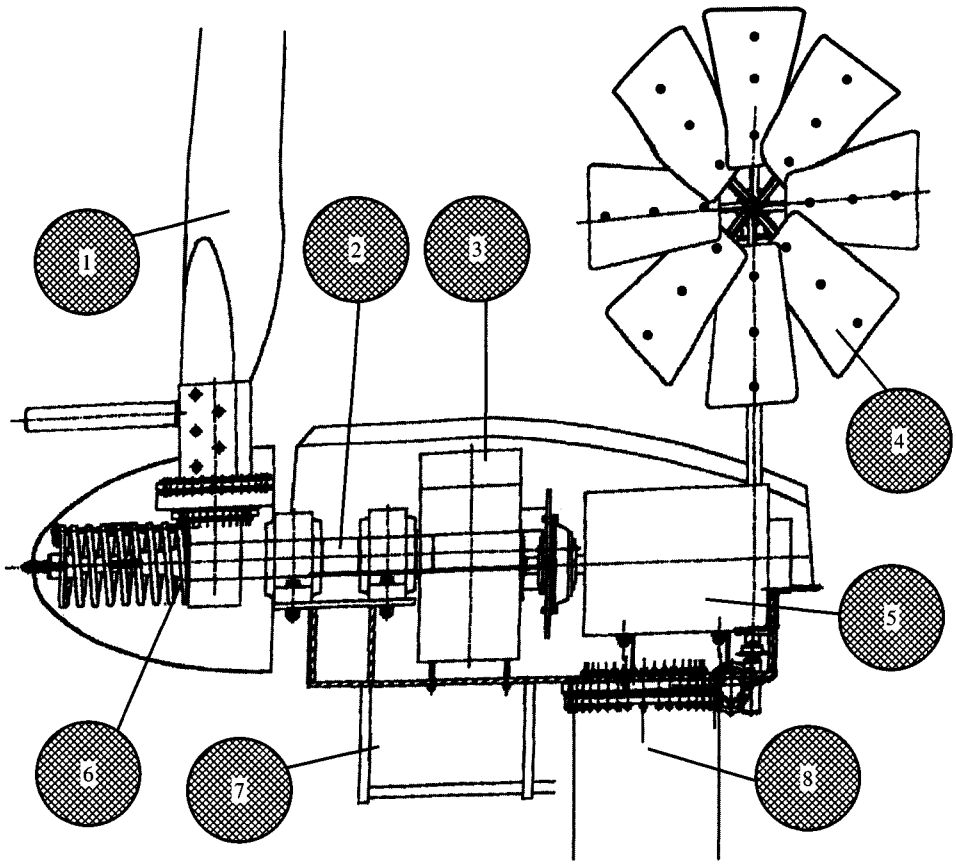


Figure 44.5 A simple application



1. Blade
2. Main shaft with bearings
3. Gearbox with brake
4. Windservo
5. Generator
6. Mast and yawing slewing ring
7. Service platform
8. Centrifugal pitch system

Figure 44.6 Typical layout of a wind turbine

- If turbine is connected to local grid, automatically disconnects turbine if no grid available
- Specially for safety of the grid: max current trip, under voltage trip and frequency trip (2 c/s)
- Specially for the electrical safety of the turbine: thermal trip, over voltage trip; optional: phase trip, asymmetric strip
- Cos phi control system
- Meet electrical standards

44.6 Principle of electronical diagram for connection to grid

The diagram (Figure 44.4) shows the principle of grid connection. The work-switch can be provided with a key lock to obtain a hard separation from the grid. In this case the work-switch will be mounted near the mast. Additional components can be mounted. For turbine with special generators the diagram is different. P.M. and synchronous machines need another control system. Feature depends on the application.

44.7 Special applications

Synchronous or p.m. generators (small turbines), can be mounted with converter back up and storage system (e.g. diesel generator and batteries). The various types are operational with grid or *stand alone mode* or in pure heating mode. Another special is a system for irrigation with axial or submersible pumps (Figure 44.5). A special system is available for smooth operation. The turbine can drive additional pumps. Additionally, systems can be matched with coolers and freezers, heat power systems with gas turbines (very suitable for swimming pools), water power turbines. For special site conditions off shore (platforms) and sites where only erection by hand is possible. There are many variations on this theme to suit varying applications.

44.8 Layout

Figure 44.6 shows the layout of a typical-windturbine

45 The engineer as an expert witness and the new civil procedure rules

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45.1 Introduction

The senior, experienced engineers normally undertake expert witness work but with the development of new technologies such as computers and robotics much expertise can be found in younger members. This chapter is directed at the younger Plant Engineer but will also be of value to the older Plant Engineer who has accumulated experience but has never acted as an expert witness. It describes the nature of the work of the expert witness and the procedure of establishing credibility.

The courts recognize expertise when the person claiming to be an expert has knowledge beyond that which the man in the street is likely to possess. There are two elements to expertise:-

- academic (theoretical) knowledge
- practical experience.

It is not necessary to know of the latest research results but essential to know what practises have been employed over the years and have been proven to be reliable. Practical experience teaches what is done but academic (theoretical) knowledge deepens the understanding of why it is done. In essence the wisdom of the expert witness is a combination the accumulated practical experience and theoretical knowledge.

Some engineers specialize during their university days and never leave their area of specialization but most progress from job to job, many joining different companies in their learning process. This provides opportunities for different and interesting experience, promotional prospects and financial gain. They accumulate experience some of a highly technical nature and some of an administrative nature. Some become expert at solving problems and some at organizing the activity associated with solving the problems. Engineers need to cultivate their experience (knowledge and wisdom) in order to extend their life cycle earnings and contribution to society.

In this age of company restructuring the older employees are encouraged to retire earlier while experiencing an environment of longer active life but it is appropriate for all employees to exploit their experience to the full. Acting as an expert witness and assisting in the resolution of technical conflict is particularly appropriate in these circumstances and Governments are increasingly recognizing that it is appropriate for earning capacity to be extended.

Engineers continually assess their career, particularly in the current employment market, where security of employment is not what is was and career changes are more frequent. This process has been recognized and assisted by the professional institutions that now actively encourages CPD, Continual Professional Development. There are many methods of advancing professional development and they include:-

- work experience, sometimes called on-the-job training,
- reading books and trade magazines,
- attending conferences devoted to specific specialist subjects and
- undergoing short courses in specialist subjects.

The Plant Engineer seeking work as an expert witness needs to obtain further training in expert witness work and this chapter offers some advice.

45.2 Classifying expertise

In the days of the apprenticeship, engineers began their career working in a factory assisting a qualified craftsman in a particular field. Theoretical training allowed him to extend his understanding of the work he was doing and progress into an area of specialization. Today most engineers decide upon a discipline by entering university to study in a particular faculty. With this fundamental knowledge they enter a particular field of employment and specialization.

The relationship between discipline, specialization and field of activity is not always understood and can confuse the identification and classification of expertise. This is particularly important since it influences the search procedure employed by clients seeking an expert witness. Each of the associations of experts listed in the reference list, ask members to identify their expertise by selecting from a list of technical subjects, of expertise which the prospective members can satisfy. The following will assist the engineer in this important task.

Disciplines include Mechanical, Electrical, Chemical, Structural and Civil engineering.

Specializations within the disciplines includes, in Mechanical engineering, Materials technology, Tribology, Hydraulics, Vibrations and Stress. In electrical engineering the specializations include power generation, distribution, high and low voltage. A chemical engineer might choose to specialize in corrosion and a structural engineer could consider tall buildings or cladding as their subject for specialization.

Fields of activity include Machine tools, Iron & Steel, Nautical, Nuclear, Aeronautical, Automotive, Railways and Process Engineering and there is also the Military. There are new fields such as, Robotics, Mechatronics, Nano technology and Bioengineering. Much activity in these fields increasingly involves interdisciplinary activity. As an extreme example laryngology can involve physiology (the structure of bodies), mechanical articulation of the cartilages and bone structure. Medical action of the muscles to move the structure including vibration of body tissue and phonation. Neurology to control the movement. but also psychology and the art of speaking and singing.

It is important to realize that a specialization e.g. tribology, is normally generic which allows the specialist to move from field to field, e.g. from automotive to nuclear. But there are other activities such as Research, Design, Development, Installation, Commissioning, Maintenance, Administration, Management and Project Management which also involve common methodologies across many fields.

45.3 Establishing credibility

Credibility will be achieved through working in the your chosen field and having membership of the professional body representing your speciality. These include the Institutions of Mechanical Engineers, Electrical Engineers, Civil, Marine Engineers etc. but for a wider audience it will be established after being checked and included on one of the established lists of Experts. These include such bodies as the professional institutions. Specific directories have also been established by bodies such as the Law Society Register, the Register of Expert Witnesses the Waterlows directory of Solicitors and Barristers.

There has also been an increase in associations such as the Academy of Experts, the Society of Expert Witnesses and the Expert Witness Institute. Membership of one of these associations enables the expert to obtain assistance in understanding the role of the expert witness. They provide documents describing the code of conduct, which the expert should adopt and what is expected of an expert witness. They have also established the terms and conditions of contract, which the expert can include in his offer to prospective clients.

The specialist professional institutions provide courses associated with areas of expertise and the Expert Witness bodies provide courses firmly rooted in the legal profession. They provide the expert with a brief understanding of the legal process.

They also cover aspects, which influence the credibility of the expert's evidence. An important item in this respect is the personal presentation of expertise in court. This is a complex issue and involves knowledge of human behaviour. The training courses can be prescriptive but cover such topics as psychology and physiology and their role in influencing the presentation of evidence in court. These topics can include posture, breathing and voice production in order to eliminate rehabilitating effects when confronted with hostile questioning.

45.4 The Woolf Report and the future

New Civil Procedure Rules stipulate that a single joint expert will replace the need for separate experts instructed by each party in a dispute.

Lord Woolf is the Lord Chief Justice and the most senior judge. Following his now famous report, when he was Master of the Rolls, a massive shake up in English law procedures took place when on the 26th April 1999 The Civil Procedure Rules 1998 came into force. Every area of civil law is affected and within the 51 parts there are rules which revolutionize the way in which civil justice is administered. This has unfortunately coincided with the demise of legal aid in civil cases, resulting in an overall drop in expert witness appointments by some 75%.

For those who choose to act as expert witnesses a new atmosphere has necessarily been created of an expert who not only must know his subject better than most of his contemporaries, but must also be an expert in legal procedures as affecting his activity as an expert witness. Part 35 directly affects the expert by its 15 rules and attached Practice Directions, which as time progresses will no doubt be enlarged and made more complicated.

Expert witnesses have been criticized by Courts over the years for being partisan, not without reason, but often aided and abetted by lawyers. The new Rules sweep away that tendency and even makes provision for single joint instructions whereby the expert is appointed to advise all parties equally, thus removing any possibility of coercion. In the past the author was rarely instructed in this way.

A short summary of the rules within Part 35 and its effect will assist the expert:-

Rule 35.1 gives the Court the power to restrict expert evidence to that which is reasonably required to resolve proceedings. In reviewing the situation at a 'Case Management Conference' the judge, who is usually a District Judge, will decide which 'track' the case will be placed in, and this will be either small claims, up to £5, 000, fast track, up to £15 000, or multi-track, over £15 000. Experts will not be allowed in small claims cases, rarely in fast track, but usually in multi-track.

Rule 35.2 identifies the expression 'expert' as being someone who has been instructed to give or prepare evidence for the purpose of court proceedings. Whilst not mentioned in this Rule or Practice Direction, an appointment as an 'Adviser' also means an expert, but one who prepares his report for one of the parties without an intention that he acts as an expert witness. However, if at a later date he is instructed as an expert witness, then his report is discoverable to the other party.

Rule 35.3 introduces and underlines previous directions from judges such as *Whitehouse v Jordan* (1981) 1 WLR 246 HL, that it is the duty of an expert to help the court on the matters within his expertise and that this duty overrides any obligation to the person from whom he has received instructions or by whom he is paid. The Courts have in the past become exasperated by experts blatantly advocating cases when in reality they could not support their views technically. It becomes obvious very quickly if an expert is being partisan and he can not only be criticized, but could even be charged with perjury in an extreme case. The golden rule is that when a report is written, the expert should ensure that if appointed by the other party, that he would give the same opinions. If that is not the case, then the report does not assist the Court and must be changed.

It is worth referring to the direction given by Cresswell J in *National Justice Compania Naviera SA v Prudential Assurance Co. Ltd.* (The "Ikarian Reefer") [1993] 2 Lloyds Rep 68 when his Lordship said:

> *"1. Expert evidence presented to the Court should be, and should be seen to be, the independent product of the expert uninfluenced as to the form or content by the exigencies of litigation (Whitehouse v Jordan (1981) 1 WLR 246, HL).*
> *2. An expert witness should provide independent assistance to the Court by way of objective unbiased opinion in relation to matters within his expertise. An expert witness in the High Court should never assume the role of an advocate.*

3. *An expert witness should state the facts or assumptions on which his opinion is based. He should not omit to consider material facts which could detract from his concluded opinion.*
4. *An expert witness should make it clear when a particular question or issue falls outside his expertise.*
5. *If an expert's opinion is not properly researched because he considers that insufficient data are available then this must be stated with an indication that the opinion is no more than a provisional one. In cases where an expert witness who has prepared a report could not assert that the report contained the truth, the whole truth and nothing but the truth without some qualification that qualification should be stated in the report.*
6. *If, after exchange of reports, an expert witness changes his view on the material having read the other side's report or for any other reason, such change of view should be communicated (through legal representative) to the other side without delay and when appropriate to the Court.*
7. *When expert evidence refers to photographs, plans, calculations, analyses, measurements, survey reports or other similar documents, these must be provided to the opposite party at the same time as the exchange of reports".*

The aspiring expert is urged to bear all of these points in mind when preparing his report.

Rule 35.4 develops the established principle by the Courts that an expert can only give evidence before a court by permission from the judge. The requirements are further spelled out in 35.4 (2) which says *"When a party applies for permission under this rule he must identify – (a) the field in which he wishes to rely on expert evidence; and (b) where practicable the expert in that field on whose evidence he wishes to rely".*

Of particular interest is Rule 35.4 (4) which says that *"The Court may limit the amount of the expert's fees and expenses that the party who wishes to rely on the expert may recover from any other party".* However, this is not a new requirement because Taxing Masters have always had that power. A Taxing Master is an official of the Court and can be the judge. He decides how much a winning party can recover in costs. Engineers are considered at the bottom of the heap as far as fees are concerned. Medical experts command almost double the hourly rate. It is a fact of life that engineers can not claim high fees, without them being reduced by the Court. This has caused many experts to give up this kind of work since the new Rules came into force. Whilst a remedy is to refuse to agree to the Taxing Master's decision and thus reduce fees, there will inevitably be difficulties in getting paid.

The expert is in the hands of those instructing him who will invariably be a solicitor or insurance company. The Court will consider the way in which the case has been handled, and if it is considered that too much use has been made of the expert, or the expert has not prepared his report to the liking of the Court, then the fees for the report can and are on occasions cut. For example, if a report is very short, without evidence of time spent, even if a great deal of time has been spent, then the fees will be cut. On the other hand, if the report appears padded out so that too much time has been spent, the fees are also likely to be cut. The fact is that it is impossible to please all judges, as the author has found over the past twenty-five years. Advice is to avoid padding out and show necessary calculations.

Rule 35.5 (1) lays down a new concept that expert evidence is to be given in a written report unless the Court directs otherwise. This is already saving in fees for experts attending court to give oral evidence, in (2) it is said that in fast track cases, the court will not direct an expert to attend a hearing unless it is necessary to do so in the interests of justice. A reason for calling the experts is where two experts cannot agree sufficiently for the court to come to a conclusion on expert evidence, therefore, both experts will need to give oral evidence and be cross-examined. The written report of the expert will serve as examination in chief, once the expert has introduced himself and confirmed his qualifications and experience.

Rule 35.6 introduces a brand new concept in law and that is that other parties' solicitors in a dispute can now put questions directly to the expert, whether he be instructed by one party, or is a joint expert. The rule for asking questions of the expert are tightly controlled and in (2) the questions:-

"(a) may be put once only;
(b) must be put within 28 days of service of the expert's report; and
(c) must be for the purpose only of clarification of the report; unless in any case
(i) the court gives permission; or
(ii) the other party agrees".

The expert is obliged to answer questions put to him, otherwise he may not be allowed to give evidence at the trial, and worse still, may end up with no fees. Neither the rules nor the Practice Direction (35PB-001) lay down a time limit for the expert to answer the questions. However, the Court is likely to have done so at a Case Management Conference. This could be as little as 14 days.

Rule 35.7 formalizes the concept of instructing a single joint expert by all parties to a dispute and underlines the power of the Court to direct that evidence be given by one expert instead of the usual 'team' of experts. This is not a new idea, the author having been instructed in this way for many years, but it has never been a popular course by lawyers. Clause 35.7 (3) develops the principle further along the lines of the traditional appointment of arbitrators in that if the parties can not agree a particular person as expert, the court now has the power to order which expert to instruct.

The Court could order that the parties abandon their proposals of each party having his own expert, and direct that one expert be appointed from the number put forward,

or any other method which the Court thinks fit. It should be understood that this rule does not apply to court experts, the expert will remain appointed by the parties who will be jointly and severally responsible for his fees.

The Court could revoke the order for a single joint expert, if it is subsequently found that the issue upon which he is instructed turns out not to lie within an established field of expert knowledge, or that the expert is blatantly inexperienced in the subject matter. However, a court may be reluctant to take this step, taking the view that the parties have made their bed, now they must lie in it.

Rule 35.8 concerns the parties' duties in instructing a single joint expert, the court's power to limit fees paid to him, and the responsibilities of the parties in that respect. The Court may order that an expert is paid £400 fees, whereas, he may have quoted £800, and unless the parties agree to pay the extra between them, the expert will not receive his full fee. This is not the same as taxation as in Rule 35.4, in that it is not the amount of fees which can be recovered from the losing party, but the fee which those instructing the expert are liable to pay. In the event that the Court orders a less fee than the expert feels he needs, then he should seriously consider declining the instructions altogether.

Rule 35.9 directs that where a party has access to information which is not reasonably available to the other party, the court may direct the party who has access to the information to:-

(a) prepare and file a document recording the information; and
(b) serve a copy of that document on the other party.

The original draft of this rule proposed that the information be provided by an expert, but this was dropped in the final version. An example of how this rule works is that of a machine which only one party could at an early stage fully understand. It would be helpful to save costs if that party could supply detailed information to the other party on how the machine works, without the expert on the other side having to do research into it.

Rule 35.10 and Practice Direction PD-001,1.1 to 1.6 sets out the manner in which the expert's report is to be drafted. This is an important rule for the expert because it is what the court will see of the expert's efforts, especially if he is not to give oral evidence. To summarize these requirements:-

1) The report must be addressed to the Court, and if proceedings have commenced, the name of the court, case and case number should be shown on the face of the report. The brief from those instructing the expert and any directions from the court should be noted.
2) Name and qualifications of the expert to be shown and details of particular experience in the subject matter for which he will assist the court.
3) Details of any documents, which the expert relies upon. Copies of the documents could be sent with the report, copyright permitting.
4) Give full details of tests and names and qualifications of anyone who assisted the expert.
5) Give range of opinions on matters dealt with and reasons for the opinions.
6) Include a summary of conclusions reached.
7) Make a declaration, to include, inter alia, a statement of truth *"I believe that the facts I have stated in this report are true and that the opinions I have expressed are correct"*.
8) Sign and date the report.

Amendments to the Practice Direction are under consideration at the present time.

Rule 35.11 says *"Where a party has disclosed an expert's report, any party may use that expert's report as evidence at the trial"*. It is also the case that if a party does not disclose his expert's report in good time or in accordance with a direction of the court, then he may not use the report, or call his expert to give oral evidence. The rule does not appear to preclude the other party from calling the expert, if they so wish, once his report has been disclosed to them.

Rule 35.12 deals with discussions between experts, which are ostensibly but not necessarily on a without prejudice basis. By RSC. 0–38, & 38 (Rules of Supreme Court), county courts have for many years had the power to order that experts meet, before or after their reports have been exchanged. This has regularly been exercised by Official Referees in the Queens Bench Division (now Construction and Technology Court) but there is a new twist to the way in which it can now be ordered by Rule 35.12. Experts are not ordered to meet, but to discuss the case and this means in more than 50% of cases either a telephone or video conference, thus saving valuable travelling time. Experts must now also work under the supervision of the parties, jointly or severally, or by order of the court who may define the issues to be discussed. Reasons must also be given when there is disagreement.

Rule 35.13 says that *"a party who fails to disclose an expert's report may not use the report at the trial or call the expert to give evidence orally unless the court gives permission"*. This is not a new requirement and is in similar terms to the former RSC. 0–38 or 36. The expert is not likely to be caught unawares when he attends court, to find a report from another parties' expert. This has occurred in the past, mainly due to solicitors not advising that a report had been disclosed. Supplemental reports can slip through without the expert having seen them. In one case, it was only revealed during examination in chief of another expert that a supplemental report had been disclosed. The judge decided to retire to read the report and the author quickly obtained a copy from the witness box and read it before the judge returned.

Rule 35.14 now gives the expert direct access to the judge before the trial. This is a helpful rule and enables the expert to ask the court for directions in carrying out his function as an expert. The expert need not give notice

to those instructing him but can write directly to the court. This new facility should be used sparingly. The author has come to the point of using it, but at the last minute the matter was resolved. In that case there was an order of the court that the experts meet and together inspect and test the operation of a machine which was the subject of a dispute as to satisfactory quality and operation. The machine performed several functions and the experts met and inspected and tested some of these functions. The other expert was instructed not to attend again and the author pointed out that the machine had not been properly tested. In the absence of co-operation from the other expert, the author was about to write for directions when it was agreed that the tests be completed.

Rule 35.15 involves assessors who sit with the judge to advise him. The assessor will write a report which is disclosed to the parties before trial, but can not be cross-examined on his report. He has a judicial role. Any party can object to a person put forward as an assessor, either personally or in respect of his qualifications.

45.5 Conclusion

In this age of the specialist, but also interdisciplinary, nature of modern life, the man in the street faces considerable difficulty when asked to understand and perhaps vote on issues involving technical factors.

The Plant Engineer has acquired experience gained through practise and comprehension of the concepts of current theoretical thinking to provide a fundamental understanding of nature harnessed to serve man through machinery and plant. The Plant Engineer recognizes his responsibility for the effect of his machinery upon the ecology and the wellbeing of his fellow man, so is well placed to act as an Expert Witness and explain the behaviour of nature and man's exploitation of it in his creations.

References

Academy of Experts, 2 South Square, Gray's Inn, London WC1R 5HP. Tel +44 (020) 7637 0333.

The Law Society 113 Chancery Lane, London WC2A 1PL. Tel Directory of Solicitors & Barristers +44 (020) 7242 1222.

Register of Expert witnesses, J&S publications, PO Box 505, Newmarket, CB8 7TF. Tel 01638 561590.

Expert Witness Institute, Newspaper House, 8–16 Great New Street, London EC4A 3BN. Tel +44 (020) 7583 5454.

Society of Expert Witnesses, PO Box 345, Newmarket, CB8 7TU. Tel 0345 023014.

Law Society list of Expert Witnesses Institution of Mechanical Engineers, Expert Witnesses List. 1 Birdcage Walk, London SW1 H 9JJ. +44 (020) 7222 7899.

Institute of Marine Engineers list of Expert witnesses, 80 Coleman Street, London EC2R 5BJ. Tel +44 (020) 7382 2670.

Waterlows Directory of Solicitors & Barristers Expert Witness Section, Paulton House, 8 Shepherdess Walk, London N1 7LB. (020) 7490 0049.

Expert Witness~Expert Consultant, Gainsborough House, 109 Portland Street, Manchester M1 6DH. 0161 279 1000.

46 Education and training

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46.1 The professional plant engineer

The profession of engineering, in contrast to many others, is extremely wide ranging in the spread of topics, technologies and specializations included under the overall heading. The early engineers, the creative geniuses of their day, encompassed all these latter-day specializations, famous examples being Brunel, Stephenson and Telford. Engineers have been at the heart of all technological and scientific progress. Without them the world as we know it today would not exist.

This has been despite the fact that the UK has developed with a culture which is indifferent to engineering, the 'respectable' professions being those such as law or medicine, offering more money and prestige. This deeply rooted British attitude was supported by an education system in which, on the whole, applied science – engineering – was not studied in schools or universities. This contrasts with the rest of Europe, where such studies were an important part of the curricula of many schools and universities as early as the eighteenth century. Engineering was not considered suitable for those with the ability to enter a British university, where arts and sciences were studied.

The need for education in engineering in the UK was met by the development of Mechanics Institutes. By the middle of the nineteenth century around 120 000 students per annum attended some 706 institutes on a part-time basis, thus laying the foundations for the pattern of engineering education in the UK. In 1840 the first chair in an engineering discipline (civil engineering) was established at Glasgow University, soon to be followed by one at University College, London. Oxford and Cambridge were late on the scene, establishing chairs in engineering in 1875 and 1910, respectively.

Also peculiar to the UK is a somewhat confusing array of professional engineering institutions. These were originally learned societies where like-minded people met to exchange views and information. They developed into qualifying bodies by setting levels of experience and academic attainment for different grades of membership. The oldest professional engineering institution in the UK is the Institution of Civil Engineers, established in 1818. The Institution of Mechanical Engineers was established in 1847 and the Institution of Electrical Engineers in 1871. Three quarters of the approximately 35 institutions which are the Nominated Bodies of the Engineering Council were founded in the twentieth century, some quite recently, reflecting the growth of certain engineering disciplines such as nuclear engineering, computing and electronics.

46.2 The Institution of Plant Engineers

The Institution of Plant Engineers (IPlantE) had its origins in the Second World War, when engineers who found themselves responsible for the operation and maintenance of the large excavators and other mobile plant brought from the USA to work open-cast coal met together for the exchange of information and to discuss their problems. These meetings were so successful that the engineers concerned decided to continue them in a more formal manner through the medium of a properly incorporated body. The Memorandum of Association of 'Incorporated Plant Engineers' was subsequently signed on 3 September 1946.

The concept of an engineering institution which covered a wide field attracted engineers from many different areas of activity, including industrial, municipal and service establishments, civil engineering projects, transport undertakings, design, research and education. By 1947 branches of the Institution were holding monthly meetings in London, Birmingham, Manchester, Leeds, Newcastle, Glasgow and Bristol, and in the following year six more branches were established. There are now 20 branches in the UK and also a large number of members in other countries.

In January 1959 the Board of Trade gave permission for a change of title from 'Incorporated Plant Engineers' to 'The Institution of Plant Engineers'. This marked an important stage in the Institution's development, enabling it to take its place alongside other established engineering institutions. The Bureau of Engineer Surveyors, whose members had particular interests and expertise in relation to the safety and insurance aspects of plant operation and maintenance, merged with the Institution in 1987, forming the basis of a new specialist division for engineering inspection.

46.3 The Society of Operations Engineers

Another milestone for the Institution was on the 1st, September 2000, it amalgamated with the Institute of Road Transport Engineers to form a new body called the Society of Operations Engineers (SOE).

The Society of Operations Engineers is therefore in many ways a small-scale reflection of the engineering profession as a whole, embracing a wide range of disciplines and activities. The Society's IPlantE professional sector members work in the fields of, and have responsibility for, designing, specifying, building, installing, overseeing, commissioning, inspecting, operating and monitoring the efficiency of plant of all kinds. This can include most types of building, plant and equipment used in the manufacturing, chemical and process industries, educational establishments, warehouses, hospitals, office and residential accommodation, hotels, banks, theatres, concert halls and all types of transportation systems. In the broadest sense of the term, these are the assets of the organization in question, without which it could not function. The plant engineer thus carries out a key role as the practical manager of these assets. The Society offers the full range of services to members and provides the opportunity for cross-fertilization of best practice between two major sectors of engineering. The titles of IPlantE and IRTE have been kept alive as **Professional Sectors** of the Society.

46.4 Aims of the Society

The **purpose** of the Society (what it aims to do) is:

To promote safe, efficient and environmentally sustainable operations engineering to the benefit of society.

Its **vision** (what it aspires to be) is:

To be the preferred professional body for those engaged in the life cycle management of systems, facilities, vehicles and equipment, and the recognized authority on these matters

These are defined by **four strategic aims:**

- Improve professional education, training, competence and ethics;
- Influence legislation and design;
- Enhance public understanding of the contribution of the Society and its membership to the community;
- Promote the benefits of membership and professional registration.

Finally, the Society's **core values** are:

- customer focus
- professional standards
- parity of esteem
- multidisciplinary approach, within and beyond engineering.

46.5 Organization

Overall direction of the Society is vested in its Council, but much of the detailed work is carried out by committees and panels of members. Branches and divisions of the Institution are run by their own committees, which arrange programmes of visits, lectures and other appropriate activities, spread throughout the year. Non-members are very welcome to attend most events. The Society publishes a monthly newsletter the 'Bulletin' and each professional sector publishes its own journal – the Plant Engineer and Transport Engineer and other technical information – conferences and seminars are also organised.

The Society's permanent staff are always available to give help and advice on matters relating to membership, education and training, and Engineering Council registration.

46.6 Membership

Membership of the Society of Operations Engineers is the hallmark of the professional plant and road transport engineer and is often a prerequisite for successful career progression. This will become increasingly so in Europe, when evidence of appropriate professional qualifications may be a legal requirement for employment in many engineering appointments.

46.6.1 Membership requirements

The principal classes of membership are:

Fellow
Member
Associate member
Associate
Graduate
Student

Up to date requirements for each class of membership may be obtained from the Society's membership department: membership@soe.org.uk or 020 7630 6666.

46.6.2 Courses leading to a career in plant engineering

The main courses leading to a career in plant engineering are the Business and Technician Education Council's (BTEC) National Certificate or Diploma in Plant Engineering and Higher National Certificate or Diploma in Plant Engineering. In Scotland the equivalents are the Scottish Technician and Vocational Education Council's (SCOTVEC) National Certificate in Mechanical Engineering (Plant Engineering Options) and Higher Certificate in Mechanical Engineering (Plant Engineering Options). Additionally, certain other National Certificates and Diplomas and Higher National Certificates and Diplomas in subjects other than 'Plant Engineering' have been assessed by the Society and approved for membership purposes. Degrees, degree course options and diplomas and higher degree course options are available at certain universities and polytechnics in the UK. Further guidance on courses and their entry requirements may be obtained from colleges or universities or from the Society's professional standards department.

46.7 Registration with the Engineering Council

An individual engineer's registration with The Engineering Council (EngC) is a further valuable indication of professional attainment and standing. The Engineering Council was originally established by Royal Charter in 1981 to:

1. Promote and develop the science and best practice of engineering in the UK:
2. Ensure the supply and best use of engineers:
3. Coordinate the activities of the engineering profession.

The Charter empowers The Engineering Council to establish and maintain a Register of qualified engineers. The registrants may, where appropriate, use one of the following titles and designatory letters:

Chartered Engineer (CEng)
Incorporated Engineer (IEng)
Engineering Technician (EngTech)

Each of these three qualifications is obtained in three stages. Stage 1 indicates attainment of the required academic standard, Stage 2 that approved training has been received and Stage 3 that responsible experience has been gained. The titles may only be used at Stage 3.

The Society is a Nominated Body of The Engineering Council and is licensed to register its members in all three grades of registration.

46.8 Registration as a European Engineer

Registration with the European Federation of National Engineering Associations (FEANI) is available to UK engineers, and may be helpful to careers in Europe. For those registered as Chartered Engineers with the Engineering Council registration with FEANI will allow the engineer concerned to use the title European Engineer. This title has the designatory letters Eur Ing, which should be used as a prefix (for example, Eur Ing John B. Smith, CEng, MSOE, MIPlantE).

Further information and FEANI application forms are available from the Society's membership department.

46.9 Professional engineering development

Throughout the professional life of most engineers there is a need to acquire new knowledge to enable them to tackle the technical and managerial problems that they face from day to day. Recent advances in technology, materials and processes emphasize this need, but with ever-increasing demands on time, opportunities to attend full-time courses are few. The plant engineer must therefore rely upon a Continuing Professional Development (CPD) to enable successful updating to take place, thus enhancing his or her professional development.

The Engineering Council places considerable emphasis on CPD as an essential part of a professional engineer's development, and recommends that CPD forms a normal part of an engineer's career and that such CPD activity be noted in his or her personal career record.

To enable those engineers engaged in plant engineering to look to the future. The Institution of Plant Engineers has formulated a procedure for recording an engineer's attendance at activities which contribute to CPD and have been approved by the Institution for that purpose. Further information may be obtained from the Institution.

46.10 Addresses for further information

The Society of Operations Engineers,
22 Greencoat Place
London, SW1P 1PR.
Tel: 020 7630 1111
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Website: www.soe.org.uk
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EdExcel BTEC
Central House
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London WC1 0HH
Tel: 020 7393 4500
Fax: 020 7393 4501
E-mail: enquiries@edexcel.org.uk
Website: www.edexcel.org.uk

Scottish Qualifications Authority
24 Douglas Street
Glasgow G2 7NQ
Tel: 041 242 2214
Fax: 0141 242 2244
E-mail: mail@sqa.org.uk
Website: www.sqa.org.uk

The Engineering Council
10 Maltravers Street
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Tel: 020 7249 7891
Fax: 020 7240 7517
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47 Waste management

Eur Ing Dennis A Snow CEng, MIMechE, HonFSOE, HonFIPIantE, HonFIIPE

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47.1 Identification of waste

Before it is possible to draw up any form of Waste Management System, it is absolutely necessary to identify and classify what is waste and where and how it should be dealt with, and most importantly – waste is not some other person's problem – if it is on your property it is your problem.

47.2 What is classed as waste?

In any industry or business waste can come in many forms and from many differing sources each requiring initial recognition, different methods of storage, treatment and disposal, each having their own associated problems.

47.3 Purchasing waste

Most purchases of materials, disposable stores, chemicals, or other usable commodities usually bring with them their own specific problems. Yes the packaging may be absolutely necessary to protect the materials or commodity from transport or distribution damages and to provide the dispatcher with a minimum of problems and as far as possible clear of insurance or providers responsibilities.

This, however, presents the receiver with a problem of disposal or in some cases a liability for the return of the container, pallet or frame as may be applicable. But in any case a problem is produced, however small, of disposal. The purchaser has therefore acquired some form of surplus materials, which has to be disposed of.

Wherever waste is concerned they are usually associated with their own problems – handling, storage, disposal all of which will probably involve a cost of some sort, and depending on the type of waste it can escalate and become a problem, especially if it means such items as non returnable containers, which may have contained environmentally unfriendly materials, like chemicals or specialized manufacturing materials, all of which, with their own, and possibly, costly solution to their disposal.

When planning a new factory, especially if it is of the manufacturing type, involving the working of materials, such as steels or other engineering materials, and the like. In such cases due consideration is usually taken into consideration during the planning process, as off-cuts and waste materials may be part of the manufacturing process, especially if the surplus can be sold or recycled, and be considered as part of the manufacturing process and the cost accounting credited or debited as part of the management cost accounting system.

47.4 Why should we worry?

Until recently waste has been quite easily dealt with by the use of land-fill sites, and because of indiscriminate discharge of materials all sorts of environmentally unfriendly situations have occurred, not least, the shortage of land-fill sites, located in areas which will not have an effect on the locality.

Years of what can be regarded as uncontrolled dumping of waste in all its differing forms. which, in turn, has lead to a more controlled look at the whole of the waste situation, not only on a national basis, but has now attracted attention of the European Community and the introduction of directives, in order to bring the waste disposal under tighter controls.

The main objectives being to reduce the amount of disposable waste, to recycle wherever possible and to convert any discarded energy, in the form of waste, into some re-usable form.

The waste industry has developed considerably over the last few years as controls have increased and costs have escalated, bringing the costs into a much higher proportion of the industrial overheads.

Every form of waste needs to be very carefully examined to see what costs are likely to be involved in their disposal or whether they have some form of monetary value, be it direct, or indirect.

For example, somewhat similar industries tend to develop in the same areas, such as laundries and dye works, each having waste products which are significantly different in themselves but can be regarded as complimentary to one another.

One discharge being very alkaline from the laundry and very acidic from the dyeworks, each carrying significant costs from the sewage authority for disposal, but if the two can combine their discharges, they may be able to, with suitable control, neutralize each other and therefore considerably reduce both effluent charges, and possibly avoid considerable 'in-plant' treatment installations.

There are likewise many other situations where industries can help each other out by utilising wastes or surpluses of commodities. Some plants may have a surplus of heat from their processes, which possibly could be used for heating purposes in an adjacent works or office block.

There are also other occasions where a plant may be generating electricity and could have a surplus of steam or hot water available for use by a neighbouring company or even a surplus of electricity if the firm is a high steam user. There are other occasions where consideration could be given to providing neighbours with other energy requirements.

There was an occasion a few years ago where a power station offered a senior association football club free surplus heat for underground heating if the club provided the pipework necessary.

This was eventually turned down on the basis of the installation costs, which on the face of it would have paid dividends as it was at a period when football matches were being cancelled due to pitch conditions.

These are examples of the sort of solutions that can be explored.

Some industrial concerns develop their own waste problems, such as large industrial contract cleaning where workwear is cleaned using the dry-cleaning process and the residue of the industrial oils collected from the processing becomes a disposal problem, which in some cases can be expensive to have removed from the premises although if sufficient research is done it is possible to

sell these residues to companies who operate in oil reclamation, although the return is far from being large, it is a far better solution than paying large sums to have it removed.

Consideration can also be given to the burning of these residual oils but it is important that all signs of solvents have been removed first as residues of solvents like 'trike & perk' give rise to the generation of phosgene gas when heated.

Whatever the problem waste must be treated as a serious part of the business, as the company must take care to know what the wastes are and how they are going to be collected and how they are going to be stored before disposal.

In the UK the waste business has really only started to develop properly over the last twenty years, and has now moved into a becoming a very technical and lucrative business and the signs are that there are great advances to be made in future as the disposal problems develop and the character of the waste changes with the changes that are taking in the manufacturing industries.

The local Authorities in the UK have started to have problems with the availability of waste-fill site and the population, in general, objecting to the development of incinerator plant being placed near to housing sites as well as near places of interest or natural beauty.

A number of local Authorities are developing their own experiments on the collection of domestic waste, where re-cycling is given a priority, and some are going to great lengths in order to follow this trend, as it is a more positive approach than straight disposal means.

This follows the shortage of disposal sites for land-filling, continually backed by the public, as an environment move.

The co-operation of the population is paramount in this approach as the whole success relies on their co-operation throughout the whole experimental procedure. Presumably if some of these experiments are successful then this will creep over into the industrial sector.

The Local Authorities are after solving their disposal problems but in due course, if successful, this could result in rate reductions.

47.5 Where do we start with the waste problem?

As with so many other problem areas, the correct approach should be based on a sound professional and organized way. In other words the first step should be: 'A Waste Audit' to find out what the problem is and how best to take steps to solve it.

47.6 The Waste Audit

A audit is not an excuse to investigate, but an opportunity, to examine your organisation, from a different perspective, with an entirely structured system, with a different set of motives, and could be likened to an energy audit, where everything associated with energy is investigated, especially costs and their effects on profitability.

A thorough examination of every area and possible classification of every source of any waste material, wherever it may originate from, and in whatever form.

This audit will enable you to discover the source, enable you to investigate the reason behind its origination, whether it be a straight excess from some production process, and if in excess, possibly identify a process malfunction, or incorrect sizing of materials, leading to an unnecessary surplus or financial wastage.

It will also enable you to take a fresh look at the way you handle your waste materials and to make decisions as to whether they are adequately stored, including safely, separated, and removed from site, and the associated costs. Usually excess of materials in the form of waste may focus your attention to identify an excess of cost of manufacture or a reduction of profits.

The audit presents an opportunity to evaluate your processes and to examine, what could be regarded as the other end of scale. There is always the tendency to look at the initial supplies from a purchasing point of view, but the tail-end tends to get neglected.

The other question during the audit should be how much surplus have we got and can it be reduced, or can the surplus be sold or reused for some other purpose, or converted or used as a by-product. How can this material be disposed of and how much will it cost to do so?

47.7 Audit assessment evaluation

Waste identified	Process involved	Source	Quantity of waste	Storage	Disposal	Value +/−

47.8 Waste identified

47.8.1 Delivery materials

The first task should be to identify the waste, in other words, find it and investigate location, what is it and where does it come from. This includes was it part of a delivery packaging, is it a returnable item, such as a wood pallet, Packing box, Cable drum, chemical container etc. Is it simple waste for easy disposal, Is it a mixed waste (consisting of more than one material requiring a more complicated disposal).

47.8.2 The offices

The offices can be put into this category, because there are at least two differing wastes and probably more. For

instance paper is the obvious classification, with very simple disposal means, but there are other items which originate in the office such as plastic cups, heavy cardboard, printer carbon containers, ink jet printer cartridges, fruit skins, apple cores, lunch packages, chewing gum, plastic & glass bottles, drink cans, discarded smoking materials etc. all of which could be separated from the waste paper. A simple experiment will soon give you an indication as to these different classifications, by providing every office with two waste bins suitably marked for each class.

47.8.3 The processes

Each process will produce its own specific waste. First of all is the packaging of materials coming in to the process and the final side will probably be surplus materials. These can vary considerably with different processes and industries, each having their own problems and requiring their own disposal system.

Depending on the quantities involved may even give rise to a deeper investigation to determine why the quantity is of such a magnitude, possibly indicating over ordering, incorrect sizing of the ordering specification, or poor housekeeping or inefficient usage by the operatives, indicating a supervision problem.

The value of waste could indicate a reduction of process profitability.

Each process should be looked at individually, suitably recorded, with its own storage and disposal problem.

47.8.4 Process involved

Having classified the waste then the record sheet should state the processes involved.

47.8.5 Source of waste

Where did it come from, was it necessary because of what it protected, could it be reduced in future or protected in a different form.

If the materials produce a quantity of waste, the use or ordering procedures and specification may requiring a change, or even a slight variation in process may make a difference to the type and quantity of the waste produced.

47.8.6 Storage

Having identified the type and quantity of waste, then the safe and correct storage must be considered. If the waste is flammable then it will be necessary to take all the necessary steps to see that safety is maintained and the correct containers are designed or employed and suitably located.

If the waste is a liquid, flammable, non-flammable or hazardous, then the storage will require a more stringent storage arrangement. This will be necessary, apart from the fire risks there will probably be an accidental leakage possibility, so it may be necessary to provide a suitable leak-proof 'bunded' area, capable of containing a larger quantity than the volume of the container.

In these cases advice should be requested from what ever authority may be interested, namely, water and fire authorities, and where chemicals are concerned, the suppliers. Extra precautions must be taken to avoid accidental spillage which could find its way into the local foul or storm-water courses, or even to your own underground ducts, which may house many differing services or lead to areas within the plant and become a hazard situation elsewhere.

47.8.7 Waste quantity

As mentioned previously the quantity of waste may lead you to other related investigations.

Depending upon the quantity of waste will ultimately lead you to decide on the volume of storage necessary to cope with the normal production with allowance for an over-run, which could be brought about by a failure of the any disposal collection contractor, to collect on time or for sudden additional production runs which could produce an increase in quantity.

47.8.8 Disposal

The ultimate problem associated with waste which is produced from a plant, or commercial organization is the disposal. Who is going to take it away and how and where is it going to be taken and eventually terminated. This could be any of a number of destinations: incineration, waste-fill, change its form and re-cycled, taken to be re-used, in the case of many metallic products, direct delivery to the steel manufacturers.

In all probability you will require to seek, not only advice from one or more waste contractors and to request quotations for whatever may be necessary. In recent years the collection and disposal of waste has become a fairly technology based industry, compared with some years ago, when there were many small contractors operating a service, sometimes dealing with a single type of waste.

Since the introduction of so many restrictions and codes of practice being brought in by the European Community, the whole industry has been changed and the contractors increased in size, with many of them covering large areas and in some cases National organizations, with multi-million pound turnovers, and good reputations to uphold. In these cases you should be able to rely implicitly on the correct procedures being used and operated and that they will comply with all the appropriate regulations, and hence relieve you of the problems of disposal.

47.8.9 Value

Waste has a value! But you are the one to decide what that value is. If it is possible to sell the waste for whatever use it may have as a scrap value, as a commodity which can be used directly or could be converted for another useful purpose. Many a company has profited considerably, from using their waste as a by-product, for instance, broken concrete slabs produced in the manufacturing process are often sold off for rockery or patio paving, or hardcore for the construction industry, thus eliminating a

disposal problem. The soft furnishings industry dispose of a considerable amounts of foam materials for use in the home or 'D I Y' activities, or for another industry making toy dolls etc.

Some sewage plants use some of their waste as compost materials either in briquette or bagged materials. Riding stables sell their horse manure for gardening or small holding use.

These are samples where the waste has a positive value, as opposed to a negative value where you have to pay for removal and disposal. The value depending on the eventual destination. The concept goes back many years with the 'Rag & Bone man' who would collect certain items of waste and in return exchange some other useful items for home use, usually in the form of pummice stones for step doorstep colouring or clothes pegs.

On the other hand, your waste may have a value to the collecting and disposal contractor, now regarded as a big business, especially as the regulation, being inflicted on disposal by governments and the European Community with the environment being the basis for many of the regulations.

It will be seen from the chapter on 'effluent' that on-site treatment is probably a cheaper alternative than discharge down to the sewage system, by reducing the strength or changing the constituency before discharge, and hence complying with the effluent authority restrictions and therefore a lower charge.

Segregation of waste can also bring with it a lower cost of disposal, where, for instance, paper can be compressed, reducing the volume and hence the disposal problem, and, possibly at no cost or at least for a small charge, if a suitable purchaser can be identified. This is a case where segregation of the office waste could be advantageous.

In the industrial dry cleaning industry, the cost of disposal of the oils removed from the process of cleaning of industrial overalls using 'Trike or Perk' experience has varied. In some cases, companies have had to pay for collection and disposal of this waste, which can be considerable, and there have been cases, where the materials have been sold and the oils reclaimed for further use, such as for boiler firing, once the traces of solvent have been removed.

In these cases it is very important that all traces of the cleaning solvents have been cleared as they contain elements which, on being burned or heated, produce phosgene gas.

47.9 The sectors

The whole waste situation revolves around the three sectors who are indirectly responsible for the production or disposal of waste:
Namely:

Industrial Sector
Commercial Sector
Domestic Sector.

Each sector having its own reason for the production of the waste, whether it be as a tool for selling a product, where volume packs, giving the impression of larger quantity or volume because of pack and presentation.

It is only a very careful examination of individual products and the packaging to determine the larger size effect.

On the domestic market, breakfast cereals are a good example where a packet gives the impression that it contains far more product than it does.

The American popcorn uncooked occupies a small volume but once opened and initially heated the volume expands to many times the original size.

The current arguments that will continue for some time as to whether waste should be incinerated or land-filled, both being the destruction of the waste when in fact the basic reduction of the waste in the first place would be the ideal solution.

Pressure from environmental groups or Government directives will be the only way to solve the problem, but self regulation with economy or profitability in mind should be way forward and each individual company should be looking at all avenues to help solve their own problems, preferably before they occur.

47.10 History and the predicted targets

It was not really until the beginning of the 1990s that the waste battle started.
In 1990 about 90% all waste was sent to landfill.
The Government started the strategy: reduce, recover, re-use, dispose.
The introduction of the Environmental Protection Act.
1996 – Waste Framework Directive, introduced into the UK through the Waste Management licensing Regulations 1996.
1996 – Introduction of Landfill Tax.
1997 – Introduction of Packaging Waste Regulations.
2005 – Recover 40% of municipal waste, re-cycle or compost 25% of household waste.
2005 – Incineration Directive applied to all plants
2100 – Programme going up towards 165 new incinerators and up to 500 new recovery and composting facilities by 2015

These may be the objectives of European or UK government but ideally each company should set their own targets and objectives for their waste policy, as the company is the only organization capable of changing their own policy in order to meet the current regulations and to change their own systems to help meet their own goals or to reduce their own costs.

It may be necessary to have to enlist the expertise of the purchasing department, the marketing department if it involves the packaging of their products to meet the marketing objectives.

Probably the last assistance will we to call in a waste disposal company to advise on how to dispose of the waste, but however, should this be the last act. Ideally a c waste disposal company or even a waste consultant could be brought into at the discussion stage so that all the alternative possibilities are explored before decisions are formulated.

The waste disposal industry has come a long way in a very short span of years, and now, with the larger companies getting far more technology minded, and having the latest techniques available to them, are well placed to be able to advise a company and possibly be able to make recommendations towards an economical way of waste control.

As with so many industries, and the waste disposal industry is also involved in mergers and groups working together, as the whole disposal business is so much dependent upon the smaller, less conventional companies, in order to be able to offer a complete package of waste disposal.

The manufacturing industries should be encouraged to work on the total lifecycle disposal policy whereby a company can recover the materials from their products when they are eventually scrapped, and that they are then reusable for the manufacture of new products. This would revolutionize the whole manufacturing industry and make the waste disposal easier and the cost of manufacturing in the future that much more economical.

Once you have a waste situation it means that you have a decision to make as to how you deal with it, and what costs, profit or re-use is available.

47.11 Your programme

Decide to look at your waste problem.
Do your waste audit.
Examine the results.
Look at each waste source
Evaluate each of the costs
See where changes can be made
Look at your purchasing specifications
Look at the possibilities of recycling your waste
Can re-cycled materials be used
What is going to happen to the materials, both packaging and the product at the end of the cycle.
Bury it, re-cycle it or just pay somebody to get rid of it.
Quantify your efforts – was it worth it?

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