Environmental Science

Ramesha Chandrappa
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Sustainable Air Pollution Management

Theory and Practice

Springer

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ISSN 1863-5520 ISSN 1863-5539 (electronic)
Environmental Science and Engineering
ISSN 1431-6250
Environmental Science
ISBN 978-3-319-21595-2 ISBN 978-3-319-21596-9 (eBook)
DOI 10.1007/978-3-319-21596-9

Library of Congress Control Number: 2015946763

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

This book is dedicated to family and colleagues

Preface

As per World Health Organization, air pollution is now the major killer. But the message has not still gone into the minds of decision makers across the globe. Since the movement of pollutants does not respect political boundaries, they kill innocents across the borders. What is more painful is changing climate is posing challenge to predict the movement of pollutants. Decisions taken based on modeling studies and legislations are not delivering desired output. There is always gap between theory and practice. This book is written after reading more than 300 literature and more than 30 years of combined experience of authors to reduce the gap.

Intended Audience

The intended audience include students of both graduation and undergraduation who take over the challenge of cleaning the mess left by their previous generation and curbing emission from own generation. Apart from students, this book is written to guide policy makers and regulators who are changing the dimension of the world.

Goals and Motivation

The text is written to provide clear and concise understanding of challenges posed by air pollution and the solutions. Many works have been done in the field of air pollution by eminent scientist and technocrats. But the authors had unique experience working in a country which is witnessing rapid economic growth and associated impacts on environment. This book also discusses practical difficulties and practices.

Unique Features

Unique features of this book include deep discussion of many pollutants which are not monitored across the globe. The photographs of many air pollution source which contribute air pollutants have been included so that the people of next generation would get a chance to know the current situation the mankind has undergone.

About the Book

The past work of first author has been used as reference book in many universities due to uniqueness and simplicity. The experience is very helpful in bringing out this book so that students and practitioners can benefit from our exposure. Many new ideas have been discussed in this book which is not discussed elsewhere so that researchers and students can carry research on those topics.

Course Suggestion

This book can be used for both undergraduate and postgraduate students. References have been listed at the end of each chapter so that reader can refer original article if required.

Acknowledgment

We would like to thank our families, colleagues, and reviewers for making this project come to fruition.

We would have not achieved the goals set by us without the support of our professional contacts who have helped us in great extent. We are extremely thankful to Ms. Vijayalakshmi; Dr. Ammar, Tutor, Anatomy Section; Dr. Varsha Mokashi, Professor and Head of Department, Anatomy Department, Vydehi Institute of Medical Science for taking picture of lungs; and Dr. Dayanada S. Bilige, Professor, Pathology Department, Bangalore Medical College. We are thankful to Girish Bellur, Transoft International, who helped in obtaining permission to reproduce some of the outputs of the models.

We thank the Swedish International Agency, the British Council, and the Swiss Development Cooperation for their financial assistance extended to the first author during his career. The authors are extremely grateful to the Centre for Science and Environment, Delhi, India, and Swedish Meteorological and Hydrological Institute

and the Swedish Environmental Agency, Stockholm, for arranging extensive international training to the first author in Sweden, which was helpful and gave an opportunity to take the photographs presented in this book.

Ramesha Chandrappa
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Chapter 1
Major Issues of Air Pollution

Abstract Environmental issues change from place to place and time to time. The issues include local as well as global issues. The understanding of issues is necessary to find solution. Air pollution issues have changed over a period of time. Issues like atmospheric brown cloud, climate change, hazardous air pollutants, black/muddy snow which are hardly discussed few decades back have now gaining importance. This chapter elaborates major issues due to air pollution.

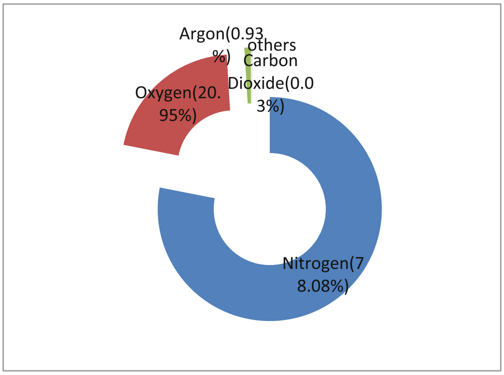
'Pollution' is originated from Latin word '*Pollutus*' which means '*foul or unclear*'. Air pollution can be defined as 'Atmospheric condition in which substances is present at concentrations higher than their normal ambient levels to produce significant effects on humans, animals, vegetation or materials' (Seinfeld 1986).

Air composition

The air we breathe is most important natural resource which allows us to survive. The composition of air around us keeps changing continuously due to both natural as well as man made emissions into the atmosphere. Earth's atmosphere is a layer of gases retained by the gravity. On an average, as shown in Fig. 1.1 dry air consists of 78.09 % of nitrogen, 20.95 % of oxygen, 0.93 % of argon and 0.039 % of carbon dioxide by volume. Minor constituents such as methane (CH_4), Ozone (O_3), Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Nitrous Oxide (N_2O), Carbon Monoxide (CO), Ammonia (NH_3) etc. are also present having very low mixing ratios. These constituents do vary place to place due to change in atmospheric conditions. The air constituents over the sea will not be same as at the shore; sea shore air may not have same concentrations of the constituents as desert air. Sea shore air will be dominated by water vapour where as desert air will have more suspended dust. Similarly, the thick Amazon forest will have more water vapour and volatile organic compounds whereas he air above solid waste dumping site is likely to have more methane and ammonia.

Low concentration of air pollutants does not mean that it can be neglected. Considering example of lead which is present in the atmosphere in traces, the total quantity in 1983 and in the mid-1990s, were estimated to be about 330,000 tonnes (Nriagu and Pacyna 1988) and 120,000 tonnes (Pacyna and Pacyna 2001), As per the study by Richardson et al. (2001), the whole emissions from natural sources were around 220,000–4,900,000 tonnes/year.

R. Chandrappa and U. Chandra Kulshrestha, *Sustainable Air Pollution Management*, Environmental Science and Engineering,
DOI 10.1007/978-3-319-21596-9_1



Neon	Ne	18.2 ppm
Helium	He	5.2 ppm
Methane	CH_4	2.0 ppm
Krypton	Kr	1.1 ppm
Sulfur dioxide	SO_2	1.0 ppm
Hydrogen	H_2	0.5 ppm
Nitrous Oxide	N_2O	0.5 ppm
Xenon	Xe	0.09 ppm
Ozone	O_3	0.07 ppm
Nitrogen dioxide	NO_2	0.02 ppm
Iodine	I_2	0.01 ppm
Ammonia	NH_3	traces
Carbon monoxide	CO	traces
Lead	Pb	traces
Mercury	Hg	traces
Persistent organic pollutants	POPs	traces

Fig. 1.1 Constuents of air

Atmosphere and its layers

When the solar system condensed out of "primordial solar nebula" which is nothing but interstellar cloud of gas and dust, the situation was not as complex as today and air pollution was not an issue. The early atmosphere of this planet was believed to be blend of carbon dioxide, nitrogen, water vapour and hydrogen. The early atmosphere of this planet was slightly reducing chemical mixture as compared to present atmosphere which is strongly oxidizing. With lapse of time, distinct layers of the atmosphere were formed with distinct characteristics. These are described below.

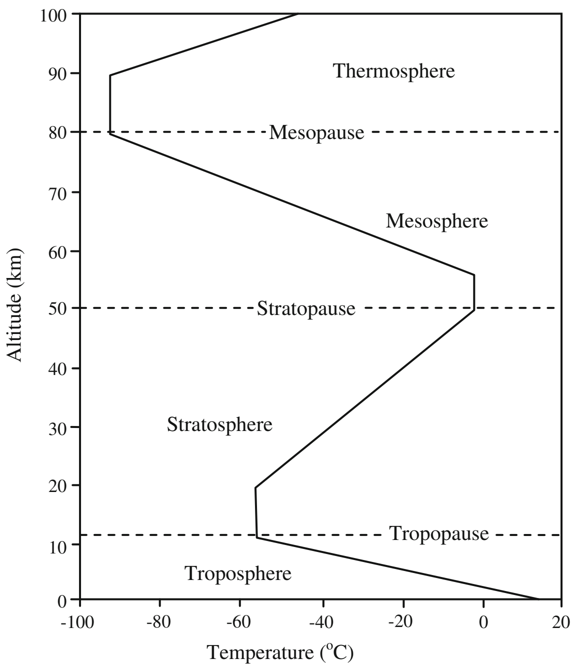
Troposphere: It is the lower most layer of atmosphere extending from the earth's surface to 10–15 km altitude depending on time and latitude (Fig. 1.2). This layer is characterised by declining temperature with height and rapid vertical mixing. Temperature at the ground is about 20 °C and it decreases gradually till the tropopause is reached. The tropopause is the boundary having constant temperature which separates the troposphere and stratosphere.

The decrease of atmospheric temperature (T) with height (z) is called as lapse rate (α) which is expressed as follows

$$\alpha = -\frac{dT}{dz}$$

The change in temperature of a mass of air as it moves upwards is called as adiabatic lapse rate. The dry adiabatic lapse rate (DALR) and the moist adiabatic lapse rate (MALR) are 9.8 and 4.9 °C/km respectively. Actual change of temperature with altitude for the stationary atmosphere or temperature gradient is known as Environmental Lapse Rate (ELR). Generally, decrease of 6.49 °C/km is considered as Environmental lapse rate. In the troposphere, atmospheric pressure also

Fig. 1.2 Temperature profile with changing altitude across different layers of the atmosphere



decreases rapidly with the altitude. One can understand that climbing to an altitude of 5.5 km, would put you above 50 % of the atmosphere's molecules where atmospheric pressure is 500 mb only. Actually, the heating of the surface creates warm air at surface. The warm air rises, but air expands as it rises and cools as it expands (Adiabatic cooling). Typically, the troposphere is characterized by warm air at surface and cooler air above. If the cooler air exists at surface and the warmer air above, this is called as Buoyancy. If a rising air parcel becomes saturated condensation occurs. The condensation warms the air parcel due to the release of latent heat. So, a rising parcel cools less if it is saturated

The atmosphere near earth's surface is divided into different layers based on wind behaviour:

The laminar sublayer also called the viscous sublayer, is the region in which the flow is laminar. With respect atmosphere it is usually less a centimetre.
The surface layer extends from ≤30–50 m. The heat and vertical turbulent fluxes in this layer are constant.
The Ekman layer is the layer in a fluid where force balance between pressure gradient force, turbulent drag and coriolis force are balanced. It was named after scientist Vagn Walfrid Ekman who explained the phenomena for the first time. Ekman layer extends to height of 300–500 m. In this layer wind direction is affected by earth's rotation. Wind speed his layer generally increases with height.
Free atmosphere is the layer above Ekman layer in which the effect of the surface friction on the air motion is negligible.

Stratosphere: It is positioned just above the troposphere extending from 11–50 km. In the stratosphere, temperature increases with altitude, from −60 °C at base to 0 °C at the top of the stratosphere. The increase in temperature is basically due to the absorption of solar energy by the ozone layer. Ozone (O_3) is effective absorbing species for solar UV radiation (200–310 nm with a maximal absorption at about 250 nm) in the stratosphere. Generally, UV-C (280–100 nm) which is highly harmful is entirely screened out by dioxygen (<200 nm) and ozone (>about 200 nm) before 35 km height. UV-B (315–280 nm) radiation is mostly screened by ozone layer. UV-A (400–315 nm) reaches earth surface having small damage e.g. premature ageing of skin etc.

Mesosphere: Just above the stratosphere, the mesosphere exists extending from 50–80 km altitude, The space shuttles orbit in this layer of the atmosphere. Due to decrease in solar heating, temperature decreases with altitude in the mesosphere, 0 °C at base, −95 °C at the top of the mesosphere. The top of the mesosphere is the coldest region of atmosphere. Polar mesospheric clouds of water ice are seen in this layer which are known as Noctilucent clouds. These are highest clouds in earth atmosphere and are seen mostly during summer months between 50 and 70 degree N and S. The D layer of ionosphere also exists in mesosphere which is seen during the day time. Meteors burn up in the mesosphere while entering the earth atmosphere.

Thermosphere: Thermosphere is the last layer of the atmosphere which exists at 80 km and above up to exosphere. In the thermosphere, the temperature increases with altitude as atoms of this layer are accelerated by solar radiation. Temperature at the base of the thermosphere is −95 °C but it is 100 °C at 120 km and 1500 °C at upper part. Though the temperature of this layer is very high but the heat content negligible. Auroras exist in thermosphere. The **Auroras are seen due** to the effect of energetic particles (electrons and photons) coming in the solar wind. Charged particle entering the atmosphere ionize atmospheric constituents. The **aurora** can be seen best in the dark sky or 'magnetic midnight' time. In northern latitudes, the effect is known as the **Aurora** borealis (or the northern lights), named after the Roman goddess of dawn, **Aurora**, and the Greek name for the north wind, Boreas, by Galileo in 1619. International Space Station orbits in upper part of thermosphere (320–380 km). In the thermosphere, ionization occurs due to UV rays. E and F regions of ionosphere exist in this layer. At the Exosphere (beginning 500–1000 km), the atmosphere turns into space.

Ionosphere: In fact, the Ionosphere extends from 50–1000 km covering partly mesosphere and thermosphere. It has diurnal and seasonal variation as the ionization depends upon Sun and its activity. As mentioned earlier, the D region of the ionosphere exists in the mesosphere while E and F regions of the ionosphere exist in the thermosphere. Ionosphere is a shell of electrons and electrically charged atoms and molecules. E and F regions are present at nights. D region is formed during day time when the E and F regions become much stronger. Often during the day, the F region is further differentiated into F1 and F2 regions. In the D region, UV rays ionize NO and X-rays ionize O_2 and N_2. In the E region, X-rays and far

UV ionize O_2^-. E region can reflect radio waves lower than 10 MHz. Extreme UV rays ionize O_2 in the F- region during nights. F layer is responsible for short wave (HF) radio communication for long distances.

History of air pollution

Ever since the discovery of fire, air pollution has been a problem. "heavy air of Rome" in 61 A.D., has been recorded by Roman philosopher Seneca. In 1273, King Edward I prohibited burning of coal in London (William and Lou 2003). By the 1280s, people were using coal as fuel in processes like limekilns and metalworking leading to air pollution which had black smoke as well as oxides of sulphur. Late 18th and early 19th centuries saw dramatic changes in manufacturing, agriculture, mining, production as well as transportation. Invention of electric power in the nineteenth century resulted in coal fired electric generation in 1880s. Very famous example of air pollution is the smog formation around Los Angeles during the 1940s which led to the passing of first state environmental legislation in USA. In 1955, the Air Pollution Control Act was enacted in USA which was the first federal environmental legislation in the country. Later on in 1960s, oil overtook coal as the source of primary energy. Extensive use of oil led to the emissions wherever vehicles moved.

With the industrial revolution in the post eighteenth century economy changed to machine-based manufacturing in many of the present developed countries. Mechanization of the textile industries and iron-making techniques increased demand for fuel and their by air pollution in those areas of such activities. The developments in 19th century led to second industrial revolution.

The construction activity also saw shift in construction material as well as technology. The invention of cement replaced mud walls (Fig. 1.3) and increase in cement demand lead to emissions from this sector.

Fig. 1.3 Remnants of historic building with mud masonry in an Asian City

Fig. 1.4 Traffic from a developing Asian country

As the European and American markets were saturated, Asian markets opened up for vehicles which are currently unbalanced where in poor people ride on bus top or trucks while rich people ride in individual cars (Fig. 1.4). While the economic crisis in Greece resulted in reduction of air pollution (Vrekoussis et al. 2013) China witnessed dramatic air quality detonation last decade. Analysis of data from monitoring network created by WHO and UNEP in 50 cities in 35 developed as well as developing countries shows that over the past 15–20 year indicate that the lessons of earlier experiences in the now developed countries have yet to be learned. Air pollution in 20 of the 24 megacities shows that ambient air pollution at levels where serious health effects (David et al. 1996). The rise of population in the developing countries in future with a lack for air pollution control will worsen in many more cities.

In the beginning of 1970s when the rapid growth in Europe lead to environmental pollution and air pollution of London which resulted in death of more than 5000 people was fresh in memory the United National Conference of the Human environment in Stockholm in 1972 lead to foundation of international cooperation in this regard. This is followed by series of development that aimed to bring down air pollution. Convention on Long-range Transboundary Air Pollution in 1979 was signed UNECE countries. Governments of UNECE member states signed the convention on Long-range Transboundary Air Pollution on 13 November 1979. The 1985 lphur Protocol or 30 % protocol aimed to bring down 30 % SO_2 at national level by countries of UNECE region.

All business decisions affect the air and atmosphere. Hence, like water which is purified, packaged and priced, soon pure air will also be priced. There are oxygen bars opened up in many parts of the world to supply oxygen to customers. However, inspite of urgent need of stringent air pollution policies and regulations in several parts of the world, air pollution control is still not a political priority as compared to the business and economy in many parts of the world. As a result the pollution is continued in one form of other, many forms are not even monitored and controlled. Over the years only few conventional air pollutants such SO_2, NO_2, particulate matter, O_3 etc. are monitored by the researchers and the pollution control authorities. Pollutants such as Persistent Organic Pollutants (POPs) were neglected in the past but have been considered recently for continuous monitoring due to their severe health effects. Both organic as well as inorganic air pollutants cause deadly deceases and hence, their monitoring is very important for humans and environment.

While many developing countries took the matter seriously others were only keen to satisfy international community. Even though environmental legislations were enacted all over the world, the capacity of enforcing agencies was limited mainly due to insufficient knowledge and research capacity with enforcing agency. Many organisations had very few staff to start with limited budget to monitor and travel. The absence of expertise had either lead to improper monitoring by selecting improper sampling site/methodology and poor analysis. Many organisations till date are dogged with insufficient manpower to the extent of one to ten technical/scientific staff for a million of citizens.

What makes air pollution most challenging compared to other pollution is its complexity. As mentioned above, unlike water which can be contained in a container for easy study it is difficult to simulate the atmospheric setup in a laboratory. Further, aerodynamics at earth's surface cannot be easily explained by mathematics as it occurs in nature. A variety of factors like radiation, friction, flow pattern, chemical reaction, influence by biological setup, changing climate, changing weather, changing living style, new inventions, social changes, law of the land, attitude of the people, physiology of people, economic changes of the region together is responsible for the scenario at a given time at a given reason.

Due to complexity of problem, air pollution has not been thoroughly understood by many developing countries and is not a priority. Issues like the poor governance, low research capability, illiteracy, corruption, national/international conflicts and political instability has often cause of low attention to air pollution in spite that millions die due to air pollution all over the world. In spite of magnitude of the problem, the loss of life and wealth due to air pollution is invisible to many government servants. This could be attributed to low emotional intelligence of people responsible to serve the people who act as trustees of the country to protect interest of people and property of the country. Illiteracy among the citizens was also cause for not complaining about the pollution. The use of staff for other duties like election/census/sports has also one of the many reason for poor implementation of environmental laws. Many of the enforcing agency are worried about financial expenditure rather pollution control as misappropriation of financial resource could end up officer responsible for appreciation in jail. On the other hand, the unaccounted pollution is not at all fault as serious as financial misappropriation. The environmental laws can also be misused to raise funds or cause inconvenience to rivals by people in power.

As shown in Fig. 1.5, issues, causes, influencing factors and impacts of air pollution can be attributed to many aspects which are not quantifiable. The corruption among governance, low ethics among industries, non availability of technology, incapability to adopt new technology and low research capability plague

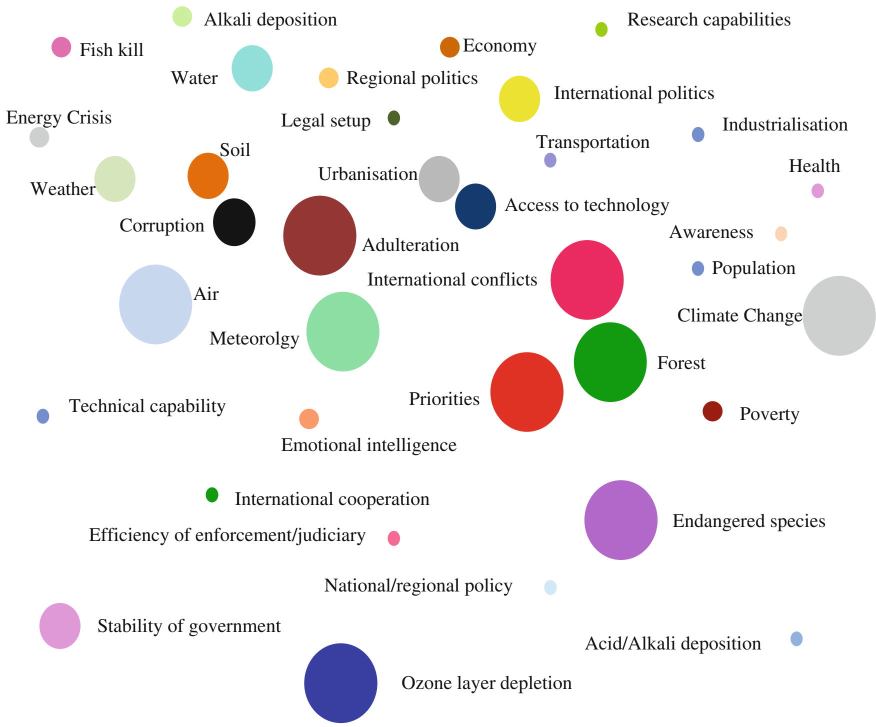


Fig. 1.5 Mosaic of issues, causes, influencing factors and impacts of air pollution

many countries. In spite of enthusiasm shown by many international agencies to support the cause it is often denied or poorly adopted by beneficiary countries.

The major sources of pollution are combustion process, industry, transportation, waste disposal, use of agro chemicals, and respiration of living organisms (Famhy et al. 2007). None of these sources can be avoided as they are meant for survival of the humans. Apart from these sources other sources like accidental fire; wind storms; natural disasters; education/research; decomposition of dead and decaying matter; wars; bursting of crackers; use of explosives; sports/events; testing/practicing of use of war weapons; launching satellites; volcanic eruption; construction; methane generation in rice fields due to biodegradation; demolition of buildings; methane generated by ruminant animals during digestion of food; painting; processing of grains; soil erosion and weathering of rock/minerals add to pollution. Service sectors like healthcare, software, Business Process out Sourcing (BPO) also contribute air pollutants while using equipments/air conditioners/ transportation. Release of pathogens from health care establishment, animal rearing, slaughtering, and research can be far more detrimental compared to conventional pollutants.

Unlike war and crime effect of air pollution usually happen in slow manner taking years before actual impact is visible. Some of the acute impact in recent past like episode in Chernobyl and Bhopal has been faded away from memory of people due to other burning issues at individual regions. Common air pollution issues are discussed below.

1.1 Acid Rain

The term "Acid rain" is commonly used to refer the wet (fog, rain, cloud water, snow, sleet, and dew) and dry (acidifying gases and particles) deposition of acidic components. In this regard, it is important to know that "Clean" or natural rain is also slightly acidic (but usually will not be lower than 5.6) due to carbonic acid carbonic acid formation in atmosphere according to the following reaction (Charlson and Rodhe 1982):

$$H_2O + CO_2 \leftrightharpoons H_2CO_3$$

Due to this fact, pH value of 5.6 is considered as the pH of natural precipitation, below this value, the precipitation is called as acid rain. Sometimes, natural rain can also contain nitric acid formed due to electric discharge such as lightning. It can also have acidity due to organic acids contributed by vegetation (Galloway et al.).

Basically, acid-base reactions in the atmosphere determine the pH of precipitation. As we know that the atmosphere is highly oxidizing medium, gases such as SO_2 and NO_x are oxidised to sulphuric and nitric acids respectively. Such oxidation occur through homogeneous or heterogeneous pathways as described below

Oxidation of SO_2

<u>Gas phase homogeneous oxidation reaction</u>

$$SO_2 + OH \rightarrow HSO_3 \quad (1.1)$$

$$HSO_3 + O_2 \rightarrow SO_3 + HO_2 \quad (1.2)$$

$$SO_3 + 2H_2O \rightarrow H_2SO_4 + H_2O \quad (1.3)$$

<u>Aqueous phase oxidation reaction</u>

Homogeneous aqueous-phase oxidation of SO_2 takes place by its dissolution and dissociation in water

$$SO_2 + H_2O \leftrightarrow SO_2{\cdot}H_2O \quad (1.4)$$

At pH 2–7, most of the dissolved SO_2 is dissociated into $HSO_3^- + H^+$

$$SO_2 \cdot H_2O \leftrightarrow HSO_3^- + H^+ \tag{1.5}$$

The HSO_3^- is oxidized by H_2O_2 or O_3 to H_2SO_4 depending on the acidity of the droplet. At pH < 5, H_2O_2 oxidation dominates while at pH > 5 oxidation by O_3 and other catalytic reactions dominates.

$$HSO_3^- + H^+ + H_2O_2 \leftrightarrow SO_4^{2-} + 2H^+ + H_2O \tag{1.6}$$

$$HSO_3^- + H^+ + O_3 \leftrightarrow SO_4^{2-} + 2H^+ + O_2 \tag{1.7}$$

Heterogeneous oxidation

However, SO_2 is also oxidized through heterogeneous reactions involving calcareous soil dust and carbon soot

$$CaCO_3 + 1/2\ O_2 + 3H_2O + SO_2 \Rightarrow CaSO_4 \cdot 2H_2O + 2H_2O + CO_2 \tag{1.8}$$

$$Soot + SO_2 + H_2O \rightarrow Soot\ sulphate \tag{1.9}$$

Infact, pathway of the reaction (1.8) is the major route of SO_2 oxidation which controls occurrence of acid rain in dusty regions. The soil-dust which is generally dominated by $CaCO_3$ effectively scavenge atmospheric SO_2 forming calcium sulphate in the atmosphere (Kulshrestha et al. 2003). Due to this reason, in the regions where ambient levels of suspended particulate matter are very high violating the limits of National Ambient Air Quality Standards (NAAQS), the pH of rain water has also been reported very high (Kulshrestha 2013). In these regions, the levels of ambient SO_2 are recorded very low due to same reason. Figure 1.6a Shows that even at higher sulphate levels, the pH of rain water is higher in Indian region but in the acidified regions such as United States, the pH of rain water is highly acidic decreasing with the increase in sulphate concentrations (Fig. 1.6b). This suggests that in the acidified regions, sulphate is present as sulphuric acid whereas in dusty regions, sulphate is present as calcium sulphate in rain water.

Rain water dominated by crustal components or mineral dust such as calcite or dolomite or dolomite has lower acidity. Most of Indian soils have very high pH. The pH of rain water in India (Table 1.1) has been termed as the mirror image of the pH of soil of that area (Kulshrestha 2001). Long-term measurement in Lhasa, of Tibetan revealed that pH values, such as 8.36 were observed during 1987–1988 period due to alkaline as well as soil-borne continental dusts (Zhang et al. 2002). The pH of precipitation during 1979–1982, in Israel is mostly alkaline with pH 6.5 ± 0.8 (Mamane et al. 1987).

Oxidation of NO_2

NO_2 is oxidized by OH

$$NO_2 + OH \rightarrow HNO_3 \tag{1.10}$$

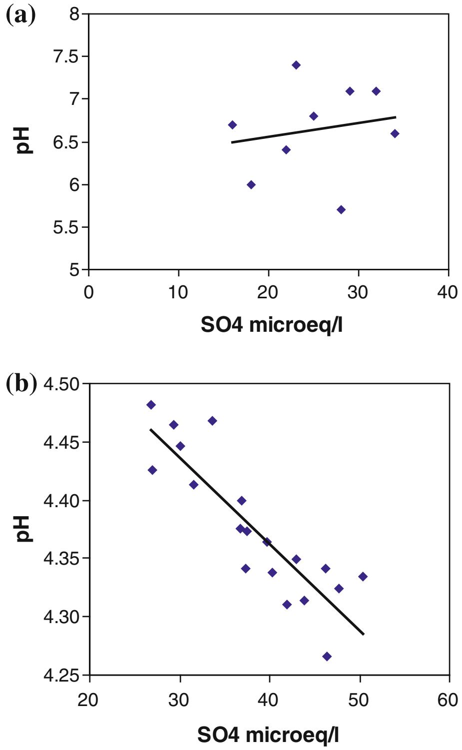


Fig. 1.6 **a** Variation of rainwater pH with sulphate in India. **b** Variation of rainwater pH with sulphate in United States

Table 1.1 pH of precipitation in India

Site	pH
Kodaikanal	6.1
Pune	6.5
Allahabad	7.1
Nagpur	6.3
Delhi	6.3
Mohanbari	6.4
Darjiling	6.4
Srinagar	7.0
Hyderabad	6.7
Jodhpur	8.3
Agra	7.1

Such NO_2 oxidation process is faster than SO_2 oxidation by OH.
Further, through ozone and NO_3 radical reactions, nitric acid is formed.
During daytime, NO_3 radical is formed

$$NO_2 + O_3 \rightarrow NO_3 + O_2 \tag{1.11}$$

During nighttime, NO_3 radical so formed reacts with NO_2 resulting in the formation of HNO_3

$$NO_3 + NO_2 \leftrightarrow N_2O_5 \tag{1.12}$$

$$N_2O_5 + H_2O \rightarrow 2HNO_3 \tag{1.13}$$

HNO_3 further reacts with dust and sea salt particles

$$CaCO_3 + 2HNO_3 \rightarrow Ca(NO_3)_2 + CO_2 + H_2O \tag{1.14}$$

$$HNO_3 + NaCl \rightarrow NaNO_3 + HCl \tag{1.15}$$

Acid rain can damage monuments and buildings. Figure 1.7 shows the corrosion impact of acid rain on a statue and the roofing of a building. The damaged walls of the buildings and monuments leave a rough surface along with the moisture, which is a favorable place for the growth of microorganisms. Acid rain can corrode sculpture and architecture, railway tracks, paints of cars, and joints of bridges and flyovers.

Global budgets of air pollutants

Over the past few decades, huge amount of coal and petroleum are consumed for meeting energy demand of mankind. Burning of such fuels has ended with the accumulation of excess concentrations of gaseous and particulate pollutants in the atmosphere disproportionately. As seen in Figs. 1.8 and 1.9, the sulphur and

Fig. 1.7 Visible impact on statue and roofing due to acid rain

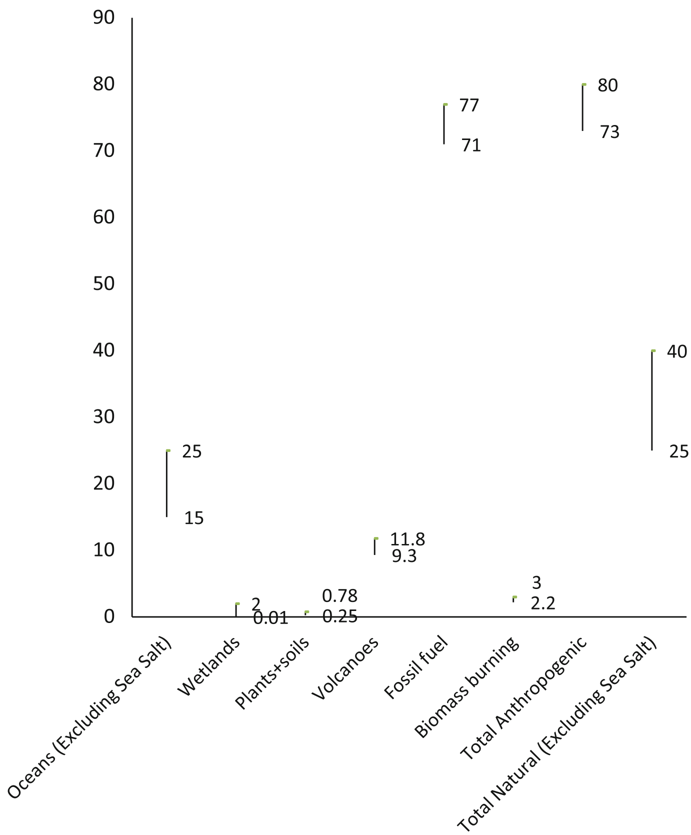


Fig. 1.8 Global Sulfur emissions Tg/yr (based on data from Berresheim et al. 1995)

nitrogen global emissions from anthropogenic sources dominate over natural sources. Total 73–80 TgS per year is emitted by the anthropogenic sources against 25–40 TgS per year from the natural sources (excluding sea salt) (Berresheim et al. Berresheim et al. 1995). Around 11 Tg of NO_x are emitted by the lightening, stratosphere and the soils representing the natural input of NO_x. Fossil fule and biomass burning are the major sources of NO_x which contribute around 40 Tg NO_x per year (IPCC 2001). In addition, anthropogenic activities such as industries and automobiles also inject an array of metals and other chemicals in the atmosphere which ultimately have adverse effects on human health and the environment.

Since 1751 industrial emissions have contributed 1450 gigatonnes of green hosue gases (GHGs). According to latest report published in Climate Change journal, 2/3 of these emissions (914 gigatonnes) are contributed by 90 companies across the globe (ref) out which 56 belong to oil and natural gas sector, 37 coal producers and 7 cement producers. Former USSR entities, Chinese government run

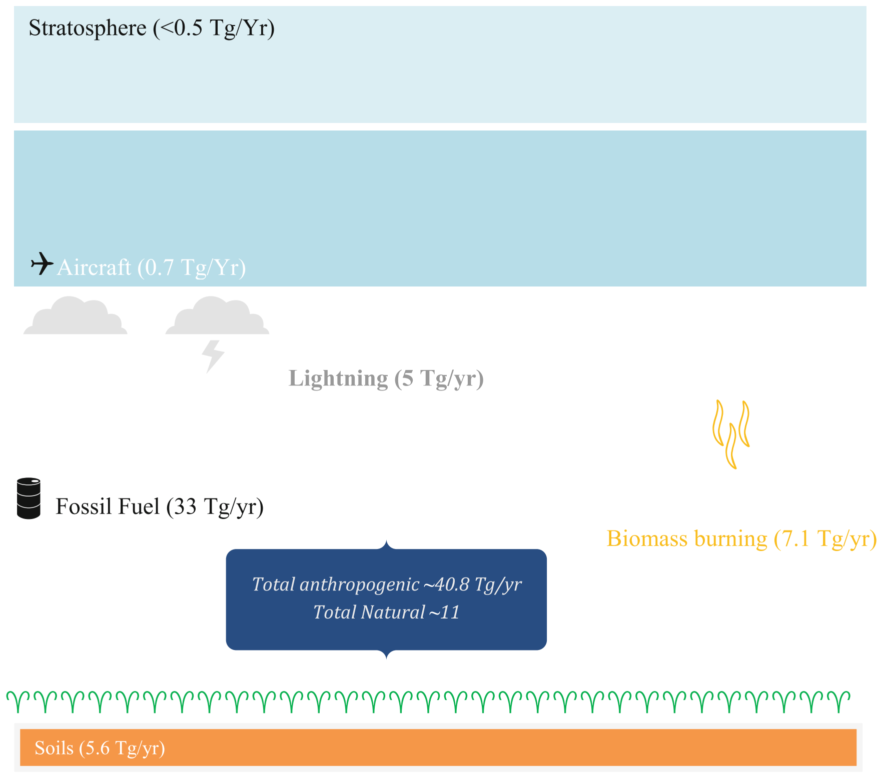


Fig. 1.9 Global NO_x emissions [based on data published in (IPCC 2001)]

entities, Chebron USA, Exxonmobil USA and Saudi Aramco Saudi Arabi have been the top emitters since 1751. List of top five companies include Chevron USA, ExxonMobil USA, BP United Kingdom, Royal Dutch Shell Netherlands and ConocoPhillips USA. Three Indian companies Coal India, ONGC and Singareni Collieries ranked at 15th, 41st and 58th places respectively.

The change in land use has also changed the generation and migration of natural air pollutants like volcanic ash, dust, pollen grains, spores, virus and bacteria. The changing climate has changed wind patterns leading to migration of pollutants in a pattern which was totally different as compared to past.

Global competition for creation of wealth and infrastructure has engulfed hills, river sand, minerals and rocks beneath the earth. The waste this activity created has contributed to methane, chemical pollutants yet to be identified and named. The new multistoried building has changed path air traversed before it was setup. The population explosion followed by urban migration has left agricultural fields barren and increased urban foot print within a span of few decades.

1.2 Global Warming and Climate Change

The "greenhouse effect" is the rise in temperature of the Earth's atmosphere due to the existence of Greenhouse Gases (GHGs) in atmosphere. Generally, the solar radiation received by earth drives the climate system. About 70 % of the incoming 'short wave' solar radiation is absorbed by the earth while around 30 % of it is reflected back to the space. When earth cools down, it releases the heat as long wave radiation. GHGs present in the atmosphere absorb this outgoing 'long wave radiation' from earth which enhances atmospheric temperature. Greenhouse is a phenomenon used in greenhouses to increase temperature capturing long wave radiation to facilitate optimum growth condition for plants. The term "Greenhouse" is borrowed to explain increase in temperature due to trapping of long wave radiation in the atmosphere. Swedish scientist Svante Arrhenius first time demonstrated global warming. Arrhenius (1896) who was awarded Nobel prize in chemistry in 1903 showed that a doubling of the atmospheric CO_2 concentration would lead to 4–5 K warming of the earth surface due to greenhouse effect. GHG increase has resulted in an increase of 0.6 °C in global mean surface temperature since the 19th century. It is expected that this will further increase up to 1.4–5.8 °C by 2100. According to IPCC, GHGs have altered the climate in past few decades resulting in impact on food, water, economy, raw materials, plant/animal health, energy, and biodiversity. It is worth mentioning that the existence of most of biosphere is due to greenhouse effect. Fig. shows that without greenhouse effect Earth's temperature would have been −17 °C (Fig. 1.10). A rise of >30 °C in the atmospheric temperature made human life possible on the earth. What worries is the sharp rise as seen during past few decades which has adverse direct and indirect effects such as global warming, sea level rise, monsoon disturbance, floods, cyclones etc.

Net radiative forcing is affected by the presence of aerosols in the atmosphere. Aerosols can absorb or reflect radiation depending on the properties of aerosols. Dark aerosols such as soot absorb radiation and light colored aerosols such as

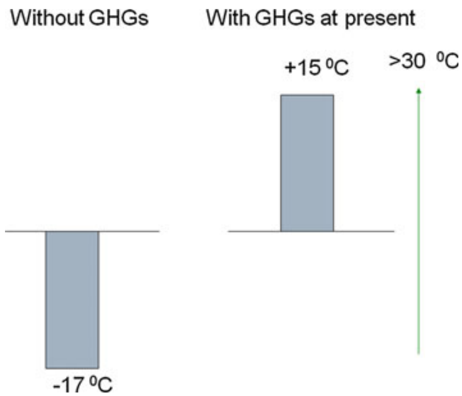


Fig. 1.10 Greenhouse effect showing its importance for sustainable temperature for biosphere

sulphate reflect radiation. It is to be noted that the combined effect of present increase in CO_2, N_2O and CH_4 would lead to an increase of atmospheric heating by 2.3 W m-2 which is 40 % lesser that of expected from observed increase in concentrations of major GHGs due to aerosol effect. However, aerosol radiative forcing calculations have huge uncertainties which need to be corrected. The higher uncertainties are primarily due to lack of measurements from the sites of different characteristics such as rural, background, urban, desert, forest, high altitude especially from tropical regions. Considerable uncertainties also exist in quantifying the role of dust aerosols in climate variability due to the difficulty in assessing direct and indirect effects of aerosols on clouds. Aerosols alter radiative balance as well as the cloud density of the atmosphere resulting in changes in atmospheric stability and cloud microphysics, which can either foster or suppress the development of clouds and precipitation (Li et al. 2011). Increase in particulate matter in the atmosphere can affect cloud development resulting in reduce precipitation in dry regions/seasons and increasing precipitation in wet regions/seasons.

Figure 1.11 shows Impact of climate change. Global warming is expected bring changes in weather patterns which may lead to disasters like storms, flood and droughts. GHG sources can be tracked to—Energy generation, Industry, Transport, Residential and commercial building, Land use change, Agriculture, Waste disposal. These activities have resulted in rise in GHGs over past decade. Combustion of fuel, degradation of organic matter in rice cultivation and waste disposal has contributed to GHG in addition to escape of GHGs manufacture in industries.

The naturally occurring GHGs are water vapor, carbon dioxide, methane, nitrous oxide and ozone. Table 1.2 gives major GHGs and their abundance and characteristics. Anthropogenic activity has increased the concentration of these GHGs and contributed gases like Perfluorocarbons and Hydroflurocabons (HCFs) (Ramesha et al. 2011). Some selected GHGs were phased out during execution of Montreal protocol.

Per capita CO_2 emissions of different countries are shown in Fig. 1.12. Australia, USA Canada are the three top nations which have highest GHG emissions while China, Egypt and India contribute the least GHGs.

Overall, the consequences of global warming (especially indirect) would be region specific and can not be generalized. This will mainly depend upon overall tolerance of that geographical area against the change in atmospheric composition and circulations due to increase of GHGs and other pollutants. The increase in atmospheric temperature due to presence of GHGs in higher concentrations will not be uniform throughout the earth. The uneven temperature which is also cause for wind patterns across the globe will change both in direction and speed bringing shift in normal pattern of rain which means rains could come during harvest time and destroy crop and rain may not come at sowing season. Further the shortage of rain could cause drought in one region while excess rain could cause flood in other reason.

The excess temperature could favor reproduction of pests where as it could alter reproduction patter in plants and animals. Flowering date can be shifted and so as

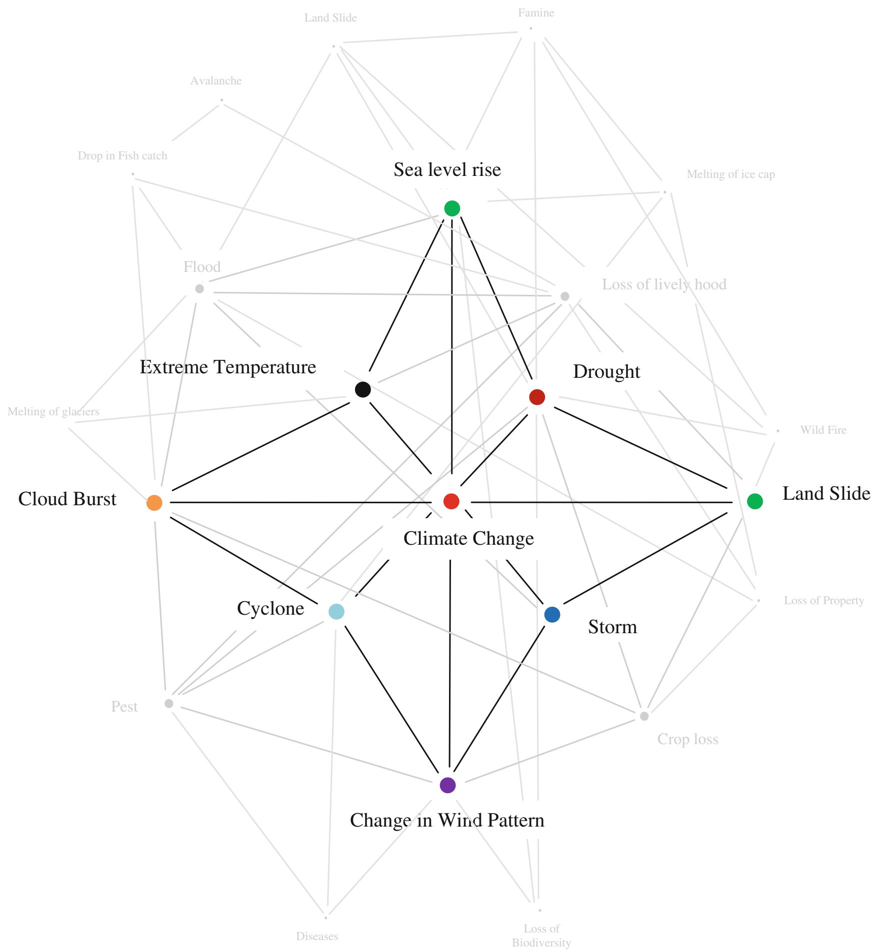


Fig. 1.11 Impact of climate change

Table 1.2 Major GHGs and their levels

Gas	Preindustrial level	Current level	Increase since 1750	Radiative forcing	GWP W m^{-2}	Life time years	Radiative forcing
Carbon dioxide	280 ppm	387 ppm	104 ppm	1.66	1	120	1.66
Methane	700 ppb	1745 ppb	1045 ppb	0.48	34	10.5	0.48
Nitrous oxide	270 ppb	314 ppb	44 ppb	0.16	250	132	0.16
CFC-12	0	533 ppt	533 ppt	0.34	~5000	~100	0.34

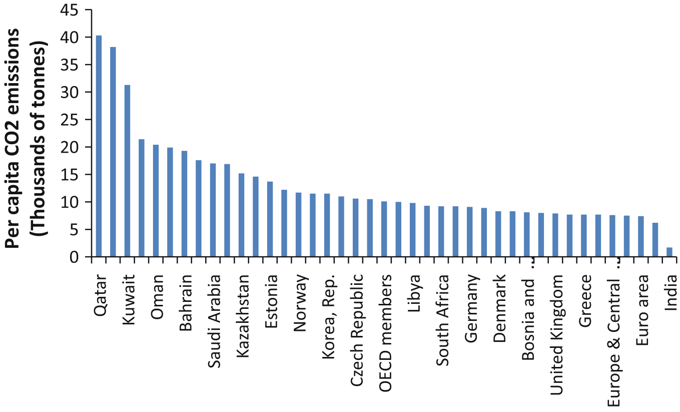


Fig. 1.12 Per capita CO_2 emissions of different countries based on 2010 emissions (*Source* based on information on www.economicshelp.org)

migration patterns of birds. Many endangered species would face hardship to survive due to a climate which may not be suitable for their living and breeding.

Rise in sea level due to excess water inflow due to melting ice caps in mountains as well as polar ice can submerge coastal area and bring in loss of economy. Due to climate change global land precipitation has increased by nearly 2 % since the beginning of the twentieth century (Jones and Hulme 1996; Hulme et al. 1998) and change is not uniform neither spatially nor temporally (Karl and Knight 1998; Doherty et al. 1999). As a result of climate change annual snow-cover extent (SCE) has decreased by nearly 10 % in Northern Hemisphere since 1966 mainly due to decline in spring and summer from the mid-1980s over Eurasian as well as American continents (Robinson 1997). The flood, storm, tornadoes, extreme temperate, cyclone formed due to climate change can trigger mass movement (land slide and avalanche) in hills and mountains leading to further disaster. The climate change has resulted in drought in north China and summer floods in south China. Change in precipitation pattern since 950 A.D. is mainly due to human-made absorbing aerosols.

Long range transport (LRT) and trans-boundary driven air pollution

Long range transport (LRT) and trans-boundary air pollution affect distance sites. Convention on Long-range Transboundary Air Pollution signed on 1979 is considered as pioneering international instrument which has paved the way for fruitful cooperation among 49 parties in Europe (Harald et al. 2004). Since, air has no boundaries, pollutants are transported globally from one geographic area. Several times remote and background sites are affected by LRT. There are examples where states having no air pollution sources are affected by LRT of pollution from distance or nearby countries or states. Rodhe (1972) demonstrated air pollution transport through air mass trajectory calculations and established that acid rain occurrence in Northern Europe was mainly due to industrial sources located in the south and west. Dust from The Thar Desert has been the primary potential source of particulate pollution in the Indian subcontinent. Also, the suspended particulate matter from the dust storms originated in Oman and other middle eastern regions has been reported to have influence on air quality in south Asia (Begum et al. 2011). Long-range transport of dust aerosols over the Arabian sea and Indian region has been reported by Badarinath et al. (2010). Kulshrestha and Kumar (2014) have reported LRT of pollution and its influence on rain water chemistry at Himalayan sites. According to the study, most of the acidic components such as sulphate and nitrate are transported from western airmasses and are deposited through precipitation having long term adverse impact on Himalayan ecosystem. Similarly, air pollution is the issue of transboundary transport of air pollution is an important issue between and within the countries. For example recent air pollution problem in New Delhi can be termed as transboundary pollution problem (Kulshrestha 2015). In 1990s, exhaust of diesel driven buses was mainly responsible for air pollution in Delhi city but after the Supreme Court decision, all the busses were replaced by CNG driven buses. This gave a big relief to the citizens of Delhi. But surprisingly, SO_2 and NO_2 levels were recorded extremely high during winter season of 2015 crossing 400 micrograms per cubic meter violating the NAAQS limit of 80 micrograms per cubic meter. Such observations were never reported in recent past winters. Such sudden increase can be explained on the basis of transboundary air pollution contributed by a number of new established brick kilns being operated in nearby states such as Uttar Pradesh, Haryana and Punjab (Kulshrestha 2015). In addition, diesel driven heavy duty trucks entering from outside of Delhi also contribute significant amount of carbon and sulphur oxides making Delhi air polluted (Gupta et al. 2015).

Global competition for creation of wealth and infrastructure has engulfed hills, river sand, minerals and rocks beneath the earth. The waste this activity created has contributed to methane, chemical pollutants yet to be identified and named. The new multistoried building has changed path air traversed before it was setup. The population explosion followed by urban migration has left agricultural fields barren and increased urban foot print within a span of few decades.

1.3 Ozone Layer Depletion

The abundance of ozone at a point in the stratosphere is controlled by production, destruction, and transport of ozone as well as other substance. The key mechanism for the generation of stratosphere ozone is the breaking of molecular oxygen by solar UV with wavelengths of less than 242 nm by photolysis to make nascent oxygen atoms which in turn combines with molecular oxygen to make ozone. Ozone destruction occurs by reactions of oxygen atoms with ozone and reactions involving certain naturally occurring species like nitrogen oxide radicals (NO_x: mostly NO and NO_2), odd-hydrogen radicals (HO_x: OH and HO_2), and/or halogen radicals. The natural Ozone concentration vary daily (due to changing weather); seasonally; and multiannually and interannually. The concentration of stratospheric ozone can be changed by anthropogenic activity. Chemicals in emissions from anthropogenic activities responsible for deletion of stratospheric ozone are called The ozone-depleting substances (ODSs). Since the 1970s it has been recognized that a numerous chemicals emitted by anthropogenic activities deplete stratospheric ozone.

In order to understand the impact on layer Ozone, National Oceanic and Atmospheric Administration (NOAA) has developed the Ozone Depleting Gas Index (ODGI) derived from NOAA's measurements of chemicals containing chlorine and bromine at various remote surface sites around Earth's surface. Index is defined as 100 at the crest in ozone depleting halogen profusion and zero for the 1980 level. Two different indices are derived one relevant for the ozone hole over Antarctica (the ODGI-A), and other relevant to ozone layer at mid-latitudes (the ODGI-ML).

ODGI-A in 2013 was 85.7 and ODGI-ML in the beginning of 2013 was 63.3. 1980 benchmark halogen level over Antarctica will be reached sometime around 2070 considering and that over mid latitude will be reached sometime in 2045 (Daniel et al. 2011). ODS restricted by the Montreal Protocol, were declining in the atmosphere by 2013 with notable exceptions being halon-1301 (a bromine-containing chemical used mostly in fire extinguishers) and HCFCs, that are used as substitution for CFCs in various applications. Decline in reactive halogen concentrations are mainly due to the rapid phase-out as well as atmospheric decline of short-lived ODGs such as methyl bromide and methyl chloroform (Montzka et al. 1999, 2003). The reduction related to CFC-11 as well as CFC-12, has been less because of continuing emissions as well as their lifetimes are long (50–100 years). Though concentrations of HCFC's continue to rise in the background atmosphere production is not scheduled for a total phase-out until 2030.

Main pathways of ozone destruction are

Hydroxy radical (OH)

$$^{\cdot}OH + O_3 \rightarrow HO_2^{\cdot} + O_2$$

$$HO_2^{\cdot} + O \rightarrow {}^{\cdot}OH + O_2$$

$$\text{Net} : O + O_3 \rightarrow 2\ O_2$$

Chlorine and bromine radical (Cl and Br)

$$Cl^{\cdot} + O_3 \rightarrow ClO^{\cdot} + O_2$$

$$ClO^{\cdot} + O \rightarrow Cl^{\cdot} + O_2$$

$$\text{Net}: \; O + O_3 \rightarrow 2O_2$$

Nitric Oxide (NO)

$$NO + O_3 \rightarrow NO_2 + O_2$$

$$NO_2 + O \rightarrow NO + O_2$$

$$\text{Net}: O + O_3 \rightarrow 2O_2$$

The Montreal protocol adopted in Montreal in 1987, [and subsequently amended in London (1990), Copenhagen (1992), Vienna (1995), Montreal (1997) and Beijing (1999)] control of production and consumption of ODS.

Nitrogen oxides from natural and anthropogenic activity catalytically destroy ozone through following reaction (Crutzen 1970; Jonston 1971).

The relative contributions of ODSs to depletion of ozone layer are quantified by ozone depletion potential (ODP). In spite of many similarities between N_2O and ODSs it is not considered to be an ODS in Montreal Protocol (Ravishankara et al. 2009).

1.4 Atmospheric Brown Cloud

Air pollution transported across the continents as well as ocean basins has resulted in trans-continental and trans-oceanic plumes of atmospheric brown clouds (ABCs) made up of sub micron size aerosols. ABCs interrupt sunlight by reflecting and absorbing reflecting resulting in large surface dimming. On the other hand, black carbon as well as some organics augments atmospheric heating increasing global warming. Black carbon is mainly emitted due to Wildfires; and combustion of Biofuel, Coal, Diesel and Gasoline. As per Ramanathan and Feng (2009) ABC warms atmosphere at elevated levels from 2 to 6 km, resulting in retreating of glaciers as well as snow packs in the Hindu Kush-Himalaya-Tibetan glaciers. Aerosols may nucleate additional cloud droplets enhancing dimming effect (Fig. 1.13). The dimming decreases evaporation of water from the earth's surface, slowing down the hydrological cycle. According to some studies, in South Asia due to ABC dimming north-south gradients in sea surface temperatures as well as land–ocean difference in surface temperatures, have slowed down the monsoon circulation and reduced rainfall over the continents. The following figure shows global estimates of dimming.

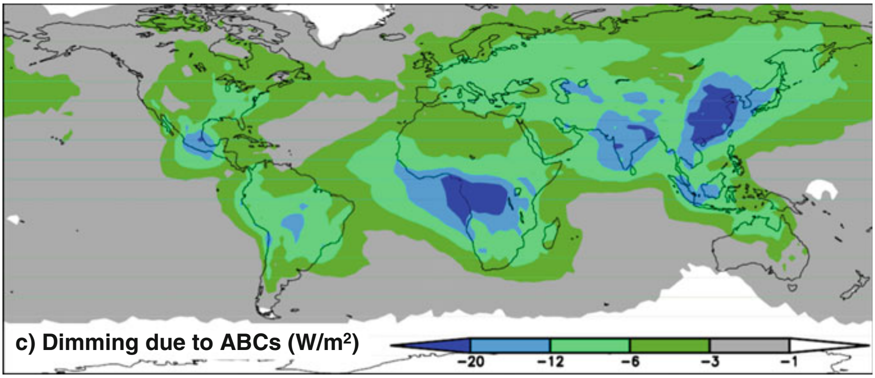


Fig. 1.13 Global dimming estimates (Ramanathan and Carmichael 2008)

1.5 Impact on Flora and Fauna

Impact of air pollution on flora can be observed in the form of discolourations of the leaf due to internal cellular damage thereby reducing the market value of agricultural crops such as tobacco and spinach where visibility is important. The air pollution can also result in reduction of the leaf surface and can provide points of entry for pathogens. Air pollutant can affect plant physiological or biochemical processes resulting in significant loss of growth/yield as well as changes in nutritional quality (Ashmore and Marshall 1999).

SO_2 entering leaves through stomata are absorbed by mesophyll (cells between the lower and upper epidermis layers of a leaf) of leaves causing toxicity due to reducing property of gas. When the limiting concentration exceeds the cells are inactivated by plasmolysis and then killed.

Many industries that emit fluorides like aluminium reduction; smelting of iron and non-ferrous ores; ceramics and phosphate reduction as well as phosphate fertilizers. The fluorides are emitted due to volatilization of molten cryolite in aluminium industry and volatilization fluoride which may present as impurity in raw material in other industry. Fluorides are of great concerns with respect to air pollution as all fluorides tend to accumulare in forage and build up concentration which causes fluorosis when consumed by cattle or sheep. Further hydrogen fluoride and silicon tetrafluoride are toxic to some plants even at the concentration as low as 0.1 ppb (Thomas 1961).

Air pollution has been recognized as reason for injury to vegetation in Europe and North America in the past few centuries. Entire forest communities were lost up to 15 km downwind of the smelter complex located at Sudbury, Canada in 1900s due to SO_2 and metal emissions with other ecological effects observed at a greater distance (Winterhalder 1996). The areas where cells are killed collapse and dry up. If only few cells in an area are injured the area will become chlorotic (yellowing or whitening of usually green plant tissue due to decreased amount of chlorophyll) or brownish red in color.

The lesions (abnormality in the tissue) due to ozone are usually confined to upper surface and are uniformly distributed as brown or white flecks or stipples or blotches. Ozone flecking was observed on grape, avocado, citrus, and other broad leaf plants in outlying regions of Los Angels Valley as well as surrounding hills (Thomas 1961).

Among the many mechanisms by which Foot and Mouth disease can be spread by transport of virus through the wind. Even though this is uncommon infection can be carried across borders and seaways (Donaldson and Alexandersen 2002).

Air pollutants affect photosynthesis and respiration of plants. The effect differs from species to species and each species will have threshold limits after which it is vulnerable for adverse effect. The pock mark type injury on the upper side of leaf has been attributed to acid aerosols associated with fog as it contains acid and other toxicants.

The NO_x concentration in atmosphere is too low to cause plant damage. Chlorine is around three times phytotoxic as SO_2. Hydrogen chloride at a concentration of 10 ppm for few hours can cause pant damage. Ammonia has around same phytotoxicity as HCl. H_2S is slightly phytotoxic (Thomas 1961).

Land use change triggers air pollution

The change in land use has also affected the production and transport of natural air pollutants like dust, pollen grains, spores, virus and bacteria. Vegetation cover is drastically reduced in the urban areas due to sudden increase in built area. Developing countries are facing significant air pollution impact of land use change due to rapid urbanization. More significant effect is seen due to expansion of the cities for housing purpose which emits a huge amount of dust during the construction of buildings. The emissions of air pollutants from these residential colonies become a continuous source of polluted air. According to the data, about 60 % of agricultural land in Delhi has been transformed into nonagricultural area resulting in decrease in net sown area from 85,000 to 46,000 ha (Mohan et al. 2011). Same is the case for most of the cities. The urban dust has been reported highly rich in carbon and sulphate (Kulshrestha et al. 2005; Kumar et al. 2014; Gupta 2015). Dust sulphate significantly affect various biochemical constituents and the morphology of the plants (Gupta 2015). Figure 1.14 shows an increase in Ascorbic acid and Proline content of foliar with the increase in sulphate levels correlating with the increase in stress level. More severe effect is reported for the industrial area as compared to the residential areas due to more stress of pollutants at industrial site which affects plant physiology and morphology. Soil dust coming out from the digging of land and the construction activities could be the sources of microbes. The relationship between different types of house dust and the concentration of fungi has reported by Kaarakainen et al. (2009).

Investigation of animals following the air pollution at Donora, Pennsylvania in 1948 disclosed that many animals were ill and died during the week of smog. Dogs were most susceptible species during the episode with 15.5 % reported to be sick

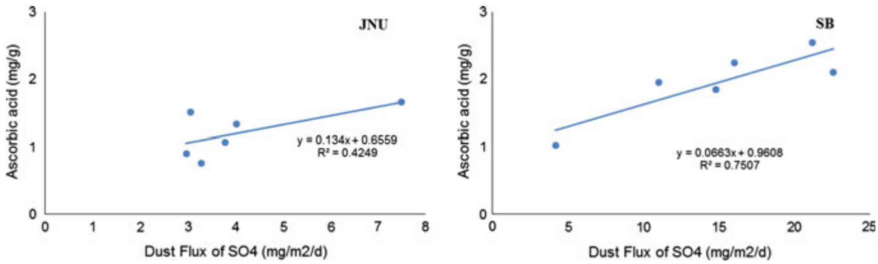


Fig. 1.14 Increasing concentrations of AsA with increasing dust flux of SO_4^- at JNU and SB sites (*Source* Gupta 2015)

and 10 canine deaths. Investigators attributed canine sickness to three syndromes—Signs of respiratory syndrome, digestive syndrome, and anorexia (poor apatite). 40 % of the birds affected by episode died. During the London fog in 1952 a number of prise cattle were severely affected. Five of the cattle died where as 11 were subjected to emergency slaughter. Post mortem examination revealed emphysema, bronchiolitis and right heart failure. Hydrogen sulphide released during pollution disaster in 1950 at Poza Rica, Mexico was responsible for death of 100 % canneries and about 50 % of the other exposed animals in the area. The important long-term effect due to air pollution of radioactive substance are cancer; shortening of life span, and genetic or mutation effect (Catcott 1961).

Health forests across the world is being affected by Air pollutants due to increasing tropospheric ozone concentrations, raise atmospheric carbon dioxide concentrations, as well as acidic precipitation. Emissions of sulphur dioxide, oxides of nitrogen, and other pollutants like ammonia affect forests in rapidly industrializing areas. Increasing levels of UV-B radiation from stratospheric Ozone depletion are possibly a threat to health of forest (Percy and Ferretti 2004).

Bioaccumulation and Biomagnification of chemicals in food web would further worsen the ecological balance. Bioaccumulation is an increase in the pollutants concentration over time in a biological organism. Compounds accumulate in living organisms as they are stored faster than they are disintegration or excretion. Biomagnification is raising accumulation of a pollutant in living beings as it moves from one level to other in a food chain.

Lead which is now drastically reduced in ambient air in many parts of the world is toxic to flora, fauna and micro-organisms and bioaccumulates in most organisms. Generally, 0.5 ppm of lead in the blood of water birds is considered toxic although toxic symptoms may appear at 0.2 ppm lead. Lead in at 5.0 ppm or more in liver of water birds is considered to be lethal. Reduced survival has been reported for some sensitive species of birds, at of 75–150 ppm body weight. Further, dietary levels of 50 ppm affect reproduction. Mortality during experimental studies in water birds normally occurs at dose concentrations of 20–40 ppm lead in with lethal levels varying from doses of 5–80 ppm (UNEP 2010). Lead concentrations of 100–1000 mg/kg soil cause visible effects on, growth, photosynthesis or other parameters (IPCS 1989).

Fig. 1.15 Dust deposition on the three

1.6 Impact on Crop Yield

Crop failure can occur due to—(a) impact of air pollutants on crop's health, (2) climate change, (3) UV ray penetration due to damage to ozone layer. Figure 1.15 shows dust deposition on the three. Such deposition is likely to cause impact on health of tree depending on the constituents of dust. Ozone is the most destructive air pollutant to crops as well as ecosystems (Heagle 1989) as it is a strong oxidant. Surface level Ozone is a secondary air pollutant created in the atmosphere from the oxidation of NO_x under bright sunlight as well as volatile organic. Ozone as well as its secondary byproducts damage plants by reducing photosynthesis as well as other physiological functions, resulting in weaker, undersized plants with inferior crop quality and decreased yields (Fiscus et al. 2005; Booker et al. 2009; Avnery et al. 2011).

Crops next to thermal power plants in India suffered most in past decades due to inefficient air pollution control equipments which emitted fly ash that deposited on the crop. The pollution during mining, construction roads and operation of hot mixing plats in developing countries have resulted damage to crop to great extent.

1.7 Impact on Material

Air pollution damages materials and involved three components—expenditures to repair, preventive measures, and loss of amenity. Impact of materials fall into four categories: soiling, material loss, discoloration, and structural failure.

The atmospheric corrosion of materials depends on acidification of the air, due to gases such as SO_2 and HNO_3. As per the reviews damage to siliceous stones is not significant, and therefore attention is restricted to calcareous stones (Harter 1986; Lipfert 1987; Lipfert 1989; NAPAP 1990;).

Impact on Material Sulphuric acid aerosols attack building material mainly those containing carbonates like marble (Fig. 1.16, 1.17 and 1.18), limestone, slate and mortar which can be explained by following equation.

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + CO_2 + H_2O$$

The Calcium Sulphate formed is washed away.

The deterioration of calcareous stone can be explained in three stages: Simple dissolution of calcium carbonate; dissolution of calcium carbonate followed by the fall-out of less soluble particles; and steady build-up of salts if the calcium carbonate is not washed away.

Statues and other ornamental material may get discolored due to deposition of air pollutants. Figure 1.19 shows statues covered with plastic covers in Bangalore, India to avoid dust deposition and soiling of statues. Mortar contains sand, calcium hydroxide as well as other carbonate phases. Cement in concrete is susceptible to acid attack leading to discoloration/soiling (Fig. 1.20), surface erosion, spalling and corrosion of embedded steel. Damage to reinforced cement concrete structure will be insignificant if the steel is provided with sufficient cover of good quality concrete.

Paint and polymeric materials can be affected due to acidic deposition as well as photochemical oxidants, particularly ozone. Impacts on this material include

Fig. 1.16 Marble within siliceous stones damaged due to air pollutants

Fig. 1.17 Intricate carvings being washed away due to air pollution

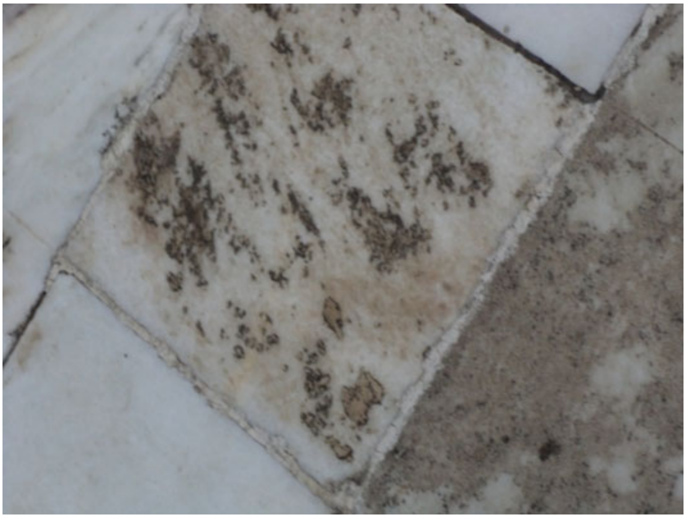


Fig. 1.18 Build up salts after attack of acidic air pollutants on marble used for flooring

erosion of polymer surfaces, loss of gloss and soiling, interaction with sensitive pigments and fillers loss of paint adhesion from and substrates. Contamination of substrate before to painting can lead to premature failure due to embrittlement and cracking.

Atmospheric corrosion of metals (Fig. 1.21) is an electrochemical process occurring when the surface is wet. Corrosion rate mainly depends on humidity,

Fig. 1.19 Statues covered with plastic covers in Bangalore, India to avoid dust deposition and soiling of statues

Fig. 1.20 Soiled walls and roofs in coastal area

precipitation, temperature as well as levels of atmospheric pollutants. SO_2 causes most damage, on metals even though chloride plays play a significant role in coastal area.

As per the studies conducted by Tzanis et al. (2011) in Athens, Greece metal and alloy specimens exposed the highest weight change is observed for unalloyed carbon steel at the level of 18 m, and lowest weight change was observed at 6 m. Values of weight change for zinc and copper specimens were about four times lower than steel and almost constant with the height. The weight loss of unalloyed carbon steel was found to be more than 15 times higher than other materials.

Fig. 1.21 Corroded steel structure

Copper and bronze suffered less by atmospheric corrosion with almost equal mass loss. Zinc mass loss was nearly 70 % greater than that of copper and bronze.

Sulfuric acid mist can damage, nylon, cotton, linen and rayon. Excess exposure to SO_2 accelerates corrosion of metals. Hydrogen fluoride will corrode many substances except polyethylene, lead, wax, and platinum.

1.8 Impact on Human Health

Human health can be adversely affected by air pollution depending on the pollutant, quantity of pollutant and path of entry into body. Human receptors include the eyes, nose, skin, or respiratory system. Eye is more susceptible to damage as well as irritation compared to the skin.

Figure 1.22 shows common forms of exposure response relationship. Relationship between the level of exposure (or dose) as well as the degree of effect (or response) usually occur in four ways: (1) effect/response increases with exposure without threshold, (2) effect/response increases with exposure with threshold, (3) effect/response versus exposure takes curvilinear shape, or (4) effect/response versus exposure takes S-shape (David 2003)

The clinical course of a disease is shown in Fig. 1.23. The living organism after exposing to disease casing factor like air pollutant can either recover or recover with disability or die. Before end results human beings usually starts therapy as soon as

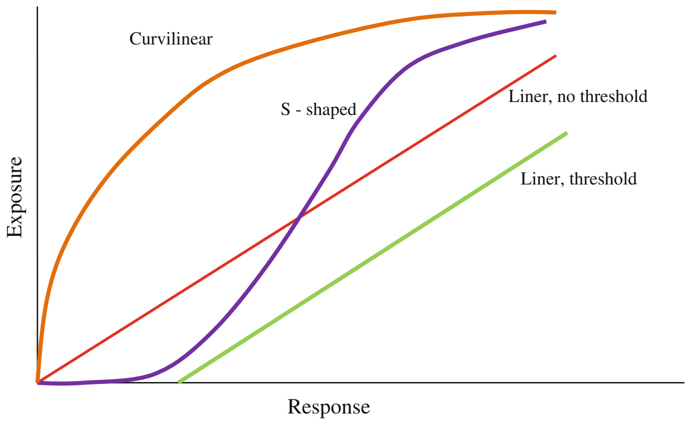


Fig. 1.22 Common forms of exposure response relationship

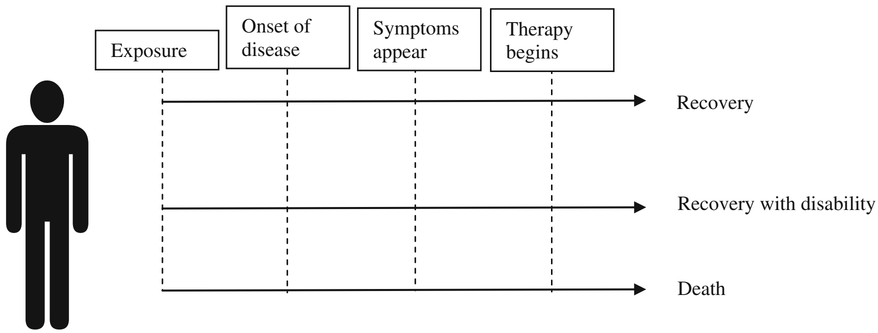


Fig. 1.23 The clinical course of a disease

symptoms of disease appear. The disease need not have to occur only to organs exposed to air pollutants. The toxins easily get absorbed by blood and varied to all parts of the body. For example chronic inhalation of cyanide compounds affects central nervous system, cardiovascular system, thyroid gland, respiratory system, eyes as well as skin.

Some gases like SO_2 cause irritation and some gases like acetylene and Carbon Monoxide cause asphyxiation (cause death without significant physiological effect). Carbon monoxide causes a chemical asphyxiation since it impairs the oxygen transport in blood vessels as affinity of CO for haemoglobin is three hundred-fold more than oxygen.

Lead in air can cause severe health damage as it is toxic at very low exposure levels. Organo-lead compounds, like tetra-alkyl-lead and tri-alkyl-lead compounds, are more toxic compared to inorganic forms of lead. Lead has acute as well as chronic effects on health of humans as it is a multi-organ system toxicant. It can cause neurological, gastrointestinal, haematological, cardiovascular, renal, and reproductive effects. The severity and type of effects depend on the duration, level, and timing of exposure. Accumulated Lead in bone may become source of exposure later in life (UNEP 2010).

The evidence indicates humans who are responsible for air pollution are adversely affected. Children's health is adversely affected due to air pollution due to incomplete metabolic systems, ongoing process of lung development and growth, high rates of infection by pathogens immature host defenses, and activity specific to children can result in higher exposure to air pollution (WHO 2005).

Figure 1.24 shows impact of air pollution on human health. Figures 1.25, 1.26, 1.27, 1.28 and 1.29 shows lungs affected by air pollution. Figure 1.30 shows food items exposed to atmosphere are often contaminated with air pollutants leading to food spoiling. The lung of developing fetal and the infant is more vulnerable to injury by lung toxicants. Air pollutants interact with environmental exposures, like

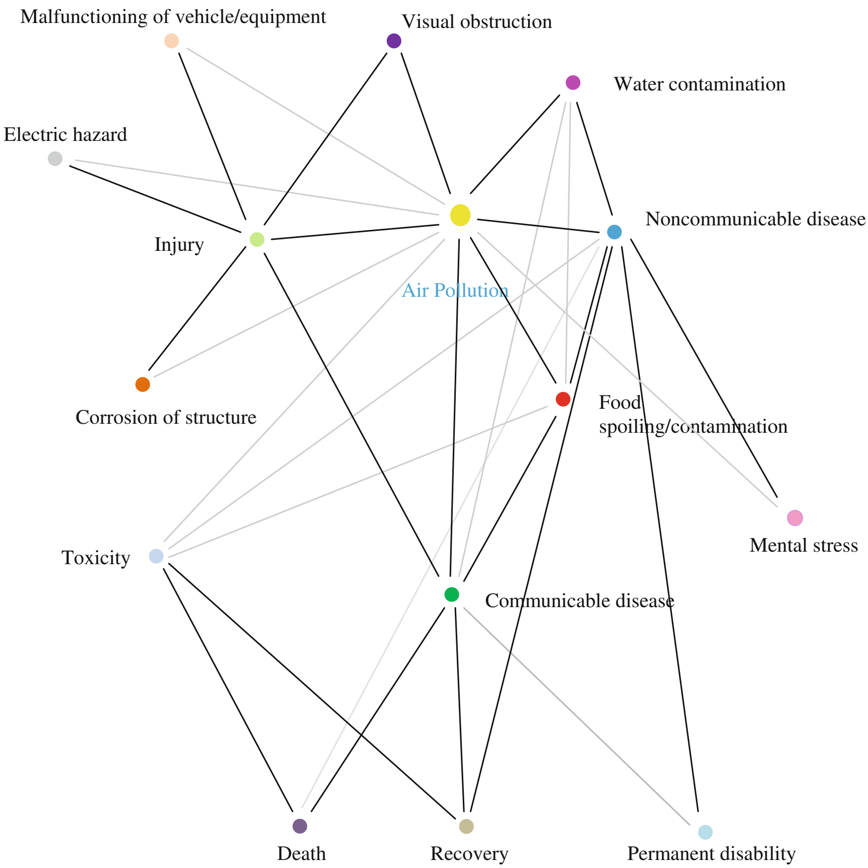


Fig. 1.24 Impact of air pollution on human health

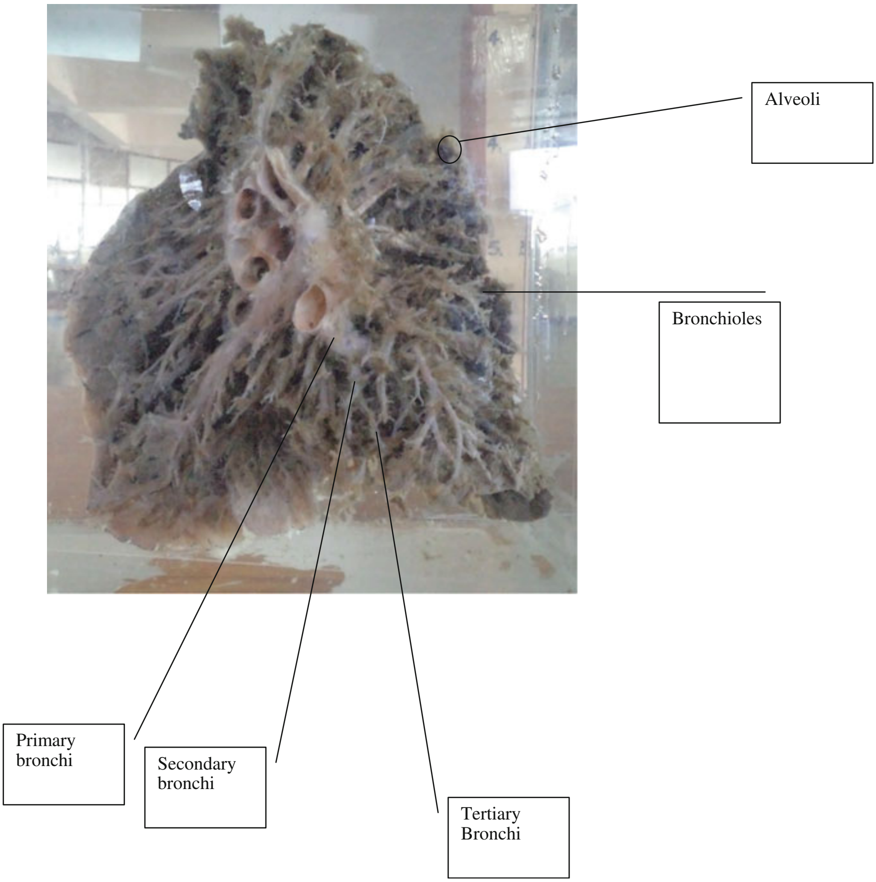


Fig. 1.25 Complex network of tubes in lungs traps most of the pollutants entering into lungs

Fig. 1.26 Section of lung showing deposit of black particles in tubes of lungs

Fig. 1.27 Un-sectioned lung with particles trapped in alveoli

Fig. 1.28 Section of lung uncoated with pollutants

allergens, viruses as well as diet that influence the effect of air pollutants on health. Four million deaths between 1997 and 1999 all over world were due to respiratory infections (WHO 2000). Particulate and gaseous pollutants can act on upper and lower airways to initiate as well aggravate cellular inflammation.

Nasal allergy to pollen is termed as pollinosis, and allergy particularly to grass pollen is termed hay fever. Plants whose pollens are dispersed by air currents are

Fig. 1.29 Section of lungs affected by cancer (cancer tumours are visible as light colored patches)

called Anemophilous and such plants generate large quantities of lightweight pollen which are carried for great distances bringing it into contact with nasal passages.

Air pollutants can get into the body through food contamination through food or water exposed to polluted air. Pollutant entering into body can remain on skin or in the respiratory/digestive system or move into the blood. Pollutants entering the bloodstream can be transported to all body parts. As pollutants moves through the

Fig. 1.30 Food items exposed to atmosphere are often contaminated with air pollutants leading to food spoiling

body it can undergo many chemical changes, becoming more or less toxic (Figs. 1.26 and 1.27).

The contamination of Meuse River Valley of Belgium resulted in death of 63 people in the first week of December 1930. The findings of investigation revealed that weather patterns had a major impact on sulfur dioxide concentrations, especially during temperature inversion (Shy 1978). Air pollution along the Monongahela River near Pittsburgh, USA in October 26, 1948, resulted in death of 20 people due to cardiac as well as respiratory diseases (Goldsmith and Friberg 1977).

As per Ostro (2004) outdoor air pollution was accounted for approximately 1.4 % of total mortality and it is the cause for 0.4 % of all disability-adjusted life years (DALYs) as well as 2 % of all cardiopulmonary disease.

In estimates released by WHO (2015a), around 7 million people died in 2012 as a result of air pollution exposure. This confirms that air pollution is now the world's largest single environmental health risk.

As per the WHO (2015b), 4.3 million deaths related to household air pollution in 2012. 1.69 million deaths occurred in the South East Asia and 1.62 million deaths occurred in Western Pacific regions. About 600,000 deaths occurred in Africa, 99,000 in Europe, 200,000 in the Eastern Mediterranean region, 81,000 in the Americas and 19,000 deaths occurred in high income countries.

In 2012 a total 3.7 million deaths linked to Ambient Air Pollution (WHO 2015c). 1.67 million death occurred in Western Pacific region and 936,000 deaths occurred in South East Asian. About 236,000 deaths occured in the Eastern Mediterranean region, 200,000 in Europe, 58,000 in the Americas, 176,000 in Africa, 280,000 in high-income countries of Europe 94,000 in Americas, 67,000 in Western Pacific, 14,000 in Eastern Mediterranean (14,000).

Breakdown by disease due to Ambient Air Pollution are: (1) 40 %—ischaemic heart disease; (2) 40 %—stroke; (3) 11 %—chronic obstructive pulmonary disease (COPD); (4) 6 %—lung cancer; and (5) 3 %—acute lower respiratory infections in children (WHO 2015a, c).

Breakdown by disease due to Household Air Pollution are: (1) 34 %—stroke; (2) 26 %—ischaemic heart disease; (3) 22 %—COPD; (4) 12 %—acute lower respiratory infections in children; and (5) 6 %—lung cancer (WHO 2015a, b) (Fig. 1.28).

Lung cancer is one the leading reason of cancer death in both men as well as women. Apart from smoking air pollution is one of the main reason. Cancer can originate from lung or other parts of the body. Cancer originating from lung cells is known as primary lung cancer. It can start in the bronchi) or in the alveoli. As per studies by Siegel et al. (2013) lung and bronchus cancer would cause death of 28 % of male cancer patients and 26 % of female cancer patients in USA.

Smoking key reason of lung cancer (U.S. Department of Health and Human Services 2004), other causes include radon (National Academy of Sciences 1999) secondhand smoke (U.S. Department of Health and Human Services 2006) and air pollutants like benzene, formaldehyde, as well as Asbestos. The size of lung may increase (due to increase in mucus) or collapse partially/wholly due to lung cancer.

Many people affected due to SARS (*severe acute respiratory syndrome*), Avian flu and Swine flu due to transmission of virus through air in last decade.

Diesel and gasoline exhaust are probably and possibly carcinogenic to humans (IARC 1989) and children living near places with high traffic density have more risk of cancer (Savitz and Feingold 1989).

More than 4,000 people lost their lives in the year 1950 due to deadly acute air pollution that occurred due to temperature inversion over London. More than 4000 people lost their lives instantly due to methyl isocyanate poisoning in 1984 and hundreds of thousands were disabled permanently.

Dioxins and furans created during manufacture of certain chemicals like herbicides; pulp and paper industry during bleaching the wood pulp; burning waste (like municipal solid waste and medical waste) or substance which has chlorine;

Secondary Copper Smelting; Forest Fires; Cement Kilns; Coal Fired Power Plants; Residential Wood Burning; burring bodies in crematorium or open fire. Dioxins and furans are known carcinogens and can change hormone levels. High doses of dioxin can lead to skin disease called chloracne. Dioxins and furans can bring changes in development of the fetus, decrease ability to reproduce and suppress immune system. Mercury which is emitted from combustion of coal and waste/substance with mercury can lead to Neurological and behavioral disorders, Kidney disorder ranging from augmented protein in the urine as well as kidney failure.

Aerobiology plays an important role in the spreading of infectious diseases. Aerobiology is the study of the course of action involved in the microorganisms' movement in the atmosphere from one location to another. Airborne particles can remain in air for many days (Wells 1934; Wells and Stones 1934; Duguid 1946). Large quantities of infectious pathogens expelled in hospitals can spread via airborne. Blockage of sunlight due to air pollution can promote spread of harmful microbe in atmosphere resulting in spread of infection.

Epidemiological studies have revealed that exposure to air pollutants during fetal development as well as early postnatal life is connected with numerous health problems including very low birth weight (VLBW); low birth weight (LBW); congenital defects; intrauterine growth restriction (IUGR); preterm birth (PTB); behavioural problems, intrauterine and infant mortality; decreased lung growth, childhood asthma, increase in rates of respiratory tract infections, and neurocognitive decrements (Wang and Pinkerton 2007).

Silicosis due to inhaling silica particles and asbestosis due to inhaling asbestoses is long known to scientific community. Studies by Kathleen and Boguang (1996) revealed that occurrence rates of silicosis increased by years of dust exposure.

PM air pollution increases risk for cardiovascular diseases (Miller et al. 2007; Pope et al. 2004) and people with diabetes are more susceptible to cardiovascular health effects connected with PM air pollution (O'Neill et al. 2005; Whitsel et al. 2009; Ursula et al. 2010).

Certain microorganisms, transforming a less toxic species into toxic derivative like produce methyl iodide, which reacts with substance like mercury, arsenic, selenium, and tellurium to form their methyl derivatives by process is known as methylation.

1.9 Black Snow and Muddy Snow

Black snow and outbreak of red-tide in lacustrine systems was observed during early 1991 in the Kashmir Himalayan valley, India. The occurrence of muddy snowfall in May 2002 at more than 4300 m above sea level in Afarwat glaciers of Kashmir, India has been attributed to changing environmental scenario of the region (Lone et al. 2010). The occurrence of "Black Snow" on the mountain peaks of Gund, Sonamarg in Kashmir, India observed in March, 1991 was due to the burning of oil-fields for the period of Gulf war (Kawosa 1991).

Occasional muddy rains were also observed in some regions of the Kashmir valley in April 2002 (Lone 2010). The occurrence of muddy snowfall in the alpine zone of Kashmir Himalaya evoked environmental concern as it has bearing on drinking water supplies as well as ecology of many natural snow-fed streams. The chemical composition shows that the particulate deposition approximately comprises 78 % of Lime stone, 20.5 % of Clay, 5 % of Gypsum and 1.5 % of Iron ore. Such a chemical composition suggests that these particulates might have origin from stone quarrying activities or cement manufacturing units.

Air pollution contributes substantial quantities of contaminants to snow. The Asian part of the Russian Federation as well as Europe contributes all but a minute percentage of the lead reaching the Arctic through air out of which 95–99 % is anthropogenic (UNEP 2010).

1.10 Water Pollution

Most of the air pollutants in atmosphere either settles down itself or get scrubbed by rain/snow/hail/dew unless otherwise it reacts with other pollutants to from secondary pollutants or absorbed/adsorbed by other living/nonliving things. The pollutants entrapped in precipitation would either stay in snow for year to come or reach surface/ground water bodies over the course of time. The material settled on the surface of solid bodies also gets washed over course of time. The acids/alkali formed in the atmosphere can dissolve chemical on the surface of the earth before reaching the water bodies. The water not only gets contaminated due to conventional pollutants, it also scrubs radioactive material released into atmosphere. Rainwater was collected in the Nijmegen area of Netherlands after Chernobyl accident, in first three weeks of May 1986 revealed presence of radioactive material (Dennis 1987). Summarises the findings of studies of rainwater from Scandinavia and Great Britain after Chernobyl accident shows that the issue is far from easily understood (Lucas and John 1987).

The organic compounds with diverse chemical structures, sources, as well as uses such as industrial compounds, pesticides, persistent degradation products, byproducts of fossil fuel combustion, and impurities during manufacture of chemicals are transported atmospherically and deposited into remote environments. Such deposition can affect plants and animals including human health.

Nitrogen controls productivity and eutrophication of estuaries. Elevated nitrogen inputs to water bodies leads to harmful algal blooms; loss of sea grasses; hypoxic and anoxic bottom waters; and reduced fish stocks (Valiela and Costa 1988; Hallengraeff 1993). These eutrophication problems are consequence of increased population growth and air pollution (Lee and Olsen 1985; Nixon 1995; Vitousek et al. 1997). A significant nitrogen inputs to estuaries in New York may be due to atmospheric deposition (Jaworski et al. 1997).

Lead is important for scientific community in environmental science as may enter surface waters due to erosion of lead-containing soil though lead is not very mobile in soil (UNEP 2010). Estimated residence times of biological particles with lead in surface waters, up to two years(UNEP 2010).

1.11 Soil Pollution

Many of the air pollutants do not remain in atmosphere for ever. Most of the air pollutants will settle on soil or water causing soil and water pollution. Airborne pollutants from anthropogenic as well as natural sources deposit on land and water bodies. Air pollutants can travel to great distances from the source. Pollutants in soil and water bodies include nitrogen compounds, heavy metal, sulfur compounds, pesticides, and other toxics.

Airborne pollutants can fall to the ground simply due to gravity. Such deposition is termed as “air deposition” or “atmospheric deposition”. Mercury extracted for centuries from sulfide ore or cinnabar has become a global pollutant. Mercury can be released into the atmosphere from many anthropogenic activities, such as municipal trash incineration, combustion of high sulfur coal which contains cinnabar, use of mercury based fungicides. Mercury has low reactivity in its elemental state and has long atmospheric residence time while the oxidized forms are removed by wet/dry deposition (Fogg and Fizgerald 1979).

Oxidized reactive gaseous mercury is very soluble in water and hence is effectively deposited on water and land by rain/snow/hail/due. Particulate forms of mercury settle as dry deposition (Keeler et al. 1995). The total quantity of mercury in the atmosphere is around 5000–6000 metric tons, and nearly 50 % of that was produced by human activities (Fitzgerals and Watras 1989).

Concentrations mercury in atmosphere peaked between 1960s and 1970s (Engstrom and Swain 1997). Anthropogenic activities contribute 70–80 % of the gross annual mercury emissions and 95 % of mercury vapor exists as elemental mercury (Fitzgerald 1995). Rest of the mercury exists as reactive gaseous mercury as complexes of divalent mercury, and/or in the organic form (Stratton and Lindberg 1995).

While deposition of H^+, $SO_4{}^{2-}$ and Ca^{2+} in numerous Central European forests has declined in the last decade, deposition of $NO_3{}^-$ and $NH_4{}^+$ remained high or increased resulting in depletion of soil Al-pools, release of $SO_4{}^{2-}$ formerly stored soil, accumulation of nitrogen in soil increasing nitrogen availability to trees and reducing Ca^{2+} concentration in the soil. Soil acidification as well as increased nitrogen availability will decrease the fine root and change the rooting zone to upper layers of soil. Such shift in rooting zone will decrease the root/shoot ratio causing increased drought susceptibility of trees (Matzner and Murach 1995).

Thirty-three years study of atmospheric heavy metal deposition in Denmark along with European emission inventories revealed concentrations of lead, cadmium, copper, zinc, vanadium, nickel and arsenic in soil at remote forest plantation on the island of Laesoe, Denmark. The accumulation of heavy metals was more in the top soil (Hovmand et al. 2008).

Deposition of particles from mineral processing and stone crushing can settle on soil leading to change in quality of top soil. The escape of materials which include by-product and products from chemical industry can contaminate soil to great extend.

As per data published by UNEP (2010) concentration in soil next to roadways and in towns was up to several thousand mg Pb/kg, and soils adjacent to smelters as well as battery factories were up to 60,000 mg Pb/kg.

1.12 Loss of Economy

Study of production, distribution as well as consumption of goods and services is called economics. An economic system of a region or nation is referred as economy. The economy differs widely between, and within, countries due to differing environments, cultures, and government systems.

The direct consequences of air pollution can cause millions of dollars if measured in terms of cost of treatment to heal sickness, lost productivity, missed educational/development opportunities. The economic loss due to climate change and disasters triggered by air pollution can take away good share of Gross Domestic Product (GDP) of any country.

Even though air pollution is spread across the world, it is most severe in cities of developing countries (David et al. 1996). But considering the spatial distribution, it is difficult to generalize the issue. Every country will have pockets of polluted areas as well as clean area. But developing world has disadvantage of high population growth rate in cities and poor infrastructure. It means poorly paved roads which rises dust increasing suspended particulate matter. The adulteration of fuel and old vehicles would add smoke to atmosphere. Air pollution in cities of developing countries can cost the nation after a decade due to unhealthy senior citizens. The immediate air pollution threat can come due to loss of tourism and crop. The soiled buildings, corroded structures and degraded construction material due to increase in acidic air pollutants can cost the owners a hefty amount even though it contributes to GDP of a country.

Fires to clear forest to accommodate large scale rubber and oil palm plantations in Indonesia resulted in major air pollution in Asia during April to November of 1997 due to wide spread of forest fires. The disaster was cause of thick smoky haze which covered Indonesia, Malaysia, Singapore, Brunei, Southern Thailand and Philippines. The fires destroyed a large area of rainforest that included endangered species. While the fire destroyed commercial timber, plantations and farmland, air pollution resulted in tourism. The smoke was also cause of temporary shutdown of industry and commerce as well as increase in health care costs. Much mortality occurred Malaysia in the period due to air pollution from Indonesia.

Fig. 1.31 Reduced visibility with time 6.00 AM, 7.00 AM, 1.00 AM on clear day in one of the location in Bangalore

As per, Teresa and Leonardo (2013) reduced cognitive potentials due to preventable childhood lead exposure translate into economic losses of $134.7, $699.9, and $142.3 billion international dollars at Africa, Asia, and Latin America/Caribbean, respectively amounting to 1.20 % of the global GDP. Lifetime economic productivity (LEP) associated due to childhood lead exposure in Low and Middle Income Countries (LMIC) currently amounts to $977 billion annually (Teresa and Leonardo 2013).

Fig. 1.32 Reduced visibility with time 6.00 AM, 7.00 AM and 1.00 AM on clear day in another location in Bangalore

1.13 Visibility

Visibility is the maximum distance in a given direction at which an object can be visually recognized with unaided eyesight (Wark et al. 1998). The destruction of visibility is mainly due to the absorption and scattering of visible light by suspended particles (Chan et al. 1999).

PM2.5, are believed to be mainly responsible for the scattering of visible light (Sloane et al. 1991). Fine particulate matter is the main pollutant in the majority urban areas in China (Zhang et al. 2009, 2013) and other countries. Hence it has acquired worldwide attention for its bad impacts on visibility (Ghim et al. 2005) as well as public health (Hong et al. 2002).

The visibility is affected by meteorology and concentration of pollutants. As could be seen from Figs. 1.31 and 1.32 the visibility is not affected much at 6.00 AM clock due to less traffic and low concentration of pollution. At 7.00 AM as the number of vehicles on road increased visibility decreased as concretion of suspended particles in atmosphere increased and low temperature hindered dispersion of pollutants. At 1.00 AM the pollutants dispersed mainly due to increase in temperature and therefore dispersion of pollutants.

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Chapter 2
Air Quality Issues

Abstract Air quality changes from place to place and time to time and so as air quality issues. The air quality issues depend on types of air pollutants, regulatory issues, activity within the region, climate. Pollutants do not respect political boundaries and hence the pollutants from one country can just damage as much or greater than the country of origin. This chapter elaborates air quality issues and possible solutions along with monitoring, inventorisation, and modeling.

Environmental pollution is presence of an agent potentially damaging to either the environment or human health. If such agent is present in air then it is considered as air pollution. Polluting agents are called pollutants which include particles, chemicals, and microorganisms. All the elements in periodic table are found in atmosphere. It is difficult to quantify all the chemicals as about 15,000 new chemicals are updated in Chemical Abstract Service (CAS) every day (CAS 2015). As on May, 2015 more than 96 million chemicals were registered in CAS.

Every substance emitted into the atmosphere removed subsequently so that cycle of elements is established through phenomena called *biogeochemical cycle*. The usual source, pathway and sinks of air pollutants are given in Fig. 2.1.

It is not practical to evolve standard and measure all chemicals known to mankind in the atmosphere. Hence six criteria pollutants were adopted across the world in 1970s: particulate matter, nitrogen dioxide, ozone, sulfur dioxide, carbon monoxide, and lead. Later many countries bifurcated particulate matter into two types: PM_{10} (Particulate matter < 10μ), $PM_{2.5}$(Particulate matter < 2.5μ) there by increasing the criteria pollutants to seven.

Even though it is known fact that micro-organisms are present in the atmospheric air, estimating the number of species of microbes is not possible with knowledge as on date. Variety of endotoxins can be released from the protoplasm of cells of organisms after death causing potential risks to health and environment. Monitoring of microorganisms and toxins released due to death the micro-organisms is not practiced as part of air quality monitoring.

Air quality continues as important issue for the economy, public health, and the environment. Although Europe has significantly cut emissions of many air pollutants greatly reducing sulphur dioxide (SO_2), benzene (C_6H_6), carbon monoxide

R. Chandrappa and U. Chandra Kulshrestha, *Sustainable Air Pollution Management*, Environmental Science and Engineering,
DOI 10.1007/978-3-319-21596-9_2

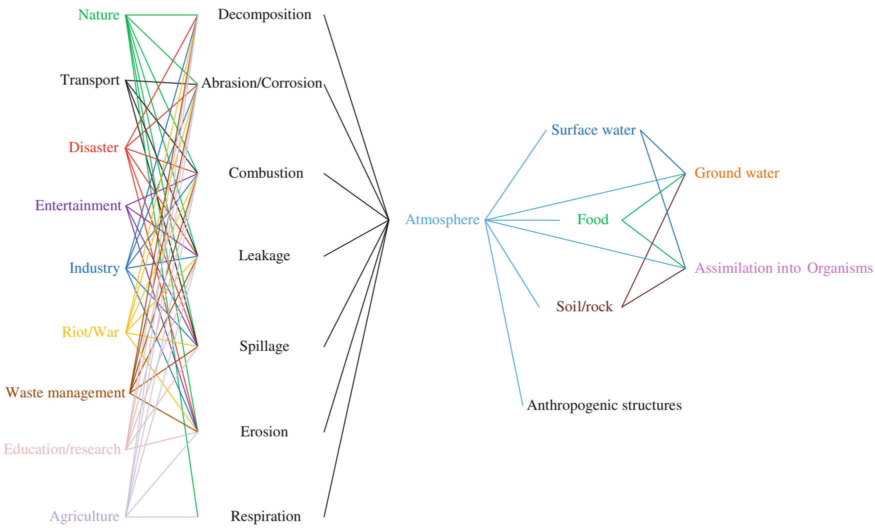

Fig. 2.1 Source, pathway and sinks of air pollutants

(CO), and lead (Pb) air pollution continues to damage human health as well as the environment (EEA 2013).

Emissions of air pollutants originate from all economic as well as societal activities. Some air pollutants are released into atmosphere intentionally (as in fumigation of operation theatre and modern agriculture practice) while other are released as unavoidable byproduct or waste product. There are other situations wherein product (as in cement manufacturing and mining) escapes into atmosphere.

Policies executed at the regional, national as well as sectoral level have resulted in decreased emissions of many air pollutants resulting in acceptable air quality levels. But, road transport, power plants, industry, households as well as agricultural activities continue to emit major amounts of air pollution. Burning of biomass by households is an important source of PM as well as polycyclic aromatic hydrocarbons (PAHs). Agricultural activity is responsible for the major amount of ammonia (NH_3) emissions.

As per EEA 2013, emission from agriculture have either decreased very little from agricultural sources and not decreased from domestic in the past decade (2003–2013) from Europe. The scenario of air quality is not monitored or poorly monitored in case of developing countries due low prioritization of issue related to air pollution.

Average time a species resides in atmosphere is called average life time or average residence time. This definition are useful in calculating some of the air polluting species in the atmosphere by applying principle of conservation of mass, for an imaginary volume, as described below.

Rate of accumulation of given species = [Rate of the species flowing in]
− [Rate of species flowing out]
+ [Rate of formation of species]
− [Rate of removal of species]

$$\frac{dQ}{dt} = (F_{in} - F_{out}) + (P - R)$$

where,

Q Total mass of substance in the imaginary volume;
F_{in} Rare of species flowing in;
F_{out} Rate of species flowing out;
P Rate of introduction of species; and
R Rate of removal of species.

If Q does not change in time than $\frac{dQ}{dt} = 0$

$$\therefore F_{in} + P = F_{out} + R$$

The average residence time $\tau = Q/(R + F_{out})$

If entire atmosphere is taken as reservoir $\tau = \frac{Q}{R} = \frac{Q}{P}$

The Clean Air Act of USA establishes hazardous air pollutants, abbreviated as HAPs and referred to as "air toxics" or "toxic air contaminants". These are 188 air toxics known or suspected to cause serious health effects even at low exposure levels. Of these 188 air toxics, about two-thirds are VOCs and the majority of the rest are metal compounds.

The dispersion of air pollutants depends on atmospheric chemistry and physics. The major chemical and physical phenomena that predominates air pollutants dispersion are

- Chemical kinetics;
- Atmospheric chemistry and photochemistry;
- Chemistry of stratosphere;
- Chemistry of troposphere;
- Chemistry of atmospheric;
- Properties of the Atmospheric Aerosol;
- Dynamics of aerosol particles;
- Thermodynamics of Aerosols;
- Nucleation;
- Mass transfer in atmosphere;
- Condensation;
- Coagulation;
- Cloud physics;
- Dry deposition;

- Wet deposition;
- General circulation of atmosphere; and
- Biogeochemical cycle.

2.1 Types of Air Pollutants

Types of air pollutants can be categorized as: (1) Natural or anthropogenic based on source of air pollution, (2) Organic or inorganic based on presence/absence of carbon and hydrogen, (3) Gas/Liquid/Solid based on state of the pollutants, (4) Primary/Secondary pollutants based on whether pollutant has come out of source or formed due to interaction of primary pollutants in the air.

Natural air pollutants are generated due to natural phenomena such as erosion of soil, disintegration of rocks/minerals evaporation of droplets of sea water, volcanoes, wild fires, and living organisms. Living organisms can generate gases due to oxidation/reduction of elements/compounds during metabolic process. Living organisms can also generate pollens/spores during the process of reproduction which may spread in air. Sources of air pollutants due to anthropogenic activity include transportation, manufacturing, cooking, waste management, etc.

Organic pollutants are originated due to: (1) incomplete combustion of organic substances like petroleum or wood, (2) manufacturing process of organic products, and (3) biological action like decomposition of organic material. Inorganic pollutants originate from complete combustion of fuel, manufacturing activity, weathering, corrosion and biological action.

Solid and liquid air pollutants occur as particles where as gaseous pollutants occur as molecules in atmosphere.

Secondary pollutants formed due to chemical changes of primary pollutants. Examples of secondary air pollutants are nitrogen dioxide formed due to oxidation of nitric oxide. If the nitrogen dioxide is formed due to combustion or chemical reaction in single stage it is considered as primary pollutant. Formation of ozone produced from nitrogen dioxide and volatile organic compound is of major health concern. Particles, emitted directly into the air are considered primary and particles are formed from other pollutants like sulphates from SO_2 and Nitrates form NO_2 are considered as secondary pollutant.

2.1.1 Natural Air Pollutants

Natural air pollutants enter atmosphere from natural activity like volcano, wild fire, soil re-suspension without anthropogenic intervention, lightening, etc. Some of the common natural air pollutants are discussed in following paragraphs.

Ammonia: Major natural sources of Ammonia are ammonification of humus, animal waste, and emission from soils.
Arsenic: Atmospheric arsenic exists mainly in particulate matter. The main natural sources of arsenic are volcanic activity and, low-temperature volatilization.
Biogenic Hydrocarbons: Vegetation releases organic compounds into atmosphere. Organic compounds emitted by vegetation include Isoprene,Camphene, 2-carene, Δ^3-carene, d-Limonene, Myrcene, Ocimene, α-Limonene, Myrcene, Ocimene, α-Phellandrene, α-Pinene, β-Pinene, Sabinene, α-Terpinene, γ-Terpinene, Teripinolene, β-Phellandrene, p-Cymene. The Largest biogenic hydrocarbon emissions occur tropics and Isopropene is dominant compound. Emission of biogenic hydrocarbons is more than anthropogenic hydrocarbons on global scale (John and Spyros 2006).
Cadmium: Main source of natural emission of cadmium is volcanic activities.
Hydrogen fluoride: Volcanoes are major natural source of hydrogen fluoride.
Mercury: Degassing of the Earth's crust as well as evaporation from water bodies are major sources of atmospheric mercury.
Methane: Methane is mainly formed due to biological activity during unaerobic degradation of organic matter in waste, marshes, rice fields, wetlands, forests, enteric fermentation etc.,
Methyl Bromide: Methyl Bromide is the most abundant atmospheric bromocarbon. Natural sources of methyl bromide are ocean, salt marshes, rice fields, fungus, wet lands and plants.
Methyl Chloride: Major natural sources of methyl chloride emission are fungi, salt marshed, wetlands, tropical plants, rice field and oceans.
Mineral dust: Mineral dust arises due to wind acting on soil particles. The largest global sources of mineral dust are Sahara-Sahel region and central Asia. Published global estimates of mineral dust vary from 1000 to 2150 Tg/year (John and Spyro 2006).
Oxides of Nitrogen: Nearly 90 % of atmospheric NO_x is produced naturally by biological processes, lightning, volcanic activity, and photochemical destruction of compounds of nitrogen in the upper atmosphere. The important nitrogen containing compounds in atmosphere are nitrogen dioxide (NO_2), nitric acid (HNO_3), nitrous oxide (N_2O), nitric oxide (NO), and ammonia (NH_3). N_2O is emitted by biological sources in soil and water. N_2O is also emitted during biomass burning, degassing of irrigation water and agricultural activities. Nitrogen oxides (NO and NO_2) are usually represented as NO_x. Reactive odd nitrogen (represented as NO_y) is the sum of NO_x and all products of atmospheric oxidation of NO_x. Atmospheric oxidation products in atmosphere include nitric acid (HNO_3), dinitrogen pentoxide(N_2O_5), nitrous acid (HONO), the nitrate radical (NO_3), peroxynitric acid (HNO_4), peroxyacetyl nitrate (PAN) and its homologs, alkyl nitrates ($RONO_2$), and peroxyalkyl nitrates ($ROONO_2$).
Ozone: Major ground level ozone is formed due to atmospheric reaction of VOCs emitted naturally from trees, anaerobic biological process, lightning, and volcanic activity.

Oxides of sulfur: Sulfur is present in the earth's crust and subsequently enters atmosphere in various form. The major sulfur compounds in the atmosphere are hydrogen sulfide, dimethyl sulphide (DMS), carbon disulfide(CS_2), carbonyl sulfide, methyl mercaptan, dimethyl disulfide, sulfur dioxide, bisulfate ion, sulfite ion, sulfuric acid, bisulfate ion, sulfate ion, Methane sulfonic acid (MSA), dimethy sulfone, Hydroxymethane sulfonic acid (HMSA). Major natural source of oxides of sulfur is from volcano and wild fire. Ocean contributes to DMS produced by marine phytoplankton. Oxidation of DMS is source of MSA and SO_2. Atmospheric conversion of CS_2 and DMS is one of the sources of carbonyl sulfide (OCS) apart from direct OCS flux from oceans and anthropogenic source.

2.1.2 Anthropogenic Air Pollutants

Anthropogenic air pollutants are of major concern to mankind as major quantity of these pollutants occurs in or near human settlement. Major air pollution sources across the world are: Motor vehicles, Residential wood combustion, glycol dehydrators, solvent use, prescribed burning, dry cleaning, solvent cleaning, coal combustion, gasoline(petrol) distribution, primary aluminium production, manufacture of motor vehicles, plastic foam products, commercial printing gravure, pulp mills, structure fire, waste dump (Fig. 2.2), and soil re-suspension.

Some of anthropogenic air pollutants which are of major concern are discussed in subsequent paragraphs:

Airborne particulate matter: Particulate matters (PM) include all solid/liquid (except pure water) substance with size larger than a molecule but less than microscopic/submicroscopic size (about 500μ). Figure 2.3 shows some of the sources of airborne particulate matter. This includes dust, dirt, soot, smoke, as well as liquid droplets. Airborne particulates may be a mixture of organic as well as

Fig. 2.2 Waste dump like this can emit numerous hazardous chemicals due to vaporisation/reaction

Fig. 2.3 Some of the sources of airborne particulate matter **a** industrial emission, **b** re-suspension on road, **c** re-suspension on unpaved sites, **d** firing litter, **e** street sweeping

inorganic substances. PM exceeding 2.5μ in aerodynamic diameter is defined as coarse particles. Particles smaller than 2.5μ ($PM_{2.5}$) are called fine particles. PM is unique in complexity. Airborne PM not only arises from source but also formed due to condensation/reaction in the atmosphere.

Acetaldehyde: Acetaldehyde is largely used as an intermediate during synthesis of other chemicals. Acute exposure to acetaldehyde leads to irritation of the skin, respiratory tract as well as eyes. Symptoms of chronic intoxication of acetaldehyde are similar to those of alcoholism. It is considered as probable human carcinogen (USEPA 1987).

Acetamide: Acetamide is used as a solvent and a plasticizer. Acute exposure leads to causes mild skin irritation.

Acetylene: This is a colourless gas which is lighter than air. Acetylen is produced from calcium carbide or from petroleum fractions.

Acetonitrile: Acetonitrile is used in lithium batteries as well as spinning fibres. It is present in air from automobile exhaust as well as manufacturing facilities. Acute exposure causes irritation of mucous membranes. Chronic exposure caused headaches, numbness, as well as tremors.

Acetophenone: Acetophenone is used as a flavoring agent in foods, in soaps and perfumes, and as a solvent for resins and plastics. Acute exposure of this chemical may produce skin irritation as well as transient corneal injury in humans.

Acrolein: Acrolein may be formed from the burning of certain organic matter or fuels such as gasoline(petrol) or oil. Acrolein is used as a biocide or as an intermediate in the production of acrylic acid. Acute inhalation exposure may result in respiratory tract irritation as well as congestion.

Acrylamide: *Acrylamide is* used as an intermediate in the manufacture of organic chemicals and polyacrylamides. An acute and chronic oral exposure leads to damage of the nervous system in animals and humans.

Acrylic acid: Acrylic acid is used in manufacture of various plastics, adhesives, paints, elastomers, coatings, as well as floor polishes. Acrylic acid is irritating and corrosive to the respiratory tract and the skin. Eye contact can result in irreversible injury.high exposure might result in pulmonary edema.

Ammonia: This colourless, pungent gas is highly soluble in water to form solutions with up to 29 % NH_3. Ammonia is used in hydrometallurgy for leaching sulfides of nickel, copper, and cobalt as ammonia forms the ammine complexes with these metals. The ammonia solution is also used in recovery of metals from solid waste (such as E-Waste) by precipitation of metals that reacts with ammonia.

Arsine: Traces of arsenic in ores, scrap, and metallurgical residues will be converted into arsine under certain conditions. This is a toxic gas with strong garlic odour formed when hydrogen is generated in presence of arsenic-bearing solutions.

Arsenic: Arsenic is a metalloid found as arsenides of copper, lead, silver, gold, and some coal. White arsenic (arsenic trioxide), emitted during roasting of sulfide ores. Major part of anthropogenic arsenic emissions are emitted from copper smelting, combustion of coal, and other nonferrous metal industries.

Arsenic Compounds: Most of anthropogenic emissions of arsenic compound origin from metal smelters and the fuel combustion, where arsenic is typically emitted in the form of arsenites (As_2O_3) or arsenates (AS_2O_5). Acute high-level exposure of arsenic compound through inhalation leads to gastrointestinal effects; central as well as peripheral nervous system disorders. Chronic inhalation leads to irritation of the skin as well as mucous membranes and affects the brain/nervous system.

Arsenic oxide: Arsenic oxides are two types—the trivalent and the pentavalent. Trivalent oxide is dangerous as it is volatile. It is generated during the oxidation of arsenic-bearing sulfide minerals under restricted supply of air. It should be collected

in the gas filtration system and should be disposed in steel barrels. Since arsenic oxide is soluble in water its storage and disposal should be monitored carefully.
Acrylonitrile: Acrylonitrile is used in the manufacture of acrylic fibres, modacrylic fibers plastics, acrylamide, adiponitrile, and nitrile rubbers from where it may find its way into atmosphere. It is likely to cause headaches, mucous membrane irritation, dizziness, and nausea
Allyl chloride: Allyl chloride is used in the synthesis of compounds such as allyl alcohol, allyl esters, allyl amines, polyesters. Allyl chloride derivatives are found in plastics, varnish, adhesives, pharmaceuticals, perfumes, and insecticides. This pollutant enters into ambient air from production and processing facilities. Acute exposure to this pollutant results in irritation of the eyes and respiratory passages.
Aniline: Aniline is used as a chemical intermediate for manufacturing dye, polymer, and rubber. It is used as a solvent, and as an antiknock compound for gasoline (petrol). It can be formed from the burning of plastics, or tobacco (USEPA 1985). Aniline is highly toxic and carcinogen. Acute exposure to high levels of aniline will result in irritation of upper respiratory tract and congestion.
Antimony Compounds: Antimony is a silvery-white metal mined and then either changed to antimony metal. The concentration of antimony in ambient air ranges from less than 1 to about 170 ng/m^3. However, concentrations may be greater than 1000 ng/m^3 (0.01 mg/m^3) near factories that convert antimony ores into metal, or antimony oxide (ATSDR 1992). Chronic exposure to antimony in humans cases antimony pneumoconiosis, alterations in pulmonary function, inactive tuberculosis, pleural adhesions, chronic bronchitis, chronic emphysema, irritation, cardiovascular effects and gastrointestinal disorders(ATSDR 1992; USDHHS 1993a, b)
Asbestose: Asbestos is a mineral fiber which is mined for commercial use. Due to its fiber strength as well as heat resistance, it has been used in roofing shingles, ceiling and floor tiles, and asbestos cement products, automobile clutch, brake, transmission parts, packaging, heat-resistant fabrics, gaskets, and coatings. Asbestos can be released to air when asbestos-containing objects are disturbed by cutting, sanding etc. Exposure to asbestos causes lung cancer, mesothelioma, and asbestosis.
Beryllium Compounds: This chemical enters air during combustion of coal, fuel oil, tobacco smoke, mining, and industrial activity involving beryllium compound. Acute exposure causes inflammation of the lungs and Chronic inhalation exposure causes chronic beryllium disease and increases risk of lung cancer.
Benzine: Benzene is released due to incomplete combustion of fuels in vehicles, domestic heating, oil refining, and handling/distribution storage of gasoline(petrol). Benzene is a carcinogenic pollutant.
Benzopyrene: Benzopyrene formed mainly from the combustion of organic material like wood, and from vehicle exhaust fumes, especially from diesel vehicles. Benzopyrene is carcinogenic to humans.
Benzotrichloride: Benzotrichloride is used in the dye industry and other chemical industry. Acute exposure to this chemical causes irritation to skin and mucous membranes.

Benzyl chloride: Benzyl chloride is a chemical intermediate in the manufacture of dyes and pharmaceuticals. The acute human exposure through respiratory track leads to severe irritation of respiratory tract, eyes, skin, mucous membranes and lung. Exposure to high concentrations affects the central nervous system.

Biphenyl: Biphenyl is used in dye carriers, heat transfer fluids, food preservatives, and as a fungistat. Acute human exposure to high concentration of this chemical causes eye/skin irritation. It imparts toxic effects on the kidneys, liver, and nervous systems.

Bis(2-ethylhexyl)phthalate (*DEHP*): This is used in the manufacturing of polyvinyl chloride. It exhibits low toxicity from chronic and acute exposures. Acute oral can cause gastrointestinal distress in humans.

Bis(chloromethyl)ether: In humans, acute human exposure to Bis(chloromethyl) ether may cause skin, mucous membrane, as well as respiratory tract irritation. Chronic human exposure to Bis(chloromethyl)ether causes chronic bronchitis, chronic cough, as well as impaired respiratory function. Bis(chloromethyl)ether is known human carcinogen(ATSDR 1989; USDHHS 1993a, b; USEPA 1999d).

Bromoform: Bromoform is used as intermediate in chemical synthesis, and as cough suppression agent; sedative; laboratory reagent; fluid for mineral ore separation during geological tests, and in quality assurance programs in the electronics industry. The acute effects from inhalation/ingestion of high levels of bromoform are slowing down of brain functions, and injury to the liver/kidney. Chronic effects include effects on the kidney, liver, and central nervous system. Bromoform has been classified as a probable human carcinogen (USEPA 1999c).

1,3-Butadiene: It is used as a monomer in the manufacture of synthetic rubber. Acute exposure to 1,3-butadiene by inhalation results in irritation of the nasal passages, eyes, throat, and lungs. Exposure may also causes cardiovascular diseases, leukemia. It is carcinogenic to humans by inhalation (USEPA 2009).

Calcium cyanamide: Calcium cyanamide is used as a pesticide, fertilizer, as well as in the production of other chemicals. Acute human inhalation exposure may cause rhinitis, pharyngitis, gastritis, laryngitis, and tracheobronchitis. Chronic human exposure can cause chronic rhinitis.

Caprolactam: Caprolactam is used in the production of synthetic fibers. Acute exposure may result in irritation and burning of the throat, eyes, nose, and skin. Chronic human exposure to caprolactam causes peeling of the hands; eye, nose, and throat irritation.

Captan: Captan is used as a fungicide on vegetables, fruits, as well as ornamentals. Acute exposure to captan may cause conjunctivitis as well as dermatitis in humans. It is classified as probable human carcinogen (USEPA 1997).

Carbaryl: Carbaryl is an insecticide. Acute and chronic human exposure will cause cholinesterase inhibition, and neurological effects. Prolonged low-level exposure can cause memory loss, headaches, muscle weakness and cramps, as well as anorexia (Sittig 1985; Budavari 1989; USDHHS 1993a, b)

Carbon disulfide: Carbon disulfide is used in the manufacture of cellophane, rayon, carbon tetrachloride, rubber chemicals and pesticides. Acute inhalation exposure can cause changes in breathing, chest pains, nausea, vomiting, headache, mood changes, lethargy, dizziness, fatigue, blurred delirium, vision, and convulsions. Chronic exposure can lead to neurologic effects (ATSDR 1996).

Carbon tetrachloride: Carbon tetrachloride is used to make refrigerants as well as propellants for aerosol cans;and as a solvent for lacquers, oils, fats, varnishes, resins, rubber waxes. It is also used as cleaning agent and as a dry as a grain fumigant. Carbon tetrachloride will affect kidneys, liver, and central nervous system (CNS). Acute inhalation and oral exposures causes headache, lethargy, nausea, weakness, and vomiting. Acute exposures to higher levels as well as chronic inhalation or oral exposure leads to liver and kidney damage in humans.

Carbonyl sulphide: Carbonyl sulfide is emitted from oceans, volcanoes as well as deep sea vents. It is used in organic compound synthesis. Acute inhalation of high concentrations of carbonyl sulfide might cause narcotic effects in humans; and irritation of eyes and skin.

Catechol: Catechol is used as a developer for fur dyes; as a photographic developer; in polymerization inhibitors, as an intermediate for antioxidants in rubber as well as lubricating oils; and in pharmaceuticals. Chronic exposure causes eczematous dermatitis, depression of the CNS and a prolonged rise of blood pressure in humans.

Chloramben: Chloramben is used as a herbicide. Acute exposure to high levels of chloramben results in dermal irritation.

Chlordane: It is a pesticide. The acute effects of chlordane in humans are gastrointestinal distress as well as neurological symptoms. Chronic inhalation exposure of humans will affect nervous system and may cause cancer.

Chlorine: This is a pungent gas with greenish yellow colour and irritating odour. This gas which is heavier than air is used to form chlorides from ores as well as concentrates. Main applications of chlorine are in the manufacture of a wide range of industrial/consumer products, disinfection, and bleaching of paper pulp. Chlorine was used as weapon as Chlorine can react with water in the mucosa of the lungs and form hydrochloric acid. Hence chlorine irritates the respiratory system. The element iron can react with chlorine at high temperatures creating a *chlorine-iron fire.*

Carbon dioxide: This is colourless, odourless gas, heavier than air generated during combustion of carbonaceous fuels.

Carbon monoxide: This is colourless, odourless gas slightly lighter than air. This is used as a reducing agent and is a major component of producer gas and BF gas.

Cadmium compounds: Key contributors of cadmium into air is drying of zinc concentrates; and roasting, smelting, refining; waste incineration; production of nickel-cadmium batteries; combustion of fossil fuel; and cement manufacturing (Kazantzis 1987). The main sources of cadmium compounds in the atmospheric air are the combustion of fossil fuels and the incineration of municipal waste. Chronic inhalation to cadmium can cause kidney disease and the acute exposure affects lung.

Chromium Compounds: Chromium naturally occurs in rocks, animals, soil, plants, and volcanic dust. It occurs as trivalent chromium (Cr III), and hexavalent chromium (Cr VI) forms. Chromium is released in the form of small particles or aerosols. The major sources of chromium are from ferrochrome production;

chemical and refractory processing; ore refining; automobile brake lining as well as catalytic converters for automobiles; fossil fuel (oil and coal)combustion; dyes for paints; rubber and plastic products; chrome plating; pharmaceuticals; stone; wood; clay and glass products; electrical/aircraft manufacturing; steam/airconditioning supply services; incineration of solid waste; cement-producing plants; leather tanneries; pulp and paper mills and chrome pigments. Chromium (III) is less toxic than chromium (VI). Acute inhalation exposure to chromium (VI) results in gastrointestinal and neurological effects. Dermal exposure causes skin burns. Chromium VI is a carcinogen.

Cobalt Compounds: Cobalt is found naturally throughout the environment but higher emission may be observed due to industrial activity. Acute exposure results in respiratory effects, like decrease in ventilatory function, edema, congestion, and hemorrhage of the lung. Chronic exposure results in respiratory irritation, asthma, pneumonia, wheezing, and fibrosis. Cadmium also affects liver, kidneys, conjunctiva, and immunological system.

Coke Oven Emissions: Emissions from coke oven comprises variety of chemicals that results in cancer, severe dermatitis, conjunctivitis, lesions of the respiratory system as well as digestive system.

Cyanide Compounds: Cyanide is emitted in vehicle and number of industries. Cyanide compounds are extremely toxic to humans and animals. Chronic inhalation affects central nervous system, cardiovascular system, respiratory system, thyroid gland, eyes and skin.

Carbon disulfide: This is a colourless liquid with unpleasant odour and boiling point of 46.2 °C. The gas is used as solvent for elemental sulfur. It is formed in small quantity when SO_2 reacts with carbon at high temperature.

Cyanogen: This is a colourless gas with distinct odour. This gas is formed when hot air contact carbon under reducing conditions (as in the iron blast furnace). Since Cyanogen is soluble in water, scrubbed water will be contaminated with Cyanogen.

Chloroacetic acid: Chloroacetic acid is used in the making of cellulose ethers, synthetic caffeine, glycine, thioglycolic acid, dyes, as well as organic chemicals. Acute inhalation or dermal exposure may damage/irritate eyes, respiratory tract, mucous membranes, skin, and cause depression of the central nervous system.

2-Chloroacetophenone: 2-chloroacetophenone is used in tear gas as well as in chemical Mace as it is a strong throat, eye, and skin irritant.

Chlorobenzene: Chlorobenzene is used as degreasing agent, solvent, and chemical intermediate. Chronic exposure of humans to this chemical affects the central nervous system.

Chlorobenzilate: This is a pesticide not currently used in the USA and Europe. It is a non-systemic pesticide that works through contact and as a neurotoxin. USEPA has classified it as a, probable human carcinogen (USEPA 2015).

Chloroform: Sources of Chloroform include hazardous waste sites, pulp and paper mills, and sanitary landfills. It may be formed during chlorination of drinking water, wastewater as well as swimming pools. Acute inhalation exposure to chloroform may cause central nervous system depression. Chronic exposure by inhalation in humans can affects the liver and may result in hepatitis, as well as central nervous system effects. USEPA (1999e) has classified chloroform as a probable human carcinogen.

Chloromethyl methyl ether: Chloromethyl methyl ether is used in manufacturing of some chemicals. Acute inhalation exposure can cause severe irritation of the eyes, skin, mucous membranes, pulmonary edema, respiratory tract, and pneumonia in humans. Chronic inhalation exposure can cause chronic bronchitis in humans. USEPA has classified this chemical as known human carcinogen (USEPA 1999n).

Chloroprene: Acute human exposure to chloroprene include headache, irritability, giddiness, dizziness, insomnia, respiratory irritation, cardiac palpitations, fatigue, chest pains, gastrointestinal disorders, dermatitis, nausea, temporary hair loss, conjunctivitis, as well as corneal necrosis. Symptoms of chronic exposure are fatigue, chest pains, dermatitis, irritability, giddiness, and hair loss.

Cresols/Cresylic acid (*isomers and mixture*): Ambient air contains small quantity of cresols from power plants, automobile exhaust, as well as oil refineries. Acute inhalation exposure to mixed cresols results in respiratory tract irritation and dermal irritation. USEPA has classified *o*-cresol, *m*-cresol, as well as *p*-cresol as Group C, possible human carcinogens (1999a, b, f).

Cumene: Cumene is used as lacquers, thinner for paints, enamels as well as a component of high octane fuels. It is also used in the manufacture of acetone, phenol, acetophenone, as well as methylstyrene. Acute inhalation exposure to cumene is skin and eye irritant. It may cause dizziness, drowsiness, headaches, slight incoordination, as well as unconsciousness in humans. It has a potent central nervous system depressant action.

2,4-D, salts and esters: 2,4-D, (2,4-dichlorophenoxyacetic acid), is a herbicide available as free acid, salts and ester. It generally has low acute toxicity via the oral/dermal/inhalation routes of exposure. At dose levels above the threshold of saturation for renal clearance, it is toxic to the thyroid, kidney, adrenals, eye, and ovaries/testes.

1,1-Dichloro-2,2-bis(p-chlorophenyl) ethylene (*DDE*): DEE is a breakdown product of DDT. EPA has classified DDE as a probable human carcinogen (USEPA 1999o).

Diazomethane: Diazomethane is used as a methylating agent. It is a strong respiratory irritant. Acute inhalation exposure of humans to diazomethane can cause irritation of the eyes, wheezing, asthmatic symptoms, cough, pulmonary edema, pneumonia, weakness, dizziness, headache, and chest pains.

1,2-Dibromo-3-chloropropane (*DBCP*): This chemical is used as an intermediate in chemical synthesis. Acute exposure to DBCP in humans results in depression of the central nervous system and pulmonary congestion. Chronic exposure affects male reproductive effects. USEPA has classified DBCP as probable human carcinogen (EPA 1997).

Ethylidene dichloride (*1,1-Dichloroethane*): Ethylidene dichloride is mainly used as an intermediate in chemical production. Acute inhalation exposure to high levels of these chemical results in central nervous system depression as well as a cardiostimulating effect. USEPA has classified ethylidene dichloride as possible human carcinogen (USEPA 1999g).

Fine mineral fibers: Fine mineral fibers include rockwool, glasswool, glass filaments, slagwool, and ceramic fibers. Cronic exposure to rockwool, glasswool, and slagwool will cause fibrosis. As per IARC, glass fibers and ceramic fibers as classified as Group 2B (possibly carcinogenic to humans), where as glass wool, slag wool, glass filaments, and rock wool, is calssified as Group 3, (not classifiable as to their carcinogenicity to humans) (IARC 1988).

Formaldehyde: Formaldehyde is an organic compound also known as methanal. A colorless gas at room temperature, it has characteristic pungent, irritating odor. It is a common precursor to more complex compounds. Formaldehyde in water, commonly called formalin or formol are used for preservation of biological specimens. It is also used in nail hardeners as well as nail varnish. It is known to be a human carcinogen.

Fluorine: This is a highly corrosive, colourless gas with a distinct odour which is heavier than air. This gas is produced by the fused electrolysis of Hydrogen Fluoride and Potassium Fluoride bath at 100 °C. Fluorine is used mainly for uranium isotopic enrichment and to produce uranium hexafluoride from uranium tetrafluoride.

Glycol ethers2: Uses of Glycol ethers2 include use as solvents as well as an ingredient in liquid soaps, cleaning compounds, and cosmetics. Acute exposure to high levels this chemical by humans results in narcosis, pulmonary edema, severe liver and kidney damage. Chronic exposure to the glycol ethers by humans may result in neurological as well as blood effects, including tremor, fatigue, nausea, and anemia.

Heptachlor: Heptachlor was used as an insecticide. Acute inhalation exposure to this chemical may result in nervous system effects. Chronic inhalation may lead to neurological effects including salivation, irritability, as well as dizziness.

Hexachlorobenzene: Hexachlorobenzene was widely used as a pesticide till 1965. Chronic oral exposure to hexachlorobenzene results in a liver disease with skin lesions.

Hexamethylene diisocyanate: This chemical is used as a polymerizing agent in polyurethane paints/coatings. Acute exposure to high concentrations of hexamethylene diisocyanate can cause pulmonary edema, coughing, as well as shortness of breath. This chemical is also extremely irritating to the eyes, nose, and throat. Chronic exposure may cause chronic lung problems.

Hexamethylphosphoramide: hexamethylphosphoramide is used as a solvent in research laboratories. The International Agency for Research on Cancer (IARC) has classified it as a Group 2B, possible human carcinogen (IARC 1987).

Hexane: Hexane is used as a special-use solvent, to extract edible oils from seeds/vegetables and as a cleaning agent. Acute inhalation exposure to high level hexane causes mild central nervous system effects. Chronic exposure to hexane in air is linked with polyneuropathy in humans.

Hydrazine: Small amount of hydrazine is present in tobacco smoke. Acute exposure to high levels of hydrazine can cause irritation of the nose, eyes, and throat. Acute exposure can also cause dizziness, headache, seizures, nausea, pulmonary edema, coma in humans and can also damage the liver, kidneys, as well as central nervous system. USEPA (1999e) has classified hydrazine as a probable human carcinogen.

Hydrogen chloride: This is a colourless gas forms dense white fumes in air due to reaction with atmospheric moisture forming hydrochloric acid. This gas may be formed accidentally in industry when gaseous chlorides leak and react with moisture in the air.

Hydrochloric acid: Hydrochloric acid is used in the manufacture of fertilizers, chlorides, dyes. It is used electroplating, textile, and rubber industries. It is corrosive to the eyes, skin, as well as mucous membranes. Acute inhalation exposure may cause irritation of nose, eye, and respiratory tract. Accute exposure can also cause inflammation as well as pulmonary edema in humans. Chronic occupational exposure to hydrochloric acid can cause chronic bronchitis, dermatitis, gastritis, and photosensitizations.

Hydrogen cyanide: This is a colourless gas with an odour resembling bitter almonds. This gas which is lighter than air may be formed during cyanidation process of gold ores. This gas is formed only at pH below 10 which may happen due to absorption of carbon dioxide in the air.

Hydrogen fluoride (*Hydrofluoric acid*): This gas is colourless, with penetrating odour, which is lighter than air. It is prepared commercially by reaction of concentrated H_2SO_4 and fluorspar(CaF_2). This gas is used in the fluorination of oxides. The Hydofluoric acid, a solution of hydrogen fluoride in water is a fuming liquid with boiling point of 19.5 °C.

Hydrogen sulfide: This is a colourless gas with odour of rotten eggs. It occurs in natural gas, and must be removed before using. The gas is used in hydrometallurgy for precipitation of copper, nickel, as well as cobalt from solution.

Hydroquinone: It is used as a developing agent in photography as well as as an antioxidant in rubber/food. Hydroquinone is a skin irritant in humans and chronic exposure can result in corneal effects, eye irritation, as well as impaired vision.

Isophorone: This chemical is a widely used solvent as well as chemical intermediate. The acute effects of this chemical due to inhalation include eye, nose, as well as throat irritation. Chronic exposure to isophorone in can cause fatigue, dizziness, and depression. Isophorone has been classified as a Group C, possible human carcinogen by USEPA (1999d).

Lead Compounds: Lead is used in batteries, metal products as well as ammunition. Mining, smelting, and processing of lead containing metal ores as well as lead are major sources of lead emissions from anthropogenic sources in addition to the combustion of wastes with lead. Lead can cause effects nervous, immune, renal, blood, as well as cardiovascular systems. Early childhood/prenatal exposures leads to learning deficits, slow cognitive development, and other effects. Exposure to high quantities of lead can cause gastrointestinal symptoms, damage the brain and kidneys. Exposure to higher amounts lead may cause reproductive effects and cancer.

Lindane: Lindane is used as an insecticide. The acute effect of lindane through inhalation leads to irritation of the nose and throat. Chronic exposure affects blood, liver, nervous, cardiovascular, as well as immune systems. USEPA (1997) has classified lindane as a Group B2/C, possible human carcinogen.

Maleic anhydride: Acute inhalation of maleic anhydride will cause irritation of the respiratory tract and eye. Chronic exposure to maleic anhydride will cause, asthma-like attacks, chronic bronchitis and irritation of upper respiratory tract as well as eye.
Methanol: Methanol is released to the atmosphere during industrial uses as well as naturally from vegetation, volcanic gases, and microbes. Acute/chronic exposure to methanol may result in headache, dizziness, blurred vision, and nausea.
Methoxychlor: Methoxychlor is a pesticide and may enter air during manufacture/use. Dermal contact to this chemical is slightly irritating to skin. Chronic oral exposure can affect liver, kidneys, as well as nervous system.
Methyl bromide (*Bromomethane*): Methyl bromide from anthropogenic activity includes fumigation, leaded fuel additive, biomass burning. Because its toxicity it is used for control of wide range of pests.
Methyl chloride: Methyl chloride is used in the production of methylate silicon, agricultural chemicals, quaternary amines, methyl cellulose, butyl rubber and tetramethyl lead. Apart from emission from manufacturing theses products dichloromethane is also emitted from coal combustion and biomass burning. Acute exposure of methyl chloride causes severe neurological effects. It also effects heart rate, liver, blood pressure, and kidneys. Chronic exposure affects liver, spleen, kidney, and central nervous system.
Methyl chloroform (*1,1,1-Trichloroethane*): This chemical is used as a solvent as well as in many consumer products. Acute inhalation leads to hypotension, mild hepatic effects, as well as central nervous system depression.
Methyl ethyl ketone (*2-Butanone*): This section is used as a solvent. Acute inhalation exposure in humans results in irritation to the nose, eyes, and throat. Chronic inhalation results in slight neurological, liver, kidney, as well as respiratory effects.
Methylene chloride (*Dichloromethane*): Dichloromethane is a colourless liquid that easily evaporates to vapour. It is non-flammable. Dichloromethane are used as paint removers; as a flame retardent after mixing with some propellants; as aerosol solvents; manufacture of steroids, antibiotics and vitamins; in the electronics industry and as an extracting/degreasing agent.
Methyl isocyanate: Methyl isocyanate is used to in production of carbamate pesticides. This chemical is extremely toxic that lead to death of about 3800 people as well as adverse health effects on 170,000 survivors in Bhopal, India.
4,4′-Methylene diphenyl diisocyanate (*MDI*): The commercial form of MDI is used to manufacture polyurethane foams. Acute inhalation of high concentrations of MDI can cause sensitization as well as asthma in humans. Acute dermal contact can cause dermatitis and eczema. Chronic inhalation exposure to MDI can cause asthma, dyspnea, as well as other respiratory impairments.
4,4′-Methylenedianiline (*MDA*): This chemical is mainly used to produce 4,4′-methylenedianline diisocyanate as well as other polymeric isocyanates. Acute oral/dermal exposure to MDA causes liver damage. MDA can irritate the skin as well as eyes in humans. IARC has categorized MDA as a Group 2B, possible human carcinogen (USDHHS 1993a, b).

Nitric oxide: It is formed in trace amounts when a fuel is burnt with air and hence will be present flue gases. This colourless gas reacts readily with atmospheric oxygen to form brownish red Nitrogen dioxide.

Nickel carbonyl: This is an odourless and colourless gas formed during nickel refining process when impure nickel reacts at high temperature and pressure with Carbon monoxide. The Nickel carbonyl need to be decomposed at atmospheric pressure and high temperature to form nickel and Carbon Monoxide for recycling.

Nitrogen dioxide: This is an orange-red gas formed during oxidation of atmospheric nitrogen in furnaces, boilers, incinerators etc., This gas is also formed when nitric acid and minerals react with each other.

Ozone: This colourless gas with peculiar odour is heavier than air. It is sometimes used as oxidizing agent. Motor vehicles, chemical industries and combustion activities are major source of ground level ozone. Ozone may be formed due to reaction of oxides of nitrogen and VOC under the influence of sunlight.

Oxides of nitrogen: Only about 10 % of all oxides of nitrogen emissions come from anthropogenic sources. Combustion of fossil fuel, waste and chemical manufacturing are major anthropogenic sources of oxides of nitrogen.

Phosgene: Phosgene which is also known as carbonyl chloride is a colourless volatile liquid below 8.2 °C which was used as a toxic gas in World War I. It is formed during the chlorination of metal oxides under certain conditions.

Phosphine: Phosphine which is also known as hydrogen phosphide is a colourless gas with odour resembling decayed fish. Acetylene, generated in metallurgical industry contains traces of phosphine. Phosphine is formed due to presence of small quantities of phosphorus in the raw materials.

Polycylic Organic Matter: These compounds are formed normally from combustion and occur in the form of particulate matter. Sources vehicle exhaust, include cigarette smoke, laying tar, home heating, and grilling meat. These pollutants can cause cancer.

Manganese Compounds: Manganese occurs naturally in many rock and soil thereby entering during re-suspension of soil and dust during agricultural and constructional activities as well as vehicular movement. Manganese can also be released by power plants, iron and steel plants as well as coke ovens. Chronic exposure to manganese by inhalation in humans may cause central nervous system effects and a syndrome named manganism. Manganism is characterized by weakness and lethargy, a mask-like face, tremors, and psychological disturbances.

Mercury coumpunds: Major sources of atmospheric mercury due to anthropogenic activity are fossil fuel combustion, mercury-cell chlor-alkali production, coke ovens, and incineration of waste with mercury and recovery of gold by the amalgamation process (now not practiced in most parts of the world). Mercury exists in the form of elemental mercury, inorganic mercury compounds, and organic mercury compounds. Chronic exposure to elemental mercury results in erethism (increased excitability), excessive shyness, irritability, and tremors. Acute exposure to high levels of elemental mercury results in mood changes, tremors, as well as slowed sensory and motor nerve function. Acute exposure to inorganic mercury orally may result in vomiting, nausea, and severe abdominal pain. Chronic exposure to inorganic mercury leads to kidney damage. Exposure of experimental animals to mercuric chloride resulted in thyroid, forestomach, and renal tumors. Chronic exposure to methyl mercury results in paresthesia, speech difficulties, blurred vision, malaise, as well as constriction of the visual field. Acute exposure methyl mercury results in deafness, blindness, and impaired level of consciousness. Children born to women who consumed high levels of methyl mercury show ataxia, mental retardation, blindness, constriction of the visual field, and cerebral palsy (ATSDR 1999; USEPA 1999h, i, p).

Nickel Compounds: Nickel is found in ambient air at very low levels as a result of releases from oil and coal combustion, nickel metal refining, sewage sludge incineration, manufacturing facilities, and other sources (ATSDR 1997) Nickel dermatitis is the common effect in humans due to chronic exposure. Nickel refinery dust as well as Nickel subsulfide are human carcinogens, and nickel carbonyl is probable human carcinogen (USEPA 1986, 1999q, r, s, t).

Radionuclides: *R*adiation from naturally-occurring radioactive materials, like uranium, thorium and radon are harmful to health. The radon gas comes from the decay of radium present in almost all soils. Quantity of radon varies place to place. Radon migrates into buildings from the soil through cracks/holes in foundations/walls. Accumulated radon, inside the buildings, can be a health hazard. Radon in the air decays into polonium, which, can damage lung cells and can lead to lung cancer.

Selenium Compounds: Selenium naturally occurring substance which is toxic at high concentrations. Acute exposure to hydrogen selenide, elemental selenium, as well as selenium dioxide by inhalation results irritation of the mucous membranes, severe bronchitis, pulmonary edema, as well as bronchial pneumonia. Chronic exposure to Seleneum compounds leads to discoloration of the skin, loss of hair, deformation and loss of nails, lack of mental alertness, excessive tooth decay and discoloration, and listlessness.

Sulfur chlorides: Sulfur dichloride (SCl_2) is a reddish brown liquid with boiling point of 59 °C while Sulfur monochloride is a yellow liquid with a boiling point of 138 °C. These chlorides are formed during the treatment of concentrates of sulfide with chlorine.

Sulfur dioxide: This is a colourless gas with characteristic pungent odour. All fossil fuel contain sulfur. Sulfur dioxide is generated due to combustion of fuels with sulfur and melting/roasting of sulfur/suphide bearing ores.

2,4,6-Trichlorophenol: 2,4,6-Trichlorophenol is used as an antiseptic; pesticide; as an anti-mildew treatment; and manufacture of other chemicals. It is not used in USA now (ATSDR 1990). Inhalation of this chemical is likely to cause respiratory effects, such as chronic bronchitis, chest wheezing, cough, altered pulmonary function, as well as pulmonary lesions. It is a probable human carcinogen (USEPA 1999k).

Triethylamine: Triethylamine is used as an accelerator activator for rubber; as a catalytic solvent in syntheses of chemical; as a corrosion inhibitor; as a propellant; as a curing and hardening agent for polymers; in the manufacture of wetting/penetrating/waterproofing agents of quaternary ammonium compounds; as well as for the desalination of seawater. Acute exposure to triethylamine vapor causes corneal swelling, eye irritation, halo vision, skin irritation and irritation of mucous membranes in humans. Chronic exposure to triethylamine vapor can cause reversible corneal edema (USDHHS 1993a, b).

Trifluralin: Trifluralin is used mainly as an herbicide. Acute animal tests on animals have shown trifluralin to have moderate acute toxicity by inhalation. (USDHHS 1993a, b).

2,2,4-Trimethylpentane: 2,2,4-Trimethylpentane is used, as a solvent, thinner, in organic syntheses, and in determining octane numbers of fuels, in spectrophotometric analysis. It is released to the environment through the production, use, and disposal of products associated with peyroleum/gasoline(petrol) industry. Exposure to 2,2,4-Trimethylpentane can cause necrosis of the skin and tissue, irritation of the lungs, edema, as well as hemorrhage(USDHHS 1993a, b; Clayton and Calyton 1981).

Vinyl acetate: Vinyl acetate is used as a monomer in the manufacture of polyvinyl acetate, polyvinyl alcohol, other chemicals, adhesives, nonwoven textile fibers, water-based paints, paper coatings, textile sizings/finishes, inks, films, and lacquers. Acute inhalation can result in eye irritation as well as upper respiratory tract irritation.

Vinyl bromide: Vinyl bromide is mainly used in the production of flame retardant synthetic fibers. Acute and chronic exposure will damage liver. In high concentrations, it may cause disorientation, dizziness, and sleepiness in humans.

Vinyl chloride: Vinyl chloride is used in production of polyvinyl chloride as well as vinyl products. Acute exposure to high levels of vinyl chloride can result in central nervous system effects like dizziness, drowsiness, as well as headaches in humans. Chronic exposure through inhalation/oral exposure can damage liver and cause cancer.

Vinylidene chloride (1,1-Dichloroethylene): Vinylidene chloride is used in chemical synthesis as an intermediate to manufacrure polyvinylidene chloride copolymers. The acute effects in humans due to exposure are on the central nervous system. Low-level, chronic inhalation exposure of vinylidene chloride may affect the liver kidneys, central nervous system and lungs.

Xylenes: Xylene is an aromatic hydrocarbon comprising of a benzene ring with two methyl substituents. Representing around 0.5–1 % of crude oil, xylenes are found in small quantities in gasoline as well as airplane fuels. Xylenes are used in solvent, paints, coatings, and gasoline(petrol).

Xylene are released from refineries during the production, transport as well as processing of petroleum. It can also enter the environment from automobile exhaust, during the use of certain solvents, as well as from hazardous waste landfills. It can also enter the environment from accidental spill/leak. Symptoms of xylene poisoning include drowsiness, excitement, tremor, headache, dizziness, nausea, vomiting, irregular heart rhythm, inflammation and fluid in the lungs, liver and kidney damage, loss of muscle coordination, and coma. Vapours of xylene are mildly irritating to the skin, but repeated/prolonged contact can cause skin to crack/peel.

2.2 Regulatory Issues

Regulations are important but effective only if implemented. Member states of United Nations published many acts, rules to protect environment and control pollution since 1972 after The United Nations Conference on The Human Environment. The effectiveness of implementation these legislations are still questionable as these laws are enforced by government institutions which are obedient to ruling parties. The legislations which came across the globe to satisfy international relationship have not met with the goals in many regions. The failure may be due to inherit weakness within the law which do not stipulate basis to calculate manpower, action against erring officers, and time bound action to curb air pollution. The implementation usually deviates from published legislation due to difference in communication from people in power which is rather oral.

Figure 2.4 shows issues affecting legal efficiency at regional level. Despite of several environmental legislations supplied to citizens by nations across the world

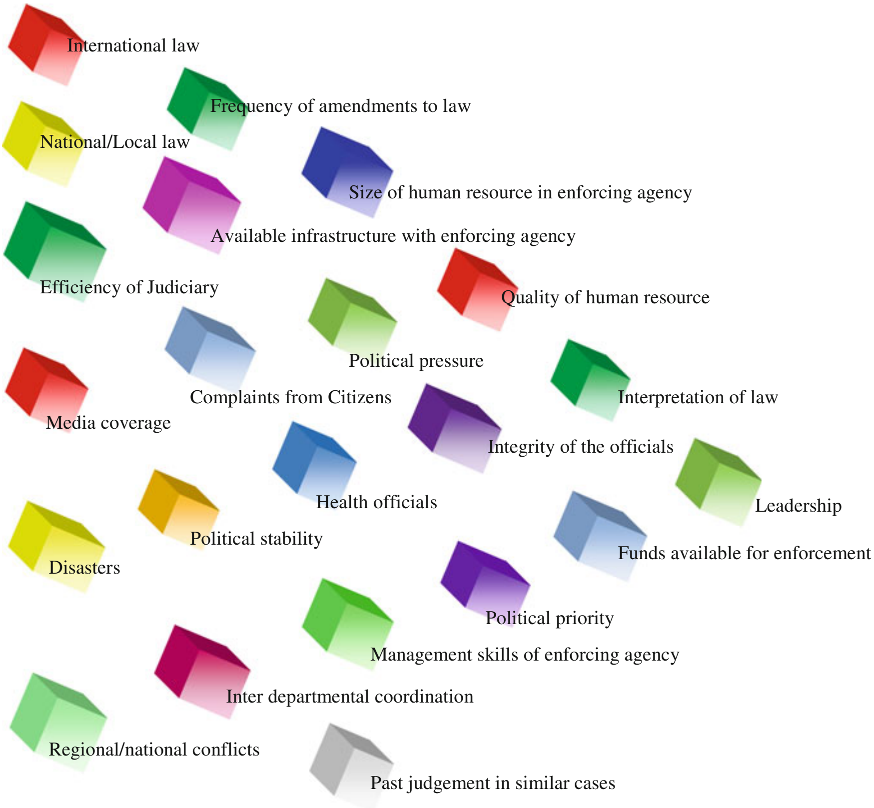

Fig. 2.4 Issues affecting legal efficiency at regional level

quality of environment has deteriorated since 1972. The reasons are due to weak institutions without skill, sufficient manpower, commitment and funds. Corruption has been part of these institution and legislations are used to generate personal and political funds by people in the power.

In theory the legislation to control Air pollution combines several approaches to prevent air pollution. One of the approaches is stipulating National Ambient Air Quality Standards that fix maximum concentration of pollutants in the atmosphere. Once the ambient air quality is fixed it is the duty of executive wing of the government to attain the goals. Some of the approached to be achieve ambient air quality standards are: (1) allowing only nonpolluting industries where a region has already been polluted, (2) insisting clean fuel, (3) regulating/restricting number of vehicles in a region, (4) sustainable urban design, (5) fixing maximum population density in any area, (6) extending tax benefits and other economic benefits to non polluting industry, (6) proper solid waste management, (7) stipulating vehicular emission standards, (8) stipulating industrial emission standards, (9) banning fuels which are harmful to environment, (10) providing sustainable transportation, (11) restricting movement of vehicles with old technology which do not comply with new standards, (12) closing the polluting industry/mines, (13) paving the unpaved roads, (14) carrying out afforestation, (15) extinguishing forest fires, (16) maintaining parks in urban area, (17) banning crackers, (18) restricting industries in valleys and adjacent to hills where dispersion of air is minimal, and (16) research and development.

Most of the legislation to protect environment are so stringent that in theory converts all the entrepreneurs into criminals. Neither the ambient air quality standards nor emission standards can be achieved by the industry. Hence the regulators turn away with blind eye or issue notices and drag the case or makes false monitoring and manipulate the analysis reports. In a system where in corruption plays major role in recruitment it is hard to get any fair officers. Further in a system, wherein political leaders raise questions in assembly and parliament, officers often fear discharging duty fairly against politicians. The fear of officers also suppress discharging duty against system where in officers are subordinate to corrupt politicians.

Impractical laws, and practical difficulties leads to poor implementation of laws.

2.3 Standards and Consents

The word ‘consent’, ‘authorisation’ and ‘registration’ are preferred instead of ‘licence’ for the permit granted by agencies designated for protecting environment. Standards are stipulated while consent to industries. The standards with respect to air are either ‘emission standards’ or ‘ambient standards’ or both. The occupier is responsible for maintaining these standards even though the occupier of unit hardly has control on ambient air quality in an area which has many air pollution source like vehicular emission, wild fires and/or volcanic eruption.

2.3.1 Ambient Air Quality Standards

Ambient air quality standards are set at national level to attain the same by policies, permits and regulation. It is the duty of executive wing of government to make policies and advice legislature/judiciary wing as required to attain the ambient air quality.

Some of the policies/permits/regulation that would help quality of air within the limits are: (1) urban planning, (2) fuel quality, (3) industrial development, (4) mass transportation, (5) permitting only non polluting industry in the area where quality of air has already exceeded standards, (6) permitting roadways considering air quality of the area, and (7) regulating product capacity of the industry in case ambient air quality exceeds the limits.

2.3.2 Emission Standards

Emission standards are limits set for the pollutants emitted from outlet of source. The outlets in mobile sources are exhaust pipe and outlet in stationary source is normally chimney or stack. These standards can be set uniformly though out the country for the activity (like thermal power plant, cupola furnace or diesel generator) or can be set case to case after considering quality of ambient air.

Emission standard helps manufacturer of vehicle and equipment to design the product to suit standards. If the ambient air is already polluted then regulatory authority usually makes standards stringent to maintain better air quality.

2.4 Agriculture and Air Pollution

Agriculture contributes to emissions of GHGs and other pollutants. The emission occur due to emissions from livestock, decay of organic matter in agricultural fields, use of agro chemicals etc., Unsustainable agriculture and associated activity could generate substantial air pollutants. The major air pollutants from agriculture and associated activity are given in Table 2.1.

About 80 % of the ammonia used as fertiliser ends up in the soil and atmosphere. Ammonia is also produced in natural setup due to biodegradation of organic matter in soil. Modern agriculture has increased ammonia emission more than 20 altering the natural nitrogen cycle resulting in eutrophication of waters and increasing tropospheric ozone due to atmospheric chemical reaction. Over application, exposure of fertilizer granules to atmosphere after application is usual reasons from ammonia emission from atmosphere which needs prudent use and education of farmers. Sustainable use of these fertilizers by loosening the soil prior to application and properly covering manure by soil help in reduction of ammonia into

Table 2.1 Major activity and pollutants released

Sl. No	Activity	Pollutants
1	Application of nitrogenous fertilisers	Ammonia
2	Spraying agrochemicals	Agrochemicals
3	Slash and burn agriculture	CO, SO_2, NO_x, particulate matter, hydrocarbons, methyl chloride, methyl bromide
4	Curing of tobacco	CO, SO_2, NO_x, particulate matter, hydrocarbons
5	Paddy fields and sugar cane fields	Methane , Methyl chloride, Methyl Bromide
6	Cattle rearing	Methane
7	Poultry	Methane
8	Fumigation for grain protection, structure protection, green house	Aluminum phosphide, chloropicrin, magnesium phosphide, methyl bromide, sulphuryl fluoride, acrylonitrile , acetaldehyde , azobenzene, chloroform , dichloronitroethane, ethylene chlorobromide, methyl allyl chloride, methylene chloride, nicotine, propylene dichloride, sulphur dioxide, methyl chloroform (1,1,1-trichloroethame)
9	Fumigation for ripening banana	Ethylene
10	Soil fumigation	Chemicals containing chloropicrin, methyl bromide, 1,3-dichloropropene, and iodomethane

atmosphere. Testing the soil prior to fertilizer application to assess the exact requirement will also help in reduction of ammonia emission from agriculture. Application of fertilizer through drip irrigation after dissolving in water also avoids excess application of fertilizers. Apart from fertilizer, fumigation is also major source of pollution.

Aluminum phosphide, chloropicrin, and magnesium phosphide are major fumigants used pesticides in the form of gases for pest control. These gases are used as they are slightly heavier than air can seep into the smallest of cracks as well as crevices. Hence they have become a popular solution to rodent infestations/insect in stored grain. But these gases are highly toxic and ultimately escape to atmosphere.

Bananas are generally ripened in rooms with 2–3 exposures to ethylene gas 6 hourly applications for 1–4 days or at 1:1000. Post-ripening storage in air with 10–100 ppm ethylene accelerates softening and fruits will remain clear yellow with attractive with few or no surface brown specks.

Apart from fumigation, spraying agrochemicals for controlling fungus, insects/pests also pollutes air affecting human/animal health.

2.5 Indoor Air Pollution

The quality of air inside homes, office and other work place has become a matter of growing concern as homes and work places are not fully safe. Our knowledge of indoor air quality has been increasing increasingly in recent years (Maroni et al. 1995). The concentration of air pollutants inside living or work space depends on a numerous of factors: (1) volume of air contained, (2) rate of release of the pollutant into the space, (3) rate of elimination of the pollutants due to filtration, reaction and/or settling, (4) rate of formation of new air pollutants die to reaction within the space, and (5) concentration of the pollutant entering from outdoors.

Indoor air pollution at homes/offices/restaurants/hotels can occur due to array of sources that include: (1) heating, (2) cooking, (3) smoking of tobacco, (4) evaporation of solvents from paints/varnishes, (5) biological aerosols arising due to coughing/sneezing and treatment of patients, (6) disintegration of building, (7) emission from office automation equipments, (8) mercury evaporation during accidental spillage, (9)spraying chemicals, (10) fumigation, (11) decaying organic matter, (12) animal hair and dandruff, (13) cosmetic/personal care products, (14) adhesives, (15) cleaning and waxing, (16) Automotive products, (17) hobby supplies(photographic chemicals, clay, wood fillers, chalk dust etc.), and (18) contaminated water/sewage.

Indoor air at foundries, assembly lines, laboratories, chemical industries, garages, waste handling units, food making/packaging industry, plastic molding, health care establishments, slaughter houses, printing, paper making, metallurgical industries, cutting/polishing of stones, timber cutting etc., will have different indoor air quality which are much more dangerous than at homes and offices. Health care establishments of humans/animals are sources of nosocomial infections which have been reason for disease spreading to doctors/visitations/staff/patients.

Emissions are complex and quantity varies at each source and time in a different manner. Studies on three dimensional printers suggest caution should be taken when operating in unfiltered or insufficiently ventilated indoor environments. Moldy surfaces in household can release volatile compounds which induce symptoms typical with Parkinson disease (Samhita 2014).

Combustion sources are the chief indoor generators of particles which contain organic and inorganic material. Sprays and cooking aerosols also contribute to particles in addition to biological contaminants such as viruses, bacteria, fungal spores, pollens, fragments of feces, dried animal secretions (e.g., urine, saliva) as well as animal dander. Coarse-mode fractions consist largely outdoor dusts, insect fragments, animal hair etc. Emissions from stoves and fireplaces vary depending on the design/operation of the unit. Emission from cooking also varies depending on the ingredients and method of preparation.

Indoor air can also have Radon (Rn) a radioactive noble gas. Radon can easily leave the place of generation (soil, rock and building material) and enter living space. The radon gas comes from the decay of radium present in almost all soils and migrates into buildings from the soil through cracks/holes in foundations/walls.

2.6 Air Pollution Management for Wildlife Conservation

Air pollution can occur in gas/liquid/solid forms. It can be highly toxic or low toxic. The wild life can react to air pollution in intricate way. It can show resistance or perish. Air pollution management to protect wild life is not a priority to air pollution managers who usually dwell in urban areas.

Air pollutants can enter wild by air pollution due to wild fire, volcano etc., and dispersion of anthropogenic emission.

2.7 Zoning Atlas for Urban Development

As the population of human settlements changed rural areas around the world gradually turned to urban areas. Most of the cities have been developed due to historic reasons. Urban settlements have been pool for tradable skills and business and holds population with particular skills like diamond trading in Antwerp; Software development in Bangalore; manufacturing skills in cities of China etc. Over the years urban development has been done keeping demands for housing and trade. Some of the cities have been developed by real estate business establishments keeping interest of their business. Most of the developing countries which are keen to industrialise gave away lands at the outskirts for industries. Location of industries adjacent to sensitive area has been cause for adverse impact on sensitive ecological setup.

Hence zones of areas is essential to limit ambient air quality by allowing proper lungspace for dispersion of pollutents.

2.8 Air Pollution Management in Urban Settlement

Air pollution management in urban settlement is complex situation which needs case to case approach as size and activities of urban area varies widely. While Geneva can be crossed within 10 min in bicycle, it needs half to one day in Bangalore to do the same task. The population, traffic, discipline among the citizens, industries, commercial activity, quality of roads, conflicts on roads, waste management, drilling borewells (Fig. 2.5), construction and demolition etc., add to urban air pollution. The source and management approach for air pollution is given Table 2.2.

There are many success stories and failure stories with respect air pollution management. The curbing of air pollution from industries have been failed due to low staff in agencies responsible for inspecting polluting industries. Many of polluters operate the polluting activities during holidays and night to avoid penal action or huge bribe to be given to inspectors. The corruption has also weakened the spirit

Fig. 2.5 Air pollution during drilling borewell

of air pollution management in many countries. In many circumstances polluter will transfer his favourite officer in the location desirable to polluter.

Certification of vehicles by private agencies recognized by government department has been in failure in many parts of the world due to nexus between these agencies and departments. The quality checking of fuel in gasoline(petrol) refilling stations across the city lead to agitation and resistance by all the gasoline(petrol) bunks in Bangalore resulting in public inconvenience. Pollution checks followed by restriction to entry the city resulted in entry of vehicles in night times in Bangalore when emission checking was not carried out by officials. An attempt to catch culprits of fuel adulteration resulted in murder of government official in India.

Covering of trucks carrying soil has been not satisfactory in many parts of the world due to corruption and resistance from truck owners association. Action to scrap aged vehicle with inappropriate pollution control technology has also been cause for agitation and strike by truck owners association in some parts India.

The covering of buildings completely so as to curb dust is inefficient due to nexus between real estate owners, politicians and government officials. Proper pavement to avoid re-suspension of dust is not priority in many parts of the world.

Table 2.2 AirAir pollution management approach in urban settlement

Sl. No.	Activity	Air management approach
1	Traffic	• Adopt national policy for emission and allow manufacture of vehicles with Best Available Technology (BAT) with respect to emissions
		• Switch over to green fuel (natural gas/ CNG/ electricity / hydrogen) driven vehicles
		• Create infrastructure for mass transportation
		• Discourage horizontal growth of cities and immigration of rural population to cities
		• Impose traffic congestion tax by collecting tax from the vehicles entering city
		• Provide ring road to divert the vehicles
		• Earmark Low Emission Zones in urban areas to restrict entry of most polluting vehicles
		• Adopt lower urban speed limits as movement of vehicles with higher speeds consumes more fuel and generates more pollutants
		• Restricting car access to sensitive/polluted areas
2	Industries	• Dissipate knowledge of clean technology
		• Insist continuous emission monitoring
3	Commercial activity	• Ensure installation of pollution control equipments in commercial establishments like restaurants
4	Quality of roads	• Improve quality of roads to reduce re-suspension of dust
		• Adopt sprinkling
5	Conflicts	• Provide good governance to avoid riots
		• Manage conflict earliest
		• Extinguish fire during riots earliest
		• Make conflict management plan
6	Waste management	• Avoid burning of waste and litter
		• Avoid re-suspension of dust during sweeping roads
		• Avoid littering and rotting of waste
		• Use of methane generated from landfire
7	Disaster management	• Manage air pollution causing disaster in shortest period
		• Mitigate air pollution from disaster prone site in earliest possible time
		• Foresee possible natural and anthropogenic disaster and prepare Emergency Preparedness Plan, and Disaster Management Plan
8	Fuel adulteration	• Take proper samples from fuel shops
		• Adopt proper investigation methodology including secrete investigation as adopted in crime
9	Land use	• Avoid encroachments of lung spaces (Fig. 2.6) like gardens and open spaces
		• Plan the land use change
		• Avoid cutting trees
		• Grow more trees

(continued)

Table 2.2 (continued)

Sl. No.	Activity	Air management approach
		• Fence and protect free spaces of government before it is converted into slums or occupied illegally by influential people
		• Provide dedicated pedestrian ways (Fig. 2.7)
10	Mass transportation	• Encourage car sharing
		• Consolidation of goods and optimization of urban freight transport
		• Encourage mass transportation by subsiding the bus/metro/tram services
11	Restriction of certain fuel	• Ban wood/coal fired boilers and stoves for domestic/commercial heating/cooking
12	Energy management	• Enhance energy efficiency during transmission
		• Increase dependency on solar/wind/tidal energy
		• Phase out thermal power plants an nuclear power plants
13	Harbour management	• The use of electric power for ships anchored in port
		• Reduce speed near cities
14	Green public procurement	• All government agencies should buy less polluting vehicle
15	Airport management	• Green approaches wherein pilot depends on communication between the airplane's computers as well as the air traffic control system to compute the aircraft's landing time and glide the aircraft during the final stage of landing using less fuel
		• Connect airport with electric train and vehicles with renewable/hybrid fuel

Fig. 2.6 Lung space

Fig. 2.7 Dedicated pedistrian way

Copying the practices of developed countries in developing countries is not possible due to various reasons. Figure 2.8 shows electric cars in Sweden which cannot be used in developing countries due to nonavailability recharging facility across the developing countries and availability/affordability of such cars. Presence of slums in the centre of cities of developing countries that contribute to air pollution act as vote banks the elected politicians. Hence developing countries usually avoid decisions and policies that affect harmony of citizens in slums. Ultimately the emissions due use of coal, kerosene, combustible waste (like waste cotton from workshops, paper cartoon box, coconut shells) in the centre of city will not be eliminated. Combustion of waste by homeless people, slum dwellers, truck drivers during winter to warm themselves is a scenario often not seen in developed countries.

Fig. 2.8 Electric cars parked in Sweden

Box 2.1 Case studies

Beijing

The government implements of Euro IV emission standards between the year 2000–2008 (pre-Olympic). The government banned diesel cars in the year 2003. The city restricted Euro III heavy duty vehicles and restricts movement of Euro I cars. The city introduced 20,000 buses, metro and light railway. The city adopted a system under which different days were fixed for allowing cars with odd or even number plates on roads. The city implemented stringent checks on industries. After the year 2008 (post Olympic period) the city capped the number of cars to be sold in a year and introduces Euro v emissions standards and fuel with 10 ppm sulphur for buses and municipal fleet in February 2013. The government introduced vehicle inspection using remote sensing technology. The city increased parking fee in February 2011. The city improved subway and light railway network. The government hiked subsidy on scrapping vehicle and promoted CNG and electric vehicles (CSE 2014).

Delhi

The city enforced Euro II emission standards in 2000 and Euro III in 2005. Further the city mandated pre-mix gasoline(petrol) to two/three wheelers and introduced unleaded gasoline(petrol). The city buses and three-wheelers switched over to CNG. Delhi phased out 15-year old commercial vehicles and banned open burning. The city expanded the metro rail network and introduced 6000 new buses. Delhi introduced Euro IV standards in 2010. The city upgraded tests for pollution certificates and starts Air Ambience Fund in 2009 for promoting clean air policies. The city also constructed 40 km of cycle tracks with new footpaths in 2010 (CSE 2014).

There are three major issues linked to air pollution in Delhi. First is natural sources such as soil dust and road dust. Secondly, local emissions from transport and industries and thirdly the pollution transported from nearby states. During 1990s, diesel driven buses were the major source of air pollution in Delhi city. But after the Supreme Court decision, the buses were run on CNG which gave a relief to the citizens of Delhi. However, at present, Delhi is victim of trans-boundary pollution from nearby states such as Uttar Pradesh, Haryana and Punjab. Hundreds of brick kiln units have come up in National Capital Region which are strong source of trans-boundary pollution in Delhi. During winters of 2014, Delhi had the worst air quality due to these sources. Crop residue burning and outside heavy duty vehicles entering into the city are also important external sources affecting air quality in Delhi. Hence, in order to solve the air pollution problem of Delhi, one joint task force involving Delhi, UP, Haryana and Punjab governments needs to be developed which will be looking for a joint action. While comparing the air pollution scenario of Delhi and Beijing, we have to consider the difference in topographical and meteorological conditions between two cities. Air pollution in Delhi gets dispersed very soon except few localities. Delhi is probably blessed with very high natural dispersion of pollution where pollution cannot stagnate more than a few days which is not the case of Beijing. The fact is that Delhi or any city in India especially the north India, atmospheric dust and black carbon are the two major pollutants which create haze reducing the visibility. So far gaseous pollution is concerned, the situation is almost controlled except carbon monoxide and sometimes ozone.

Stockholm
The city adopted congestion tax and environmentally efficient mass transport. The city was planned and incorporated open space within the city. Building under construction will be completely covered. The construction of building in the city by prefabricated components has reduced emission and solid waste. Stockholm-Arlanda has shown preference to eco taxis. These taxis can often leave the holding area immediately to separate queue for renewable or hybrid fuel powered taxis outside the terminals. Green approaches were introduced at Stockholm-Arlanda air port in the year 2006 wherein pilot depends on communication between the airplane's computers as well as the air traffic control system to compute the aircraft's landing time and glide the aircraft during the final stage of landing, with engines running at lower speed avoiding waiting time in the air thereby reducing fuel consumption, noise and air pollution. Each green approach saves up to 150 kg of fuel.

2.9 Air Pollution in Rural Areas

The main source of air pollution in rural areas depends on which part of the world is rural area. The emission depends on the activity. The rural activities usually do not include industrial emissions. Apart from natural emissions like volcanic eruption and wild fire, emission from rural area include:

- Emission from marshes and paddy fields;
- Emission from cattle;
- Emission from waste dumping/management;
- Emissions from cooking;
- Emissions from pot making activity;
- Emissions from burning in fields;
- Emissions from dehusking and grain separation processing;
- Spraying of agrochemicals;
- Pollen grains; and
- Re-suspension of Soil in tilled land.

2.10 Air Quality Deterioration

Emissions of air pollutants originate from almost activities. Population living in/around urban area are normally exposed to deteriorated air. The quality of air in urban will usually have more pollutants compared to its outskirts with some exception like region with wild fires. Policies implemented national and sectoral level have resulted in reduction in emission of many air pollutants (e.g., Pb and CO) in Europe. But road transportation, power plants, industry, agricultural activities as well as households continue to release significant quantities of air pollution. Combustion of wood and coal by households is an important source of PM as well as polycyclic aromatic hydrocarbons (PAH). Agriculture is major ammonia source emissions. Emissions from agriculture have decreased very little and emissions from domestic activity have not decreased. Biomass combustion has become more important as wood burning is cheap, renewable and carbon-neutral source of energy. Many air pollutants are transported from other countries and continents. Trans-boundary air pollution is a major challenge in Europe as less than 50 % of $PM_{2.5}$ concentrations originate from their own emissions (EEA 2013).

Air pollutant emissions in East Asia is responsible around 36, 29, and 36 % to worldwide emissions of SO_2, NO_x, and $PM_{2.5}$ respectively which is more than those of the USA and Europe (Cofala et al. 2012; Wang et al. 2014). NO_x emissions in China have increased during 1995–2010, with growth rate ranging from 5.5 to 7 % (Zhao et al. 2013; Zhang et al. 2007, 2012a, b) degrading regional air quality (Wang and Hao 2012) and human health.

There have also been considerable efforts to avoid air quality deterioration. In Japan, best available technologies have been put in use to control SO_2, (NO_x, as well as PM for most power generation. The use of wet- flue gas desulfurization (FGD), Low NO_x Burner (LNB) and Selective Catalytic Reduction (SCR) and high efficiency deduster (HED) has increased air pollution slightly between 2005 and 2010 (Klimont et al. 2009). LNB was the main NO_x control technology in coal-fired power plants of China by 2010. In the 12th Five-Year Plan, Government of China aims to reduce the national NO_x emissions by 10 % of the emission in 2010 by the year 2015, and the main measures to accomplish this target is use of SCR and Selective Non-Catalytic Reduction (SNCR) facilities.

2.11 Air Quality Monitoring and Inventorization

Air quality evaluation is necessary for developing plans for air quality management to safe guard environment and public health. One of the important functions of the monitoring is estimating the level and distribution of pollutants. Air quality is assessed at source (like chimney and vehicle exhaust) or at recipient (Ambient air quality).

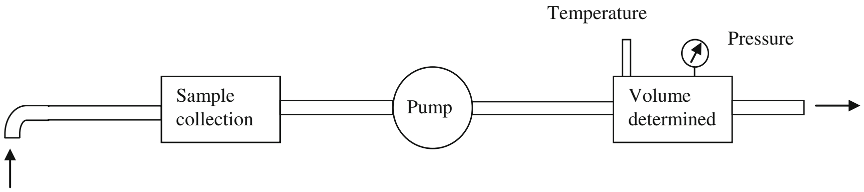

Fig. 2.9 Sampling train

2.11.1 Sampling

A typical sample train for monitoring chimney is shown in Fig. 2.9. In some systems the components might be combined. Care need to be exercised to assure that no leaks occur in the train. It is necessary to ensure components of the train are identical for sampling and calibration. The pump used for monitoring stack must be oil-less and leakproof.

Usually operating curves are provided along with sampling equipment if the sampling train is assembled in factory. Otherwise operating curves shall be prepared before taking the sample train to the test site.

Some of the useful operating curves include (1) velocity versus pressure at different temperatures, (2) flow versus pressure drop, and (3) probe tip velocity versus flowmeter readings at different temperatures.

Pollutants in stack will have very different characteristics from the carrying gas stream. It is therefore important to collect sample maintaining same velocity in the probe tip as it exists in the adjacent gas stream. This type sampling is known as *isokinetic* sampling.

For sampling of gases, the sample can be collected by any of several devices. Some commonly used manual methods include Orsat analyzers, absorption systems, adsorption systems, bubblers, reagent tubes, condensers, and traps. Continuous analyzers are now more widely used than manual methods. Some types of continuous analyzers include infrared and ultraviolet instruments; flame ionization detectors; mass spectrometers; colorirnetric systems; gas, liquid, and solid chromatography; colometric and potentiometric systems; chemiluminescense; and solid-state electronic systems. Since gases undergoing analysis do not need to be sampled isokinetically, it is only necessary to insert a probe and withdraw the sample.

Continuous air quality monitoring system (air pollutants form chimney will continuously enter the system and get analysed) can be used for both ambient air quality monitoring and emission monitoring from stack (Fig. 2.10).

The ambient air monitoring network includes three types of monitoring stations:

- **Continuous stations**—these stations monitor air quality by drawing air in through a tube and analyses air pollutants.
- **Noncontinuous stations**—these stations collect air pollutants on filters and in that are collected by technicians in the field and sent to laboratory for analysis.

Fig. 2.10 Online monitoring equipment

- **Mobile monitors**—these consist of a numerous instruments installed in a vehicle/airplane for monitoring air pollutants.

It is good practice to monitor air quality at numerous locations which includes areas industrial area, kerbside, residential areas, parks and rural areas.

The monitoring station should be located it a place where interferences are not anticipated/present. The station should be away from chimneys; absorbing surfaces; obstructions. All the sides of monitoring station should be open, and intake should not be located in a confined space.

Criteria for selection of sites are usually published by designated organsation in each country. Following guidliens suggested by CPCB for siting the monitoring station (CPCB 2003).

(i) The sampler must be more than 20 m from trees.
(ii) Height of the inlet must be 3–10 m above the ground level.
(iii) Distance of the sampler to any air flow obstacle must be greater than two times the height of the obstruction above the sampler.
(iv) There should be no nearby furnace/incinerator fumes.
(v) There should be unobstructed airflow in three of four quadrants.

Sampling intake is done usually at a height of 3 m above the street level for traffic pollution monitoring to prevent re-entrainment of particulates from the street.

2.11.1.1 Passive Sampling

Nearly century years after the first use of passive monitoring of atmospheric Ozone (O_3) concentrations (Fox 1873), there has been an growing interest to use passive samplers to monitor gaseous air pollutants (Namiesnik et al. 1984; Cao and Hewitt 1991).

New methods for monitoring air quality are being developed in recent years (Tremolada et al. 1996; Peters et al. 2000; Harner et al. 2003). Passive air sampling is one of the methods presently considered as suitable for cheap and versatile monitoring programs. Scientists use this technology for quantifying ambient air pollutants in remote wilderness areas. Demands have resulted in the development of different passive air samplers (Bartkow et al. 2004). Passive samplers are capable of being installed in many places at the same time (Krupa and Legge 2000).

Air pollution estimations are done either by calibration based on parallel passive and active samplings or using the permeation reference chemicals (Ockenden et al. 2001; Soderstrom and Bergqvist 2004).

Passive air sampling use semi-permeable membrane devices (SPMDs), polyurethane foam disks (PUFs) and XAD resins which can be exposed over several weeks or months. Use of passive samplers have following advantage over active sampling using high volume samplers: (1) No moving parts and no maintenance, (2) No need for person to change sample after four to eight hours, (3) no need to change motor brushes, and (4) no need for electric power.

Table 2.3 gives list of adsorbents used for passive sampling. The adsorbed samplers are analyzed in lab to determine the concentration of pollutants in the atmosphere.

2.11.2 Source Apportionment Study

Ambient air quality data analyses as well as receptor techniques are important component of successful air quality management. Identifying the emission sources, and their relative contributions to air pollution helps to control air pollution. Chemical Mass Balance (CMB) techniques are adopted when a prior knowledge of main sources in area are known. The Factor Analysis and Positive Matrix Factorization use ambient measurement data.

Emission factors facilitate estimation of emissions from known sources of air pollution. These factors are averages of all available data of satisfactory quality.

The equation for emissions estimation is:

Table 2.3 Adsorbents used to monitor some of the air pollutants

1	Air pollutant	Adsorbent
2	Ammonia	Oxalic acid
3	Carbon monoxide	Y-type zeolite of which sodium ion was partially exchanged with Zn ion
4	Formaldehyde	2,4-dinitrophenylhydrazine
5	Hydrogen sulfide	Silver nitrate
6	Nitric oxide	2-phenyl-4,4,5,5-tetramethylimidazoline-3-oxide-1-oxyl
7	Nitrogen dioxide	1. Sep-Pak C18 cartridge impregnated with triethanolamine-potassium hydroxide
		2. Triethanolamine (TEA)
		3. Sodium iodide + sodium hydroxide
8	Nitrous oxide	Molecular sieve
9	Ozone	1. 1,2-di-(4-pyridyl)ethylene (DPE)
		2. 10,100-dimethyl-9,90-biacridylidene
		3. Indigo
		4. Indigo carmine (5,50-disulfonate salt of indigo)
		5. Nylon-6 polymer, potassium iodide
		6. Sodium nitrite, 3-methyl-2-benzothiazolinone acetone azine (MBTH), p-acetamidophenol (p-ATP), indigo carmine
		7. Sodium nitrite
10	Photochemical oxidants	Curcumin, indigo carmine, 1-methyl pyrimidine, phenoxazine
11	Polychlorinated biphenyls	Triolein containing semipermeable membrane
12	Sulfur dioxide	1. Sep-Pak C18 cartridge impregnated with triethanolamine-potassium hydroxide
		2. Sodium carbonate
		3. Sodium hydroxide
		4. Triethanolamine (TEA)

(continued)

Table 2.3 (continued)

13	Volatile organic compounds	1. Activated charcoal
		2. Graphitic carbon black
		3. Carboxen 1000 + carbotrap B
		4. Tenax GA
		5. Tenax GC
		6. Tenax-GR, Tenax-TA, Carbotrap and Chromosorb 106

Source Based on Krupa and Legge (2000), Adema et al. (1993), Sommer et al. (1996), Schjoerring (1995), Lee et al. (1992), Levin et al. (1985, 1986), Mulik et al. (1989), Grosjean and Williams (1992a), Larsen et al. (1992), Shooter et al. (1995), Mulik et al. (1991), Nishikawa et al. (1986), Nishikawa and Taguchi (1987), Palmes (1981), Cadoff and Hodgeson (1983), Hangartner et al. (1989), Atkins et al. (1990), Hewitt (1991), Krochmal and Górski (1991), Campbell et al. (1994), Lee et al. (1995), Sickles et al. (1990), Gair et al. (1991), Ayers et al. (1998), Ferm and Sjödin (1992), Ferm and Svanberg (1998), Bishop and Hossain (1984), Hauser and Bradley (1966), Monn and Hangartner (1990), Surgi and Hodgeson (1985), Werner (1989), Runeckles and Bowen (1999), Grosjean and Hisham (1992), Grosjean and Williams (1992b), Grosjean et al. (1995), Scheeren and Adema (1996), Kanno and Yanagisawa (1992), Zhou and Smith (1997), Koutrakis et al. (1990), Liu et al. (1994, 1995), Brauer and Brook (1995), Manning et al. (1996), Grosjean et al. (1992), Ockenden et al. (1998a, b), Tang et al. (1998), Krochmal and Kalina (1997), Begerow et al. (1995), Otson (1989), Pérez Ballesta et al. (1992), Shields and Weschler (1987), Bertoni et al. (1990), Uchiyama et al. (1999), Roche et al. (1999), Beveridge and Duncan (1981), Coutant (1985), Lewis et al. (1985), Cao and Hewitt (1993, 1994a, b)

$$E = (A)(EF)\left(1 - \frac{ER}{100}\right)$$

where:

E emissions;
A activity rate;
EF emission factor;
ER overall efficiency of emission abatement system (%).

Key objectives of source apportionment are:

- To quantitatively relate pollution source to receptor site;
- To assess the effectiveness of control strategies;
- Strengthening environmental management; and
- To improve and validate emission inventories.

Source apportionment studies using positive matrix factorization method in Beijing was studied by Yu et al. (2013) wherein seven sources (Secondary sulphur, vehicle exhaust, soil dust, road dust, biomass burning, metal processing) with their contributions to the total $PM_{2.5}$ were identified and quantified.

Factor analysis is a statistical method employed to describe variability among observed, related variables in terms of a prospective lower number of unobserved variables. These unobserved variables are called factors. To assess the pollution released from sources it is necessary to identify pollutants resulting from the activity. The measured pollutants are then correlated to sources. Factor analysis depends on the internal variability of the data. Samples from many locations over a long time period are employed this method.

Positive Matrix Factorization is a group of algorithms where in one matrix is factorized into two matrices. All three matrices have only positive elements. Since the problem is not precisely solvable it is usually approximated numerically.

2.11.3 Remote Sensing and Geographic Information System

Remote sensing of air quality by Satellite has evolved radically over the last decade. Global observations are available for a broad range of air pollutants that include aerosols, CO, tropospheric O_3, tropospheric NO_2, HCHO, as well as SO_2 (Martin 2008). Satellites can measure the majority of important air pollutants, and provide timely, spatially explicit, information on distribution of pollutants in a cost-effective manner. Citizens in some cities of developed countries are already provided with air pollution alerts via mobile phone text messages, email, or via websites.

New generation Earth-observing satellites have been able to detect tropospheric air pollution since the mid-1990s at increasingly high spatial and temporal resolution. The satellite measures radiation from the ultraviolet to the visible in the range of

~0.23–0.9 μm as well as in the infrared from ~4 to 50 μm. Chemical species are detected by the absorption, of radiation of particular wavelengths along the path.

The advantages of remote sensing air pollutants are many which include flexibility of deployment as well as avoidance of extractive sampling. It gives overall scenario of the region which would have been not measured or wrongly measured in the field. It gives the direction in which air pollutants are travelling and possible destination over a period of time. The technology is boon wherein pollution in multiple countries are monitored and recorded and hence can be shared with least developed countries which do not have skills and capabilities to monitor air pollution.

Observations are made at wavelengths from 260 nm in the ultraviolet through to radar wavelengths (0.1–10 cm) as the capability to see through clouds exists at radar wavelengths. Cloud cover is a major limitation of satellite observations for air quality. Strong absorption by ozone in the stratosphere obscures lower tropospheric measurements of several UV wavelength-absorbing gases. Bright surfaces like deserts, snow, urban areas confuse the ability to distinguish scattered light from the atmosphere. There are now active instruments in space that generate the radiation identified by the satellite after scattering (Hoff and Christopher 2009).

Atmospheric SO_2 can be measured by sensing of scattered sunlight using its unique absorption property in the ultraviolet region. But, the sensitivity of the SO_2 measurement depend very much on surface albedo, spectral interference, and varies with wavelength as Rayleigh scattering (elastic scattering of electromagnetic or light radiation by particles smaller than the wavelength of the radiation) increases at shorter wavelengths. The monitoring of aerosols by near the surface in situ measurements as well as column integrated satellite observations are useful tool for better understanding their impact on human health as well as climate (Gupta et al. 2013).

Processing of satellite measurements for oxides of nitrogen usually involves three or more steps. Calibrated Level 1 satellite data include high-resolution solar as well as earthshine spectra for each individual measurement. In order to linearize the NO_2 retrieval problem Earthshine radiances are divided by a reference solar irradiance spectrum. Two CO spectral bands, the thermal infrared essential at 4.6 μm as well as the near infrared overtone band at 2.3 μm, can be used for passive remote sensing (Edwards et al. 1999). Methane can be retrieved from measurements of solar backscatter in the shortwave infrared and of terrestrial radiation in the thermal infrared.

2.11.4 Air Quality Modelling

Atmosphere is a complex reactive system in many physical, chemical and biological processes occur simultaneously. Ambient air quality measurement provides snap shot of air pollution at particular location, time and atmospheric conduction. Models use available data to predict concentration at future time.

Models can be physical or mathematical. Physical models are used to simulate physical representation of actual system in small scale. In physical model a replica of area of interest can be created within a wind tunnel to study possible pollution dispersion. In a mathematical model a set of mathematical equations are used to simulate the area of interest.

The easiest example to explain use of mathematical model is its use for decision making about upcoming thermal power plant by government authority. The project proponents normally prepare an Environmental Impact Assessment (EIA) in which mathematical model would be integral part. The proponents monitor the project location as well as surrounding and add the outcome of the mathematical modelling to compare with national ambient air quality standards to prove the pollution level after project would be within the ambient air quality standards.

The accuracy of the model output depends on data input and equations used within the model. Since most of the equations used in mathematical models are nonlinear in nature, a small deviation in input can give an output favourable to proponents. Hence team which prepare/scrutinises the EIA should have proper knowledge of the limitations of mathematical model and should have utmost integrity to protect the environment.

Figure 2.11 shows schematic diagram of mathematical model. Sophesticated mathematical model considers topographical data, emission data and weather data.

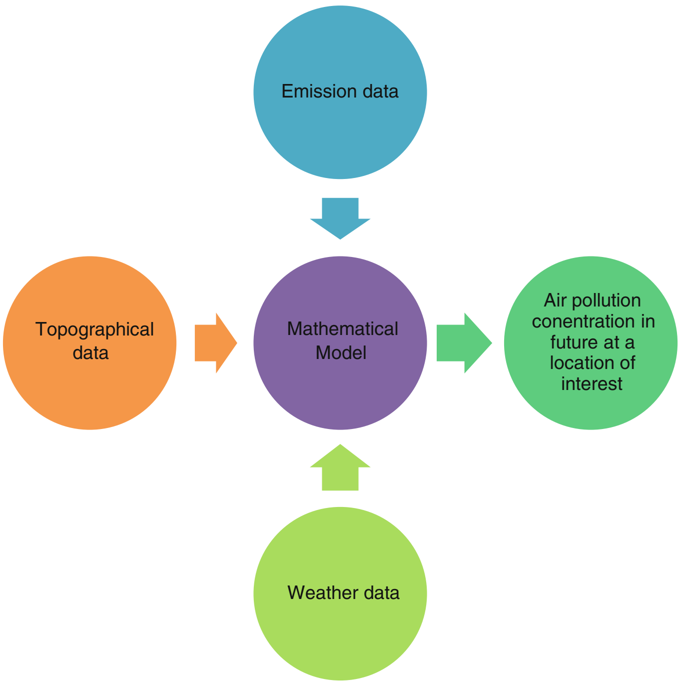

Fig. 2.11 Schematic diagram of mathematical model

There are three main types of air pollution emission plumes: Buoyant, dense and passive. Buoyant plumes are lighter than air since they are at a higher temperature or lower density than surrounding ambient air. Dense gas plumes are heavier than air since they have a higher density than the surrounding ambient air. Passive or neutral plumes are neither lighter nor heavier than air.

Pollutant emission sources are normally characterized point, line, area or volume sources. A point source is a single, identifiable source of air pollutant emissions like emissions from a flue gas stack. A line source is one-dimensional like emissions from vehicular traffic on a roadway. An area source is a two-dimensional source like emissions from a forest fire or landfill. A volume source is an area source with a third dimension (e.g.: the fugitive gaseous emissions from equipment at various heights in industrial facilities.

Other emission/source characterizations of air pollutants are: stationary, mobile, urban, rural, surface, near surface, elevated, puff and continuous. Flue gas stacks are examples of stationary sources and ships are examples of mobile sources. Urban areas are characterized by *heat island* that results in more turbulence above urban area compared to atmosphere above a rural area. Puff or intermittent sources are short term sources (e.g.: accidental release due to explosion of fuel tank). Continuous or long term source are emit air pollutants for long term (e.g.: emission from flue stack emissions).

Mathematical models can be used for variety of decision making which include: (1) urban design, (2) New industry/project, (3) fuel specification, and (4) population policy.

Considering population growth of an urban settlement in developing countries, policy can be made to curb population influx and hence air pollution into city. But in reality this may not happen as people in power usually buy land at cheaper rate and influence government to permit them to develop the area.

2.11.5 Scale of Model

The domain of the atmospheric model varies from micro scale to global scale. Figure 2.12 shows spatial and temporal scales of variability. The computational domain normally contains an array of computational cells where pollution concentration is assumed to be uniform. Scale of model used for analyzing air pollution depends on the pollutants as the certain species live loner compared to others.

2.11.5.1 Global

Typical domain scale for global model is 65,000 km × 65,000 km × 20 km with typical resolution of 5° × 5°. Motions of whole weather systems need to considered while analyzing air pollution in this scale.

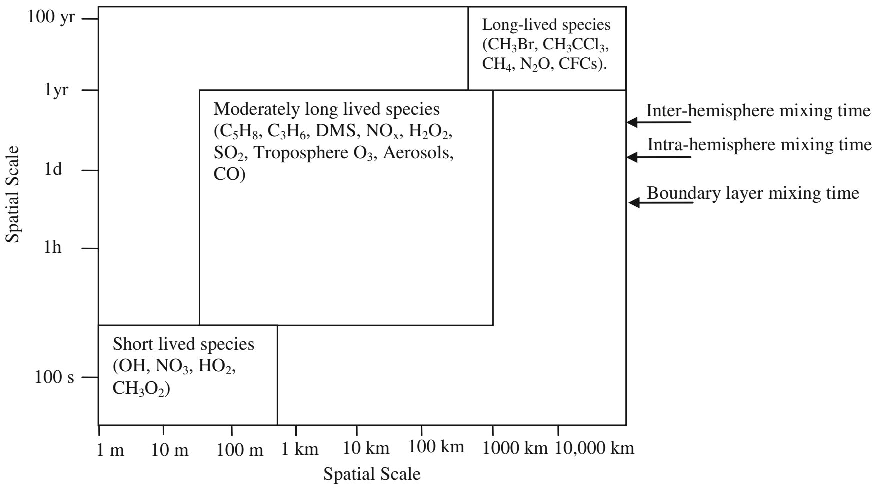

Fig. 2.12 Spatial and temporal scales of variability

2.11.5.2 Continental

Typical domain scale for global model is 3,000 km × 3,000 km × 20 km with typical resolution of 80 km. Motions of whole weather systems need to considered while analyzing air pollution in this scale.

2.11.5.3 Regional

Typical domain scale for regional model is 1000 km × 1000 km × 10 km with typical resolution of 20 km. Motions of whole weather systems need to considered while analyzing air pollution in this scale.

2.11.5.4 Mesoscale

Some of the countries like Singapore or Luxembourg are as big as cities of third world. Typical domain scale for mesoscale model is 100 km × 100 km × 5 m with typical resolution of 4 km. Air pollution in city/county is studied/analyzed in this scale. Phenomena to be considered in this scale are land-sea breezes, migratory high/low pressure front, mountain valley winds.

2.11.5.5 Microscale

Typical domain scale for microscale model is 200 m × 200 m × 100 m with typical resolution of 5 m. Phenomena such as meandering and dispersion of plume and flow regime in small area like street canyons are studied/analyzed in this scale.

2.11.6 Trajectories

Trajectories are the paths of substance in the atmosphere as they move through time as well as space. Substance 'marked' at a certain point at a given time in space can be traced backward or forward in time along their trajectory. Figure 2.13 shows example of output of typical trajectory model. Backward trajectories indicate the past path of a substance and forward trajectories indicate the future path of a substance. Models of trajectories are used track pollutants to know where they are coming from or where they are going to. These models are particularly useful if the monitoring stations shows abnormal concentrations of pollutants especially when it is sure that no such pollutants are emitted in the vicinity.

Trajectory models can be used to investigate air flow around mountains; identify pathways of desert dust; water vapor transport; establish relationships between source and receptor of air pollutants; pollen measurements to track locations of marijuana cultivation; track source of radioactive elements entering the territory of country; track pollutants due to war and accidents in nuclear reactor etc.

Theoretically wind velocity vector can be represented as

$$\frac{d\mathbf{X}}{dt} = \overline{\mathbf{V}}$$

where,

X the position vector in a time step d*t* resulting due to the wind velocity v;
$\overline{\mathbf{V}}$ Wind velocity vector

Hence,

$$\mathbf{X(t) = X(X_0, t)}$$

Position of a parcel of air or pollutant can be identified by

$$\mathbf{X(t) = X(t_0) + (\Delta t)\frac{dX}{dt}\bigg|t_0 + \frac{1}{2}(\Delta t)\frac{d^2X}{dt^2}\bigg|t_0} + \cdots$$

Errors in trajectory model can occur due to wind field errors, starting position errors, amplification of errors, truncation errors, interpolation errors, errors due to assumption regarding vertical wind. Wind field errors can be due to analysis or

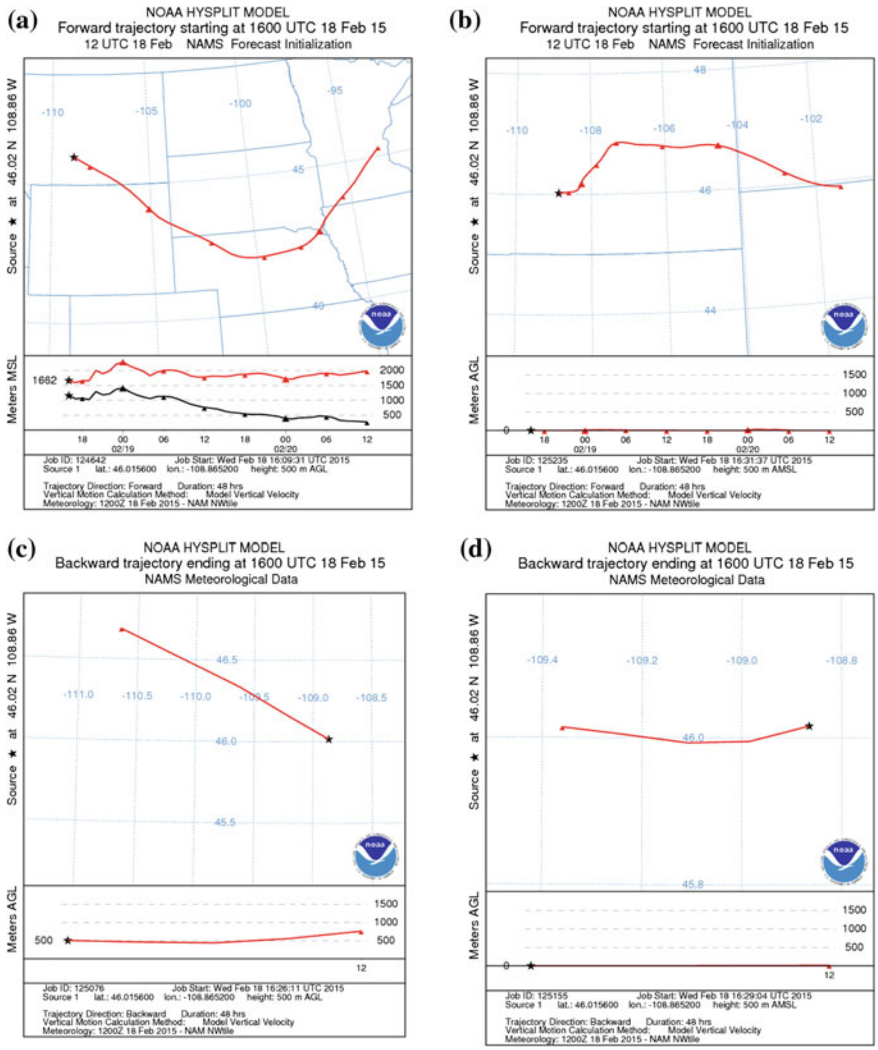

Fig. 2.13 Trajectories calculated for duration: 48 h, Date 18 Feb 2015 using HYSPLIT—Hybrid Single Particle Lagrangian Integrated Trajectory Model on internet http://ready.arl.noaa.gov/HYSPLIT.php. **a** Forward trajectory of particle moving from Lat.: 46.015600 (46°0′56″N), Lon.: 108.865200 (108°51′55″W), 500 m above ground level. *Black line* indicates ground level. **b** Forward trajectory of particle moving from Lat.: 46.015600 (46°0′56″N), Lon.: 108.865200 (108°51′55″W), 500 m above mean sea level. **c** Backward trajectory of particle moving to Lat.: 46.015600 (46°0′56″N), Lon.: 108.865200 (108°51′55″W), 500 m above ground level. **d** Backward trajectory of particle moving to Lat.: 46.015600 (46°0′56″N), Lon.: 108.865200 (108°51′55″W), 500 m above mean sea level. [The authors gratefully acknowledge the NOAA Air Resources Laboratory (ARL) for the provision of the HYSPLIT transport and dispersion model and/or READY website (http://www.ready.noaa.gov) used in this publication]

forecast errors. Starting position errors can occur as starting point of the trajectories are not exactly known. Start positions may not be exactly entered into model due to the differences between the real topography and the model topography. Truncation errors come from the solution to trajectory equation which is approximated in computer. Interpolation errors occur due to the availability of limited wind data due to which wind speed must be calculated by estimation at the trajectory position.

2.11.7 Mathematical Principles

A fluid flow may be described in two ways: (1) the Eulerian approach (named after a Swiss mathematician Leonhard Euler), and (2) the Lagrangian approach (named after the Joseph Louis Lagrange a French mathematician). In the Lagrangian approach, a parcel is selected and is followed as it travels through space with time. In the Eularian approach flow are given at rigid points in space as time varies.

Eulerian description is a field description that is easy to apply. The velocity, pressure, density can be mathematically represented as: v(x, t), p(x, t), ρ(x, t).

Lagrangian description is harder to apply. Here the quantities of the flow are vary with times. The velocity, pressure, density, can be mathematically represented as: v(t), p(t), ρ(t).

2.11.7.1 Box Model

Box model assumes that the airshed is in the shape of a box and air pollutants inside the box are homogeneously distributed. This model is very limited in its capability to accurately forecast dispersion of air pollutants.

2.11.7.2 Gaussian Model

The Gaussian model assumes air pollutants from plume disperse as a Gaussian distribution (Fig. 2.14). This model is most often used for forecast the dispersion of uninterrupted, buoyant air pollution plumes.

Guassian model can be represented by following equation

$$\mathrm{C_{x,y}} = \frac{Q}{\pi u \sigma_z \sigma_y} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

where

C pollutant concentration, g/m^3

Q pollutant emission rate, g/s

π pi, 3.14159

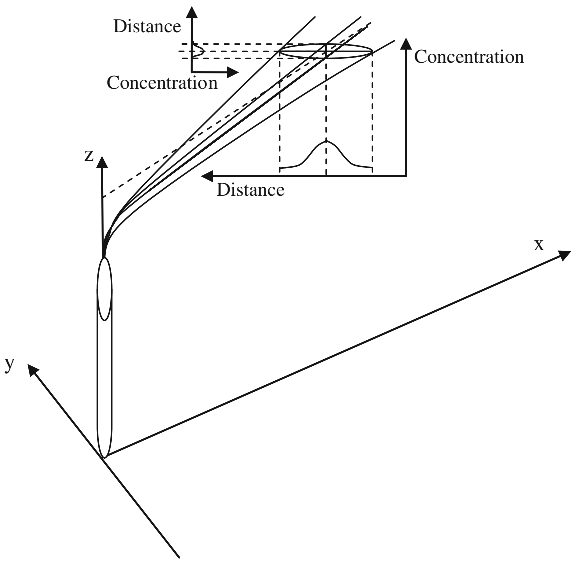

Fig. 2.14 Schematic diagram of air pollution desperation with Gaussian distribution of pollutants

u mean wind speed, m/s
σ_y standard deviation of horizontal plume concentration, evaluated in terms of downwind distance x, m
σ_z standard deviation of vertical plume concentration, evaluated in terms of downwind distance x, m
exp base of natural logs, 2.71828183
H effective stack height, m
x downwind distance along plume meancontreline from point source, m
y cross wind distance from centreline of plume, m

2.11.7.3 Eulerian Model

The Eulerian model focuses on particular position in the space through which the fluid flows with time. Eulerian modeling framework remains fixed in the space and pollutant enters and leaves the cells through wall. Eulerian model make use of a

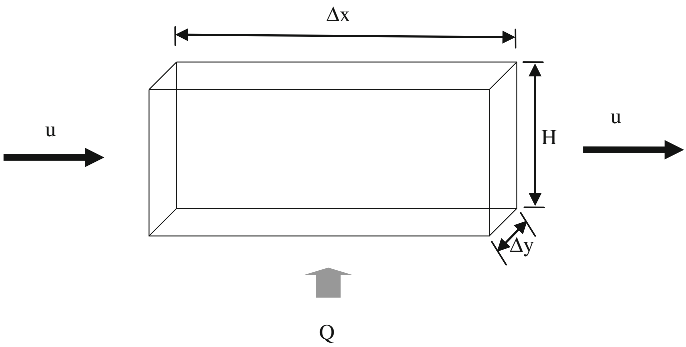

Fig. 2.15 Schematic diagram for single box for Eulerian model

fixed three-dimensional Cartesian grid as a frame of reference. An Eulerian dispersions model also tracks the movement of numerous pollution plume parcels.

A mass balance for Fig. 2.15 for concentration c_i of species i can be expressed as

$$\frac{d}{dt}(c_i \Delta x \Delta y H) = Q_i + R_i \Delta x \Delta y H - S_i + uH\Delta y\left(c_i{}^0 - c_i\right)$$

where,

Q_i mass emission rate of i
S_i removal rate of i
R_i chemical production rate
c_i^0 background concentration of i
u wind speed

Figure 2.16 shows Schematic diagram for Eulerian model for area spread over large area by splitting area into boxes of convenient sizes. Outgoing emission from once box will act as input to adjacent cell

2.11.7.4 Lagrangian Model

Lagrangian model make use of a three-dimensional moving frame of reference and individual fluid parcels are followed through time. In the Lagrangian model, the flow is described by a function X (a, t) for defining position of the parcel '**a**' at time '*t*'.

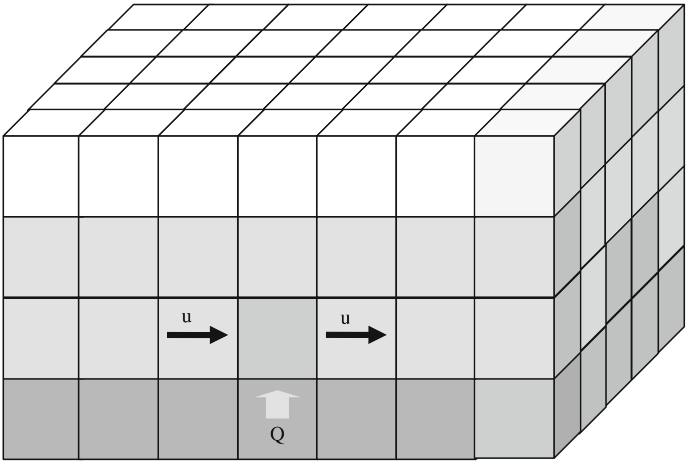

Fig. 2.16 Schematic diagram for Eulerian model for area spread over large area by splitting area into boxes of convenient sizes. Outgoing emission from once box will act as input to adjacent cell

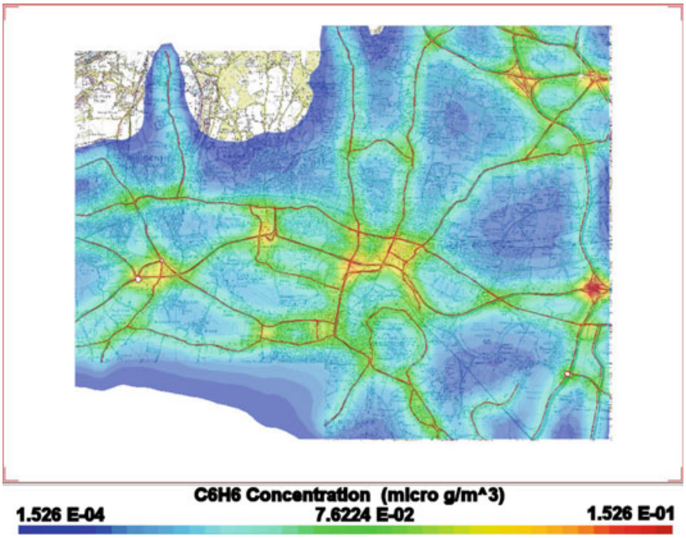

Fig. 2.17 Simulation of C_6H_6 dispersion in road network (*Courtesy* Transoft international)

In the Lagrangian frame, concentration fields as well as its turbulent flux are defined by the statistics of collection of dispersing marked fluid parcels as well as the strength and spatial distribution of sources sinks. This approach is applicable as

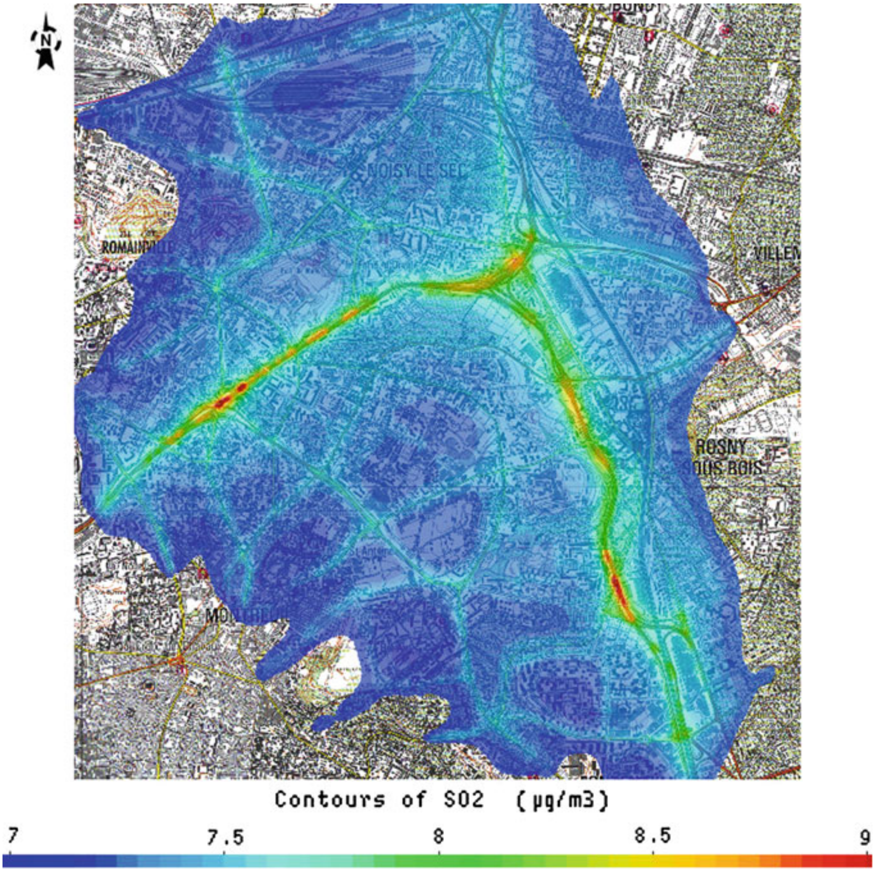

Fig. 2.18 Simulation of SO_2 dispersion in road network (*Courtesy* Transoft international)

long as the molecular diffusion within a fluid parcel is negligible compared to its turbulent diffusion.

Figures 2.17, 2.18, 2.19, 2.20, 2.21, 2.22, 2.23, 2.24 and 2.25 show different output of analysis of dispersion using mathematical models.

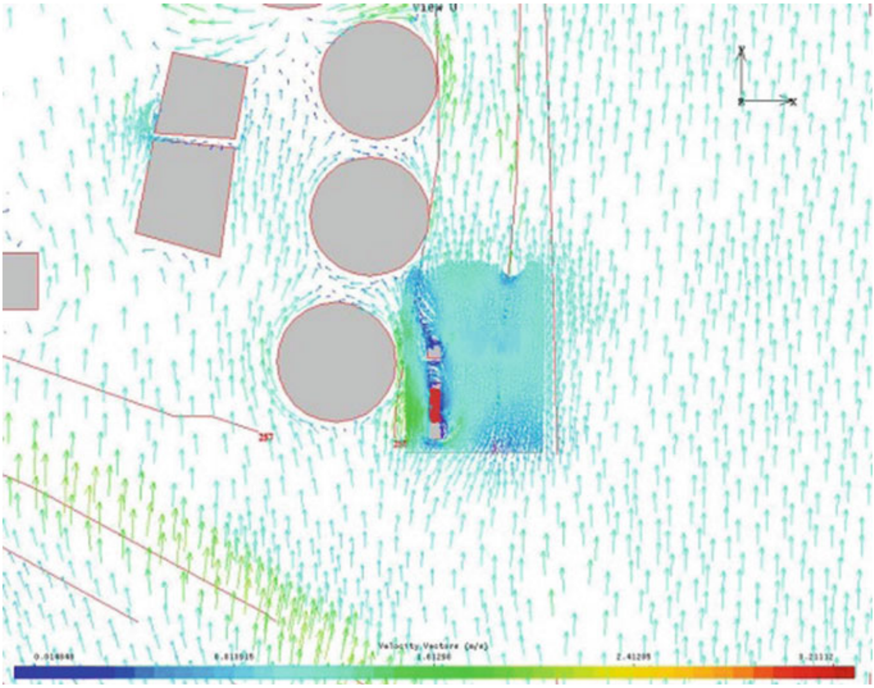

Fig. 2.19 Wind flow around the obstacles (*Courtesy* Transoft international)

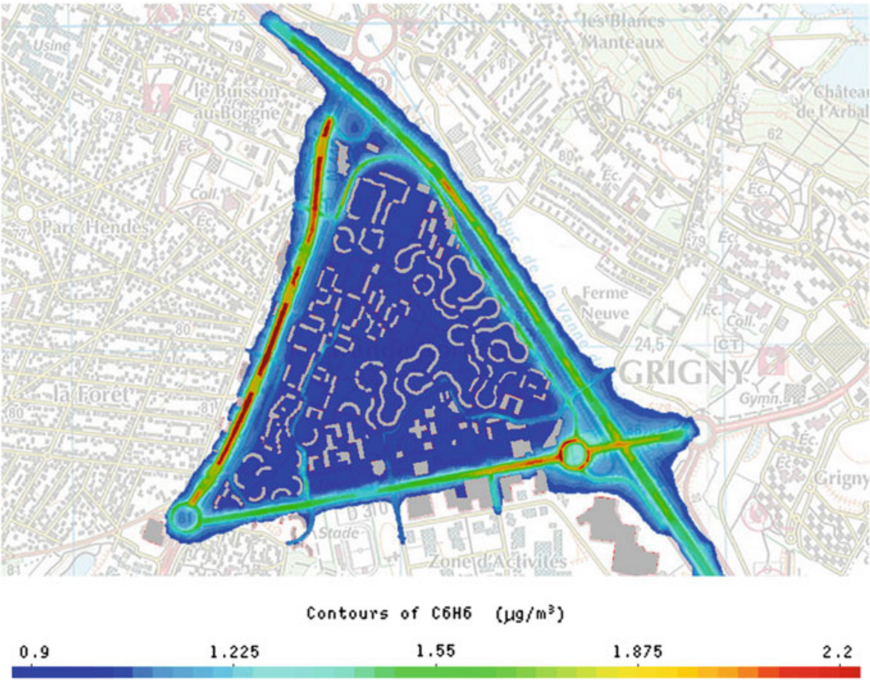

Fig. 2.20 Modelling of urban region (*Courtesy* Transoft international)

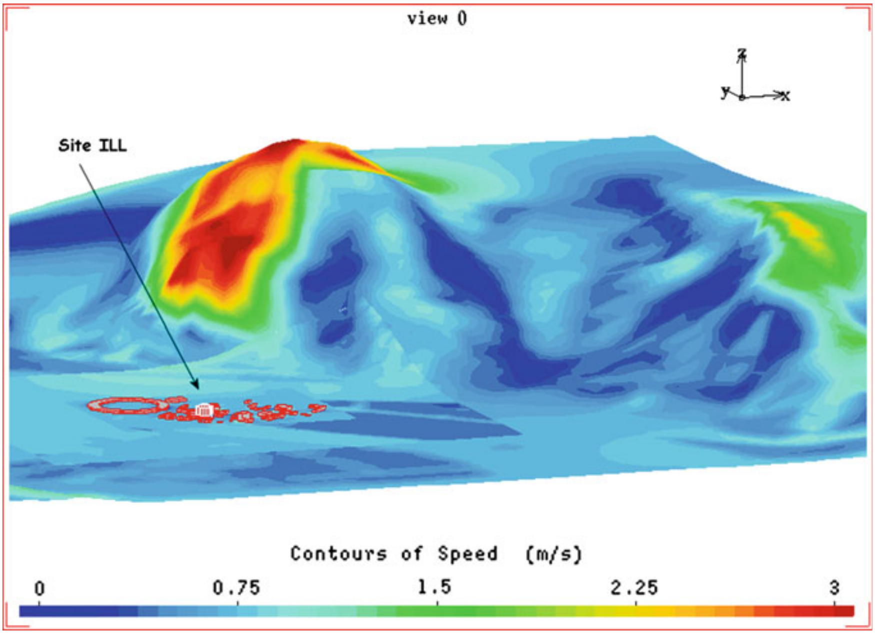

Fig. 2.21 Flow contours over and around hilly region (*Courtesy* Transoft international)

Fig. 2.22 Wind flow inside a building (*Courtesy* Transoft international)

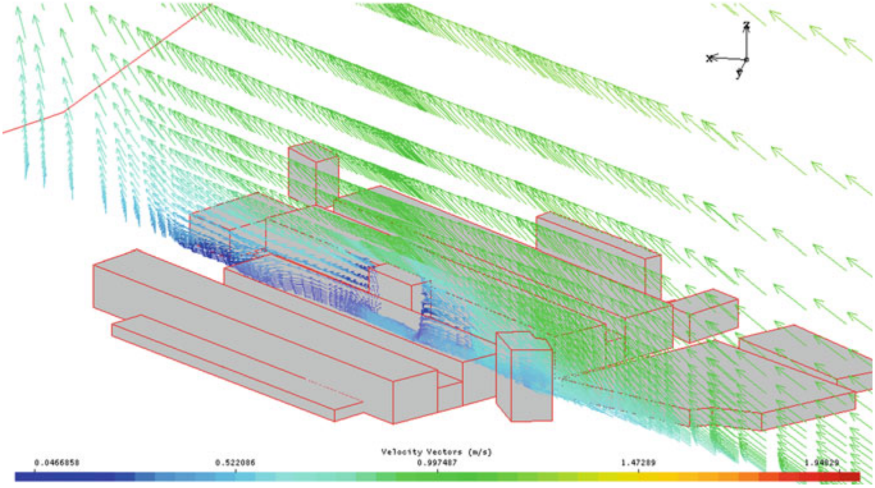

Fig. 2.23 Wind patters (*Courtesy* Transoft international)

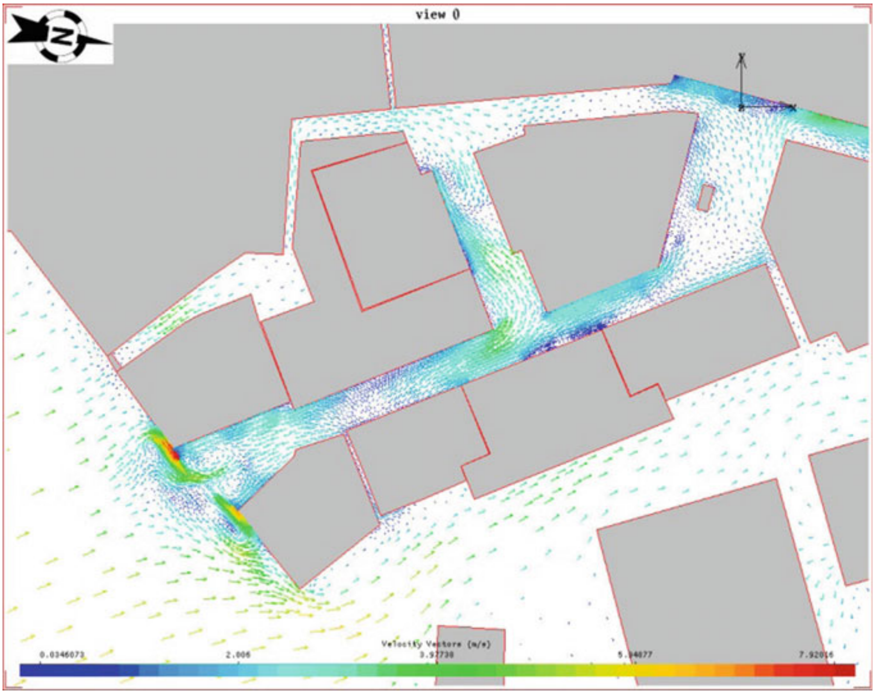

Fig. 2.24 Wind flow showing flow pattern stagnant (*Courtesy* Transoft international)

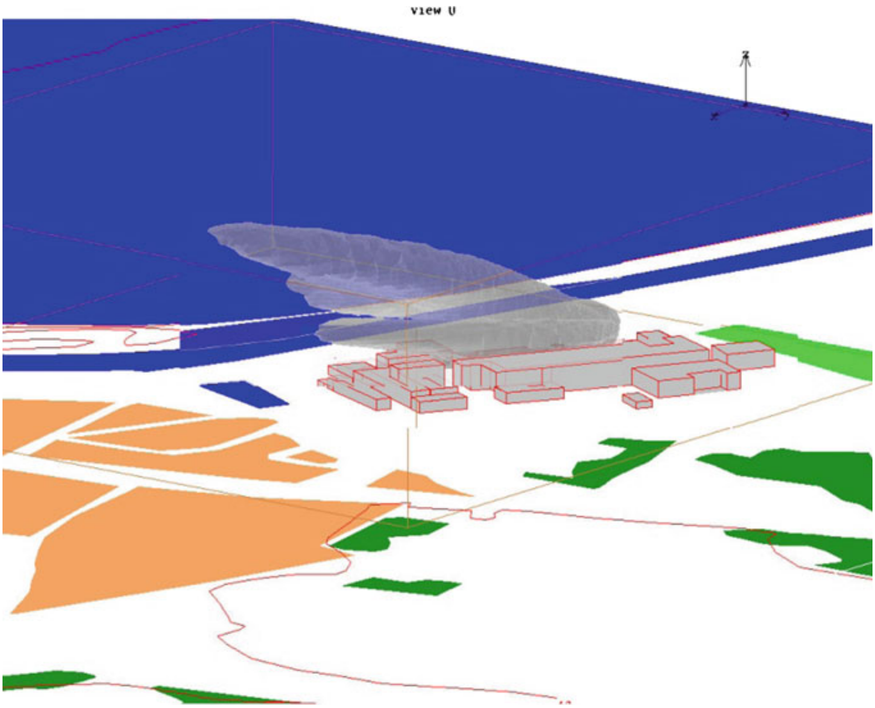

Fig. 2.25 Model of three dimension pollutants plume in a industrial complex (*Courtesy* Transoft international)

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Chapter 3
Needs and Perspectives of Sustainable Air Pollution Management

Abstract Needs and perspectives of air pollution management have changes over the time from region to region. There are considerable changes in air pollution sources on a global perspective as changes with respect to development and consumption pattern has changed the dimension of pollution. Sustainability of air pollution management not only requires technical and scientific solutions it also needs urban planning, financial instruments, regulatory setup, policy, awareness and more than anything else un-debauched decision making regulators. This chapter discusses theory and practical difficulties with respect to sustainable air pollution management.

Sustainable development is influenced by economy, environment, social, and political changes. Any development needs economy to develop and if the government is corrupt then obviously irrespective of technical capability, the society cannot achieve sustainable development. A development at the cost of pollution and resource depletion can only bring in some pain and diseases rather than joy to public (Table 3.1).

Sustainable development depends on millions of individuals and businesses that depends on markets, contracts, laws, and regulations. Complex systems have a lot of unexpected characteristics. Even a modest change can cause a large, possibly catastrophic impact. The failure of a one business can lead to a global downturn like the one occurred in September 2008 due to failure of Lehman Brothers investment bank.

Similarly impact of air pollution cannot be restricted or explained only in terms of increase in concentration of few pollutants. The implication can be many and beyond the boundaries of nations where pollutants origin.

Technological advances drive long-term economic growth. Speedy growth of the global economy since 1750 due to technological advances is also cause of population explosion and pollution. Some of the inventions are determined by the luck of individual inventors. But other invasions are result of research to pursue profits.

As on date good governance is not just influenced by people working in government. Rich multinational companies can change governance by bribing officials to change regulations and tax policies.

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DOI 10.1007/978-3-319-21596-9_3

Table 3.1 Examples of decisions at micro/meso/macro level that results in air pollution

Sl. No.	Decision required	Size of decision (micro/meso/macro)	Decision taking person	Consideration made by decision maker	Implications
1	Operating air pollution equipment in industry	Micro	Owner of the industry	Saving electricity and consumables	Release of air pollutants
2	Fuel adulteration	Micro	Driver/owner of vehicle or fuel vendor	Absence of proper law/enforcement	Adulteration leads to air pollution
3	Initiating action on defaulting industry	Micro	Enforcing officer	Corruption, shortage of man power, lack of knowledge, political pressure	Non-initiation of action leads to air pollution and encourages other to violate legislation
4	Pavement of roads	Macro	Cabinet/minister	Availability of funds	Absence of proper pavement leads to re-suspension of dust
5	Scrapping of polluting vehicles	Macro	Policy makers	Pressure from owners of vehicles	Continuation of movement of old vehicles leads to air pollution
6	Replacing manual sweeping with sweeping machines for cleaning urban streets	Micro	Local authority	Availability of funds	
7	Phasing out of ODS/POPs	Macro	Policy makers	International law	
9	Deforestation/aforestation	Macro	Policy makers	Demand for land, corruption	
10	Change in land use	Macro	Policy makers	Demand for land, corruption	

(continued)

Table 3.1 (continued)

Sl. No.	Decision required	Size of decision (micro/meso/macro)	Decision taking person	Consideration made by decision maker	Implications
11	Change in fuel in public transportation	Macro	Policy makers	Pressure from public, direction from judiciary	
12	Imposing desulphurisation of coal in thermal power plant	Macro	Policy makers	Pressure from industrialist, corruption	Emission of SO_x
13	Permitting polluting industry	Micro	Permit granting authority	Demand for product, need for development, corruption	Pollution in the area depends type of industry
14	Improving efficiency of enforcing agency	Macro	Policy makers	Pressure from employees of the organisation, corruption, judiciary intervention in recruitment/administrative efficiency of enforcing agency	Air pollution control depends on efficiency of enforcing agency
15	Importing fuel	macro	Cabinet/minister	Demand for fuel in the nation and absence of alternative energy resources	Quantity and quality of fuel defines emission of air pollutants
16	Giving birth to offspring	Micro	Parents	Affordability to look after the child	Enhancement in demand for goods as well as service and emission during manufacture of these good an demission

Humanity has become threat to other species as well as itself. Economic activity is changing the Earth's water cycle, climate, nitrogen cycle, as well as ocean chemistry. Humanity is fragmenting the wildlife habitats and corridors that have evolved over millions of years.

Many ideas can be used by common sense to fight air pollution. Some of them are given below:

- Some cars give more mileage compared to other. Many rich people buy luxury cars that are big and consume more fuel. Hence banning all cars that give mileage less than 20 km/L of gasoline(petrol)/diesel can be one of the solution. Alternatively ban gasoline(petrol)/diesel cars and allow only those cars that run on LPG/CNG.
- Many government vehicles allotted for official purpose are used for personal purpose like attending wedding, droping children to school, shopping etc. Some people in power get one more car exclusively for family members who do not contribute anything to official work. On the other hand those who work have to use own/public transportation. Hence GPS based vehicle tracking may be made compulsorily installed to all government vehicles to curb misuse and curb air pollution.
- Power sector is major contributor of GHG emissions. Hence it is right time to switch over to unconventional power by changing all street light to solar powered street light.
- Power connection from grid should not be given to those houses which have not installed solar panel to fulfill at least 10 % of power requirement.
- Currently many industries are established in developing country without obtaining permission from regulating agency. Such practice would lead to air pollution due to absence of condition to curb air pollution. Hence no power connection shall be given to any industry which does not have permission of regulating agency.
- Tobacco cultivation and curing do generate huge amount carbon emission due combustion of wood. The combustion of wood is also reducing trees. Hence cultivation of tobacco can be totally banned. Further green tax shall be imposed on tobacco products which shall be used to grow trees.
- Agriculture sector emits a major amount of CH_4 mainly from animal husbandry. Hence green tax can be imposed on meat and tax collected can be used to grow trees that act as sink to carbon in the atmosphere.
- Imposing green tax on petrol/diesel/coal and using it to subsidize public transportation can encourage people to shift to public transport there by reducing air pollution.
- While many poor people are dying due to snake bites at night time, urban people are using it for flood light matches and drinking liquor. Flood light matches shall be banned which consumes huge power to entertain rich which otherwise can be used by poor in villages. Otherwise green tax can be imposed for viewing flood light matches. The green tax can be used for growing trees or installing solar lights in rural area.

3.1 History of Air Pollution and Its Management

History of pollution is not documented in detail like the details of kings and queens who ruled the countries. As the civilization grew, the pollution became part of it and some civilizations were able to tackle it scientifically.

Natural air pollution existed in the form of dust, volcanic eruption, pollen grains etc. Humans might have generated dust from dry soil while walking, but anthropogenic air pollution intensified when the he/she first lighted fire. The burning of fuels contributed to the air pollution apart from saving them from animals in the night. The walls of caves, inhabited many years ago, are covered with layers of soot. Most of the lungs of mummified in the past have a black tone (Makra and Brimblecombe 2004).

It was noted the easterly transfer of yellow Loess (aeolian sediment formed due to the accumulation of wind-blown soil) dust for many of kilometres (Chun 2000). New Stone Age people mining flint might have suffered from silicosis (Markham 1994). In the ancient cities, unpleasant odours were important. Smoke-stained marble in old towns gave them a greyish tone (Makra and Brimblecombe 2004). The Roman Senate made a law against pollution, according to that: *Aerem corrumpere non licet* (‘Polluting air is not allowed’). Lead mining started around 4000 B.C., and significant exploitation started about 1000 years later (Makra and Brimblecombe 2004). After the fall of the Roman Empire, lead concentration in suddenly dropped, but in the Medieval and Renaissance Ages it reached a concentration twice that detected during the Roman Empire (Boutron 1995; Makra and Brimblecombe 2004). Copper was made from native copper about 7000 year ago followed by invention of smelting technique (Makra and Brimblecombe 2004) and associated emissions.

Colonization resulted in spreading of human population leading to anthropogenic activities across the world. Migration of people also leads to destruction of forests which acted as source of oxygen and sinks to many pollutants.

Up to the industrial revolution mankind’s relied only on muscular/biomass sources for energy. Most works were done by manual labor and animals. Biomass in the form of firewood provided energy for heating and cooking. Contribution from windmills and watermills was marginal. By the mid 19th century, usage of coal increased. As the 20th century began, gradual shift towards oil, natural gas, and nuclear energy enhanced. The 21st century witnessed major shifts in energy towards more efficient fossil fuels like natural gas, biofuels, nuclear energy, and hydrogen.

Around 1900 A.D. most of the metallurgical industry emitted waste gases at ground level. Roasting of sulfide ores and the making of coke were carried out without chimneys. Stacks were built in later years that were only high enough to provide sufficient draft for furnaces. As the scale of metallurgical activities increased the air pollution posed to flora, fauna and humans in the vicinity.

The central and southern England witnessed rise in air pollution resulting in 14 % rise in London ambulance service on 2nd April 2014 due to light easterly winds bringing pollutants from Saharan dust causing thick layer of dust on cars and buildings (bbc_a 2014; bbc_b 2014). The event was less sever compared to great London smog that started on December 4, 1952, which lasted until March of 1953 due to trapped air pollutants in cold air arising from burning of coal from houses, vehicles and industries. Noxious emissions from industries gave them bitter taste, a dirty yellow colour and an unpleasant odour and came to be known as 'pea soupers' for smog in 1952.

Invention of radioactive material lead to new problems associated with it. The ill effect of air pollution and associated radiation in various intentional and accidental episodes proved costly both in terms of human lives and monitory burden. The pollution became international issue and international cooperation became important to avoid impact of air pollution arising from other countries. The stringent enforcement and use of technology to fullest capability within the country did not improve air quality as the pollutants do not respect political boundaries.

The past world wars had its contribution to degradation of global air quality in the atmosphere. Invention of new chemicals due to innovation in science and technology lead to emission of almost all the chemicals that occurred naturally and formed artificially. The effect of many chemical in the atmosphere is still unknown and not all chemicals in the atmosphere.

The airborne pathogens raised concerns in last decades due to spread of swine flu and avian flu. Common infections are also spread by airborne transmission which includes Anthrax (inhalational), Chickenpox, Smallpox, Cryptococcosis, Influenza, Measles, and Tuberculosis.

Air pollution has now become source of environmental degradation in Asia. Rapid industrialization in China has resulted in dramatic air pollution around 2000 AD. China also experienced severe dust storms, due to over-farming, and over-grazing. Plumes of dust and toxic air pollution are major public health concern in Korea, Japan and China. Some of these plumes have reached USA.

3.2 Air Pollution Sources

Air pollution sources need not be from only anthropogenic activities. It can happen due to natural sources like forest fire (Fig. 3.1) and reaction of different molecules within the air. The high temperature of lightening can bring in fusion of molecules to form oxides of nitrogen. The erosion of surfaces of rocks/minerals/buildings contributes to air pollution as well as waste management and evaporation of volatile substances also contributes to pollution to great extent. Figure 3.2 shows Sources of air pollution and Annexure I shows typical sample table for inventory of air pollutants.

The source apportionment is essential for controlling the air pollution. Without the knowledge of air pollution sources it is not possible to formulate strategy to control air pollution.

With increased research and anthropogenic activity the sources have increased many fold. A relatively insignificant activity like spraying pesticide in houses, restaurants and shops can cumulatively contributes release of tons of such chemicals worldwide. Cooking can also can release variety of air pollutants. Simple laboratory experiments can release chemical fumes into atmosphere.

Fig. 3.1 Forest fire

Transportation is most important source for air pollution in the world. Most of the vehicles in developing countries are old and emit more pollutants.

Due to lower oxygen content of the atmosphere at high altitudes, combustion processes in motors are sub-optimal when they travel in high altitude. Carbon monoxides and VOC emissions are much higher at higher altitude compared to their emissions at normal air pressure.

World population growth, energy demand, industrialization, and environmental goals are currently driving speedy global change in emissions with complex outcomes for air quality, climate, and ecosystems (Jacob et al. 2011). As developed countries strive to reduce emissions of air pollutants, rising emissions in the developing world may augment concentrations of air pollutants.

3.2.1 Unsustainable Characteristics

Air pollution has many unsustainable characteristics as they affect resources of future generation. The release of air pollutants can contaminate many food items and reduce quality of many products. High ozone concentrations can be observed in many city due to formation of secondary pollutants due to reaction in atmosphere.

Intercontinental transport of air pollution between North America, Asia, and Europe takes place by means of the prevailing westerly winds. Satellite observations of dust transport across the Pacific show that, sources in Asia can have an effect on U.S. in less than a week (Husar et al. 2001), even though the usual transport time is 2–3 weeks (Liu and Mauzerall 2005). Asian emissions of mercury are fast increasing over the past two decades (around 1986–2006) (Wu et al. 2006) whereas North American emissions are decreasing. As per Selin (2005) regulation of mercury can best be achieved by a global emissions treaty. The atmospheric residence time of Hg(0) is around a year (Selin et al. 2007) which is sufficient to transport on a global scale. Even though local emissions may change near-source

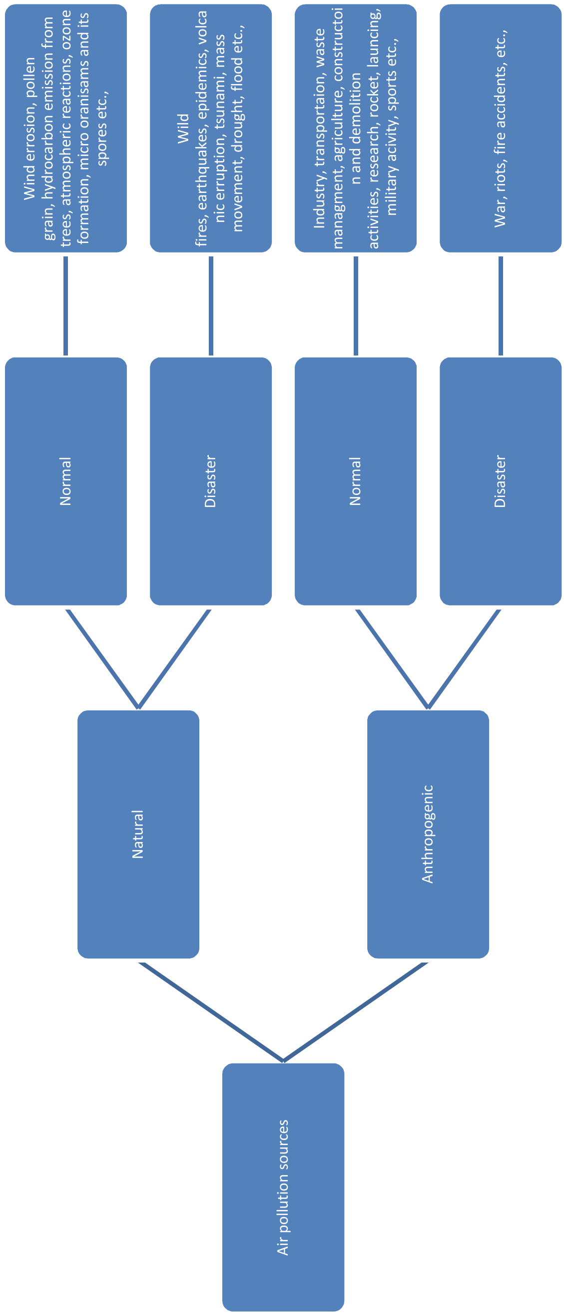

Fig. 3.2 Sources of air pollution

"hot spots" (Dvonch et al. 2005; Keeler et al. 2006), only 20–30 % of U.S. mercury deposition begin from North American sources, and Asian sources add a rest of fraction (Seigneur et al. 2004; Selin and Jacob 2008; Selin et al. 2008).

Intercontinental influence on PM on North America is limited by scavenging while transport (Tarrason and Iversen 1998) with a main exception is the Arctic in winter–spring, where transport of European pollution leads to the phenomenon called as "Arctic haze" (Barrie 1986). Observations and models shows that the surface air concentrations of Asian sulfate for western United States indicate of the order of 0.1 μg m^3 on an annual average basis (Heald et al. 2006; Park et al. 2006; Liu and Mauzerall 2007; Liu et al. 2008), whereas as per van Donkelaar et al. (2008) the values are 0.13–0.17 μg/m^3 for western Canada during spring.

3.3 Air Pollution Control Systems

Management air pollution in a country or region needs policy, resource, legislation and equipment. Figure 3.3 shows factors influencing air pollution control system. Depending on simplicity or complexity of the situation single or chain of equipments are used to control emission. Conventionally "Air pollution control system" means individual or chain of equipments installed for the purpose of reducing/eliminating emission of air pollutants to the atmosphere. The economy, regulation, standards, space constraints and availability of equipment in market defines choice of equipment.

Low cost and easy to operate equipment like cyclone separators which cannot achieve desired efficiency are usually used prior to high efficiency equipment like bag filters or Electro Static Precipitators (ESP) in cement industry. The cyclone separators reduce the load on high efficiency equipments thereby enhancing life of the equipment and reducing need of higher investment.

Further if the production of chemical emits PM as well as gaseous pollutants then equipment capable of removing PM usually precede equipments meant to remove gaseous pollutants.

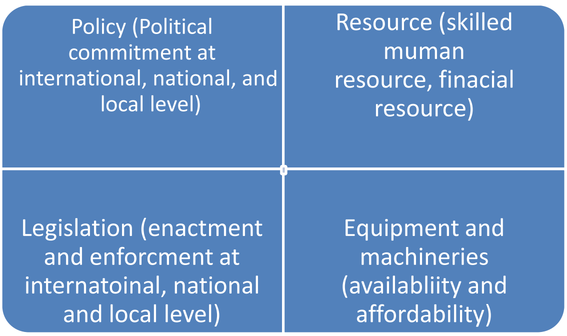

Fig. 3.3 Factors influencing air pollution control system

3.4 Influence of Meteorology on Air Pollution

Meteorology has great bearing on dispersion of air pollutants. Air quality is greatly sensitive to weather. Hence change in climate will have important air quality implications. Jacob and Winner (2009) give a review these implications. Major heat waves in the eastern USA in 1988 as well as in Europe in 2003 were associated with extreme pollution episodes (Lin et al. 2001; Guerova and Jones 2007). Heat waves are likely to become frequent in the future (Christensen et al. 2007). In Mexico, there are concerns about the effects of forest fires due to drought on air quality. The effect of forest fires on air quality in Mexico can be significant.

In the spring of 2005 metropolitan Guadalajara witnessed one of the most severe air quality episodes due to a fire in the forest at La Primavera (INE-SEMARNAT 2006). The cold air related with cyclones sweep the polluted air, replacing it with cleaner polar air (Cooper et al. 2001; Li et al. 2005). General Circulation Model (GCM) simulations by Mickley et al. (2004), Murazaki and Hess (2006), as well as Wu et al. (2008) show a higher incidence of summer pollution episodes in the eastern and central USA in the future. Such a trend in cyclone is a strong characteristic of GCMs at least in winter (Lambert and Fyfe 2006). This can be explained by diminishing of the meridional thermal gradient due to strong Arctic warming. Past observations for several decades show a significant decline in mid-latitude cyclone frequency (McCabe et al. 2001). GCM simulations for climate in the 21st century find inconsistent results (Jacob and Winner 2009). Climate change may increase or decrease mixing depths. According to Jazcilevich et al. (2000, 2003a, b, 2005), speedy urbanization and associated landuse changes have had a great effect on mixing depths as well as urban-scale circulations affecting quality of air in Mexico.

3.4.1 Lapse Rate and Dispersion

When a parcel of air rises in the earth's atmosphere it expands as it experiences lower pressure from the neighboring air molecules. This expansion reduces its temperature. The parcel cools at a rate of 1 °C/100 m rise at dry conditions. This is called *dry adiabatic lapse rate.*

The temperature profile of the air is called the *ambient lapse rate* or the *prevailing lapse rate or environmental lapse rate.* This is measured using a balloon fixed with thermometer.

When the temperature of atmosphere decrease more than 1 °C/100 m it is called *super-adiabatic lapse rate* or *a strong lapse rate occurs*.

If the temperature of atmosphere is characterized by temperature drop of less than 1 °C/100 m it is called *sub-adiabatic* or *weak lapse rate*.

Inversion is a special case of weak lapse rate wherein warmer layer is located above colder air.

The dispersion of pollutants is very much aided by the convective as well as turbulent mixing in the lower atmosphere. Figure 3.4 shows effect of lapse rate on plume behaviour.

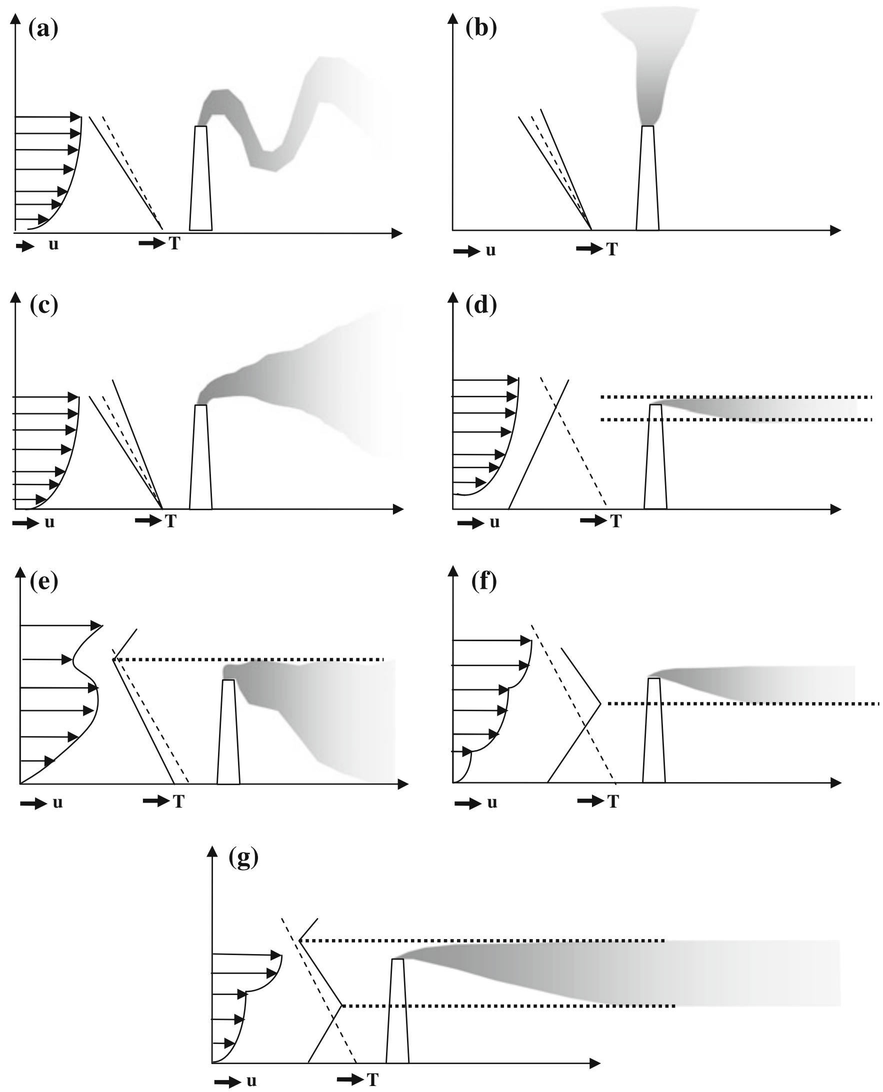

Fig. 3.4 Effect of lapse rate on plume behaviour **a** Looping, **b** neutral, **c** coning, **d** fanning, **e** fumigating, **f** lofting, and **g** trapping

3.4.2 Pressure System and Dispersion

Pressure systems also influence on dispersion of pollutants. High pressure systems are related to light winds, clear skies, and atmospheric stability resulting in build up of air pollutants.

Low pressure systems are linked with unstable atmospheric conditions and contaminant buildup is less likely to happen in low pressure cell. Initially, a warm front will reduce air-contaminant concentrations, primarily through the storm activity along its leading edge. As the warm front develops, however, more stable conditions will result, with an accompanying increase in air pollution potential.

3.5 Winds and Dispersion

Wind is air in motion. On global scale wind patterns are formed due to (1) unequal heating of surface of earth by solar radiation, (2) rotation of the earth, and (3) the variation between conductive capacities of water bodies and of land. Mesoscale circulation patterns are developed due to regional or local topography such as mountain ranges, deserts, grass lands, waterbodies, forest, etc. Meso scale variation influence wind patterns up to a few hundred kilometers. Microscale phenomenon occurs in areas of less than about 10 km extent.

Wind speed also varies with height and reaches maximum value at around 200–500 m above ground.

Winds from hot area like desert will be hot and raises temperatures over which it passes. Winds blown from cold areas will travel with low temperature and will bring down the temperature over which it passes. Land heats and cools faster than the sea and therefore coastal areas have a lower temperature range compared to those inland areas.

Slopes facing the sun are warmer. South facing slopes in the northern hemisphere and north facing slopes in the southern hemisphere are warm.

The sea breeze and land breeze is formed due to differential heating of water and land surfaces by incoming solar radiation. Solar radiation penetrates several meters into a body of water and it warms water very slowly. In case of land only upper few centimeters of land is heated by solar radiation, but warming occurs rapidly in response.

Any general flow due to large-scale pressure systems may either reinforce or inhibit sea breeze.

Sea breeze

A sea breeze (or onshore breeze) is wind that develops over water bodies near land due to differences in air pressure due to their different heat capacity. It is usually observed along coasts during the morning as land gets heated up more quickly than the water.

Land breeze

A land breeze (or offshore breeze) is caused by land cooling more quickly than water. It is usually observed in the evening.

Mountain and valley winds

Solar heating as well as radiational cooling influence air flows in valleys and mountain. In case of south-facing side of mountain, as the slope heats, air attempts to ascend due to decrease in density (Fig. 3.5).

Near the pinnacle of the slope, the air tends to go up vertically. This upslope flow is called valley wind.

During night when radiational cooling happens on slopes, the cool dense air near the surface go down along the slope. This is the down slope wind (Fig. 3.6).

Urban–Rural circulations

Urban areas have roughness and thermal characteristics which is different from their rural surroundings. Urban areas heat quickly in addition to high heat-storing capability compared to the rural areas.

Under the calm conditions the air over the warmest part of the urban core raises drawing cooler air from all directions from the surroundings. Subsidence replaces

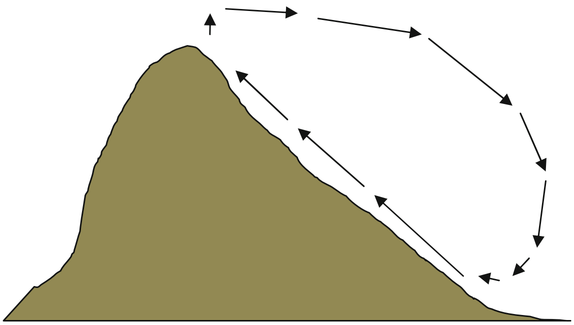

Fig. 3.5 Upslope wind (day) due to greater solar heating on slope

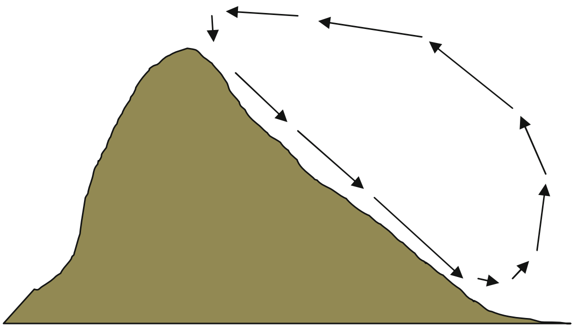

Fig. 3.6 Downslope wind (night) due to greater cooling on slope

this air in rural areas. This circulation is known as the *urban heat island.* The effect of urban heat island is overcome in Japan by sprinkling treated wastewater on roads. Such sprinkling would also suppress dust. When the regional wind permit the outflow to take place in mainly in one direction and the rising warm urban air travel off with this regional flow, the circulation is termed the *urban plume.*

Flow around structures
When the wind comes across objects in its path the flow is normally strongly agitated and a turbulent wake is formed in the neighborhood of the structure, particularly downwind side of building.

3.6 Economics of Air Pollution

Economics is the study of production, distribution as well as consumption of goods and services. An economic system of a nation or region is referred as economy. Table 3.2 shows contribution of different sectors to air pollution. The impact of air pollution on economy can be many fold it can affect agricultural production and health of citizens. At the same conventional measurement may mislead calculation due to demand for medical services arisen due to air pollution.

The impact of air pollution on a country's economy is often invisible or not clearly visible. The impact on material, health, ecology due to air pollution will not

Table 3.2 Contribution of different sectors to air pollution

Sector	Description	Example	Air pollution sources
Primary	Changing natural resources into primary products	Agriculture, agribusiness, forestry, fishing, mining and quarrying	Air borne dust/chemicals/smoke due to use of agro chemicals and crushing of mineral/rock
Secondary	Create a finished, usable product	Brewing industry, automotive industry, textile industry, chemical industry, energy industry, steel production, paper industry, consumer electronics, tobacco industry	High energy consumption and associated air pollution
Tertiary	Servicing	Government, public health, waste disposal, healthcare/hospitals, education, insurance, financial services, banking, legal services, consulting, hospitality industry, news media, tourism, franchising, real estate, retail sales	Air pollution due to transportation, energy consumption for lighting and air conditioning

be usually included in national budget with a clear cut allocation to correct the losses.

3.7 Integrated Air Pollution Management

Failure to integrate air quality considerations in planning has resulted in increased air pollution form energy, transportation, solid waste disposal, industry, housing, land use, and other development activities. Solving one problem at time in many countries has neglected air pollution only to find out the severity of impact afterwards.

The first priority has always has been to survive. This has lead to migration leading to urbanization which in turn had snowballing effect due to creation of new jobs and hence greater migration resulting in more traffic, service and manufacturing activity. The effects of poor air quality in Europe has mainly on human health and biodiversity (EEA 2013) where as it can also lead to climate change; acid/alkali rain; ozone layer depletion; atmospheric brown cloud; crop yield; eutrophication of lakes; reduced visibility; black/snow cloud; water pollution; soil pollution; and loss of economy.

The hierarchies of pollution control are:

- **Elimination**: remove the sources of pollution.
  - e.g., do not burn garbage, do not permit industries,
  - **Substitution**: Substitute to the less risky substance to high risky substance e.g., switch to the use of safer chemicals. Switch to solar energy instead of thermal power plant.
- **Engineering controls**: Prevent exposure to a hazard by barrier or pollution control equipment
  - e.g., install an ESP in thermal power plant, covering construction activities (Fig. 3.7)
- **Administrative controls**: Change work practices as well as management policies
  - Monitor ambient air/stack and take corrective action like stopping polluting activity or enhancing efficiency of pollution control equipment
- **PPE**: use gloves, masks, hearing protection, safety eyewear, respirators, or other protective equipment
  - e.g., Use of respirator when pollution is uncontrollable (like forest fires)

"Top Runner program" of Japan set energy efficiency targets for appliances. There has been a steady improvement in the fuel economy from 13.5 km/L in 2000 to 17.8 km/L in 2009 (Energy Conservation Center of Japan 2011). Application of

Fig. 3.7 Construction activity a covered to avoid air pollution

BAT to control SO_2, NO_x, and PM has be achieved by wet-FGD, LNB, SCR and high efficiency deduster (HED) like Fabric filter and electrostatic fabric integrated precipitator) (Klimont et al. 2009). The average efficiency air pollution control equipment kept increasing as old facilities retired in industrial sector. In 2004, target was to reduce the nonmethane volatile organic compounds emissions by 30 % of quantity emitted in 2000 by 2010 and it was estimated that the actual emission reduction were higher (Wang et al. 2014).

3.7.1 Afforestation

Afforestation is growing a forest in forestless area. Reforestation is the reestablishment of forest cover. Afforestation can control air pollution by avoiding soil erosion due to wind, absorbing gaseous pollutants and trapping particulate matter. But plants themselves may die due to exposure to high air pollution.

Afforestation/reforestation can reduce climate forcing in many ways:

- Reductions in emissions of air pollutants;
- Conservation of existing carbon stocks (biomass, peatlands, and soil carbon);
- Reductions of carbon losses from biota as well as soils;
- Enhancement of carbon sequestration in soils and biota; and
- Changes in albedo (Portion of solar radiation reflected by a surface or object).

3.7.2 Urban Planning

Urban planning over the year has taken different dimensions. World is witnessing major migration of population from rural to urban area. Apart from other stress the new people also contribute to deterioration air quality.

Land use mix (diversity as well as integration of land uses like residential, park, commercial) at a given scale. Separation of land uses, was motivated by the pollution from industries. However, when land uses are separated, the distance between homes and work/shopping will be longer (Kockelman 1997). Hence, diverse as well as mixed land uses can reduce travel distances and enable walking/non-motorized transportation (Kockelman 1997; Permana et al. 2008), thereby decreasing vehicular movement and associated air pollution (Seto et al. 2014).

Same population density can be achieved through multiple land use configuration (Fig. 3.8). High-rise buildings consume higher energy but allow space for roads and trees. Hence urban planner should think optimum solution with different configuration to achieve best air quality.

While the cities in developing countries are still in infant stage to plan the city with quality environment there has been considerable effort by cities like Stockholm to set example to rest of the world.

In order to achieve good air quality Stockholm has planned to increase number of green cars by switching motor vehicles owned/leased by the Stockholm's municipal committees as well as boards to green cars. It is also planned to increase number of electric cars in the Stockholm's vehicle fleet, with the exclusion of emergency/special purpose vehicles. The city authorities have set a target wherein 85 % of the fuel used will be hybrid biogas, ethanol, or plug-in hybrid vehicles. It is planned that at least 55 % of contracted transport be accomplished with green vehicles (Stockholm stad 2012). The city also plan to encourage pedestrian and bicycle riders by providing infrastructure for bicycling; bicycle parking in prime locations in sufficient quantities; good winter road clearance on bike paths. The city plans to consider pedestrians' needs in traffic and construction projects. The city has set a target to increase green fuel 16 % between 2012 and 2015 by making it easier to buy/charge electric cars, (2) developing infrastructure for alternative fuels. The city also plans to reduce emissions of dangerous substances from buildings and increase proportion of environmentally certified buildings.

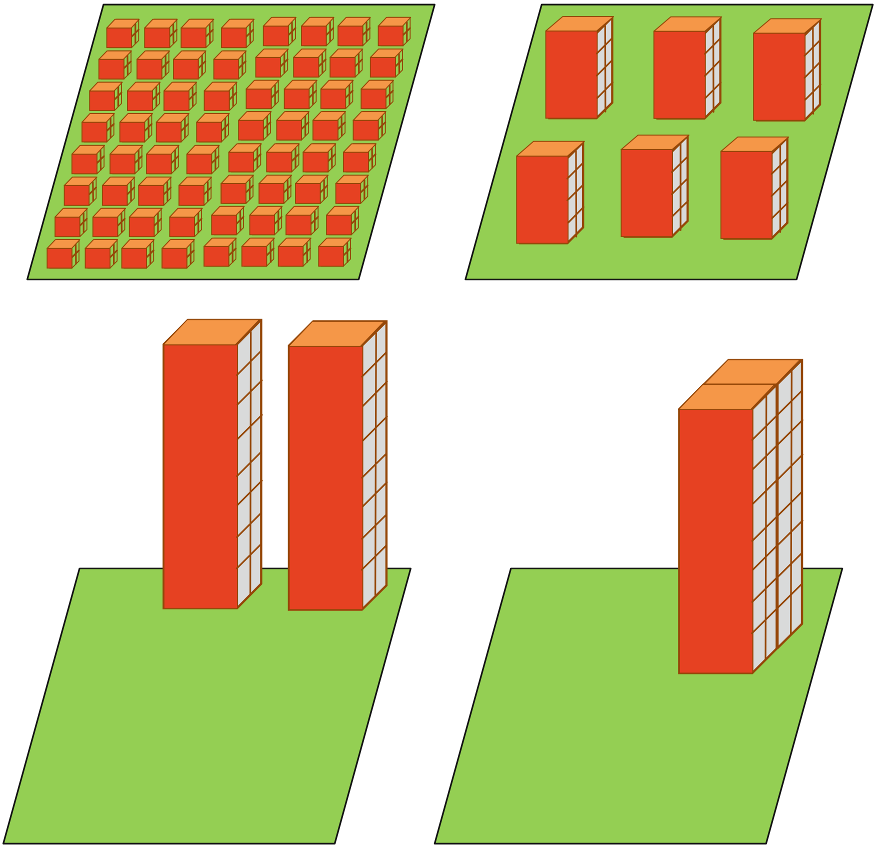

Fig. 3.8 Same densities in four different layouts

Higher energy means higher emission hence Stockholm has incorporated plans to reduce energy use in its operations by at least 10 % and designing new buildings such that energy use will be less than 55 kWh/m^2. Stockholm has set a target to procure electricity for municipal activities that meets the requirements for eco-labelling. The City's buildings will be made energy efficient in connection with major renovations (Stockholm stad 2012).

Many cities in developing world have been taken into clutches of private builders and poor urban planners. The Cities in developing countries has seen major shift in settlement with existing infrastructure contributing to traffic jams and inefficient energy consumption. There have been encroachments of water bodies and free spaces by slum dwellers or influential developers. Roads are being widened by sacrificing footpaths. There is considerable drop in bicycle riders due to poor traffic management which has lead to accidents. In many parts of the Bangalore single houses are being demolished to build apartments. The population and government are still using old vehicles that are not eco-friendly. Shortage in power generation in developing world is discouraging people to buy electric cars. These cities have no plans to discourage use of hazardous chemicals in construction activity. Frequent engine failure, in-consistent timings, thefts, molestation and rapes in public transport is discouraging people to use public transport. The cities in developing countries are expanding horizontally without proper planning. Cities in developing countries have poor connectivity to hospital and educational institutes by public transport. The rampant corruption among political parties and bureaucracy has made it possible for development at the cost of environment and public health.

The City of London (also known as the Square Mile) which is a city within London constituted from its settlement by the Romans has listed 32 actions to improve air quality between the year 2011–2015 (city of London 2011): (1) monitor air pollutants, (2) introduce policies to improve air quality if possible, (3) Undertake air quality impact assessments transport, (4) model the air quality impact of taxi emissions, and low emission buses, (5) Investigate further options for parking policy to encourage use of low emission vehicles, (6) continue to manage its vehicle fleet to decrease emissions of PM_{10}, NO_x, and CO_2, (7) continue to trial vehicles with alternate fuel and raise the number of low emission vehicles where appropriate, (8) continue to encourage use of low emission vehicles by its contractors, (9) work with public as well as private bodies to develop guidance for low emission procurement, (10) engage with the City Police to decrease emissions from their fleet, (11) continue with its efforts to establish ways to prevent drivers from idling vehicle engines unnecessarily, (12) work to designate the entire of London a no-idling zone, (13) trial a method of dust suppression along Victoria Embankment through to Tower Hill, (14) consider rolling dust suppression to other areas of concern, (15) continue to explore as well as implement energy efficiency measures its buildings, (16) engage with City businesses to get their support to improve air quality, (17) consider air quality in all development, (18) encourage major developments to get maximum points for the pollution section of the BREEAM [(BRE Environmental Assessment Method) an environmental assessment method for buildings] assessment Pertaining to NO_x emissions, (19) to develop local best practice guidance for emission control from gas Combined Heat as well as Power plant, (20) encourage developers to install non-combustion renewable energy technology, (21) insist for detailed air quality impact assessment for any development for proposed on-site energy generation using biofuel/biomass, (22) consider cost effective ways to reduce emissions from back up generators, (23) secure air quality improvements where appropriate through the S106 process (Section 106 of the Town and Country Planning Act 1990 in UK allows local planning authority to enter into legally-binding agreement/planning obligation with a developer which is termed as S106 (Section 106) Agreement), (24) continue to establish best practice for reducing emissions from demolition, construction, and street works, (25) to pay particular attention to control PM_{10} emissions from construction, demolition as well as street works in and around the way from Victoria Embankment through to Tower Hill, (26) to assist the Mayor of London to control dust and emissions from Construction and Demolition, (27) to encourage the use of green roofs and green walls in buildings (28) to continue to enhance public understanding of poor air quality, (29) to continue to promote, reward and publicize best practice for tackling poor air quality by the Sustainable City Awards as well as the Considerate Contractor Scheme Environment Award, (30) to continue to working in partnership with important organisations to develop local, regional as well as national air quality policy, (31) to continue to lobby the Mayor of London as well as the Government to make sure that the Limit Values for PM_{10} and NO_2 are met in the Square Mile, (32) to produce an annual report specifying progress with the actions.

3.7.3 Pollution Tax

Pollution tax is the tax imposed on polluters to discourage pollution. On the other hand Ecotax (short for Ecological taxation) refers to taxes to promote environmentally friendly activities.

Examples of pollution tax or ecotaxes which could be implemented or increased are:

- Carbon taxes on the use of fossil fuels;
- Duties on imported goods containing significant non-ecological energy input;
- Taxes on the extraction of mineral, energy, and forestry products;
- Tax for camping, fishing, hiking, hunting as well as associated equipment;
- Taxes on technologies as well as products that are associated with substantial negative externalities; and
- Congestion tax for vehicles to control congestion and associated pollution in the city.

3.7.4 Pollution Trading

Emission trading or pollution trading is considered as one of mode of controlling air pollution by controlling emission in the place where it can be done cheaply. Pollution trading allows a polluter to increase/forego pollution at its facility in exchange for decreasing emission elsewhere.

Even though theoretical foundation with respect to emissions trading was introduced during the 1960s, the first emissions trading were introduced in USA at the end of the 1970s. This methodology was also adopted in Kyoto protocol for trading GHGs. The Ontario Emissions Trading Code allows emissions trading under the Environmental Protection Act in Canada.

On 2nd May 2007 the Swedish Maritime Administration, the Swedish Environmental Protection Agency the Swedish Energy Agency, and the Swedish Institute for Transport and Communications Analysis reported system for emission trading for sulphur and nitrogen oxides for the shipping sector (Swedish maritime

Administration 2007). Under this system vessels with superior emission performance can generate and sell to the land-side in industry and energy sectors or, nations account.

Pollutants from seller will not move to buyer. But it will only help in bringing down or maintaining pollution at global level.

The Kyoto Protocol adopted in Kyoto, Japan, in 1997 and entered into force in 2005, allow emissions trading wherein countries that have spare carbon credits can sell excess capacity to other nations. Clean development mechanism (CDM) under the protocol allows a nation with an emission reduction commitment under the Kyoto Protocol to implement an emission-lessening project in developing nation and get saleable certified emission reduction (CER). Joint implementation (JI) under the protocol allows a nation to earn emission reduction units (ERUs) from emission removal project in another nation.

The Kyoto Protocol sets binding targets for 37 industrialized countries as well as the European community for reducing GHG emissions to an average of five percent against 1990 levels over the period 2008–2012.

3.7.5 International Laws

International law in the form of treaties, conventions, international agreements etc. are soft in nature will not have any punitive action against defaulters. But some laws at international level as in European Union can result in punitive action against the erring countries as well.

The principles behind International Environment legislations are: (1) State sovereignty, (2) Co-operation, (3) Preservation and protection of the environment, (4) Prevention, (5) Precaution, (6) The “Polluter Pays Principle”, (7) Information and assistance in environmental emergencies, (8) Information and consultation in cross-boundary relations and (9) The Rights of Individuals. State sovereignty is one of the key principles of international law which means State has exclusive jurisdiction on its territory.

The Air Quality Directives 2008/50/EC and 2004/107/EC is an example for international law which sets binding limits for ground-level concentrations of air pollutants in European countries. Limit values are set for individual pollutants. Target values that are not legally binding are to be attained where possible. The concentrations are to be reduced depending on the mean three year PM2.5 urban background concentrations from 2008–2010 to 2018–2020.

Other major international agreements are:

- Convention on Long-Range Transboundary Air (CLRTAP), Geneva, 1979.
- *Environmental Protection: Aircraft Engine Emissions Annex 16, vol. 2* to the 1944 Chicago Convention on Civil Aviation, Montreal, 1981.
- Framework Convention on Climate Change (UNFCCC), New York, 1992,
- Kyoto Protocol, 1997.

- Georgia Basin-Puget Sound International Airshed Strategy, Vancouver, Statement of Intent, 2002.
- Vienna Convention for the Protection of the Ozone, Vienna, 1985, including the Montreal Protocol on Substances that Deplete the Ozone Layer, Montreal 1987.
- Air (bilateral U.S.-Canadian agreement on acid rain), 1986.

The CLRTAP, is intended to protect the environment against air pollution in addition to gradual reduction and prevent air pollution, together with long-range transboundary air pollution. CLRTP is implemented by the European Monitoring and Evaluation Programme (EMEP). Executive Secretary of the United Nations Economic Commission for Europe (UNECE) is its secretariat.

The Chicago Convention on Civil aveation establishes rules of airspace, aircraft registration and safety. *Annex 16 – Environment Protection* of this convention elaborates aircraft noise and Air craft engine emissions.

United Nations Framework Convention on Climate (UNFCCC) lead to Kyoto protocol which aims to mitigate climate change by reduction in GHG emission.

3.7.6 National and Regional Laws

National and regional laws are enacted by individual nations/regions. The air pollution act may vary within the nation. The states and local body may adopt laws and standards more stringent than national law/standards. The international agencies usually do not have any say or influence on day to day functioning of the institutions which enforce the local law.

Environmental laws at national level are usually considered as criminal law. The criminal has following broad objectives that are broadly accepted for enforcement:

1. Retribution—Criminals should *suffer* in some way.
2. Deterrence—The aim of this objective is to impose a sufficient penalty to discourage the offence.
3. Incapacitation—The purpose of this objective is simply to keep criminals *away* from society in order to protect public from the misconduct of criminal. This is usually achieved by prison sentences.
4. Rehabilitation—This objective aims at transforming an offender into a valuable member of society by convincing the offender that their behaviour was wrong.
5. Restoration—The goal of this objective is to repair, through state authority, any injury imposed upon the victim by the offender.

Apart from above objectives environmental laws have following principles

1. Sustainability,
2. Precautionary principle,
3. Pollution prevention,
4. Polluter pays,

5. Cumulative impacts,
6. Intergenerational equity, and
7. Public participation.

Institutional framework and capacity vary from country to country and region to region. Presence of legislation does not mean the implementation will be fool proof and perfect. Political pressure, corruption, internal politics within the organisation, conflict within the organisation could just weaken the spirit of legislation.

The international community frequently refers institution failure as main reason for failure of pollution prevention.

As per Ramesha et al. (2011), following are some of the reasons gist why pollution control institutions responsible for enforcing environmental legislations.

- Increase in legislation and policy
- Lower manpower
- Non-implementation of laws in nights and holidays
- Use of pollution control monitoring officer to other duties
- Corruption
- Poor leadership
- Slow decision and communication
- Technology shyness

Apart from above reasons the institution fail as they are hindered by discouragement to hardworking people; interference to recruitment; sacms; lack of motivation; poor understanding of environmental issues and pollution; devotion to protein activity like issuing permits; unskilled staff. Many scams and arrest of officials on the grounds of corruption has hindered smooth functioning of government organisations thereby affecting citizens. Misplacement/loss of document may also hider functioning of enforcing agencies. Public consultation is also not done in many countries to obtain feed back on functioning of public authorities and pollution control. With its limited staff and wisdom government agency can not achieve organisational goals without public participation.

Even though almost all countries have legal and institutional frame work, some countries are more prepared and has good institutional capacity compared to others.

In many countries procedure for enforcement is not matured and judgment with respect of environmental cases may take decades. In many instances the main accused will be in foreign and international cooperation would usually do not contribute much to hand over accused to government where pollution has occurred. Even though international cooperation is one of the major principles in international environmental law, people would escape the clutches of law. Union Carbide chairman Warren Anderson, accused No. 1 in the criminal case pertaining to the Bhopal gas tragedy that resulted in death of thousands of people and injury to many people in December 2 and 3, 1984 (Singh and Sunderrajan 2014) was released on bail within hours of his arrest and never turned up for trial and was declared absconder (Praveen 2014).

There is also confusion in case of transboundary movement of pollutants wherein laws of pollution recipient country do not have jurisdiction to punish polluter in other country.

Many polluters like owners of industries are usually members of parliament or legislative assembly or contributors to political party funds. Hence action against these people usually does not happen.

Even though pollution control laws are criminal laws, unlike police, enforcing agency of pollution control laws do not possess arms to fight with polluters. The pollution control laws also do not allow taking polluters into legal custody or encountering criminals as done by police.

Most of the enforcing institutions still have illiterate or under literate staff who are protected by labour laws in respective countries. Many enforcing institutions are understaffed and the head of institutions usually do not take interest to recruit additional staff due to which the aged senior officers are burdened without any assistance. In many instances the gap between two recruitments is high due to which the seniors cannot pass on the intuitional memory and capacity to full extent.

The end result in environmental episode is also due to series of events which may lead to unclear culprit. The breakage of thermometer with mercury may lead to mercury pollution and so as combustion of coal in cooking. Both the events in developed countries would escape legal clutches as usually law will not have provision to bring such *small polluters* into legal framework. But multiple releases of such pollutants would definitely affect environment.

3.8 Population Control

Higher population means higher activities and hence higher pollution. Growth of population is characteristic of developing countries. The growth of urban population due to migration and reproduction has been relatively higher compared to developed countries.

Migration of population has many reasons. Relatively lower education/employment opportunity in rural area and access to good health care establishments is main driving forces for increase in population in urban area.

Urban population control is not favourite option to politicians or businessmen. The real estate agency which provide both housing and political party fund would always support urbanisation irrespective of impact of their projects on environment. Figure 3.9 shows growth of population and number of vehicles in Bangalore where in vehicles increased with increase in Population.

Emission inventory is prepared by TERI (2010) revealed total pollution load in Bangalore in 2007 to be 54.4 T/d for PM_{10}, 217.4 T/d for NO_x and 14.6 T/d for SO_2. The major sources of PM_{10} emission are transport (42 %), road dust re-suspension (20 %), construction (14 %), industry (14 %), Diesel Generator Sets (7 %) and domestic (3 %). Similarly major sources of NOx are transport (42 %), Diesel Generator Sets (23 %), industry (8 %), and domestic (1 %). In case of SO_2,

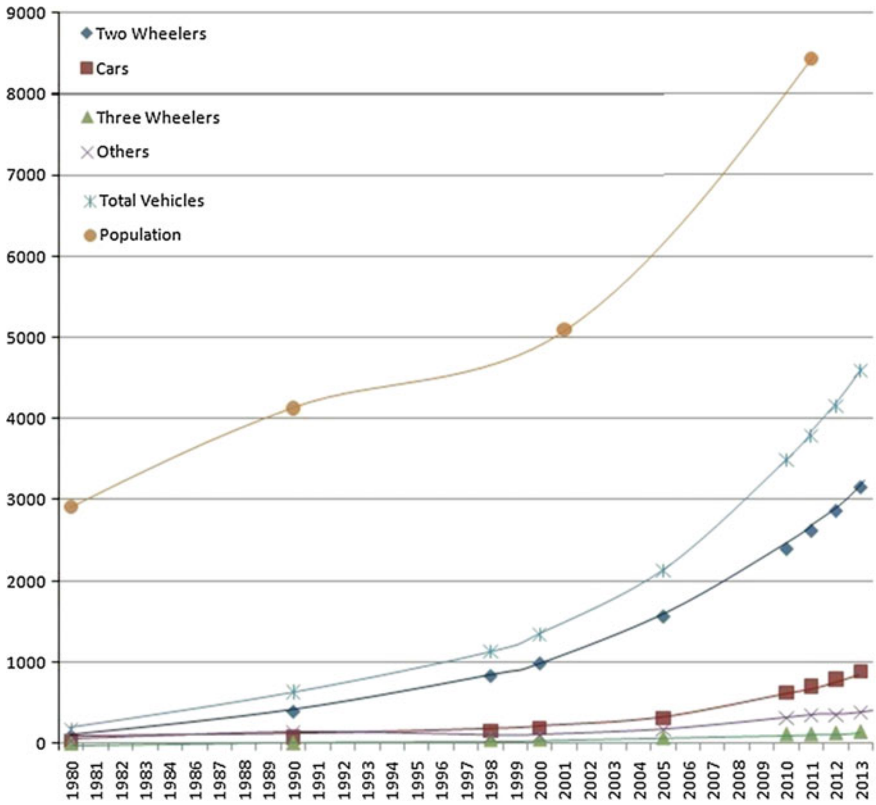

Fig. 3.9 Growth of population and number of vehicles in Bangalore [*Source* Based on information in Sastry (2013) and Wikipedia (2013)]

major contributors are industry (56 %), Diesel Generator (23 %) and transport (16 %). The studies also revealed that in the business as usual scenario PM_{10} increase from 54.4 T/d to 95.8 T/d between 2007 and 2017. Similarly the NOx would increase from 217 T/d to 460 T/d.

Even though several options (like change in fuel; mass transportation; kerb to kerb paving; proper inspection and maintenance of vehicles/Industries; proper inspection and maintenance of Diesel Generator Sets, proper solid waste management) are available for improving ambient air quality, the same result may be achieved by decreasing/stagnating the population of city. With decrease/stagnating population, pollution level will decrease and people exposed to pollution will also decrease.

The people migrate to cities for employment, education, business and as dependents of earning members of family. Decrease in population can be achieved by many possibilities. In 1950 Norrköping, Sweden had 54 factories out of which 18 of them were closed due to competition from abroad and in 1970 only 10 factories remained. To counter the effects, many government establishments were relocated to Norrköping from Stockholm. Such relocations will have advantage of improving/maintaining regional economy and at the same time reducing population explosion in single city.

Apart from moving government establishments, other means of reducing/stagnating population are: (1) not permitting new business/industry, (2) creating mass awareness and requesting not to settle in the populated city, (3) relocating universities and industries, and (4) not permitting new residential areas.

3.9 Air Pollution Management by Citizens Initiative

It is often thought that only government, international agencies industries need to work for the betterment of air quality. But there are numerous instances wherein the citizens action have resulted in improvement in environment quality. Many citizens intentionally use public transportation even though they have enough money to own car. Many emails have message advising to consider printing emails only if necessary to save paper. Many citizens use and buy only energy efficient electric appliance and minimum clothing. Some people do not consume meat to lead environmental friendly life.

Apart from adopting life style changes, some citizens start organisation to promote awareness.

3.9.1 Public Interest Litigation

Government organisations responsible for protection of environment are most often do not protection environment due to vested interest.

Public Interest Litigation (PIL) is a legal tools which allow groups, individuals and communities to challenge decisions and activities of government in a court of law for the benefit of public interest.

One of the prime examples of PIL with respect to air pollution was to safeguard Tajmahal, India. The PIL helped to achieve improvement in air quality by closure/relocation of air polluting industries.

PIL regarding vehicular pollution in Delhi in the year 1998 improved air quality by—increasing number of busses in public transport; elimination of leaded gasoline (petrol) from National Capital Territory (NCT) Delhi; supply of only pre-mix gasoline (petrol) for two stroke engines of two wheelers; replacement of old public transport vehicles with vehicles that uses clean fuels; location of new Inter State Bus Terminus at entry points in North as well as South-West of Delhi; increase in CNG supply outlets; establishment of two independent fuel testing laboratories; establishment of inspection as well as maintenance facilities for commercial vehicles; comprehensive inspection as well as maintenance programme by transport department and private sector; and establishment of more air quality monitoring stations.

In an another PIL in the year filed in 1985 in Delhi resulted in improvement in air pollution by stopping hazardous/noxious/heavy/large industries, hot mix plants, brick kilns, arc/induction furnaces.

3.9.2 Complaints and Letters

Complaints are expression of aggrieved person or group of people. Apart from complaints government institution also receive suggestion and explanation of issues from eminent persons, institutions and public. Complaints draw attention of government agencies to the grievance aced by public. The number of complaints on an issue also indicates the seriousness of the issue.

The complaint also gives an opportunity for the government to correct itself. But there is also other side of the issue where in some people/organisation may complain due to personal grudge or to exploit money there by hindering functioning of government organisations.

Complaints are addressed to people in power, which include anticorruption department; department responsible for environment protection; chief justice; chief minister; chief secretary of state; local police station; local politicians; prime minister; president of the country; united nation; and mass media (press, TV, radio) etc.

Complaints may not give immediate relief to complainant. But over period of time it becomes records in the public documents and media. Too many complaints on same issue would draw the attention of responsible person who can take suitable action or judiciary system which register sumoto case.

Many complainants also enclose video/photographic evidence to enable public authority to take up further investigation. The responsible pubic authority will investigate the issue more seriously if the complaint gets registered in anticorruption department or in the office of prime minister or president of the country.

Letter to editors of dominant news paper is another way of drawing attention of public authority as many of the government agencies would collect articles/letters published in news paper and initiate further course of action.

3.9.3 Website and Blogs

Website and blogs have become cheap platform for the exchange and showcasing of ideas. Many blogs on internet posted by enthusiastic citizens provide knowledge about the environmental setting and environmental problem usually not published by government and other agencies.

3.9.4 Agitation

Agitations often are result of inaction of government or concerned organisation to fulfil the need of affected people. The agitation some time may lead to violence and inconvenience to public at large. But aggrieved people choose agitation as they will not have funds choose to follow normal procedure of complaining and filing litigation. In other circumstance people agitate as they think it would give justice or desired government decision earliest possible time.

3.10 Air Pollution Management by Initiative of Mass Media

Mass media like press, TV channels, radio can do favour to protect environment by spreading the issues by publishing in the media owned by them. Some media choose to specialise in some subject like (sports, music, food etc.) and keep silent about other aspect. Even such media can conserve environment by creating awareness.

New generation journalism has been tremendously active in documenting the environmental episodes with evidences. Both print media and TV have been active in recent years. Telecasting and broad casting was done by government agencies in many countries in the past thereby hiding the facts which would embarrass government. The current trend of opportunity to view hundreds of channels has created competition among the channels to telecast news which has not been telecast by others.

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Chapter 4
Fundamentals of Treatment, and Process Design for Air Pollution Control

Abstract Sustainable technological solution can be low-tech or hi-tech which involve high cost or low cost. To be sustainable the solution should be low-carbon, low-energy and low-chemical. This chapter discusses the fundamentals of array of solution available in literature and practice so that one can chose from many possible solutions to achieve sustainable solution.

Series of inventions since industrial revolution has lead to many activities that emitted air pollutants. The enhancement in air pollution as well as associated problems lead to searching solutions from different scientific and engineering branches. The major solution came from chemical engineering. The equipment used for manufacture and separation were used for controlling air pollution which is still being practiced with modification wherever required. The equipments later modified to cater the statutory requirements. The heights of chimneys were increased to safeguard people and property. Many techniques used for production like absorption, absorption settling, filtration, combustion, condensation, were used at the end of pipe to separate pollutants.

The key challenges in using manufacturing equipment for air pollution control are: (1) low concentration of particles and chemicals in air streams compared to product formation and separation, (2) additional investment towards operation and installation of equipment, (3) fulfillment of regulatory requirement, (4) disposal of waste recovered, and (5) safety.

Not all air streams will have low concentration. While emission from thermal power plant will have substantial particulate concentration, other industries like pharmaceuticals will have low particulate concentration. Hence the particle/liquid/gas separators employed in production obviously need modification.

The identification of equipment or system of equipments depends on pollutants emitted from the manufacturing. The pollutants emitted are identified by actual measurement and theoretical calculation.

The equipment selection and design needs following information: (1) quantity of emissions, (2) concentration of pollutants, (3) physical and chemical properties of pollutants, (4) available space, (5) equipment location, (6) ambient conditions,

R. Chandrappa and U. Chandra Kulshrestha, *Sustainable Air Pollution Management*, Environmental Science and Engineering,
DOI 10.1007/978-3-319-21596-9_4

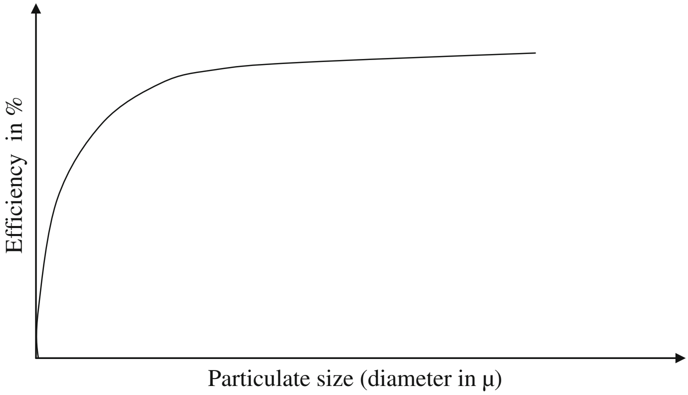


Fig. 4.1 Typical partial efficiency curve for cyclone separator

(7) statutory requirements, (8) aesthetic considerations, (9) contribution of air pollution control system to wastewater and land pollution.

Chemical characteristics usually considered for design of air pollution control system are: reactivity, corrosivity, abrasiveness, toxicity, flash point, and vapour point.

Physical stream characteristics considered in design of air pollution control system are: volumetric flow rate, composition, temperature, pressure, humidity, viscosity, density, conductivity, resistivity, particulate shape, as well as particle size distribution.

Evaluation of efficiency of equipment is measured based on overall pollution abatement collection and size/weight fractional of pollutants. The fractional efficiency (collection efficiency versus particle diameter) in equipment used for controlling particulate emissions are of great importance while assessing performance of such equipments. Figure 4.1 shows typical partial efficiency curve of cyclone separator. Other considerations in air pollution equipment selection are pressure drop, reliability, dependability, power requirements, temperature limitations, and utility requirements.

The pollutants characteristics are used in calculating dimension of the equipment and material of construction. While corrosive air stream do need corrosion resistant construction material [like polyvinyl chloride (PVC) or fiberglass], temperature of air stream determines thermally stable material.

4.1 History of Air Pollution Regulatory Issues Across the World

Air pollution has been public issue for centuries. In 1306 King Edward I of England banned use of coal in London (Glen et al. 2011). In 1789 Alkali Act was enacted to control air pollutants in England (Habashi 2011). The cities of Chicago as well as

Cincinnati adopted clean air legislation in 1881. The Air Pollution Control Act of 1955 was adopted by USA followed by the Clean Air Act of 1963 followed by Motor Vehicle Air Pollution Control Act in 1965. The Clean Air Act was passed by Singapore on in 1971. India passed The Air (Prevention and Control of pollution) Act in 1981. National Environmental Management: Air Quality Act was enacted by South Africa in 2004.

Absence of legislation specific to air pollution does not mean that other countries do not have mechanism to control air pollution. Pollution of air can be considered as nuisance and action can be initiated under legislation enforced by police and local bodies. In many countries the enactment new legislation specific to air act had lead to non-enforcement of provisions within other laws to protect environment.

Presence of legislation does not mean that the concerned countries is enforcing the laws. Practical difficulties have always been a challenge all over the world. No penal action can be taken on anybody if the deterioration of air quality beyond national ambient air quality standards occurs due to forest fire or fire accidents. Many countries still does not have good air quality monitoring network. Transboundary movement of air pollutants is also one of the practical difficulties wherein the parcel of polluted air from one country leads to pollution in other countries. The pollution due to international conflicts which has lead to war and subsequent pollution can‘t be controlled by national laws.

Many countries which have fixed national ambient air quality standards by group of experts fail to implement in field due to absence of any motive/procedure at field. Corruption, lack of manpower/motivation/knowledge also is one of the causes for deterioration of air quality beyond national ambient air quality. Many times corrupt people would pressurize subordinate staff to perform illegal activity.

Nonfunctioning of enforcing agencies in night/holidays and non measurement of emission due to unsafe chimneys pose practical difficulty in controlling pollution. Many agencies across the world have been setup to international community. In reality these institutions are interrupted by political and influential people. The poor administration often leads to misuse of vehicles, absence of stationary in the office, non-punctual staff and nonfunctioning equipments.

4.1.1 Low-Tech Versus Hi-Tech

Air pollution control need not always be technology oriented. Simple common sense and long term goals can achieve good air quality. Some of the measures like protection of forest and proper urban planning with stuffiest lung space does not need high technology. Development slums in the centre of cities overnight by political/influential people will have its implication in movement of air.

Industrial air pollution can also be cheap both during investment and operation provided the control options are known. But most of the time control equipments are decided by consultants who provide solution right from the site preparation to production.

4.1.2 Low Cost Versus High Cost

Cost of the air pollution control depends on technology, manpower, energy and other miscellaneous expenditure like spare parts. Depending on the material of construction the equipment need to be replaced once in 25–30 years. But poor construction material and hiring poor man power may cost dearly if the lifespan of equipment are lessened. Most of the metal chimney also needs replacement once in 20–30 years.

The air pollution control in cities by proper policy also need not be costly. Narrow roads with tall building on both the sides always stagnates the sir pollutants. The problem is noteworthy in cites of India and China which have attracted people, vehicles and investment. This has resulted in construction of high rise building without widening roads that has resulted in high traffic congestion and air pollution in the vicinity.

4.2 Design Principles for Sustainable Air Pollution Management

An air quality management system has the following components: (1) air quality assessment, (2) Assessment of environmental damage, (3) assessment of abatement options, (4) cost-benefit analysis, (5) selection of abatement measures, and (6) optimum control strategy. One should consider low energy and low chemical option to make the system environmentally sustainable.

4.2.1 Low Carbon

The CO_2 and other GHGs in air has been proved as cause of global warming and climate change. CO_2 was present in atmosphere even before contribution by mankind due to anthropogenic activity. The concern is addition of CO_2 and GHGs by combustion of fossil fuel which was present deep inside the earth. The concentration of CO_2 was constant over the year through carbon cycle but use of fossil fuel over the years has moved carbon in the layers of earth's crust to atmosphere. Avoiding use of fossil fuel in anthropogenic activity is one of the solution which has been attempted by shifting dependency of fossil fuel by generation and use of nonconventional energy resources like solar power, wind energy, biofuel etc.

The low carbon means emission of less CO_2 while performing an activity should be minimal.

As discussed in subsequent chapters air pollution need to be reduced during: (1) production of product or performing service, (2) transportation, (3) city planning, and (4) Disaster.

Table 4.1 Usual pressure drops across the air pollution control equipments

Sl. No.	Equipment	Pressure drop (cm of water)
1.	Settling chamber	2–3
2.	Cyclone separator	1–20
3.	Spray tower	2–3
4.	Packed bed scrubber	2–8.5 cm/m of column packing
5.	Ventury scrubber	12–250
6.	Buble cap tray absorbers	2.5–15
7.	Bag filter	25–250
8.	Electro Static Precipitators	0.25–1.25
9.	Biofilter	25–250
10.	Condenser	1–2
11.	Direct flame afterburner	2.5–3

The energy consumption in air pollution control equipment will be more if the pressure drop (Table 4.1) across the air pollution equipment is more. Hence proper maintenance and frequent cleaning of clogged particulate matter shall be carried out. The blowers used for transporting polluted air show varied consumption pattern due to design.

4.2.2 Low Energy

Most of thee pollution control system needs energy to operate blowers/equipment. Absence of energy conservation practice would lead to waste of energy and may also result in CO_2 emission elsewhere in power plant.

It advisable to adopt following measure in air pollution control system:

- Make use of smooth, well-rounded inlet cones for fan air intake;
- Reduce fan inlet/outlet obstructions;
- Avoid poor flow distribution at the inlet of the fan;
- Regularly check and clean screens, filters/fan blades;
- Check belt tension regularly;
- Reduce transmission loss by use low slip belts;
- Use energy-efficient motors;
- Minimize bends in duct works;
- Eliminate leaks in duct works;
- Turn off fans/blowers when not required;
- Reduce pressure drops by improving the duct system;
- Operate the fan near best operating point;
- Ensure proper alignment between drive as well as driven system;
- Regularly check for vibration and take action with respect to failures like bearing; damage, misalignments, unbalance, foundation looseness etc.; and
- Make sure proper power supply quality to the motor drive.

Energy efficiency: Energy is used in industry for chemical reactions, to generate heat, as well as to perform mechanical work. Over the last four decades there has been continual improvement in achieving energy efficiency. In industry, energy efficiency opportunities can be sector specific or systems specific (steam systems, electric motor systems (e.g., pumps, fans, refrigerators, material handling) and process heating systems (furnaces and boilers) (Fischedick et al. 2014).

Practices to improve heat management comprise improved insulation, better heat exchange between hot/cold gases and liquids, capture and use of heat in hot products, as well as use of exhaust heat as an input to lower temperature processes or for electricity generation.

Recycling can also help to reduce energy demand. Recycling is already widely practiced for metal, paper, and glass. Producing new material from old avoids energy required for intensive chemical reactions.

Material efficiency in production Material efficiency (delivering services with less new material) is an important opportunity for industrial emissions abatement (Allwood et al. 2012).

Two key strategies used in material efficiency are:

- Reducing material loss during production, manufacturing, as well as construction.
- Re-using old material.

Material efficiency in product design Even though new inventions have evolved light weight cars, in practice cars continue to be heavier as they are larger as well as have more features. Many products could be lighter without loss of performance (Carruth et al. 2011) by optimization of design and production.

Using products more intensively Products, such as food and beverages are in many cases used inefficiently. Estimates show that up to 1/3rd of all food in developed nations is wasted (Gustavsonn et al. 2011). Reduction in such wastage reduces energy consumption in industrial production.

Using durable goods for longer could reduce demand for replacement goods, thereby reducing industrial emissions (Allwood et al. 2012).

Decreasing overall demand for product/services Industrial emissions would be decreased if overall demand for product/services were decreased (Kainuma et al. 2013)—if the population chose to travel less, or reduce unnecessary consumption of products.

4.2.3 *Low Chemical*

Chemicals in air pollution control are mainly used in scrubbing liquid, adsorption and catalyst. Apart from technical feasibility, some consultants and designers would prefer technology which is costly as it would fetch more business to them. But air pollution control is not directly related to investment and cheaper and effective option has to be chosen on case to case basis. For example use of seawater for wet scrubbing to remove SO_x can reduce use of chemicals.

4.2.4 Modelling of Treatment Processes to Attain Sustainability

Mathematical models are used to explain phenomena/processes in mathematics. Models based on experiments are known as *empirical models*. Models that describe processes are called *mechanistic models.* Deterministic models ignore random variation and stochastic models are based on statistics. *Black-box* models are just group of equation that gives results but do not describe changes in the process mathematically (Chandrappa and Das 2014).

Performance of all the air pollution equipments can be expressed mathematically. For example the efficiency of cyclone separator can be calculated at different velocities, dimensions and particle characteristics by simulation if the process is mathematically represented. Such knowledge cuts down costly and series of experimental studies. The mathematical model becomes much more useful if the process involves more than one phenomena like electrocyclone or electro-statically enhanced cyclone separator.

Figure 4.2 shows schematic diagram of multiple influence on pollutants in electrocyclone. In electrocylone both electrostatic forces and centrifugal are used to

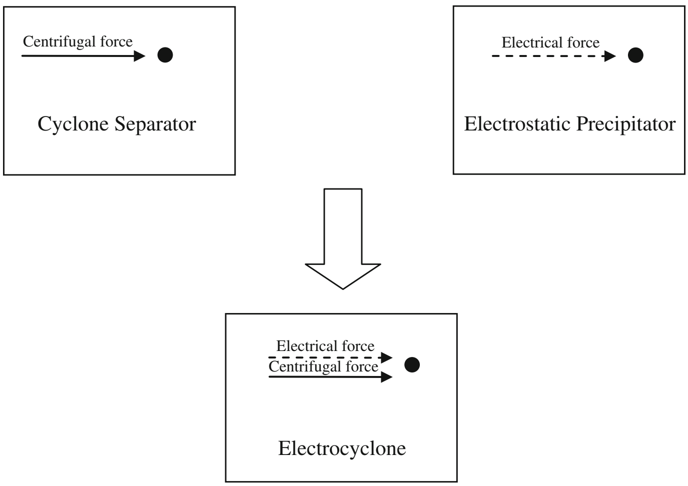


Fig. 4.2 Schematic diagram of multiple influence on pollutants in electrocyclone

separate particulate matter. Hence force on individual particle is sum of electric force and centrifugal force which is ultimately used for calculating efficiency of electrocyclone.

4.2.5 Operation, Management, Financial, Socio-economic Aspect

It is often felt that economic growth is good for the citizens. But materialistic comfort will not come without sacrificing natural environmental setup. In economics an Environmental Kuznets Curve (EKC) is often referred to explain this hypothesis. The EKC is a hypothesized relationship between environmental quality as well as economic development. Figure 4.3 shows typical EKC. Environmental degradation get worse as economic growth occurs until it reaches a certain point and then it decreases.

The reasons for improvement in environmental quality with economic growth are many. First, rich countries may be better able to meet the demands for environmental protection through their institutional capacity (Neumayer 2003). Second, the economic growth increases introduction of more modern and less pollution intensive technology (Grossman and Krueger 1995). Third, with increase in economic development, industrial activity will go down and services goes up (Jänicke et al. 1997). Fourth, with rising income population growth goes down, hence pressure of population on the environment decreases. Fifth, in a developed country public will be more active and so as judiciary system. Sixth, the legislative systems in richer countries will enact new stringent laws.

There are many people who do not agree with the EKC. Some argue that the theory is 'license to pollute'. They argue that environmental degradation can be controlled even before it worsens.

Many of the air pollutants increase with economic development as the polluters as well as enforcement institutions will not have knowledge to control the pollution.

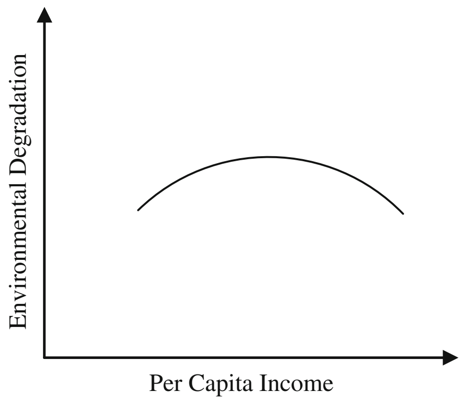


Fig. 4.3 Typical environmental Kuznets curve

With time the enforcement institution would have gained enforcement skills and so as polluters. The raise in income will also help polluters and government to invest on pollution control activities/equipments.

4.3 Air Pollution Control Equipment for Stationary Sources

Stationary sources of air pollution include exhaust from kitchen, industries restaurants, diesel generator sets, process emissions, and burning of fuel for energy recovery. Irrespective of the pollution control equipment/process adopted the air plume has to be let into atmosphere. Sustainable practice should ensure proper stack height, diameter, gas velocity and location of the stacks.

In many locations short stacks are installed after air pollution control equipment to disperse the exhaust gases. As compared to "tall" stacks, which are usually more than 300 m short stacks typically less than 40 m. For structural stability, the diameter at the bottom of the stack is slightly larger than diameter at the top. A short stack is made up of steel, brick, or plastic. The material of the stack depends on properties of the gas stream, such as temperature, corrosiveness and acidity. Liners of stainless steel, Fibre Reinforced Plastic (FRP) are used to protect the stack from the gas stream as liners are less expensive and easier to replace than the entire stack.

Tall stacks are provided with access door, ladders, lightning protection system, a sampling platform, as well as aircraft warning lights. The access door is used for removal of accumulated materials at the bottom of the stack as well as provides access repair of stack. Sometimes steel structure may be used to support chimney (Fig. 4.4).

The flow of fluids in any stack/hood/duct/pipe is governed by Bernoulli equation (which states that the entire mechanical energy of an element of fluid flowing is constant throughout the system) given below.

$$\int_1^2 v dp + \Delta z \frac{g}{g_c} + \frac{\Delta u^2}{2g_c} = W - F$$

v specific volume of fluid
p static pressure
z height of fluid above some reference
u fluid velocity through duct, hood, etc.
g gravitational acceleration
g_c gravitational constant
W work added by fan, etc.
F energy lost due to friction

Fig. 4.4 Chimney with external support

Area of the cross section of stack can be calculated by:

$$A_d = \mathrm{Q/u}$$

If the cross section of stack is circular diameter can be calculated using following formula

$$A_d = \frac{\pi D_d^2}{4}$$

A_d = cross-sectional area of duct
D_d = duct diameter

Stack height calculation should essentially consider thickness of laminar sub-layer, surface layer, Ekman layer, stack exit velocity, stack temperature and ambient temperature, height/shape/arrangement of structures (natural and anthropogenic). Due to complexity involved the minimum chimney height in most of the legislation across the world is limited to 30 m which is typical height of surface layers.

Effective stack design height comprises of the height of the stack (*Hs*) as well as the plume rise height (*Hpr*) expressed by following equation.

$$H_e = H_s + H_{spr}$$

To ensures that emissions from stack do not cause excessive pollution due to atmospheric downwash, eddy effects, wakes, etc., the height determined by following equation (USEPA 1985):

$$Hs = H_b + 1.5\,L$$

where,

Hs	Good Engineering Practice stack height,
Hb	height of nearby structures
L	lesser dimension (height or projected width of nearby structures)
Nearby structures	Structures touching/within a radius of 5L but less than 800 m.

Structures located near chimney influence dispersion of pollutants coming from chimney. Figure 4.5 shows example of wrong practice—diesel generator next to building with exhaust not attached to tall chimney. Figure 4.6 Schematic diagram for explaining dimensions of good engineering practice for chimney height.

Many equations and rules are used across the world for calculation of chimney height. But such practice would not take background concentration into consideration. Hence best approach would be using calculation of chimney height by substituting desired ground level concentration to Gaussian model.

Fig. 4.5 Example of wrong practice—diesel generator next to building with exhaust not attached to tall chimney

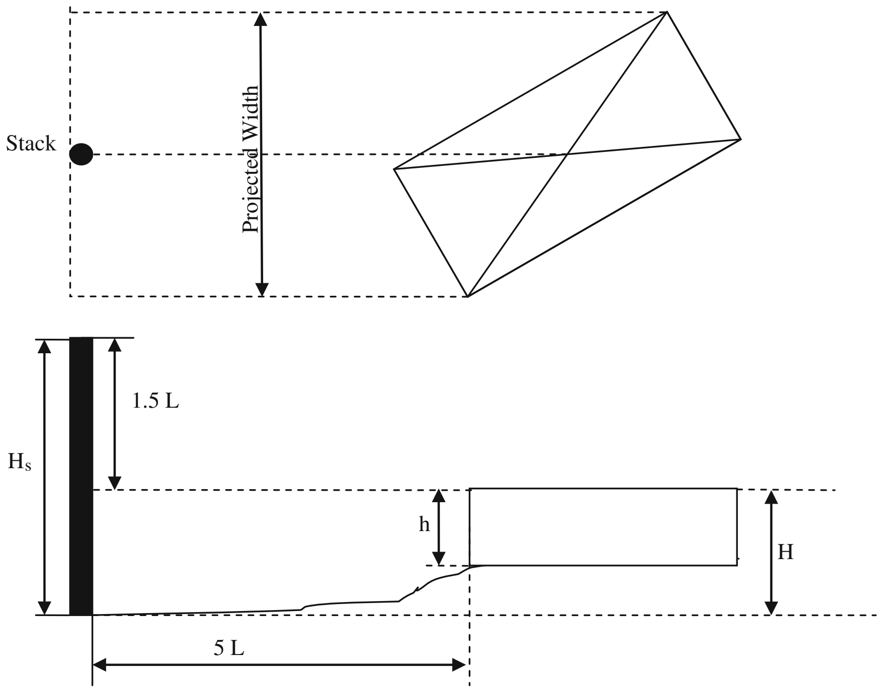


Fig. 4.6 Schematic diagram for explaining dimensions of good engineering practice for chimney height

The Bangalore city which has a population of ten million has Diesel Generator (DG) sets from 5 kVA to more than 1000 kVA. Interrupted power supply by responsible company has lead to installation of DG sets in apartments, healthcare establishments, shops, residential offices, industries, offices, commercial complexes. The scenario is similar in any Indian cities. The exhaust out let are is located at a height of 0.5 m above ground level to little above the multi storey building. Such practice has lead to accumulation of exhaust gases in the vicinity at lower layer of atmosphere during power failure in the grid.

Figure 4.7 shows examples of chimneys without bend and with bend. Bend in later location is provided to avoid entry of rain water. A cowl (Fig. 4.8) is a covering used to increase the draft of a chimney as well as prevent backflow. If the winds are strong pressure of the wind may overpower the updraft resulting in reverse flow. Another function is to prevent squirrels/birds nesting in the chimney and act as a rain guard. A metal wire mesh is sometimes included as a spark arrestor. But disadvantage of cowl is it inhibits plume rise thereby decreasing dispersion compared to chimney without cowl.

Fig. 4.7 Examples of chimneys without bend and with bend. Bend in later location is provided to avoid entry of rain water

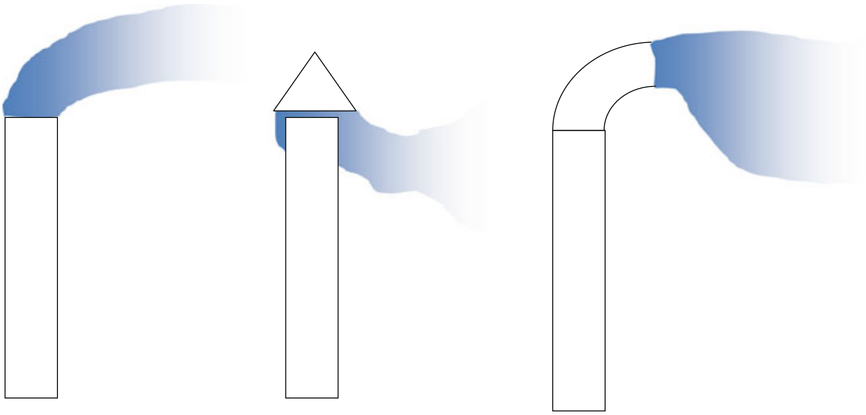


Fig. 4.8 Chimney without and with cowl

4.3.1 Settling Chamber

The particle laden gas stream is introduced into chamber where the particles settle to the floor of the chamber due to gravity. Gas velocities through settling chamber (Fig. 4.9) must be low enough so that they are not re-entrained (Flagan and Seinfeld 1988). The gas velocity is reduced by expanding cross section of chamber so that

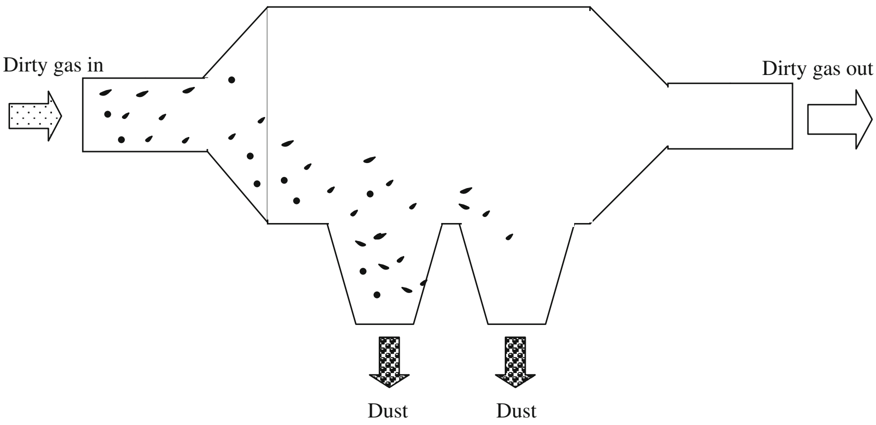


Fig. 4.9 Gravitational settling chamber

velocities suitable for gravity settling are attained. Applicability of settling chambers is restricted to particles larger than about 50 microns. Advantages of settling chambers are: (1) low cost, (2) simple construction, (3) low pressure drops, and (4) collection of particles without water. The disadvantage of settling chambers is that it required large space.

4.3.2 Centrifugal Collectors

Centrifugal collectors are simple air pollution equipment that uses centrifugal force for separating particulate matter from airstream. Cyclone separators (Figs. 4.10, 4.11 and 4.12) are commonly used air pollution control equipment that uses centrifugal force for removing particles from industrial air streams because of their relative ease of operation. Simple construction combined with high reliability and low maintenance costs have lead cyclones to an extensive application in air pollution control technology. Cyclones have been widely used as solid—gas separators for many years because of their distinct advantages: much higher separation efficiency than gravity or inertial devices, simple structure, low pressure drop, and adaptability to special circumstances. Whilst cyclones have been successfully used for many years throughout the process industries, their grade efficiency falls off drastically for particulates smaller than about 10 microns and this limits their application (Ramesha 1995).

Conventional cyclones are classified into following categories: (1) reverse-flow cyclones, (2) straight-through-flow cyclones, and (3) impeller collectors.

The centrifugal force on particles in spinning fluid stream is much greater than gravity. Hence these equipments are effective in the removal of smaller particles that cannot be separated by settling chambers.

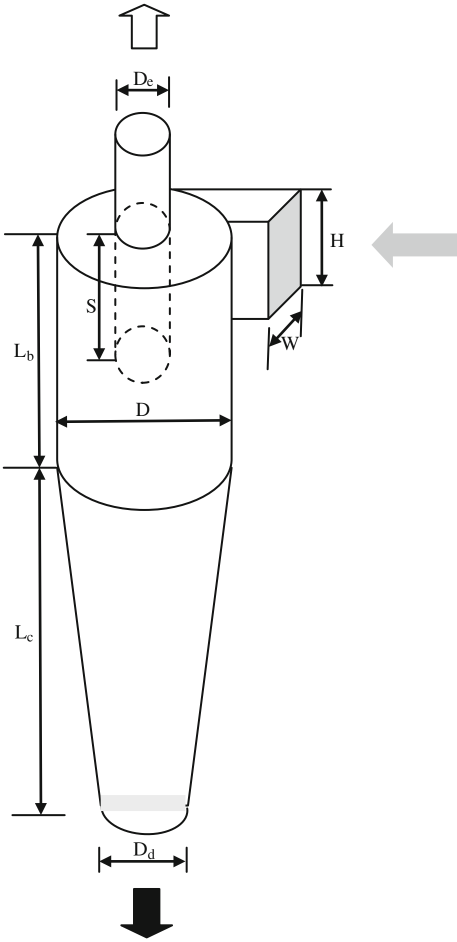


Fig. 4.10 Cyclone separator

Fig. 4.11 Cyclone separators in a E-waste processing unit

Fig. 4.12 Cyclone separator in cement industry

In straight-through-flow cyclone separator the inner vortex of air leaves at the bottom. In the impeller collector, particle laden gases enter a many-bladed impeller around its circumference where the particles are thrown around the periphery.

A reverse flow cyclone separator contains a cylindrical shell with a conical base, dust hopper and an inlet (Table 4.2). The inlet could be tangential or axial, through which gas with particulate matter enters at a velocity of 10–20 m/s. The inlet produces a swirling movement of gas, which moves the particles towards the cyclone wall. The stream then swirls down over the wall of cyclone. The particles leave the cyclone separator through base while the gas swirls up in the middle and leaves the cyclone outlet in the centre. Hence, the performance of cyclone separator depends on turbulence characteristics as well as interaction between particles (Utikar et al. 2010).

Table 4.2 Standard dimensions of cyclone separator

	High efficiency		Conventional		High throughput	
	Stairmand (1951)	Swift (1969)	Lapple (1951)	Swift (1969)	Stairmand (1951)	Swift (1969)
D/D	1.0	1.0	1.0	1.0	1.0	1.0
H/D	0.5	0.44	0.5	0.5	0.75	0.8
W/D	0.2	0.21	0.25	0.25	0.375	0.35
D_e/D	0.5	0.4	0.5	0.5	0.75	0.75
S/D	0.5	0.5	0.625	0.6	0.875	0.85
L_b/D	1.5	1.4	2.0	1.75	1.5	1.7
L_c/D	2.5	2.5	2.0	2.0	2.5	2.0
D_d/D	0.375	0.4	0.25	0.4	0.375	0.4

The dominant flow pattern consists of an outer vortex (formed when gas stream enters the cyclone separator) spiralling downward along the cyclone walls. As the gas spiral reaches below the gas outlet duct, the gas begins to flow radially inward forming an inner vortex. The particles are thrown to walls that slide down to be collected for disposal. The separation efficiency depends on extent of the centrifugal forces exerted on the particles.

$$F_c = M_p(v_i^2/R)$$

where,

F_c	Centrifugal force
M_p	Particle mean mass
v_i^2/R	centrifugal acceleration
v_i	Particle velocity
R	Radius of the cyclone (Table 4.2)

4.3.3 Filter

Filters have been in use since years. But technology has improved over the year and new material and learning mechanism has improved efficiency and life span of filtering material.

Bag filter

Bag filter (Figs. 4.13 and 4.14) made up of fabric media is one of the simplest and efficient methods for controlling particulate contaminants from gas streams. The fabric filter is capable of removing particles as small as 0.1 mm. Industrial fabric filter comprises of a woven or felted fabric through which polluted stream is forced. The bag filter eventually filters particles through (1) physical trapping, (2) impingement, (3) electrostatic attraction, (4) adsorption, (5) interception, (6) impaction, and (7) Diffusion.

Important fiber characteristics considered for use in bag filter are: (1) ability to withstand temperature, (2) resistance to Corrosiveness, (3) resistance to hydrolysis, (4) dimensional Stability, and (5) Cost.

The usual filter media used are given in Table 4.3. Bag filters can be made of non woven or woven filter media. Nonwoven materials can be felted or membrane. Nonwoven fabrics are usually attached to a woven base called a *scrim*. Felted filters are made up of randomly placed fibers that are compressed into a mat and attached to backing material. Membrane filter are thin, porous membrane (expanded polyfluorocarbon) bonded to the support fabric or scrim. Woven filters are usually

Fig. 4.13 Arrangement of bags in side bag house

used with low energy cleaning methods like shaking or reverse-air whereas felted fabrics are normally used with higher energy cleaning systems like pulse-jet cleaning.

The true filtering surface comprises of dust layer and bag provides the support and surface for capture of bigger particles. Life of a bag filter is shortened due to thermal durability, abrasion, as well as chemical attack.

The fibers used for fabric filters depend on the industrial application. Synthetic fibers are used widely today as they resist chemical attack and can operate at higher temperatures. The fibreglass are most often used for high temperature application where as polypropylene are used for low temperature applications.

Nylon is the most abrasion-resistant synthetic fiber and Dacron fibers can resist acids, alkalines, as well as abrasion. Nomex fibers can resist to relatively high temperatures and abrasion.

Dust enters the baghouse through inlet above the hoppers. Larger particles settle into hopper while smaller dust particles collect on bags. When the dust layer thickness causes predetermined *pressure drop*, bag cleaning is initiated.

Fig. 4.14 Bag filter in cement plant near material handling equipments

Baghouses can be classified based on cleaning mechanisms into (1) *pulse jet* (compressed air cleaning), (2) *reverse air,* and (3) *shaker*.

Reverse air baghouses are compartmentalized so that cleaning of bags can be made off-line by stopping the polluted air stream flow with air from a separate fan. Cleaning shaker baghouses is done off-line by shaking the bags. In **Pulse jet baghouse a** pulse of compressed air is blasted through the filter bags to clean the bag. Sonic Cleaning uses Sonic horns powered by compressed air.

The filtering velocity for reverse-air baghouses, varies between 0.50 and 2.0 cm/sec where as filtering velocity for shaker baghouses ranges from 1.02 and 3.05 cm/sec. Filtering velocities in pulse-jet baghouses varies between 1 and 7.5 cm/sec.

Air-to-cloth ratio (A/C ratio) in bag filter typically varies between 1.5 and 3.5 m/min. Reverse-air units typically operate at 1 $(cm^3/sec)/cm^2$ or lower. Bag life varies from material to material and pollution load. But typically vendors guarantee a life span of 2400 h.

Another advantage of a fabric filter is it can remove high acid gas, chlorides, SO_2.

Table 4.3 Usual filter media used in bag filter

Sl. No.	Media	Use	Advantage	Disadvantage	Maximum temperature (°C)	
					Continuous	Surges
1	Cotton	Low temperature applications	Good flex abrasion resistance	Low temperature capability	82	107
2	Polypropylene	Low temperature applications	Demonstrates good cake release. Does not readily absorb moisture	Very sleek fabric	88	93
3	Polyester	Low temperature applications like woodworking, quarry, sand handling operations etc.	Good resistance to acids and alkalies. Very sturdy material		135	163
4	Nomex	Asphalt, carbon black, steel, and cement industries	Extremely sturdy material. Good temperature capability	Poor acid resistance	204	218
5	Teflon	Lead smelting, carbon black industry, coal-fired boiler	Chemically inert	Very expensive	232	260
6	Fiberglass	High temperature applications	Temperature resistance		260	288

Sources Based on information from McKenna and Turner (1989), Grener (1993), Beachler et al. (1995) and onbservation by authors

High-Efficiency Particulate Air Filter

High-efficiency particulate air (HEPA) filter have many applications, which includes use in medical facilities, aircraft, automobiles, and homes. HEPA filters contains a mat of randomly arranged fibres usually composed of fiber glass with diameters from 0.5 to 2.0 micrometers with air space between fibres typically more than 0.3 μm where particles are trapped through a combination of the *Interception*, *Impaction*, *Diffusion*.

Rotary drum filter

A rotary drum filters are commonly used to clean dust in room air such as textile mills. The dust is removed from the surface of the drum by simultaneous traversing suction nozzle.

4.3.4 Scrubber and Absorption Towers

Wet collectors, or scrubbers, use water to remove particles from gas stream. Scrubbers remove particle matter from gas streams by incorporating particle into liquid drops. Scrubbing is a effective means to remove small particles from particulate laden gas. A scrubber simultaneously removes soluble gaseous pollutants.

Absorption of pollutant gases in scrubber is achieved by using a selective liquid (Table 4.4). Pollutant gases commonly controlled by absorption include SO_2, H_2S, HCl, Cl, NH_3, NO_x and low-boiling hydrocarbons. The scrubbing liquid should be chosen based on the gas being removed. The solubility of gas in the liquid solvent

Table 4.4 Pollutants and scrubbing fluids

Sl. No.	Pollutants	Scrubbing fluid
1.	SO_2	Sea water, Sodium hydroxide (NaOH), Calcium hydroxide ($CA(OH)_2$), Sodium carbonate ($NaCO_3$), Sodium sulfite (Na_2SO_3), Potassium hydroxide (KOH), Potassium carbonate (KCO_3), Potassium sulfite (KSO_3), Magnesium oxide (MgO), Magnesium hydroxide ($Mg(OH)_2$), Zinc oxide (ZnO), Calcium oxide (CaO), Calcium carbonate ($CaCO_3$), Ammonia (NH_3)
2.	NO_x	$Ca(OH)_2$, MgO, Na_2SO_3, $NaHSO_3$, Urea, H_2O_2
3.	Hydrogen cyanide (HCN)	NaOH
4.	Bromine (Br_2) and fluorine (F_2)	NaOH or KOH
5.	Cl_2	Water, NaOH, NH_3
6.	Nitric acid (HNO_3), hydrogen bromide (HBr) and hydrogen iodide (HI)	NaOH
7.	Carbon dioxide	Ethanolamines [monoethanolamine (MEA), diethanolamine (DEA) and triethanolamine (TEA)] Other amines used in this field of application are activated methyldiethanolamine, diisopropanolamine and monoethylamine
8.	Hydrogen sulphide	NaOH, Na_2CO_3, KOH, K_2CO_3, green liquor (dissolved smelt of sodium carbonate, sodium sulfide as well as other compounds from the recovery boiler in the kraft process), ethanolamines (monoethanolamine (MEA), diethanolamine (DEA) and triethanolamine (TEA)) Other amines used in this field of application are activated methyldiethanolamine, diisopropanolamine and monoethylamine
9.	Hydrogen chloride	Water, NaOH, NH_3, $Ca(OH)_2$ and $Mg(OH)_2$

Lists some of the commonly used scrubbing fluids should be high so that maximum quantities of solvent are required. The solvent should have low vapor pressure; low freezing point noncorrosive; nonflammable; inexpensive; chemically stable; and nontoxic. Hence water is used as the most popular solvent in absorption devices as it may be treated with an acid or a base to removal of a specific gas. If CO_2 is present in the air pollution stream carbonic acid will gradually replace the water where ever water is used as scrubbing fluid.

Water is a poor scrubbing solvent with respect to SO_2 but readily soluble in an alkaline solution. Hence scrubbing solutions containing amines or ammonia are used in commercial applications. Chlorine, hydrogen chloride, as well as hydrogen fluoride are readily soluble in water. More recently, the light hydrocarbon vapors at petroleum refineries as well as loading facilities are absorbed, under pressure, in liquid gasoline(petrol) and returned to storage.

Simplest form of the scrubber is a spray tower (Fig.4.15) wherein liquid is sprayed with a droplet size of 0.1–1.0 mm into particulate laden stream. The

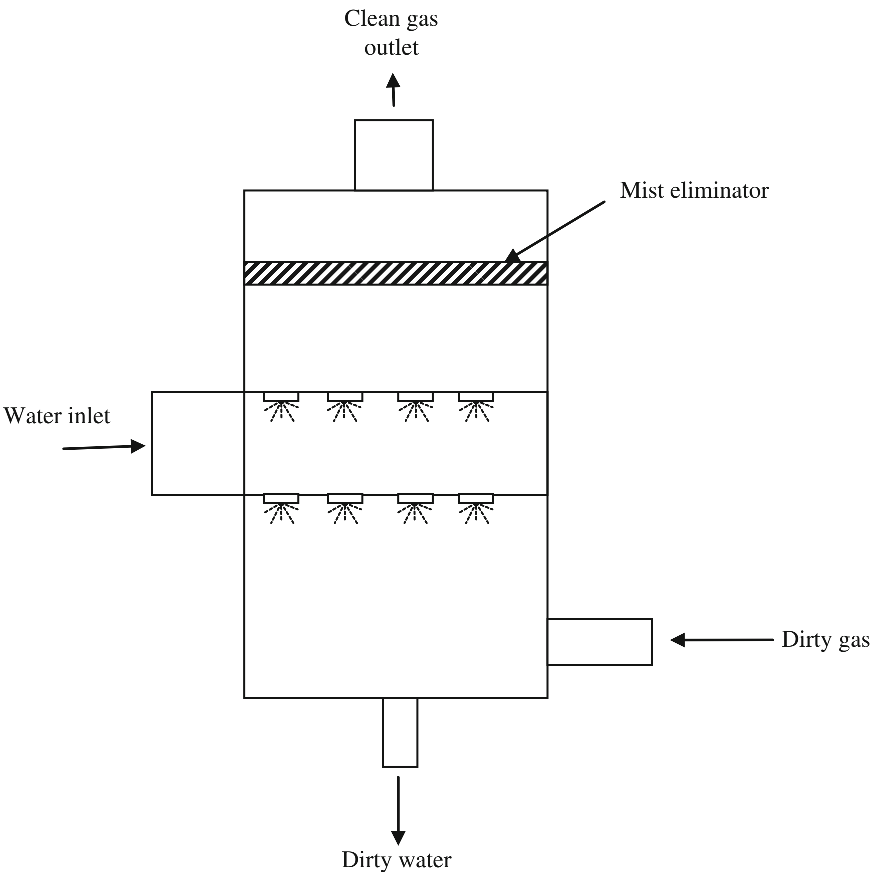


Fig. 4.15 Spray tower

air-water direction may be countercurrent or Cross-current or Cocurrent. With virtually no particle entertainment wet collectors can provide low cost solution for air pollution problem. The scrubbed liquid or absorbing liquid is recycled after treatment and make up.

Sodium hydroxide is the conventional scrubbing medium for NO_x. The absorbed NO_x is converted to nitrate and nitrite which may pose wastewater disposal problems. Scrubbing solutions containing hydrogen peroxide adds no contaminants to the scrubbing solution and allows commercial recovery of nitric acid. 0.5–1 % of H_2O_2 and 35–45 % of nitric acid are used to scrub nitric oxide and nitrogen dioxide.

Ventury (Figs. 4.16 and 4.17), packed beds, and sieve plate tower (Fig. 4.18) are commonly used scrubbing types for controlling air pollution. Packed beds contain packing media usually made of plastic/ceramic. The packing medium is used to increase contact time between liquid and vapour.

4.3.5 Biofilters

Biofilter (Fig. 4.19) are used for the biodegradation of air pollutants wherein pollutants are biodegraded into innocuous compounds. In biofilter humid polluted air stream is made to enter porous packed bed on which a culture of pollutant-degrading organisms is present where biological oxidation of pollutants occurs.

Biofilters are used to treat many organic and inorganic pollutants such as ammonia, mercaptan, hydrogen sulphide, disulphides, propane, styrene, methanol, phenols, butane, ethylene chloride, etc. Studies have shown that 60 HAPs can be treated successfully with biofiltration (Devinny et al. 1999a, b; Muralidhar et al. 2010; Shareefdeen and Singh 2005a, b).

Biofilters have following advantages: (a) low operating as well as capital costs, (b) Low pressure drop, (c) capable of treating large quantity of VOCs/odorants, and (d) Do not produce secondary waste streams.

Biofilters have following disadvantages: (a) clogging of the medium, (b) medium deterioration, and (c) lower treatment efficiency at higher pollutant concentrations.

The open design bofilter require large areas and normally installed outside buildings. The close design biofilters are normally installed in closed rooms and need less space compared to the open configuration.

The biofilm (mass of microbes growing on media) thickness is influenced by many factors - type of pollutant, the bedding material used, rate of flow, and the design/configuration of thetreatment system. Thickness of biofilm normally varies from few micrometers to more than a centimeter (Shareefdeen and Singh 2005a, b).

The activity increases as the thickness of the biofilm increases, up to a level called the ‘active thickness’ above which the diffusion of food to microorganism becomes a limiting factor (Devinny 1999a, b).

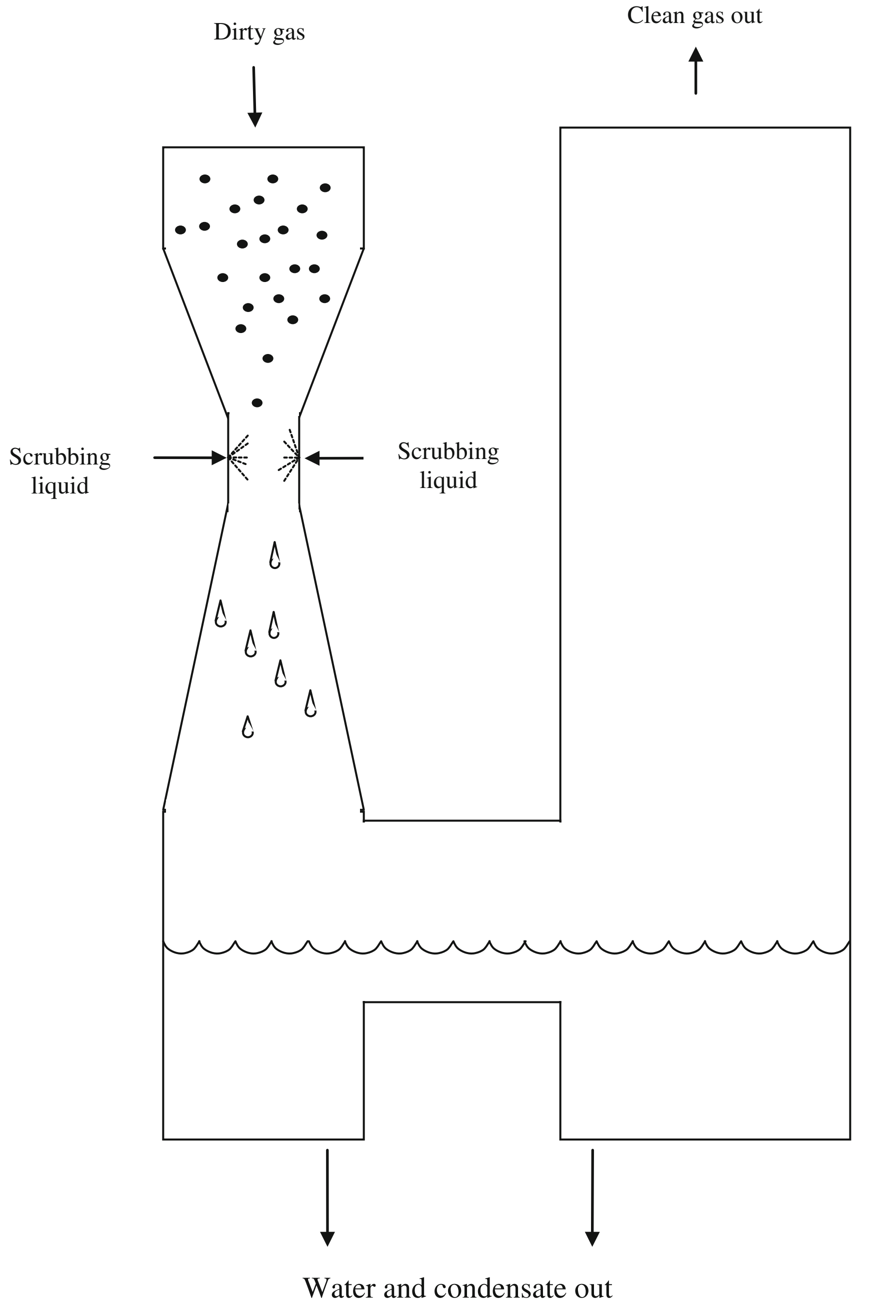


Fig. 4.16 Ventury scrubber

Fig. 4.17 Ventury scrubber at an installation

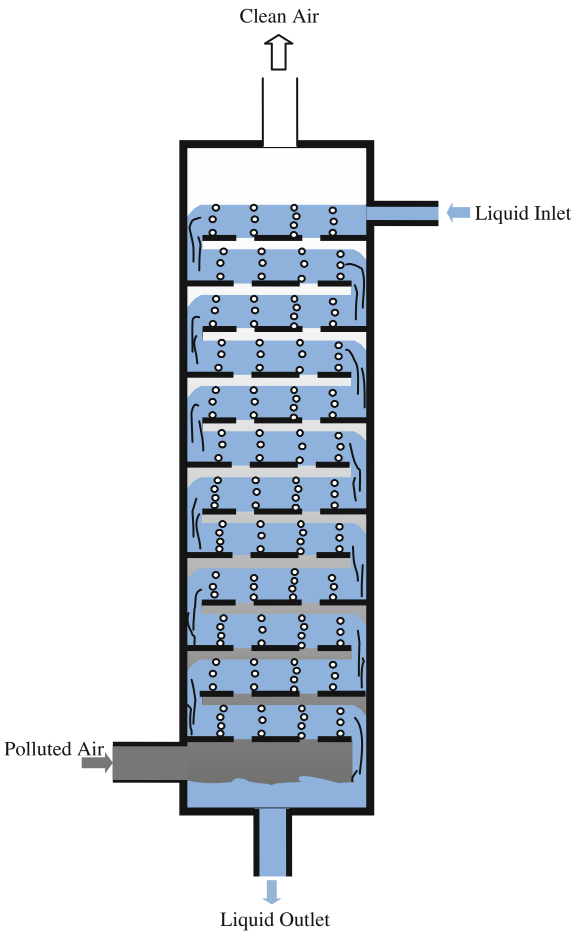


Fig. 4.18 Sieve plate tower

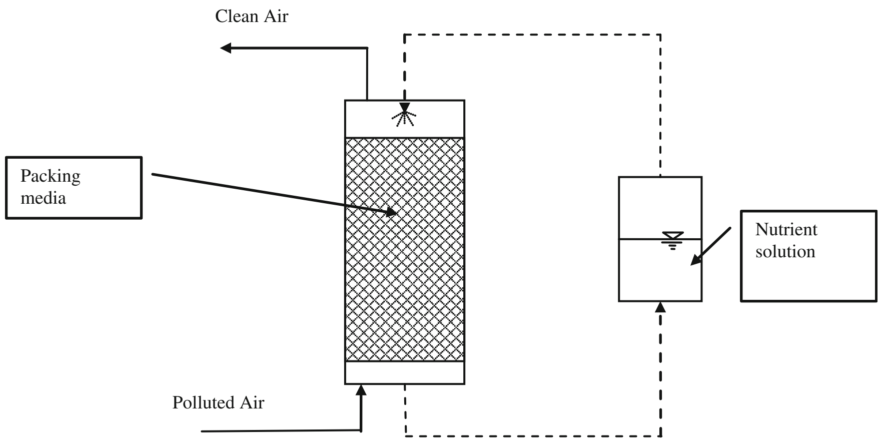


Fig. 4.19 Schematic diagram of biofilter

The important characteristics of the biofilters bed should have are: (a) high specific surface area, (b) high porosity, (c) a good water retention capacity, (d) availability of nutrients, and (e) presence of a dense/diverse microbes capable of degrading target pollutants.

Peat, compost, soil, and wood chips, are frequently used in biofilter beds. Soil offers rich as well as varied microflora but contains limited nutrients, it generates high-pressure drops and has low specific surface area (Swanson and Loehr 1997).

Peat has high specific surface area, high organic matter, and good water holding capacity as well as good permeability. But it does not contain nutrients/microbes. Compost contains dense/varied microbes, good air permeability, good water holding capacity, and large quantity of intrinsic nutrients. Utilization of compost in biofilters is an effective way of utilizing and recycling waste such as activated sludge from ETP/STPs, domestic residues, forest products, etc. (Alexander 1999).

4.3.6 Electrostatic Precipitator

Electrostatic precipitator (ESP) is particulate control equipment that employs electrical forces to move particles in exhaust onto collection surfaces. The particles are given an electrical charge as they pass through a corona, a region where gaseous ions flow. Particle charging in ESP is achieved by means of a corona, which generates ions that gets attached to the particles. The electric field causes ionization of the gas thereby generating ions that collide and attach to particles thereby changing the particles. The charged particles are collected on large surface that are earthed. Particles are removed by coalescing and draining in the case of liquid aerosols, and by periodic rapping in the case of solids.

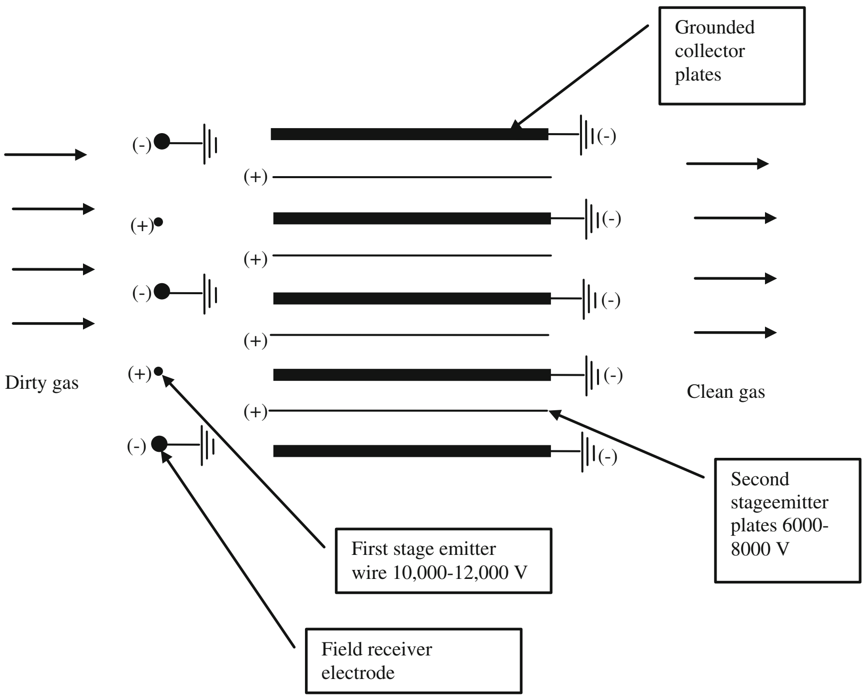


Fig. 4.20 Low-voltage two stage ESP

ESPs are gas cleaning equipment wherein forces are applied directly to the particulates and hence the energy required is considerably less compared to other types of gas cleaning equipments. Gas pressure drops through ESP will be of the order of 2.5 cm of water or less as compared to 25–250 cm of water for scrubbers and bag houses. This advantage of ESP has resulted in wide applications where large volumes of gas are to be handled with high efficiencies for small particles. The electrostatic precipitation process comprises of: (1) Particle charging, (2) Particle collection, (3) Particle removal.

Low-voltage ESPs have a separate ionizing zone located ahead of the collection plates (Fig. 4.20). High-voltage ESPs (Fig. 4.21) will operate at the range of 30,000–100,000 V and will have both ionisation and precipitation in single-stage.

Pulsating DC voltage between 20,000 and 100,000 are used by using power supplies to convert the AC voltage (220–480 V). Larger particles (>10 μ) absorb more ions than small particles. Hence forces are stronger on the large particles and hence these particles are removed with higher efficiency. Operating current density varies from 5 to 50 nA/cm^2 and dust layer thickness varies from 1/2 to 2.5 cm.

The auxiliary power requirement in a coal fired thermal power plant varies between 9 and 9.5 % of the total power generated. About 10 % of the auxiliary power consumption is attributed to ESP operation. As per the studies conducted by

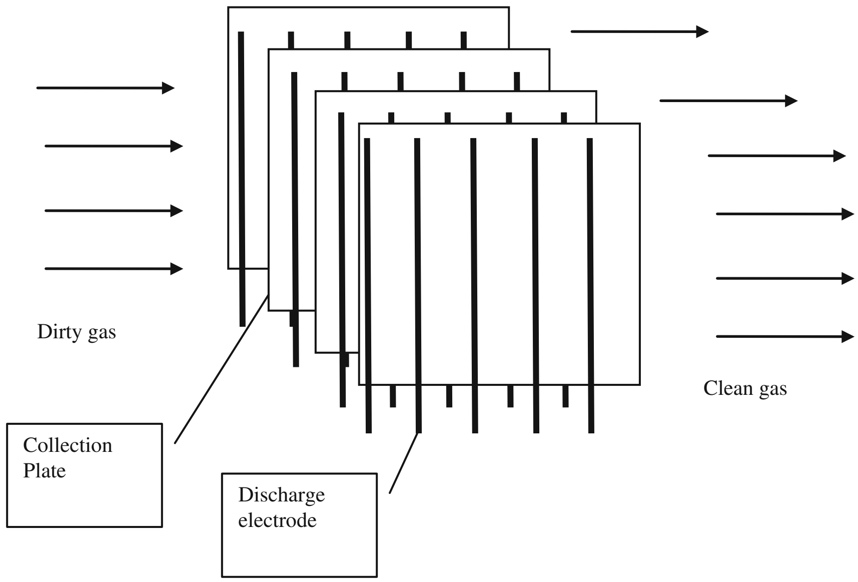


Fig. 4.21 High voltage ESP

Central Pollution control Board (2007) a 210 MW unit needs an auxiliary power of 20 MW out of which 2 MW is used to operate ESP.

The presence of electric charges makes dry ESP restricted to non-combustible pollutants. Wet ESPs are used when the materials to be collected are sticky, wet, explosive, flammable, or has a high resistivity. Wet pipe-type ESPs are frequently used by the textile industry, pulp and paper facilities, the metallurgical industry, hazardous waste incinerators, coke ovens and sulfuric acid manufacturing plants (EPA 1998).

In wet ESPs, the collectors are washed either intermittently or continuously by a spray of liquid, normally water. The wet effluent is collected for further treatment.

In a wire-pipe ESP also referred as a tubular ESP, the exhaust stream passes vertically through conductive tubes. Usually many tubes operate in parallel in tubular ESP. The tubes may be circular, hexagonal honeycomb or square. Pipes are usually 7–30 cm wide and 1–4 m in length. Sharp points are added to the electrodes in some designs at the entrance of tube or along the length to provide additional ionization sites (EPA 1998; Flynn 1999).

Wet ESPs require a wash water to be sprayed/injected near the top of the collector pipes either at timed intervals or continuously. The water flows with the particles collected into a sump from where it is pumped or drained for recycling/treatment. Because of the high humidity the resistivity of particles is reduced in a wet ESP eliminating the “back corona”. The washing of the pipes also reduces/eliminates particle buildup on the collectors.

ESPs in general are not suited where characteristics of gas stream are highly variable as they are very sensitive to fluctuations of gas stream conditions.

The general range of Specific Collection Area (SCA) is 11–45 m^2 per 1000 m^3/hr. Most ESPs are designed to have SCA between 20 and 25 m^2 per 1000 m^3/h with collection efficiency of more than 99.5 %.

The *aspect ratio* (ratio of length/height of an ESP) is an important factor in reducing dust re-entrainment. Aspect ratios for ESPs vary between 0.5 and 2.0. However, for high-efficiency ESPs the aspect ratio will be in the range of 1.0–1.5.

The *corona power* (power that energizes the discharge electrodes) or *specific corona power* normally will be between 59 and 295 watts per 1000 m^3/h even though some ESP installations have been designed to use specific corona power of 470–530 watts per 1000 m^3/h.

The size of the ESP is sensitive to the dust characteristics. The range span from easy to difficult dust is in the order of factor 5, for the same efficiency. The main characteristic reposnsible for such variation is insitu resistivity as well as particle size. The ESP efficiency improves with the power supplied until it reaches the limit for back corona (White 1963). Hence, efforts have been made to optimize the principles as well as control of the ESP energisation to minimize the effect of back corona (Elholm et al. 1998). The conventional way to attain this purpose is using thyristor. Another method is use micro second pulse that uses two individual power supplies. One power supply is used generation of a DC base voltage and another for charging the oscillating circuit for generation of the superimposed micro second pulse (Elholm et al. 1998).

Typical value of *Current density* (ration of current supplied by the T-R set to plate area) varies between 5 and 50 nA/cm^2. Gas velocities vary between 0.6 and 2.4 m/s with the optimum value between 1.5 and 1.8 m/s.

Power consumption of ESP can be as high as 22 w/m^2 of collecting electrode area. Treatment time in ESP is normally 20.0 s.

An ESP is divided into a sequence of independently energized *bus sections* (also called fields or stages) in the path of the gas flow. Optimum sparking rate varies from 50 to 150 sparks per minute per electrical section. Precipitator performance depends on the number of individual bus sections, or fields, installed.

Each field has individual T-R sets. Most ESP will have at least three or more fields. The need for separate fields arises mainly because power requirements differ at different locations within a ESP.

As the size of the ESP increases, other technologies become cost effective. For low sulfur applications, fabric filters are an attractive option. Normally, the pressure drop across a flange to flange fabric filter will be in the range of 15–20 cm water column(w.c) as compared to an ESP which is about 2.5 cm w.c.

ESP required skilled man power. As per the case study published by CPCB, nine technical persons is required in three-shift operation to operate the ESP in a 210 MW TPP (CPCB 2007).

Good design practices of ESP calls for 5 or 6 separately energised series of high tension sections. The number of fields depends mainly on the efficiency required and on the redundancy required to ensure performance with section outages.

In today's highly competitive markets ESPs are optimized using self-adapting ESP process expert software that maximises the collection efficiency of individual ESP bus section to achieve maximum efficiency with optimized power consumption.

4.3.7 Adsorption

Adsorption is process in which residual molecular forces at the surface of solids is used to remove air pollutants. The reverse process called desorption. The adsorbing solid is called adsorbent. The adsorbed gas molecules are called adsorbate. Adsorption is an exothermic process, and desorption is endothermic. Hence heat must be used to separate the adsorbate from the adsorbent.

Adsorption of pollutant gases occurs when molecules of selective chemicals are retained on the surface/pores/interstices of prepared solids.

Porous solid materials with extremely large surface-to-volume ratios are used as adsorbents. Activated carbon, alumina, silica gel and zeolites(molecular sieves) are used widely as adsorbents. Commonly used adsorbents for pollution control is given in Table 4.5. Activated carbon, is excellent for removing light hydrocarbon molecules. Silica gel, is a adsorbent for polar gases. Some small units use throw-away adsorbants but majority of industrial adsorbers regenerate the adsorbent in order to recover adsorbent and adsorbate, which normally has economic value.

The efficiency of adsorbers is around 100 % in the beginning of operation and remains high until a breakpoint occurs when the adsorber need to be renewed or regenerated.

The adsorption process is either physical or chemical. In physical adsorption the pollutant is bonded to the adsorbent surface by intermolecular cohesion, whereas in chemical adsorption sharing/exchange of electrons takes place.

In physical adsorption the forces active are electrostatic in nature. Physical adsorption occurs due to orientation/dispersion/induction effect. Chemical adsorption, or chemisorption, results due to the chemical interaction between molecules.

Adsorbents are usually used in granular form. The size varies from about 10 mm to 50 μm in diameter. Porosity of the adsorbent bed varies between 20 and 85 %.

4.3.8 Condensation, Refrigeration and Cryogenics

Condensation (Fig. 4.22) is the change of substance from gas phase into liquid phase. Condensation is reverse of vapourisation. Any gas can be changed to liquid by lowering temperature and/or increasing pressure. Condensation of a vapour can occur as a film of the condensed substance on the wall of condenser or as a series of drops on the surface. Most of the equipments used are of film type as not much information is available on dropwise condensation (Karl and Charles 2002).

Table 4.5 Common adsorbents used in air pollution control

Adsorbant	Nature	Average pore diameter (nm)	Particle porosity (cc/g)	Surface area (m^2/g)	Sorptive capacity ($kg\ kg^{-1}$) (dry)	Pollutants removed
Activated alumina	Hydrophilic amorphous	4–14	50	320	0.1–0.33	Fluoride
Activated carbon	Hydrophobic amourphous	1–4	40–85	200–1200	0.3–0.7	Volatile organic carbon
Activated carbon impregnated with sulphuric acid (2–25 %)	Hydrophobic amourphous	1–4	40–85	200–1200	0.3–0.7	Ammonia, Amine, mercury
Activated carbon impregnated with potassium carbonate (10–20 %)	Hydrophobic amourphous	1–4	40–85	200–1200	0.3–0.7	HCl, HF, SO_2, NO_2
Activated carbon impregnated with zinc oxide (10 %)	Hydrophobic amourphous	1–4	40–85	200–1200	0.3–0.7	Hydrogen cyanide (in gas masks)
Activated carbon impregnated with Triethelene diamine (10–20 %)	Hydrophobic amourphous	1–4	40–85	200–1200	0.3–0.7	Radioactive methyl iodide
Activated carbon impregnated with Chromium-Copper-Silver Salts (2–5 %)	Hydrophobic amourphous	1–4	40–85	200–1200	0.3–0.7	Phosgen, chlorine, sarine, arsine, and other nerve gases

(continued)

Table 4.5 (continued)

Adsorbant	Nature	Average pore diameter (nm)	Particle porosity (cc/g)	Surface area (m^2/g)	Sorptive capacity ($kg\ kg^{-1}$) (dry)	Pollutants removed
Molecular sieve carbon	Hydrophilic, crystalline	0.3–0.6	35–50	400	0.2–0.5	Organic pollutants
Molecular sieve zeolites	Hydrophilic crystalline	0.3–1	20–50	600–700	0.12–0.42	SO_2, CO_2, H_2S, C_2H_4, C_2H_6, and C_3H_6 normal paraffins frombranched-chain and cyclic hydrocarbons, mercaptans, H_2O
Polymeric adsorbents	Hydrophobic, amorphous	4–25	40–60	80–700	0.45–0.55	VOC
Silica gel	Hydorphilic, amorphous	2–5	47–71	300–850	0.35–0.5	

Perry and Green (1997), Seader et al. (1998), Henning and Schäfer (1993) and observation by authors

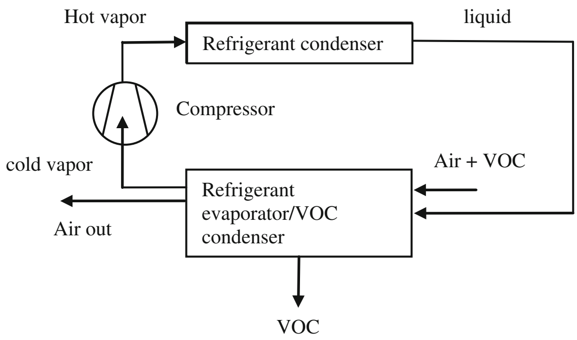


Fig. 4.22 Schematic diagram of condensation unit

Condensers are usually used for pretreatment ahead of incinerators, adsorbers and absorbers to reduce gas volume. In case of surface condenser the gas comes in contact with cooled surface.

In contact condenser, contact is established between gas to be condensed with cold liquid. Condensation scrubber with combined principles of condensation and scrubber are used to control fine particulate matter.

A refrigerated condenser is used for streams containing high volatile organic emissions (EPA 2001). They are less efficient on dilute streams. Refrigerated condenser are used in dry cleaning industry; degreasers using halogenated solvents; storage/transfer operation of petroleum product and volatile organic liquid.

When liquid nitrogen is used for cooling the process is called cryogenic cooling. Release of nitrogen to the environment is not considered pollution and process involves liquid nitrogen which may be delivered in the form of cold liquid.

4.3.9 Combustion

Though combustion is major source of combustion, it can be used for controlling air pollution by converting contaminants (normally hydrocarbon or carbon monoxide) to innocuous carbon dioxide and water. Different types of combustion devices are used that are listed in following paragraphs.

A gas flare (Fig. 4.23), or flare stack, is normally used to burn pollutants escaping into atmosphere in chemical plants, petroleum refineries, natural gas processing plants and oil or gas production sites and landfills.

Flare stacks are used for burning off flammable gas released during industrial process by pressure relief valves during unexpected over-pressuring of plant equipment.

When petroleum crude oils are extracted and produced from oil wells, raw natural gas is produced to the surface and such associated gas and are commonly flared.

Fig. 4.23 After burners

Steam is very frequently injected into the flame to decrease the formation of black smoke. Too much steam may result in reduced combustion efficiency. A small amount of gas is continuously burned to keep the flare system functional.

Even though flaring is solution to protect the environment by pollution it can affect wildlife by attracting insect and birds to the flame.

4.3.10 Catalytic System

A catalyst is a chemical which influence the rate of chemical reaction by reducing its activation energy. Amount of catalyst doesn't change before and after the chemical reaction. Catalysts influence a chemical reaction by altering its mechanism:

Reaction without catalyst:

$$A + B \rightarrow AB$$

Reaction with catalyst:

$$A + K \rightarrow AK(\text{transient product})$$
$$AK + B = AB + K$$

where,

A and B	reactants
K	catalyst

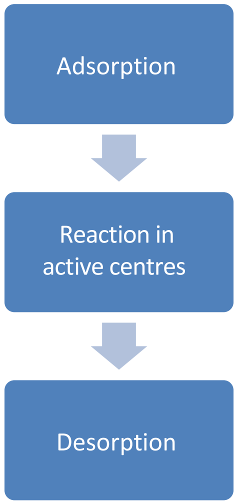


Fig. 4.24 Mechanism of heterogeneous catalysis

AB product
AK transient product

Catalysis reactions can be homogeneous (catalysts and reactants in same phase) or heterogeneous Catalysis (catalysts and reactants in different phase). Heterogeneous catalysis is used for air pollution control wherein surface of solid catalyst are used to control air pollution.

The mechanism of heterogeneous catalysis is shown in Fig. 4.24. Table 4.6 shows usual catalysts used for different reactions.

Catalytic reactions are used for oxidation, reduction, hydrogenation and dehydrogenation.

Deactivation of catalysts

In theory catalysts do not wear out in chemical reactions but in reality their time of activity is restricted due to the deactivation (reduction of catalyst activity due to adsorption of some chemicals on catalyst).

Heterogeneous catalysts are deactivated by chlorines, mercury, lead, arsenic, phosphorus,sulfur compounds, HCN, CO, compounds of phosphorus, mercury salts, arsenic and lead.

Table 4.6 Usual catalysts used for different reactions

Sl. No.	Reaction	Catalysts
1	Oxidation	Platinum, palladium, rhodium
2	Reduction	Platinum group, gold, iridium, chromium
3	Hydrogenation and de-hydrogenation	Platinum group, cobalt, nickel, cuprum, zinc

Catalysts are usually coated on catalytic carriers made up of Ceramic/Metal. Ceramic carriers have following Advantages and disadvantages:

Advantages

- Low costs of manufacture;
- Easy formation;
- Strong adhesion of active substance;
- Large inner surface;
- Resistance to corrosion; and
- High temperature of melting.

Disadvantages

- Low resistance for temperature variations; and
- Low resistance for vibrations.

Metallic carriers have following advantages and disadvantages:

Advantages

- Efficient heat transfer;
- High resistance to mechanical stresses;
- Low hydraulic resistance; and
- Low weight.

Disadvantages

- Higher cost compared to ceramic; and
- Prone to corrosion.

The important applications of catalysts in combustion as well as related technologies

- Removal of NO_x and SO_2 from flue gas (vehicle industry);
- Reburning of CO and CH in flue gas;
- Burning of low-caloric waste gases as well as oxidation of odours (chemical technology, food industry, and painting);
- Selective catalytic reduction of NOx with ammonia; and
- Low-temperature combustion.

Advantages and disadvantages of catalytic combustion are:

Advantages

- Combustion with considerable excess air excess.
- Low NO_x emission.
- Combustion at low temperature.

Disadvantages

- Low thermal resistance of catalysts.
- Low mechanical resistance of catalysts.
- Temperature of catalytic combustion limited to 800 °C.

Catalytic combustion of low-caloric waste gases
Catalysts neutralize organic compounds in waste gases by oxidation and utilization of thermal energy. This process is carried out at a temperature of 250–450°C using platinum as catalyst.

Catalytic gas turbines
Catalysts in catalytic gas turbine allow burning of lean gas mixtures; reduce emission of NO_x; reduce unburnt fuel; and decrease of heat loss.

Catalytic removal of SO_2 form flue gas
SO_2 is oxidised to SO_3 over the vanadium catalyst in the presence of oxygen present in flue gas at the temperature between 400 and 470 °C. The SO_3 thus formed is absorbed by water and converted into the sulfuric acid. The oxidation reaction is:

$$SO_2 + \frac{1}{2}O_2 \rightarrow SO_3 (\text{catalytic})$$
$$SO_3 + H_2O \rightarrow H_2SO_4$$

4.3.11 Thermal Oxidation

Oxidation systems are used to destroy HAPs and VOCs to form CO_2 and H_2O. In many cases, thermal oxidizers are equipped with regenerative or recuperative heat exchangers to reduce operating costs (Mines 2014).

Regenerative thermal oxidizer (RTO)
RTO are very versatile and extremely efficient. They are regularly used for reduction of solvent fumes, odours, etc. from industries.

Regenerative catalytic oxidizer (RCO)
Use of a catalyst requires reduced temperatures for oxidation. Most RCO systems operate in the range of 260–540 °C range. Some systems are designed to function both as RTO and RCO.

Ventilation air methane thermal oxidizer (VAMTOX)
VAMTOX are used to destroy CH_4 in the exhaust air from underground coal mine shafts by converting CH_4 into CO_2 and H_2O. On start-up, the system preheats by increasing the temperature of the heat exchanging ceramic matter in the bed at/above the auto-oxidation temperature of methane followed by turning off pre-heating system and introduction of mine exhaust air.

Thermal recuperative oxidizer
These oxidizers have primary and/or secondary heat exchanger within the system. The primary heat exchanger preheats the incoming gas stream by recovering heat from the exiting clean air by a heat exchanger.

Catalytic oxidizer
In this system catalyst is used to augment the combustion using less energy.

Direct fired thermal oxidizer—afterburner
In this equipment a process stream is passed into a firing box burner to achive the preferred destruction removal efficiency (DRE).

4.4 Air Pollution Control in Mobile Sources

Mobile sources include vehicles in air, water and land. Vehicles with internal combustion engines (ICE) can be broadly classified as road/non-road vehicles. In the start of the 21st century such vehicles exceeded more than 600 million. These vehicles operate by combustion of fossil fuel derivatives resulting in emissions of air pollutants. The main pollutants from vehicle are carbon dioxide, methane, carbon monoxide, sulfur dioxide, nitrogen oxides, non methane VOC and particulate matter. Toxic chemicals emitted include aldehydes, benzene, butadiene, ethers, methanol, etc. Automobiles are main sources of CO, unburned hydrocarbons, as well as NO_x.

Vehicle design change, clean fuels, post combustion control equipments, inspection, maintenance, etc. may be employed to increase efficiency and reduce emission of pollutants from transportation.

Spark-ignition (SI) and diesel engines are the two common engines used in vehicles. SI gasoline(petrol) engines have four-stroke or two stroke design. Most passenger cars, light-duty trucks and some heavy-duty trucks use SI gasoline(petrol) engines. SI engines are also designed to use natural gas, alcohols, LPG and hydrogen. SI gasoline(petrol) engines may be designed as two-stroke or four-stroke engines. Air pollutants from motor vehicles are determined by the engine type and the fuel.

Composition of engine exhaust depends on type of engine and driving conditions. Use of leaded fuel emits lead and its compounds. The vehicle/fuel characteristics influencing motor vehicle emissions are: (1) engine type and technology (two-stroke, four stroke; fuel injection, turbocharging; type of transmission systems, etc.), (2) exhaust, crankcase as well as evaporative emission control system (catalytic converters, exhaust gas recirculation, air injection vapour recovery system), (3) maintenance of vehicle, (4) air conditioning and other vehicle appurtenances, (5) fuel properties and quality, (6) quality of tyres, and (7) deterioration of emission control equipment.

Two-stroke engines are lighter, cheaper, and can produce better power output per unit of displacement. They are widely used in outboard motors, small motorcycles, and small power equipment. Two-stroke engines release 20–50 % of their fuel unburned resulting in high emissions as well as poor fuel economy. Since the crankcase pumps the air-fuel mix through the engine, these engines require lubricating oil be mixed with the air-fuel mix to lubricate bearings and pistons. Some of this lubricating oil appears as white smoke in the exhaust.

All gasoline(petrol) engines in larger vehicles use four-stroke design, even though advanced two-stroke engines are being developed (Faiz et al. 2002). In the recent year four-stroke engines have also been used for motor bikes. Advanced two-stroke engines under improvement would achieve lower emissions as well as fuel consumption compared to four-stroke engines and retain the advantage of two-stroke engine.

Most heavy-duty buses, trucks, some light-duty vehicles as well as passenger cars have diesel engines. Diesel engines do not premix fuel with air prior to the cylinder. In case of diesel engines the fuel is injected at highpressure. Once injected, the fuel is heated due to self ignition by the compressed air in the cylinder. Hence there will be no need for a separate spark-ignition system.

Compared with gasoline(petrol) SI engines, diesel engines have lower carbon monoxide as well as hydrocarbon emissions but higher particulate matter and nitrogen oxide emissions. Black smoke from diesel engines are source of high ambient concentrations of particulate matter in many developing countries which are now being phased out due to adoption of better technology by vehicle manufacturers. Sulfur oxides emissions from vehicle directly depend on sulfur content of fuel.

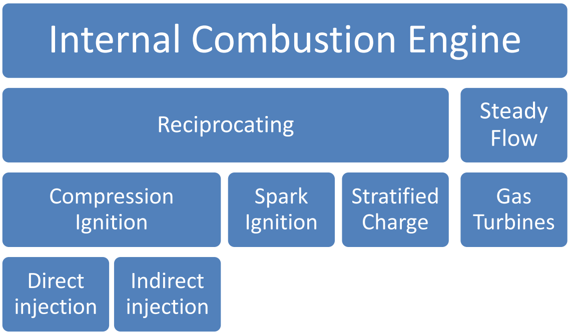
Another technology called *Rotary Engines* utilizes a triangular rotor that turns within a combustion chamber. Production models of passenger cars as well as motorcycles have been built with this technology (Faiz et al. 2002).

ICE operates by combustion of fossil fuel derivatives. Air pollutants from internal combustion engine vehicles (ICEV) impose major impact environment in urban area.

In order to reduce lead n air leaded gasoline(petrol) was banned in 1995 in the USA, 1980s in Brazil and Japan in 1993 in was Austria.

ICE can be classified by various criteria - fuel type, power, ignition type etc. One such classification (Fig. 4.25) is combustion chemistry and air pollution—(1) reciprocating piston engines (engines where combustion is performed in a chamber

Fig. 4.25 Classification of internal combustion engine



of changing volume), (2) steady flow (engines with constant volume combustion chamber).

The first group may be divided into compression ignition (CI) engines and spark ignition (SI). SI engines can be classified as two stroke as well as four stroke engines. CI engines can be classified into direct and indirect injection engines.

The second group comprises the gas turbine which uses turbo compressor and normally used in aircraft jet engines. It normally uses a liquid fuel and generally employs air as oxidation agent. The rocket jet engines will have chemical agents as fuels as well as oxidizers.

A number of irreversible processes limit its capability to attain a highly balanced efficiency in ICE. The rapid expansion of gases within the cylinder generates high temperature differences, turbulent fluid motions as well as huge heat transfers commencing from the fluid to the piston crown along with cylinder walls.

In IC engines a huge quantity of energy is lost through the exhaust gas in the form of heat. It is observed that the percentage of energy in fuel converted to useful work is only 10.4 % and the thermal energy lost during exhaust gas is about 27.7 %. Fuel energy is transformed to the brake power is around 9.7 % and the exhaust around 8.4 %. But according to Dolz et al. the value of exhaust gases is 18.6 % of total combustion energy. It is also observed that by installing heat exchanger energy consumption can be saved up to 34 %.

ICE has two major exhaust heat gas sources - exhaust gas systems and the radiator. The radiator system is employed to avoid overheating as well as seizure. The exhaust gas system in an IC engine is employed to discharge the expanded exhaust gas. Presently thermoelectric generators (TEG) are put in the exhaust gas system due to its simplicity as well as low influence on the engine operation.

Modern *SI engines* in passenger as well as freight vehicles are four-stroke. Two-stroke engines have advantages of lower weight as well as low cost per unit of power output. Two-stroke engines are extensively used in small motorcycles and other small power equipment.

CI engines are usually used in medium and larger vehicles as they provide higher power output as well as better efficiency. These engines are noisier. Indirect injection engines are more common for passenger cars because of lower noise as well as high performance characteristics. In indirect injection engines ignition takes place in a pre-chamber, by a glow spark. The combustion then stretch into the main chamber.

Diesel engines can be also categorized as naturally aspired, supercharged or turbo charged based on the organization of the airflow as well as its pressure prior to spraying the fuel. If properly controlled, air pollution from turbo charged engines are lesser than the other two types.

Compared to the usual gasoline(petrol) SI engines, light and heavy duty diesel engines have higher compression ratios as well as better fuel efficiency, resulting in lower CO as well as hydrocarbon emissions. Light duty vehicles also emit less NO_x than gasoline(petrol) engines, but NOx from heavy-duty diesel engines are greater. Particulate matter as well as the polycyclic carcinogenic hydrocarbons is eight to ten times more than gasoline(petrol) counterparts.

Stratified charge engines are a mix between typical gasoline(petrol) as well as diesel engines. Indirect injection engines depend on spark for ignition of fuel air mixture. The non-uniform fuel distribution in these engines improves turbulence mixing, and greater efficiency avoids fuel rich zones. Direct injection engines use a high-pressure injector to produce a swirl tangential movement of the fuel in the direction of the spark plug. Stratified charge engines have greater fuel efficiency but not emission performance.

Under ideal reaction conditions CO_2 and water are the likely products. But in reality reactions are not ideal. Under the non-ideal conditions, the fuel undergoes pyrolysis as well as oxidation pyrolysis before reaching the flame spread zone. The method of fuel ignition and the intermediate products determines type as well as the quantity of pollutants formed.

Hydrocarbon emissions from ICE engines comprise of unburned fuel from ICE engines and hydrocarbons synthesized during combustion.

The main sources of unaltered hydrocarbons are the fuel tank, the combustion chamber and the crankcase. In the combustion chamber of a SI engine, some hydrocarbons escape from the combustion process. Combustion gases leak between the cylinder walls and the piston into the crankcase which is called "blow-by". Blow-by emissions from gasoline(petrol) engine comprise hydrocarbon in the range of 6,000–15,000 ppm. Blow-by gases are vented from the crankcase together with lighter lubricating oil hydrocarbons, to the atmosphere. Some of the lubricating oil are partially burned and emitted with the exhaust (Cholakov 2006).

CO is an intermediate product during transformation of its precursors in burning of aliphatic compounds and aldehydes or is formed during the first reduction of cycles of arene (aromatic hydrocarbons) compounds (Cholakov 2006). Pure CO is difficult to ignite. In the presence of hydrocarbons, it may be oxidized by hydroxyl radicals. But in fuel rich conditions the hydrocarbons are more competitive for the reacting with the hydroxyl radicals. As a result significant quantity of CO is converted into CO_2.

NO_x formed in combustion are normally classified as prompt, thermal or fuel bound. Nearly 90 % of NO_x from ICE is considered to be NO.

Thermal NO formed due to the fixation at high temperatures. The formation of thermal NO is sensitive to temperature as well as oxygen access.

Prompt oxides are formed in the beginning as well as the end of combustion in fuel rich conditions, by fixation of nitrogen in air with organic radicals.

Emissions of SO_x are generated due to the oxidation of the sulfur compounds present in the fuel.

The pollution control from ICEV is accomplished by designing the combustion systems of the engine, and/or by treatment of exhaust gases.

Emissions from *four-stroke SI engines* are susceptible to the air-fuel ratio. In earlier designs, the four stroke SI engines are provided by mechanical carburetors. These mechanical carburetors are not suitable for accurate control. Modern engines use electronic fuel injection. Sequential multiport systems allow better air-fuel mixing as well as performance, resulting in lesser emissions. At high altitude air contains low oxygen as well as low density which may lead to an enriched mixture (about 25 % at 2000 m above sea level) and enhanced pollution.

Combustion timing determines the relationship between the movement of the piston as well as the combustion of the charge. It is controlled by the timing of the opening spark to achieve a most favorable residence time of the burned gas at elevated temperatures. If this time is long, excessive quantity of thermal NO_x are formed, if it is too low the emissions of hydrocarbons as well as CO increase. For lean-burn engines, faster burning are used. Faster burning decreases NO_x emissions and provide for higher compression as well as efficiency.

Modern engines employ flexible electronic ignition systems that optimize the quantity and the delivery time of the spark energy as required by the air-fuel ratio.

The compression ratio directly influences efficiency of ICE, fuel detonation as well as emissions. Cold-start emission controls (like automatic chokes as well as inlet heaters) use of enriched mixtures for starting the engines.

Idling emission controls as well as fuel cut-off systems are designed to limit emissions during idling periods.

Spark ignition engines

The fundamental principle of operation of SI engines is movement of piston in a cylinder transmitting its motion through a linking rod to the crankshaft that drives the vehicle. The common engine cycle has four strokes:

1. *Intake*: In this stroke the descending piston draws a blend of fuel as well as air through the open intake valve. The fuel-air mixture is premixed in a carburetor at a ratio between 0.7 and 1.4. The ignition system is designed so as to ignite the mixture of air and fuel at the optimum instant.
2. *Compression*: In this stroke the intake valve is closed. The rising piston compact the fuel-air mixture. The spark plug is fired near the top of the stroke igniting the mixture.

3. *Expansion*: In this stroke the burning mixture expands, pushing the piston down thereby delivering power.
4. *Exhaust*: In this stroke, the exhaust valve opens as well as the piston rises, forcing out the burned gas from the cylinder.

The common engine cycle for two strokes:

1. ***Upward stroke:*** A pipe is opened and lets the fuel mixture that is already compressed a bit. The fresh gases expulse the exhaust through an ejection pipe that is open at this moment.
2. ***Downward stroke***: Fuel gas mixture is compressed ignited by the sparking plug. The piston is pressed back while it compresses fresh fuel-air mixture in crank case pushing the mixture into cylinder.

Evaporative emissions in SI engines originate from the fuel tank as well as the carburetor. When the fuel is added to tank the vapor in the tank is displaced into atmosphere. The quantity of vapor expelled is equal to the volume of the fuel added and depends on the type and temperature of the fuel.

Fuel evaporation from the carburetor occurs during the period immediately after the engine is turned off. As airflow ceases when the engine is stopped, thereby facilitating absorption of heat by carburetor bowl from the hot engine. This causes increase in fuel temperatures to 293–313 K above ambient temperature thereby causing gasoline(petrol) to vaporize. This condition is known as *hot soak.*

Evaporative emission control methods used in control of emission are the *adsorption-regeneration system* and the *vapor-recovery system.*

The crankcase is employed in the vapor-recovery system, for storing vapors from the fuel tank as well as carburetor. In the hot-soak period the decreasing temperature in the crankcase results in reduction in crankcase pressure adequate to draw in vapors. During the hot soak, these vapors from the carburetor are pulled into the crankcase. Vapor from the fuel tank is carried to a condenser as well as vapor-liquid separator, with the vapor being sent to the crankcase as well as the condensate to the fuel tank. During engine starting, the vapors present in the crankcase are moved to the air intake system by the crankcase ventilation system.

In the adsorption-regeneration system, a container of activated charcoal accumulates the vapor and retains it until it can be fed into the intake manifold.

Exhaust gas treatment in SI engines

Modification of engine results only small emission reductions. Vehicle emission contains CO, unburned hydrocarbons, and NO_x. It is necessary to *oxidize* hydrocarbons and CO while *reducing* nitrogen oxides.

Thermal reactors The gas-phase oxidation of CO slows as combustion products cool, however the reaction does not end entirely. Oxidation of hydrocarbons homogeneously need a retention time of 50 ms temperatures in more than 900 K. Homogeneous oxidation of CO need temperatures higher than 1000 K.

A multiple-pass arrangement is used in thermal reactors to guard the hot core of the reactor from the relatively cool surroundings to achieve nearly adiabatic operation for significant conversion. Higher temperatures as well as long residence times are normally required to attain increased conversions. The heat released during oxidation reactions can result in a temperature rise thereby, promote better conversion. Therefore thermal reactors with fuel-rich cylinder exhaust gas as well as secondary air addition will provide better fractional reductions in hydrocarbon and CO levels than reactors with less fuel cylinder exhaust.

Temperatures of the exhaust gases of SI engines can fluctuate between 600 and 700 K at idle to 1200 K at some stage in high-power operation. Exhaust temperature normally vary between 700 and 900 K, which is too low for proper homogeneous oxidation. Spark retard enhances the exhaust temperature, but with significant loss in efficiency (Richard and John 1988).

Catalytic converters By the using oxidation catalysts, the oxidation of hydrocarbon vapors and CO can be promoted at lower temperatures. The decrease of NO is also achievable in catalytic converters, provided that the O_2 content of the combustion products is kept low. In the catalytic converter, combustion products are passed through a bed of thermally stable support substance such as alumina coated with a base metal oxide or noble metal. Alumina has a greater surface area due to its porous structure.

Compression ignision

Like SI engine, the CI engine is also reciprocating engine, but no carburetor is used on the diesel. The common engine cycle in CI engine has four strokes:

1. *Intake*: A mixture of fuel as well as air is forced by atmospheric (or greater by air pump) pressure into the cylinder through the intake port.
2. *Compression*: The piston returns to the top of the cylinder compressing the fuel-air mixture.
3. *Power*: The compressed air–fuel mixture ignites due to the heat generated by compression in a CI engine. The resulting pressure due to combustion of the compressed fuel-air mixture forces the piston back down.
4. *Exhaust*: The piston once again returns to top dead centre while the exhaust valve is open from where spent fuel-air mixture escapes through the exhaust valve(s).

Air is drawn into the cylinder from the intake valve. Fuel is injected into the cylinder of the engine, toward the last part of the compression stroke. As the compression heated air blends with the fuel spray, the fuel ignites. Relatively high pressure is needed to attain reliable ignition. Higher pressures are evaded by injecting the fuel slowly, continuing into the expansion stroke.

In direct injection (DI) diesel engine, fuel is injected directly into the cylinder of the engine. The use of a prechamber, improves the mixing of the fuel as well as air in the prechamber diesel engine or indirect injection (IDI) engine.

Emission control in diesel engine

Direct injection of the liquid fuel into the diesel engine's combustion chamber avoids the crevice as well as wall quench that permits hydrocarbons to escape oxidation in carbureted engines, hence hydrocarbon emissions from diesel engines are comparatively low. Further diesel engines normally operate fuel-lean, hence there is adequate oxygen to burn some of the CO and hydrocarbons formed in midair in the cylinder.

NO, emissions from prechamber diesel engines are less due to staged combustion in the prechamber. Particulate emissions from diesel engines are higher than that of gasoline(petrol) engines.

NO, levels are high due to combustion in the turbulent diffusion flame in diesel engine in regions that are close to stoichiometric. Since the diesel engine normally operates in lean fuel condition, reduction catalysts are not feasible solution to the *NOx* reduction. The exhaust temperature changes significantly with load and it is on the lower side for non-catalytic lessening by ammonia. Hence, till a practicable system for eliminating *NOx* from diesel engine exhausts is developed, control strategies should be based on alteration of the combustion process. Diesel *NOx* emissions occur due to the thermal fixation of nitrogen in atmospheric, hence control of these emissions need to be achieved by decreasing the peak flame temperatures.

The diffusion flame permits most of the combustion to occur at locally stoichiometric conditions despite of the by and large equivalence ratio. The peak temperatures can be decreased through recirculation of exhaust gas or delay in the injection timing. Recirculation of exhaust gas in the diesel engine provides reduction in the peak flame temperature by dilution with combustion products. Injection timing delays results in the heat release to happen late in the cycle, thereby reducing the peak temperatures.

CO, hydrocarbon, as well as particulate emissions are not significantly influenced by less than 30 % exhaust gas recirculation. Emissions of NO are significantly reduced at this level of exhaust gas recirculation (EGR). As the EGR is increased further, CO and hydrocarbon emissions increase sharply.

Turbocharging is used to enhance engine efficiency as well as power. It might reduce particulate emissions by supplying more oxygen, possibly increasing mixing as well as soot oxidation, and by enhancing the intake temperature enhancing fuel vaporization. Turbocharging decreases the rise in particulate emissions with increase in EGR and decreases fuel consumption and hydrocarbon emissions. NO, emissions are increased by turbocharging.

Filling diesel in SI engine the fuel injectors nothing would happen since the diesel fuel will not evaporate well and hence the spark plugs would not ignite the fuel and the engine would not start. If gasoline(petrol) fuel is filled in diesel car's tank, excess gasoline(petrol) will cause failure of injector pump thereby damaging the injectors. Diesel engines can be operated, on heavier liquid fuels but the likely contributions of fuel-nitrogen to NO formation must be considered (Richard and John 1988).

Exhaust gas treatment An oxidation catalyst will be useful for the oxidation of CO and hydrocarbons. Particulate matter deposition on the catalyst can affect the performance.

Filters or ESPs can be employed to remove particles from the exhaust emission. After significant amount of particulate matter has been trapped to sustain combustion, the trapped material can be ignited by an additional heat source and burned for cleaning trapped particle. A filter element can be impregnated with a catalyst for promoting oxidation of the collected pollutants at lower temperatures.

Stratified charge engines

Stratified charge engines depend on a spark for ignition but utilize a non-uniform fuel distribution to make easy operation at lower equivalence ratios. The spark ignites the fuel-air blend in the prechamber. As it the fuel-air mixture burns, the rich blend expands, resulting in formation of jet through the orifice between the two chambers. The hot combustion product mixes rapidly and ignites the fuel-air mixture in the main cylinder. Thus NO, formation is slower compared to homogeneous charge engine.

Gas turbines

The engine volumes as well as weight are normally much smaller than that of reciprocating engines with same output hence gas turbine engine is used in aircraft, where both weight as well as volume should be minimized. *Gas turbine engines* are extensively used in aircraft, marine vessels high speed trains, and stationary applications. The emissions from these engines per power output are lower than other engines. They use jet fuel. At low loads, temperature as well as NO_x emissions are less, but CO as well as hydrocarbon emissions are greater. At high loads, CO as well as hydrocarbon emissions are less, but temperatures as well as NO_x emissions are more. Soot is formed at high loads, due to imperfect mixing as well as fuel rich zones. The speedy quenching of combustion products in these engines results in emission of considerable quantities of NO_2 The gas turbines are also preferred for electric power generation. The temperature exhaust emissions from the gas turbine very high and hence can be used to generate steam and can be used to drive a steam turbine.

These engines have higher output and low emissions in relation to engine size due to low-pressure combustion process. Even though this technology is been tested in road vehicles since the 1960s, no commercially viable vehicle has been developed.

The control of air pollution from gas turbine engines involves following factors:

1. *Atomization and mixing*: Poor atomization as well as imperfect blending in the primary combustion zone allows unburned hydrocarbons and CO to continue into the secondary zone, where the cooling occurs. It allows stoichiometric combustion and accelerate the formation of NO_x.
2. *Primary zone equivalence ratio*: To reduce NO_x emissions at high load, it is required to lessen the peak flame temperatures.

3. *Scheduling of dilution air introduction*: By diluting the combustion products complete oxidation, at low loads can be achieved.

Non-conventional IC engine

Many non-conventional IC engine have been researched and used to increase energy efficiency, emission reduction and other advantages discussed in below:

Dual-fuel engine: This operates on two fuels. Gaseous fuel (primary fuel) is either introduced with intake air or injected into the engine cylinder and compressed. The ignition of air–gas mixture is achieved by timed injection of diesel (pilot fuel) near the last part of the compression stroke.

Free-piston engine: These are also called 'crank less' engines. In this type of engine piston is directly joined to a linear load device like electric power or hydraulic pump, so the piston motion is not limited by the position of rotating crankshaft.

Gasoline(petrol) direct injection (GDI) engine: In this engine fuel is injected directly into the cylinder thereby avoiding problems related to the fuel film in the port. In this engine the evaporation of the fuel cools the air that allows higher compression ratios.

Homogeneous charge compression ignition (HCCI) engine: This engine is a hybrid of conventional CI as well as SI engines. Ignition in the HCCI is controlled by the charge mixture composition as well as its temperature history. Hence, HCCI can produce near zero NO_x as well as soot emissions.

Lean-burn engine: In this type of engine, air–fuel ratio used is more than the stoichiometric requirements. It is one of the techniques to improve the fuel economy, thermal efficiency, and to reduce exhaust emissions.

Variable compression ratio (VCR) engine: In this type of engine, a high compression ratio is used for good stability at low load operation. Low compression ratio is employed at full load operation to attain high specific outputs.

4.4.1 Positive Crankcase Ventilation System

A Positive Crankcase Ventilation (PCV) system is a one way opening for gases to escape in a controlled way from the crankcase of an ICE. This is essential since internal combustion unavoidably involves a small continual blow-by that occurs when the gases from the combustion leak past the piston rings to end up inside the crankcase, resulting in pressure to build up in the crank case. To control of the pressure inside crank case a PCV is used.

4.4.2 Diesel Particulate Filters

A diesel particulate filter (DPF) is used to remove diesel particulate matter from the exhaust gas in a diesel engine. Diesel generate a variety of particulate matter during operation of engine due to incomplete combustion. The composition of the particulates depends on engine type, and age. DPF can achieve efficiency of more than 85 %. Some DPF are intended for disposal once it is accumulated with particulate matter. Others are designed to oxidize the accumulated particulate matter or through other methods. This process is called "filter regeneration". Cleaning is also necessary as part of periodic maintenance.

Cordierite wall flow filters
Cordierite is a ceramic material that is used as catalytic converter supports. Cordierite filters are relatively inexpensive, and installation in the vehicle is simple.

Silicon carbide wall flow filters
Silicon carbide or SiC has a higher (2700 °C) melting point compared to cordierite. Silicon carbide filter cores look like catalytic converter cores.

Ceramic fiber filters
These filters are made from different types of ceramic fibers mixed together to form a porous media.

Metal fiber flow through filters
Filter made up of metal fibers—normally woven into a monolith have been used to control particulate matter. Metal fiber cores are more expensive compared to cordierite or silicon carbide cores.

Paper
Disposable paper cores are commonly used in coal mines or when a diesel machine such as forklifts that are used indoors for short periods of time.

4.4.3 Advanced Diesel Engine Technologies

The rising demand for mobility has increased number of automobiles on the road. Continuous improvement in technology has emerged series of advanced diesel engines technologies with power, performance and efficiency.

The water injection in the combustion chamber of CI engine has been proposed to overcome shortcomings of poor fuel atomization as well as high NOx emission. Studies by Fahd et al. revealed that injection of 10 % emulsion projected similar values of BTE compared to performance without emulsion. Further considerable reductions in CO and NO emissions at maximum load were observed.

Rotary engines have a triangular rotor that replaces the piston. Their CO and hydrocarbon emissions are greater than from conventional engines. The NO_x emissions in these engines are same as conventional engines.

Rocket internal combustion engines use petroleum fractions, hydrazin, alcohols, liquid hydrogen, ammonia, etc. as fuels. These engines use the oxidation agents which include tetranitromethane, nitric acid, liquid oxygen, hydrogen peroxide, etc. The emissions from these engines are highly toxic.

Steam Engines used in early automobiles lost favor to spark-ignition engines. These engines are theoretically capable of achieving high fuel efficiency, and low emission levels but not practical for automotive use.

Electric and Hybrid Vehicles have been currently favored in developed countries because of their mechanical simplicity as well as the absence of direct pollutant emissions. In Hybrid vehicle designs, internal combustion gas-turbine or Stirling engine would supplement the batteries.

Electric vehicles are not accepted in large numbers in developing world due to lack of recharging facility during travelling and emergency. Many developing countries have adopted this technology as power supply is available in parking areas and work places.

Fleet characteristics that influence emissions are: number and type of vehicles in use, vehicle utilisation, Age profile of vehicle fleet, choice of mode for passenger/goods, and availability of vehicles with new technology in the market. Operating characteristics that influence emission of air pollutants are: Altitude, ambient temperature, humidity, length of trips, number of cold stats, speed, loading, driving pattern, traffic congestion, capacity/quality of instructor, traffic control system.

4.4.4 Adsorption System

Evaporative emissions in vehicles are the result of fuel vapors escaping from the fuel system of vehicle. Vapors from the fuel tank as well as carburetor bowl vent (in carbureted vehicles) are connected to canisters containing activated carbon where the vapors are adsorbed. During certain engine operational modes air is drawn into engine through the canister where it burns.

4.4.5 Catalytic Systems

Diesel Oxydation Catalysts (DOCs) have been used since 1967. They were initially used for indoor forklifts as well as underground mining vehicles as air quality for workers was a main issue (Heck and Farrauto 1995). First oxidation catalysts lowered hydrocarbon and carbon monoxide. Later catalysts were used to reduce nitrogen using two-stage process. During 1980s, hydrocarbons, carbon monoxide as well as nitrogen oxides were simultaneously converted in a single ‘three-way catalyst’.

Limited emissions of gas pollutant (NO_x, CO, hydrocarbon) can be achieved from SI (spark ignition) car engines by catalytic systems.

Three ways catalysts TWC (reduction and oxidation) control the air pollution by following reactions

1. Reduction of NO (by CO)—over the rhodium catalyst (this is effective when oxygen is not present in flue gas):

$$2NO + 2CO \rightarrow N_2 + 2CO_2$$

2. Oxidation of CO as well as hydrocarbons—over the platinum catalyst (in the presence of small concentration of oxygen):

$$2CO + O_2 \rightarrow 2CO_2$$
$$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$$

Selective catalytic reduction

The term “selective” in **Selective Catalytic Reduction** (SCR) system indicates that the reducing agent prefers to selectively oxidize with the oxygen contained in the oxides of nitrogen instead of the oxygen in the exhaust gas. In SCR the reducing agent is injected into the exhaust system and converted to NH_3 and CO_2. The resulting NH_3 is used within a catalyst in the exhaust stream. The resulting reaction converts the unwanted NO_x into harmless nitrogen and water.

The catalysts used in SCR are platinum, palladium, titanium oxides, wolfram, vanadium.

The reduction process depends on chemical reactions of amine radicals (arising from ammonia decomposition) with NO as well as NO_2. The summary reaction assumes:

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$
$$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$$

These reactions undergo in vanadium catalytic reactor at the temperature of flue gas in the range of 330–430°C.

SCR has also found applications for removal of NO from flue gas of Gas turbines and Coal-fired boilers in power plants.

Ammonia by itself is toxic and hence urea and water is used as the reducing agent in the SCR system from which ammonia is extracted during an “on-board” chemical reaction.

4.4.5.1 Electrically/Chemically Heated Catalytic Systems

Electrically heated catalytic converters (EHC) raises the exhaust gas temperatures of low-temperature diesel cars up to 100 °C. EHC can prevent the catalytic converter from cooling during intermittent diesel engine operation in hybrid vehicles with a range extender. It can ensure maximum conversions immediately after the engine restart.

4.4.5.2 Close-Coupled Catalyst

Diesel engine operates at relatively low temperatures compared to gasoline(petrol) engines. Hence the exhaust gas temperature is maintained over the minimum light-off point of the exhaust system by positioning emission control system close to the engine. Such calytic system is termed as close-coupled catalyst.

4.4.5.3 Lean NO_x Catalysts

Since NO decomposition catalysts had many shortcomings to produce a commercial catalyst system (Iwamoto et al. 1991), several catalysts were promoted to achive selective catalytic reduction of NOx by hydrocarbons or other exhaust gas (Shelef 1995). Such systems used for selectively promoting the reduction of NOx by hydrocarbons are termed “lean NOx catalysts” (LNC) or “DeNOx catalysts”.

In the selective catalytic reduction, HCs react with NOx, instead of O_2, to form nitrogen, CO_2, and water.

$$\{HC\} + NOx \rightarrow N_2 + CO_2 + H_2O$$

4.4.5.4 Diesel Oxidation Catalyst

The diesel oxidation catalyst (DOC) promotes oxidation of many exhaust gas components by oxygen present in diesel exhaust. When passed over an oxidation catalyst CO, HC, and organic fraction of diesel particulates can be oxidized to harmless products. Additional advantage of the DOC includes oxidation of many non-regulated, HC-derived emissions, like aldehydes or PAHs, and reduction/elimination of the odor in diesel exhaust.

The emission reductions in the DOC can be explained by the following chemical reactions.

$$\text{Hydrocarbons} + O_2 \rightarrow CO_2 + H_2O$$

$$C_nH_{2m} + (n + m/2)O_2 \rightarrow nCO_2 + mH_2O$$

$$CO + 1/2O_2 \rightarrow CO_2$$

Oxidation catalyst will promote oxidation of all compounds. Oxidation of SO_2 to SO_3 with the subsequent formation of H_2SO_4, described by equation given below

$$2SO_2 + O_2 \rightarrow 2SO_3$$
$$SO_3 + H_2O \rightarrow H_2SO_4$$

Oxidation of NO to NO_2 is another undesirable reaction in some applications:

$$NO + 1/2O_2 \rightarrow NO_2$$

4.4.5.5 New Catalysts

Many catalysts were investigated since they are first used. Metals like copper, nickel as well as other base metals were very sensitive to fuel pollutants and lacked sufficient thermal durability (YuYao and Kummer 1977). Platinum group metals, showed good oxidation performance and good thermal durability, and have been used in catalytic converters (Twigg 2006). Rhodium is sometimes also added, for NO_X reduction (Twigg 2006).

Platinum, palladium as well as rhodium are coated on a carrier in the exhaust system of vehicles and act as catalysts to reduce levels of hydrocarbons, CO, and oxides of nitrogen. Autocatalysts lessen the pollutants in diesel exhaust by converting over 90 % of CO, hydrocarbons, and PM into CO_2 as well as water vapour.

Diesel engines operate at lower temperatures compared to gasoline(petrol) engines and run with a leaner gas stream containing more of oxygen. Under such conditions, platinum is a more active catalyst for conversion of CO as well as hydrocarbons to harmless emissions. Addition of some palladium to the platinum can improve its thermal stability.

Palladium is used as an oxidation catalyst, rhodium is used as a reduction catalyst, and platinum is used both for reduction as well as oxidation. Cerium, iron, manganese as well as nickel are also used as catalyst although each has limitations.

4.4.6 Other Control Technologies and Future Trends

One of the main disadvantages of IC engines is low efficiency and pollution due to incomplete combustion. In order to improve the emission properties as well as performance an additives are added to gasoline(petrol). Fuel additives are chemical compound that helps in improving engine performance as well as control emission characteristics.

Commonly used additives are:

Oxygenates additives

- Di-methyl carbonate (DMC);
- Ethyl tert-butyl ether (ETBE);
- Methyl tert-butyl ether (MTBE); and
- Ethanol.

Antiknock agent

- Ferrocene;
- Toluene;
- Iron pentacarbonyl; and
- Iso-octane (2,2,4-Trimethylpentane).

4.5 Needs of Electrical, Instrumentation and Mechanical Equipments

Electrical and mechanical equipment within an air pollution system in industries should have easy access to all potential maintenance areas and easy access to all inspection and test areas. Commissioning of air pollution control equipment involve visual inspection of structural connections for tightness and duct flanges for proper seal. This would be followed by checking System fan, electrical controls, alarm system, and leaks if any. Installation errors can have a negative effect on the operation and maintenance of the air pollution control equipment.

4.5.1 Electrical Equipment and Energy Requirement

Air Pollution control should not be energy intensive. Most manufacturing units use fans as well as blowers to supply air for process and ventilation.

Fan systems comprises of a fan, a drive system, an electric motor, flow control devices, ducts or piping, and air conditioning equipment (cooling coils, filters, heat exchangers, etc.).

Electricity needed to function fan motors makes a large fraction of the energy expenditure for space conditioning (US DOE 1989). Specific ratio is used to define fans, blowers and compressors which is the ratio of the discharge pressure to the suction pressure. Fans will have specific ratio up to 1.11 where as Blowers will have specific ratio of 1.11–1.20. Compressors will have specific ratio of more than 1.20.

The system resistance due to elbows, filters, bends, and equipments etc., enhances energy consumption.

4.5.2 Instrumentation in Air Pollution Control Equipment

Air pollution instruments can be grouped into: (1) concentration measurement instruments, (2) Continuous Emission Monitoring System (CEMS), (3) air measuring devices, (4) Meteorological Instruments.

Concentration measurement instruments
Measuring the pollution concentration is an important aspect in maintaining the air quality. These instruments are used to continuously monitor pollution concentration to measure the efficiency of air pollution control equipment.

Air measuring devices
These devices are used to measure velocity, volume or flow rate of air. Volume meters are used to measure the volume of gas and rate meters are used to measure the flow rate. Velocity meters are used to measure the linear velocity of a gas.

Meteorological instruments
Meteorological instruments are used are used make atmospheric dispersion related measurements.

4.5.3 Introduction to Piping and Instrumentation (P&I) Diagram

Conversion of a conceptual idea into execution of process industry is the aim of process engineer. Normally a project passes through: (1) basic engineering, (2) detailed engineering equipment fabrication/procurement, (3) civil/structural work, (4) erection as well as commissioning. **Figure 4.26 shows making of any P & ID.** Figure 4.27 shows sample P&I diagram and Fig. 4.28 shows tag description.

A piping and instrumentation diagram (P&ID) is a drawing in the process industry which shows the piping of installed equipment and instrumentation of the process. The P&ID shows pneumatic/hydraulic/electrical elements as well as instruments on the same diagram. It shows the interconnection of process equipment as well as the instrumentation used for controlling the process. The instrument symbols used in P&I diagram are normally based on International Society of Automation (ISA) Standard S5. 1. Letter combinations in PI&D diagrams is done according ANSI/ISA S5.1-1984 (R 1992).

P&I diagram comprises of (1) instrumentation and designations, (2) mechanical equipment with names as well as numbers, (3) valves and their identifications, (4) process piping, sizes as well as identification, (5) miscellanea—vents, sampling lines, reducers, drains, special fittings, etc., (6) start-up and flush lines, (7) flow directions, (8) interconnections references, (9) control inputs as well as outputs,

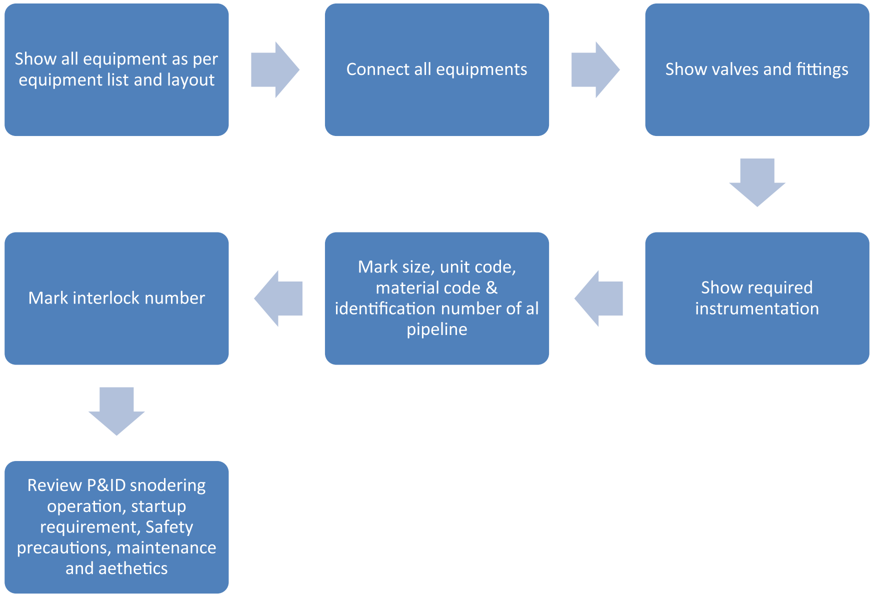


Fig. 4.26 Making of P&I diagram

interlocks, (10) interfaces for class changes, (11) computer control system input, (12) identification of components as well as subsystems delivered by.

Any wrong information in the P&I diagram may lead to disaster.

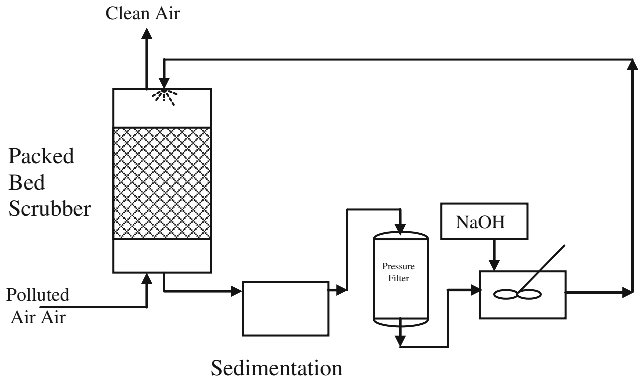
4.5.4 Mechanical Equipment Requirements and Related Issues

The main mechanical equipments in the air pollution control system are fans/blowers/tappers that comprise of moving parts attached an electrical motors. Apart from these equipments wet air pollution system also requires pump and compressors.

Fans

Fans are classified in two major types—centrifugal fans (uses a revolving impeller to move the air) and axial fans (move the air beside the axis of the fan).

Centrifugal fans enhance the velocity of an air stream by means of a rotating impeller. The speed amplifies as it reaches the ends of the blades. These fans are capable of producing high pressures, making them suitable for systems with moist/dirty air streams, high temperatures, and material handling.



Process diagram

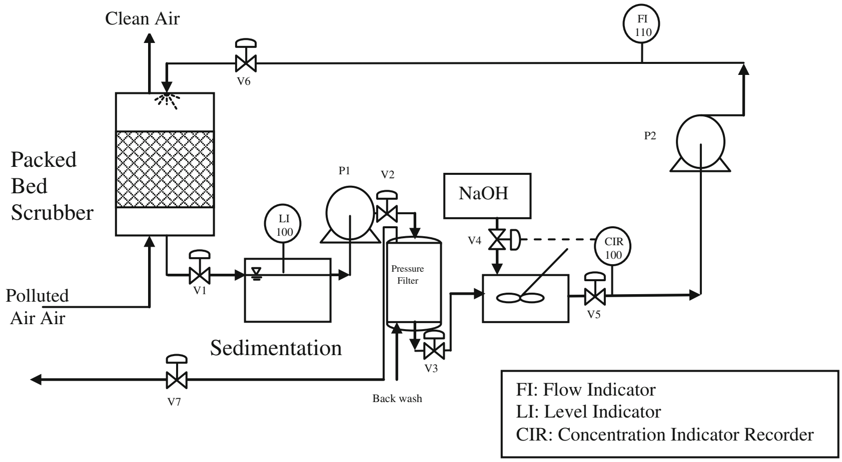


Fig. 4.27 Sample P&I diagram

Improper fan installation can result in early failure, which can cause damage the fan and production losses. Proper fan operation requires adequate foundation characteristics, correct drive alignment, as well as true fit-up to connecting ductwork (US DOE 1989).

Axial fans

Axial fans displace an air stream alongside the axis of the fan. They are inexpensive, compact and light. The three main types of axial flow fans are tube-axial, propeller, as well as vane-axial.

Blowers can achieve higher pressures as high as 1.20 kg/cm^2 compared to fans. They are also employed to generate negative pressures for vacuum systems. Blowers are of two types—the the positive displacement blower and centrifugal blower.

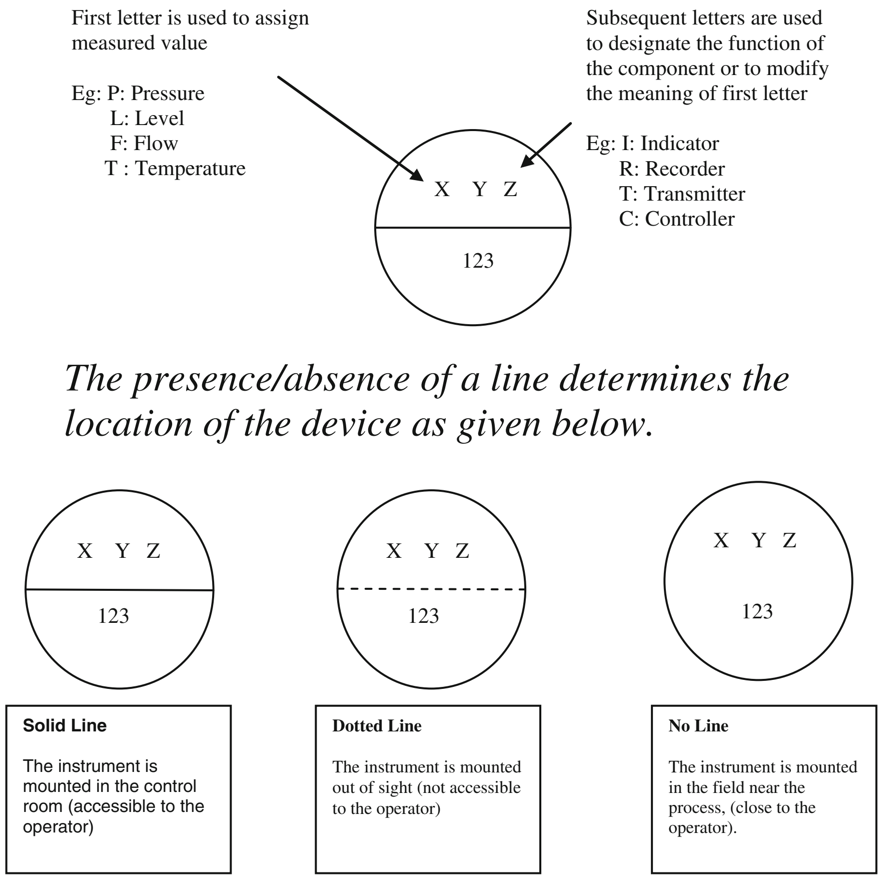


Fig. 4.28 Tag description

Centrifugal blowers

The impeller of centrifugal blowers is normally gear-driven and rotates at a rate of 15,000 rpm. Air is accelerated as the air passes through each impeller in multi-stage blowers as against the single-stage blower where air does not take many turns. These blowers usually operate against pressures between 0.35 and 0.70 kg/cm^2. Since the airflow tends to drop severely as system pressure enhances, they are usually used for applications that are not subject to clogging.

Positive-displacement blowers

Positive displacement blowers comprises of rotors that will "trap" air and push it. These blowers give a constant volume of air even when the system pressure changes. They are suitable for uses that are prone to clogging. They are usually belt driven to make possible speed changes.

4.5.5 Systems and Operational Issues

Many of the air pollution equipments are similar to chemical reactors and need safety precautions and skilled dedicated operators. The equipments in some places are just show pieces without contributing to any reduction of air pollutants.

Energy consumption and blower efficiency depends on design and technology which changes constantly. Many vendors often keep the technology as business secrete while some people patent the technology. Proper management of air pollution equipment needs spare parts and chemicals at site.

4.5.6 Real Time Control

Real time control of air pollution control system in most of the large scale industries is achieved by SCADA (supervisory control and data acquisition). It is a system operated by coded signals over communication channels to provide control of remote equipment. SCADA is a type of industrial control system (ICS). Figure 4.29 shows typical control room with SCADA. A SCADA system usually consists of: (1) Remote Terminal Units (RTUs), (2) programmable logic controller (PLCs), (3) telemetry system to connect PLCs and RTUs, (4) data acquisition server, (5) human–machine interface, (6) historian software, (7) supervisory (computer) system, (8) communication infrastructure, and (9) numerous process and analytical instrumentation.

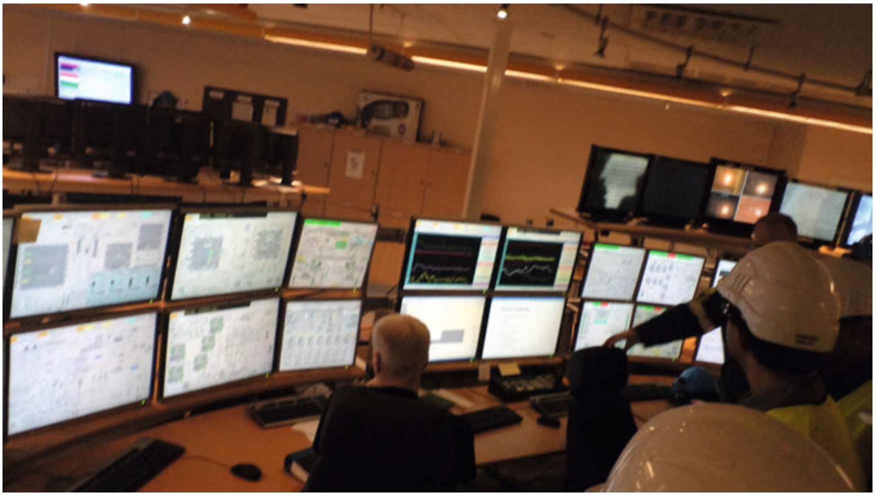


Fig. 4.29 Typical control room with SCADA

4.5.7 Indicators of Sustainable Performance; Systems Approach for Sustainability Assessment of Air Infrastructure

Sustainability performance indicators (SPIs) are used to measure an organization's performance, to monitor as well as report on future progress. SPIs can be grouped based on: (1) economic performance indicators (company turnover, quantity of products sold, profit, etc.); (2) social performance indicators (labor practices, broader issues affecting consumers, community, human rights, and stakeholders in society); (3) environmental performance indicators(greenhouse gas emissions, waste output, Pollution, water consumption, etc.)

4.5.8 Trouble Shooting

Choking, uncontrolled/undesirable reaction, electric shortcuts, corrosion, erosion can lead to trouble shooting. Hence the operator should thoroughly understand the principles of equipment and common trouble shooting problems associated with the equipments.

4.5.9 Operational Checks for the Air Pollution Control Equipment

Operation of any equipment needs routine checking for safety and economic reason. The daily operation checks usually involve pressure drop, flow rate, observation of stack outlet, cleaning cycle, pilot lights, and meters on control panel. This is done on routine with or without aid of instrument. Walk through inspection of the plant should include air pollution equipments and it should be checked for abnormal visual and audible conditions.

Apart from daily maintenance checks, the weekly, biweekly, monthly, quarterly and annual checks are carried out to replace parts with lower life span. Depending on the air pollution equipment an elaborate need to be prepared by operational personnel. Following paragraphs lists some of the operational checks need should be used for common air pollution control equipment.

Settling chamber

1. Container is not damaged
2. All access/hopper doors closed
3. All interlocks operational and locked out
4. No broken or missing keys

5. Covers on all locks are intact
6. Chamber and ducts are leakproof
7. Cover on all rotating equipment like, blowers, fans and pumps are not damaged and intact
8. The equipment and location are not slippery

Cyclone Separators

1. Inlet velocity adequate range of around 15 m/s
2. Container is not damaged
3. All access/hopper doors closed
4. All interlocks operational and locked out
5. No broken or missing keys
6. Covers on all locks are intact
7. Chamber and ducts are leakproof
8. Cover on all rotating equipment like, blowers, fans and pumps are not damaged and intact
9. The equipment and location are not slippery

Bag filter
Filter cloth

1. Cloth is not damaged
2. Sufficient stock of cloth is available

Rappers/pulse-jets

1. Rappers/Pulse jet are in working condition
2. Compressor is working and sufficient compressed air is available in case of bag filter with pulse jet

Hoppers

1. Discharge throat and poke holes clear
2. Baffle door as well as access door closed
3. Heaters, vibrators, as well as alarms operational

Housing

1. Container is not damaged
2. All access doors closed
3. All interlocks operational and locked out
4. No broken or missing keys
5. Covers on all locks

Bio towers

Packing media

1. Proper solid to void ratio is maintained
2. No variation in pressure, velocity

Health of biomass

1. Micro organisms are not subject to shock loads
2. Micro nutrients are provided if necessary

Housing

1. Container lining material is not damaged
2. All access doors closed
3. All interlocks operational and locked out
4. No broken or missing keys
5. Covers on all locks
6. Container is not damaged
7. All access/hopper doors closed
8. All interlocks operational and locked out
9. No broken or missing keys
10. Covers on all locks are intact
11. Chamber and ducts are leakproof
12. Cover on all rotating equipment like, blowers, fans and pumps are not damaged and intact
13. The equipment and location are not slippery

Scrubbers/absorption equipment

Pumps

1. Working and not leaking
2. Do not make abnormal noise
3. Energy consumption is normal

Spray nozzle

1. Nozzles are not choked
2. The droplet sizes are uniform and as per requirement
3. The connecting pipes are not leaking

Packing media

1. Proper solid to void ratio is maintained
2. No variation in pressure, velocity

Absorbing liquid

1. Chemical property and concentration are adequate
2. Sufficient stock of concreted absorbing chemical is maintained

Treatment plant of absorbing liquid

1. Treatment plant to treat dirty absorbing liquid is functional

Housing

1. Container lining material is not damaged
2. No broken/missing keys
3. All access doors closed
4. Covers on all locks
5. All interlocks operational as well as locked out
6. Container is not damaged
7. All access/hopper doors closed
8. All interlocks operational and locked out
9. No broken or missing keys
10. Covers on all locks are intact
11. Chamber and ducts are leakproof
12. Cover on all rotating equipment like, blowers, fans and pumps are not damaged and intact
13. The equipment and location are not slippery

ESP

Blowers

1. Pressure drop is within limits specified by manufacturer/vendor
2. Velocity and flow quantity is as per manufacturer/vendor
3. No undesirable noise is heard
4. Guards are in position
5. The blower case is free of damage

Collecting plates

1. Free of bows and sharp edges
2. Free of excessive dust buildup
3. Support system is square as well as level
4. Corner guides as well as spacer bars free
5. Gas leakage baffles in place as well as not binding

Hoppers

1. Discharge throat as well as poke holes clear
2. Baffle door as well as access door closed
3. Level detector unobstructed
4. Heaters, vibrators, as well as alarms operational

Discharge electrodes

1. No breaks or slack wires
2. Suspension weight free on pin
3. Wires are free in guides
4. Rigid frames square and level
5. Rigid electrodes are sound and straight
6. Excessive dust buildup is absent

Top housing or insulator compartments

1. Insulators/bushing clear and dry
2. All grounding chains in storage brackets
3. Heaters intact,
4. Seal-air system controls, alarms,as well as dampers, are in place and operational
5. Seal-air fan motor rotation correct, or vent pipes free
6. All access doors closed

Rappers

1. Swing hammers or drop rods in place and free
2. Guide sleeves and bearings undamaged
3. Control as well as field wiring are properly terminated
4. Indicating lights as well as instrumentation is operational
5. All interlocks are operational and locked out
6. No broken or missing keys
7. Covers on all locks

Transformer-rectifier sets

1. Surge arrestor not cracked/chipped and gap set
2. Liquid level acceptable
3. High-voltage connections are proper
4. Precipitator, output bushings, bus ducts, conduits are grounded
5. Field wiring between controls as well as devices prior to startup is correct, complete, and labeled properly

Rectifier control units

1. Controls grounded
2. Power supply as well as alarm wiring properly completed
3. Interlock key in proper place

Housing

1. Contaner is not damaged
2. All access/hopper doors closed
3. All interlocks operational and locked out
4. No broken or missing keys
5. Covers on all locks are intact

6. Chamber and ducts are leakproof
7. Cover on all rotating equipment like, blowers, fans and pumps are not damaged and intact
8. The equipment and location are not slippery

4.5.10 Odour Management

An odor is physiological response to commencement of the sense of smell (Stern 1977). It can be caused by one or mixture of many chemical compounds. Objectionable odor is cause for complaint.

Odors as well as objectionable vapors are controlled by Afterburners, vapour condenser, catalytic oxidation and absorbers. In Afterburners odorous vapors are exposed to a high temperature flame at 1200–1400 °F and are oxidized into carbon dioxide and water vapor.

Vapor condensers are used in processes where the emissions contain large quantities of moisture. *Catalytic oxidation* in the presence of a suitable catalyst is used for odor management. But main disadvantages of catalytic oxidation are: High initial capital costs and periodic replacement of catalysts. Absorption systems for odor control use of liquid absorbents to remove odorous substance from emissions.

If the odor is not a toxic substance, dilution is the least expensive control method. Dilution can be achieved by adding dilution air to emission or by using tall stacks. Height of a stack needed to reduce the odor can be calculated by applying the diffusion equations.

Closing an odorous system is one way to prevent the release of the odor. Another way is to substitute a less acceptable odor within a process. Many odorous compounds can be converted to compounds of nonodorous substances.

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Chapter 5
Sustainable Industrial Air Pollution Management

Abstract Gone are the days wherein industries are considered as main culprits of air pollution. The industries chimneys with emissions are hardly symbol of development and most of the air pollution equipments are available at competent prices with good service backup. Apart from end of pipe pollution control equipment this manufacturers are adopting new methods. This chapter discusses extended producers responsibility, extended polluters responsibility, zoning atlas for siting industries, green technologies, green belt, environmental impact assessment and solutions in some important air polluting industries.

Since industrial revolution the air pollution increased in urban areas. The landscape of industries changed over the years and shifted from UK, Europe, USA to countries in Asia. The reason is simple. The stringent environmental laws and costly man power resulted in establishment of most of the manufacturing units in Asian countries while the developed countries shifted their focus on education, consultancy etc. The Asia also became market for new products and services.

Apart from chimney fugitive emissions (Fig. 5.1) also contribute to air pollution in Industries. A wide range of pollution control methodologies have been developed and it is now possible to reduce or entirely eliminate pollution.

Few large scale industries and many small scale industries have clustered together in few cities based on access to market; infrastructure pertaining to transportation; skilled man power; subsidies; availability of raw material and political support.

Technology development has shown the ability of providing advantage of economic growth and other benefits. It has also shown ability to also minimizing the negative impact on the environment. The interrelation between the environment as well as technology is complex and inconsistent (Grübler 1998; Grübler et al. 2002). Technologies use resources as well as impose environmental stress. Technologies can also lead to efficient use of resources, reduce stress on the environment. It can also be used for cleaning the environment which referred to as sustainable technology development (Weaver et al. 2000). In order to make development of technology sustainable, change in technology alone is not sufficient. It should also include changes in the social as well as institutional dimensions, like the regulations, user practices, and industrial networks (Geels 2002; Musango 2012).

R. Chandrappa and U. Chandra Kulshrestha, *Sustainable Air Pollution Management*, Environmental Science and Engineering,
DOI 10.1007/978-3-319-21596-9_5

Fig. 5.1 View of piping arrangements with fugitive emissions in a paper industry

5.1 Sustainable Principles in Industrial Air Pollution Management

Industrial air pollution management is a regulated activity. In practice law of land is not enforced at many places due to loops holes within the system like low manpower with enforcing agency, corruption, poor record maintenance, misplaced records, poor quality of manpower, political intervention and prioritization of industry against environment. The following paragraphs discuss in brief the sustainable principles that need to be adopted by policymakers.

Prioritize air pollution in policies
This participle needs to be adopted by policy makers. The urge to enhance GDP, living conditions, number of cars, per capita electricity consumption often makes policy makers to oversee impact of air pollution. Air pollution can impact environment and health of people immediately or slowly. While acute impact draws the media/public attention immediately the chronic impact goes unnoticed. Figure 5.2 shows lungs of people affected in Bangalore. The anatomy and forensic department of medical collages in Bangalore have observed that the lungs of adults are gray due to deposition of pollutants over the period as against the lungs of young children. The lungs of goat/sheep in slaughterhouse and meat shops of Bangalore are pink as they are reared in pollution free countryside and slaughtered within few year of their birth.

The urbanisation and subsequent air pollution due to poor transport and improper industrial location across the world has taken lives of citizens and fragile environment which is not documented properly.

Define Airshed and formulate air quality Management plan
An airshed is an area where air the movement (and, hence, air pollutants) can be restricted by local geographical/weather conditions. For the convenience of implementing policy, concerned authority or project team define airshed considering following inputs:

Fig. 5.2 Views of lungs in Bangalore affected by coating of particles

1. **Geophysical boundaries**: In some cases geographical boundaries for sir shed can be well defined(e.g., in area of steep hills and coast). Whereas in other instances it is difficult define the airshed boundary. Hence the boundary is earmarked considering the importance to planning authority or project team.
2. **Emissions information**: This information is used to identify high density emission area so that importance and resources can be used effectively to improve the air quality of the area (like highly polluted area of a city or industrial cluster).

3. **Local weather**: Weather is a complex setup in any given area. It defines and restricts movement of pollutants. Hence the area where spread of pollutants are restricted (due to restriction of movement of air parcel is considered to define boundary of air shed).
4. **Political and administrative boundaries**: The airshed boundaries normally aligned to city and district boundaries so that the area is published as legal document and responsibility of the particular airshed can be given to a agency/organization.

Once the airshed is defined it is easy to formulate air quality management plan (AQMP) to highly critical area. AQMP are developed to improve air quality; decrease negative impacts on human/animal health as well as the environment.

Financial instruments

Financial instruments are used to lure polluters to curb pollution for financial gains. It is human tendency to possess more wealth. Hence both individuals and corporate bodies tend to accumulate more wealth and in the event many people/corporate don't mind violating laws.

The usual financial instruments used for protection environment protection are:

(a) **Taxation**: Taxation towards damaging environment would make people think more to avoid pollution.

(b) **Loans**: Financial assistant in terms of loans towards green technology and pollution control equipment would make polluters to opt for loans. Loans to government by international cooperation or by world bank, Asian Development Banks etc., would also help to polluters to get funds for the cause. But many organizations avoid projects under international funding to avoid additional work and financial audits.

(c) **Insurance**: Governments can oblige polluters to obtain insurance against damage to national property and/or third parties. Many countries have passed legislation in this regard.

(d) **Grants and subsidies**: Subsidies or reduced taxes for less polluting business, favourable interest rates for environmental friendly business; accelerated depreciation allowances,; etc., can motivate investors to buy the pollution control equipments.

(e) **Negotiable Permits and joint implementation**: Negotiable permits, fixes the total quantity of pollution permissible in an area. These financial instruments help to reduce the costs of environment protection by emissions trading through tradable certificates.

(f) **Deposits**: Deposits from polluter to enforcing agency is some time used as financial instrument to force him/her to install pollution control equipment/system. The deposit will be forfeited if polluter fails to install pollution control equipment/system as advised by enforcing agency.

(g) **Labeling**: The "green" or "ecolabel" is used to advice encourage "learned costumers" so that the service/products will gain popularity and capture greater market share. One practical successful example is "green taxi" in

Stockholm wherein less polluting taxies would be allowed to use unique symbol on car so that customers can prefer such cars. Further such taxies have the privilege to jump the taxi queue at airports.

Monitor air pollution
Monitoring air pollution is not complete solution to air pollution. But it captures data to make prudent decisions and planning. The monitoring should be made accurately without manipulation to avoid delay in proper decision.

Indentify sources of air pollution and pollutants
Identifying sources of air pollution both natural and anthropogenic is essential to improve air quality.

Trade between long term and short term gains
As discussed in previous paragraphs the economy of an area may improve by sacrificing health of citizens. But over the period they pose burden to economy due to medical cost and loss of skilled manpower. Hence policies and decisions should aim to achieve clean environment in long term.

Build smaller self sustaining cities
Cities in many countries have grown due to demand for housing and land for industries. No efforts have been made by government to curb growth of the cities/countries. The market, infrastructure and employment have propelled the growth of cities. Governments across the world have nurtured growing cities instead of curbing growth of cities. The mega projects, airports, harbours, have been the reason for influx of people.

Clean fuel
Not all fuels are eco-friendly. Some generate more emission than others. Eliminating non-eco-friendly fuel from market can create a better environment for the citizens.

Reduce consumption
Consumption of any goods will contribute carbon emission as well as air pollution due to activities involved in producing/transportation of goods. Public awareness to reduce consumption of unnecessary goods like cigarette and alcohol would not only reduce air pollution it will benefit the consumer as well.

Recycle waste
Creation of any product from virgin raw material would harm environment more harm as it consumes more energy and pollution. Recycling of material from waste helps achieving air pollution. Manufacturing metal objects by extracting metal from mining compared to recycling metal from waste.

Reduce construction
Real estate business and infrastructure have been major contributors of air pollution. It may not happen at construction site but the raw material production and transportation would pollute the air elsewhere as construction activity needs metal, aggregate, cement and other construction material apart from transportation.

Increase livestock food quality
Increase in livestock food quality can bring down methane emission from ruminants (mammal that digests food by softening in one of the four chambers and then regurgitating the semi-digested mass followed by chewing). Good quality food would reduce formation of methane during digestion.

Slaughter animals when they attain optimum weight
One school of thought to cut down addition of methane to atmosphere is to slaughtering animal when it attains maximum weight because further feeding would not generate additional meat but only generates methane. But the idea is cruel.

Increase research with respect to additives as well as vaccination to avoid methane generation in ruminants
Research on additives and vaccination to reduce methane emission from ruminants is under progress but not economical. A promising economical food additives and vaccination in future may help reduction in methane emissions from ruminants.

Decrease energy use
Decreasing energy by replacement of energy efficient machines/practice in industry would bring down emissions especially in countries where energy production depends on thermal power. Energy can be saved by avoiding its use where it is absolutely not necessary. Illuminating only those places where people move by installing proper sensors can greatly reduce unnecessary use of energy. Apart from saving electricity, reducing unnecessary travelling by using Information and Communication Tools (ICT) tools would also help citizens to cut energy.

Reduce energy loss/theft
Energy theft can occur in many ways. The practice of steeling energy from grid is common practice in developing country wherein the energy is stolen without formal connection and payment to concerned authority.

Reduce use of carbonaceous fuel like coal, oil
Reduced use of carbonaceous fuel and increased use of nonconventional energy sources like wind and solar power would be beneficial to quality of atmospheric air quality.

Behavioural change
Switchover to vegetarianism as major non-vegetarian eats ruminants which is major cause for global anthropogenic emission.

Avoid unnecessary travelling/entertainment which could cause air pollution
Crackers, unnecessary travelling and other unnecessary events can cause air pollution. Avoiding such activity can reduce emission of air pollutants. Increasing use of ICT by increasing video conferencing, teleconferencing, electronic communication, etc., can avoid travelling.

Increase forest area

Forest area is being sacrificed rapidly in developing countries for agriculture, industrialization, creation of large dams and other infrastructure. Trees acts as sink for variety of pollutants and increase in forest area and protecting them would help reducing air pollution in the area.

Proper waste management

Waste management is always thought collection, transportation, treatment and disposal. But this conventional approach has become source of mafia and pollution. Waste quantity is usually enhanced in records (compared to what is actually generated) to siphon funds from local bodies. Consumerism and purchasing power has been driving power for most of the economy. But at the same time it is also cause for waste generation. Waste dump in developing countries liberates noxious gases. Further in some places the waste is burnt onsite to reduce waste quantity.

Trap and use methane from waste processing and disposal activities

Waste methanisation and use has been successfully implemented in many parts of the world. Further the methane generated in landfill is also trapped and used in many developed countries. Such practice is yet to be started in many parts of the world especially in developing countries.

New polices and legislation

In spite of development, many countries are yet to change policies and legislation to changing scenario. Many countries still have standards for only criteria pollutants and do not bother to address the issue of toxic pollutants into the policies and legislation. Such practice often leads to monitoring of only those pollutants stipulated in the legislation thereby totally neglecting other pollutants which are more dangerous to health of citizens and environment.

Incorporation of carbon or energy taxes

Incorporation of carbon or energy tax is an economic solution to pollution problem. Such tax are not practical in rural and tribal settlement where forest residue and agricultural residue forms main source of energy.

International cooperation

International cooperation has been success in many instances. Montreal protocol is one such success story wherein many of the GHGs were phased out as part of exercise carried out. The funding and technical knowhow was exchanged among the countries to implement the obligation towards Montreal protocol.

Liberal funding towards research

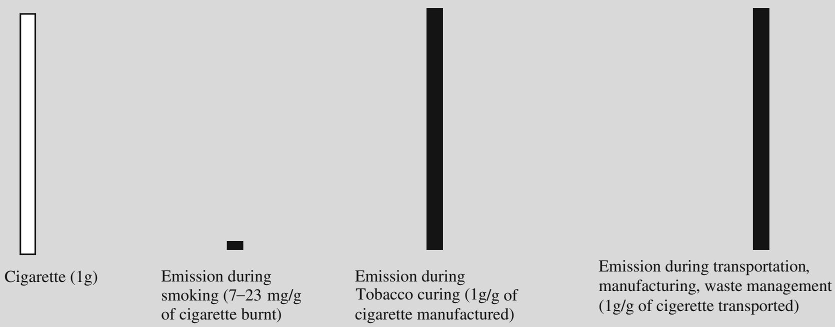
Funding towards research often is missing in most of the developing. The research would help decision makers and entrepreneur to adopt technology and policy to curb air pollution.

Penalties to air polluters
Penalties to stationary and mobile air polluters can be solution to air pollution. The practice needs legislation and enforcing agency to implement the law.

Subsidies and incentives for lowering air pollution
Subsidies and incentives especially to industries that curb air pollution can help reduce air pollution from the industrial activities.

Dissipation of air pollution related information
Dissipation of information about air quality and good practice can change attitude of people and helps curbing pollution. Box 5.1 shows example of pictorial representation of air pollution due to cigarette.

Box 5.1 Pictorial representation of air pollution due to cigarette
The pollutants from cigarette not arise from the burning tobacco and paper it also adds air pollutants during curing. The cigarette not only kills smoker, it also kills million of trees cut for the curing of tobacco. The cigarette is not only injurious to smokers lungs it is also injurious of forests which is cut for wood to cure tobacco and manufacture paper to wrap and pack cigarette. A cigarette less than one gram emits 7–23 mg of $PM_{2.5}$ but wood burning and waste incineration, add *particulate matter to atmosphere*.



5.1.1 *Extended Producer Responsibility*

An extended producer responsibility is a concept where in producer takes the responsibility to curb pollution even after its sale by establishing sinks to absorb/curb pollution generated during its production/use. The sinks need not be established at the point of production. It can be established where resources are available in adequate quantity. Sink should be established in such a way that it

Table 5.1 Examples of producer responsibility

Sl. No.	Product	Possible/suggested responsibility
1.	Coal mining	Plant and nurture one tree for every 1000 MT of coal mined
2.	Four wheeled vehicles	Plant and nurture four tree for every vehicle manufactured
3.	Two wheeled vehicles	Plant and nurture one tree for every vehicle manufactured
4.	Paper	Plant and nurture one tree for every ton of paper manufactured
5.	Oil refineries	Plant and nurture one tree for every 1000 MT of crude oil refined
6.	Cement	Plant and nurture one tree for every 1000 MT of cement manufactured
7.	Metal	Plant and nurture one tree for every 1000 MT of metal manufactured

Table 5.2 Extended polluters responsbility

Sl. No.	Product/service	Possible/suggested responsibility
1.	Railways	Plant and nurture one tree for every 1000 km travelled
2.	Ships/aircraft	Plant and nurture four tree for every 1000 km travelled
3.	Vehicles in road	Plant and nurture one tree for every 1000 km travelled
4.	Power plant	Plant and one tree for every 1000 t of fuel used
5.	Industries	Plant and nurture one tree for every 1000 MT of fuel used
6.	Saw mills	Plant and nurture 100 trees for every tree sawed

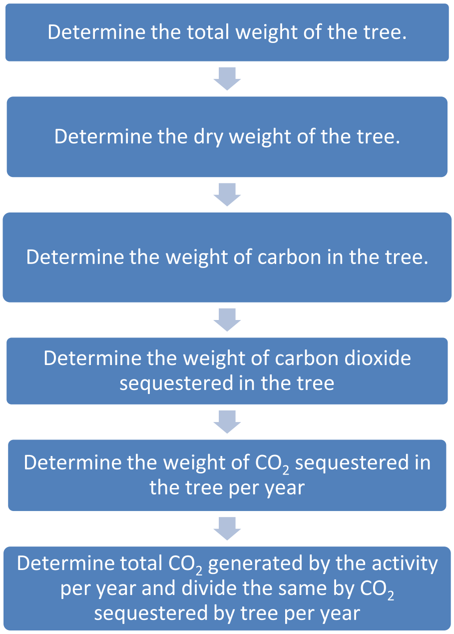
absorbs pollution created during manufacturing/use. Table 5.1 gives some of the examples of extended producer responsibility.

5.1.2 *Extended Polluters Responsibility*

Polluters often think there responsibility is over if they curb pollution at pont of generation. Under extended polluters responsibility polluters shall create sinks especially for pollutants like CO_2 which is not removed at the point of generation. Table 5.2 gives some of the examples for extended polluters responsibility.

A more elaborative way of calculating number of trees required to absorb CO_2 emitted from an activity is determining the average weight of CO_2 sequestered in a tree per year and dividing the total CO_2 generated by activity in a year (Fig. 5.3).

Fig. 5.3 Calculating number of trees required for CO_2 sequestered from activity



The root system weighs around 20 % of above-ground weight of the tree. Hence multiply the above-ground weight of the tree by 120 % to calculate total weight of tree. Average tree is 72.5 % dry matter as well as 27.5 % moisture. Hence, to determine the dry weight of the tree, multiply the weight of the tree by 72.5 %. To determine the weight of carbon in the tree, multiply the dry weight of the tree by 50 % is average carbon content of wood is 50 %.

CO_2 is madeup of one molecule of Carbon and two molecules of Oxygen. The atomic weight of Carbon is 12 and the atomic weight of Oxygen is 16. Hence the molecular weight of CO_2 is 44.

The ratio of CO_2 to C is 44/12 = 3.67.

Hence, to determine the weight of CO_2 sequestered in the tree, multiply the weight of carbon in the tree by 3.67.

Divide the weight of CO_2 sequestered in the tree by the age of the tree to get CO_2 sequestered per year.

But in practice it is difficult to calculate the amount of CO_2 sequestered per tree due to the complexity of the variables involved. Further no one is sure about the life of the tree due to changing climate, depleting ground water table, pest attack, death of tree due to disaster, cutting tree for making way to development, injury to tree during life time. Further sawmills and paper manufacturing will stop the life of a old tree and its sequestering activity and hence require more tree sapling to be replaced considering it slow growth phase to attain the age of tree sawed or pulped.

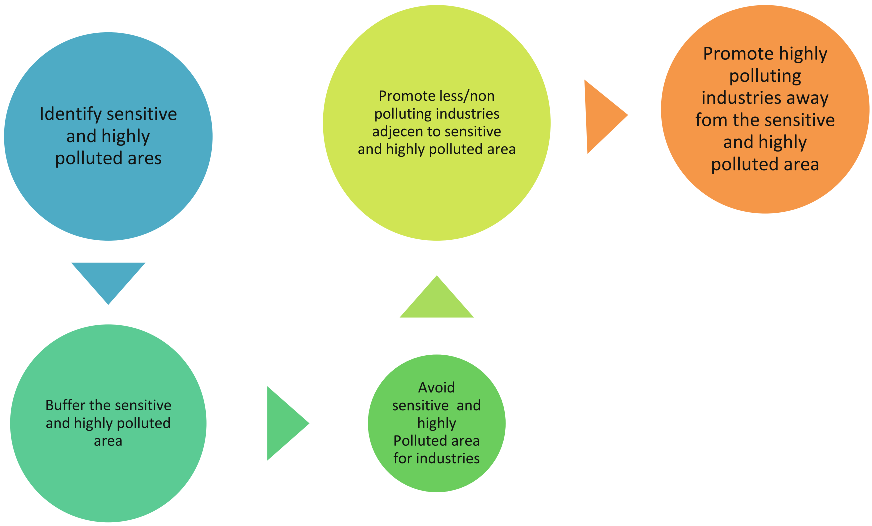


Fig. 5.4 Concept of preparing zoning atlas

5.2 Zoning Atlas for Siting Industry

For centuries, urban air pollution has been problem for city dwellers. The industrial revolution increased number of point sources of larger emissions. Elevated stacks were used as only mode of to control air pollution. Pollution from transportation increased 20th century. The key factors that determine the quality of ambient air quality are: (1) emission sources and quantity/quality of emission; and (2) topography as well as climate of the area.

Zoning Atlas can be adopted to establish new industry or industrial area considering sensitive areas. Area within a country or district can be identified that are suitable for industry using Geographic Information Software (GIS) software. The concept of preparing coning atlas is given in Fig. 5.4. The preparation of Zoning Atlas for Siting Industries (ZASI) involves identifying sensitive areas and creating buffer around sensitive areas. Figure 5.5 shows schematic diagram of zoning atlas.

Sensitive areas includes but need not be restricted to: (1) Reserved forest, (2) Prime agricultural, (3) Human settlement, (4) Monuments, (5) Hills and valleys, (6) Water bodies, (7) international/interstate borders, and (7) Zoos. Highly polluted areas are those areas where pollution level in ambient air quality exceed standards set by country.

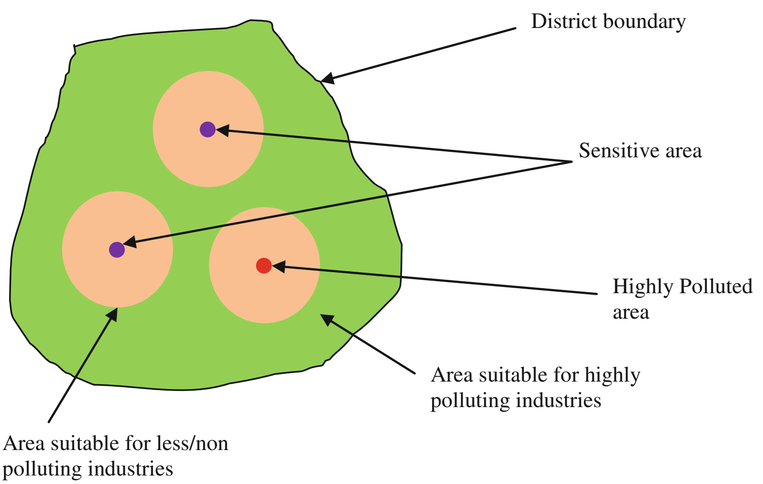


Fig. 5.5 Schematic diagram of zoning atlas

5.3 Green Technology

Resource scarcity, inefficient use of resources, pollution, hazardous substances/ waste, inefficient energy consumption and carbon emission has lead to innovation that can use resources optimally an reduce waste/pollution. Green manufacturing aims to reduce the quantity of natural resources required to produce goods through efficient manufacturing processes and reduce waste/pollution by efficient transport and logistics.

Green technology is the use of the environmental science/technology for the development as well as application of equipment, products and systems to preserve the natural resources and environment (Show 2011).

The green technology or green manufacturing or sustainable manufacturing can help clients to optimize the energy needs. Benefits of greening include:

- Reduced material waste
- Increased energy efficiency
- Improved corporate image

Figure 5.6 shows schematic diagram of concept of green market. Greener products and services are more desirable to growing segment of consumers as well as business customers. Green supply chain management has been favored in the last few years due to public awareness, environmental, economic, or legislative reasons. But main barriers to green technology is resistance to technology adoption, lack of organizational encouragement, poor quality of human resources, market competition, lack of government support, lack of top management commitment, and cost implications.

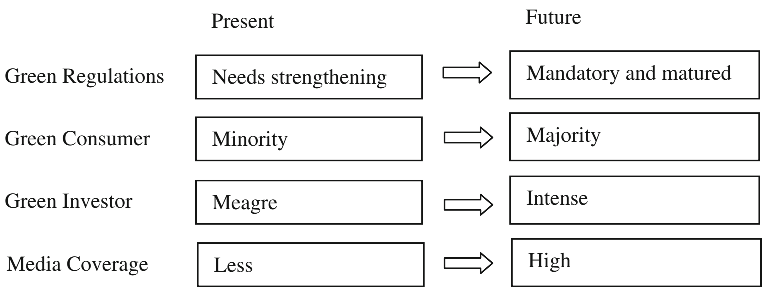


Fig. 5.6 Schematic diagram of concept of green market

The field of green technology include evolving group of environmental friendly process as well as materials, such as generation/use of solar power. Limited knowledge of the availability as well as benefits of green technology has resulted its limited use. Potential users also face problem of identifying suppliers of the knowledge and machineries.

5.4 Green Belt

Even though numerous pollution control equipment is available for controlling air pollution, some trace quantities of pollutants are still released. Green belts (Figs. 5.7 and 5.8) are effective in such scenario. Leaves and other aerial parts of plants sorb pollutants on their surface thereby reducing pollution in ambient air. Plants grown to function as pollution sinks are called green belts.

Since the plants are leaving organism, they have tolerance towards pollutants, crossing threshold limits will harm the plants. In a nut shell green belts are effective as long as pollution is within tolerance limits of plants.

Fig. 5.7 Trees adjacent to roads

Fig. 5.8 Green belt developed in a thermal power plant

For effective removal of pollutants, it is necessary that plants grow with adequate nutrition and water supply. Plant species with adequate height of crown, openness of foliage in canopy and broad leaves will trap pollution more effectively. For removal of particular matter apart from sufficient height/spread of crown, leaves should be supported on firm petioles and trees should have: (a) roughness of bark, (b) epidermal outgrowths on petioles, and (c) abundance of axillary hairs.

Choice of plants for roadside should act as screen between traffic and roadside residence/pedestrians. Hence choice of plants should include shrubs and trees. Since safety of traffic is a major concern, shrubs in traffic islands should be below eye-level of motorist.

Trees are efficient in trapping atmospheric particles (Freer-Smith et al. 2005; Nowak et al. 2006; Peachey et al. 2009; Qiu et al. 2009). Trees pose hindrance to free movement of air pollutants and hence it may stagnate in roads where there is high traffic.

Trees can improve the environment by improving air quality, providing shade and humidity, increasing biodiversity and aesthetic qualities. But they require maintenance and can also damage property. Trees persist and flourish at favorable condition without human interference.

The trees remove pollutants by (1) entrapment in the leaves and bark, (2) augmenting the settlement of particulate by reducing speed, (3) impingement of particulate matter by leaves and twigs, (4) adhesion of pollutants on wet surface, and (5) absorption of pollutants on wet surface. Trees can emit VOCs that form secondary pollutants after reacting with oxides of nitrogen. Trees also remove carbon dioxide by photosynthesis. Removal of pollutants is a local effect, whereas the formation of secondary pollutants from chemicals emitted by trees occurs downwind of the trees. But the overall benefit due to trees can exceed impact due to contribution of secondary pollutants.

Nations across the world have responded to growing problems associated with extensive development patterns by creating a range of policy instruments to manage urban growth as well as protect open space (Bengston et al. 2004; Bengston and

Yeo-Chang 2005; Richardson and Bae 2004). But the efficiency of these policies needs to improve. National urban containment policies are in place for many years in some countries. In the USA local urban containment programs are created by individual municipalities (Dawkins and Nelson 2002).

In the context of urban setup a greenbelt is a greenspace such as farmland/forest, that surrounds an urban area and is anticipated to be a permanent barrier to urban growth. Development need to be strictly regulated/prohibited in greenbelt area. Greenbelts may be created by acquisition, as in Boulder, Colorado (Pollock 1998), or may be created by regulation of private property.

In practice greenbelt development in developing countries will have practical difficulty due to real estate mafia and pressure to provide housing to citizens. The rapidly growing cities in developing countries have expanded many folds in past few decades.

London was the first main city to establish a greenbelt in the late 1930s (Munton 1983). Other cities that include are Ottawa and three other Canadian cities (Taylor et al. 1995); Tokyo, Seoul, and Bangkok (Yokohari et al. 2000); and Vienna, Berlin, Barcelona, as well as Budapest (Kuhn 2003).

Greenbelts also generate social as well as environmental benefits such as amenity as well as recreational value protection of open space, and ecosystem services (Bengston and Yeo-Chang 2005).

5.5 Environmental Impact Assessment

Environmental Impact Assessment (EIA) is evaluation of possible impact of proposed project on environment. The study plays a main role in large projects like thermal power plants, highway construction, airports etc. How big a project should be to conduct EIA studies depends on the law of the land and conditions laid down by lending/donor agency. Over the years EIA has become part of legislation in most of the countries. It is also an important step in decision making about mega projects. Many donor/lending agencies have set their own guidelines and so as many countries.

EIA is usually carried out by a consultant or consulting agency hired by project proponent. The report is usually reviewed by an array of experts of government/lending/donor agency.

The governing principles of EIA preparation are—(1) defining base line, (2) explaining proposed project, (3) identifying probable impacts and charting required mitigation measure. Disaster Management Plan (DMP) and Emergency Preparedness Plan (EPP) are also prepared in most of the project.

The baseline in the context of EIA means existing environmental setup which includes but do not restrict to geological/biological/meteorological/social setup.

Usual aspects and subaspects of baseline studies are given in Table 5.3. Geological set up includes rocks, soil, minerals, geological formation in the area. Contours maps, toposheets and satellite pictures are extensively used to define the geological setting.

Table 5.3 Usual aspects and sub aspects of baseline studies

Sl. No.	Aspect	Sub-aspect
1	Air	SPM
		SO_x
		NO_x
		CO
		Pb
		Hydro carbon
2	Water	Surface water quality
		Ground water quality
		Surface water bodies in the project vicinity
3	Soil	Soil quality
		Soil distribution in the project vicinity
4	Noise	Sources
		Background noise levels
5	Meteorology	Temperature
		Wind speed
		Wind direction
		Precipitation
		Cloud Cover
		Humidity
6	Topography	Hills and valleys
		Plains
		Slopes
7	Geology	Rocks
		Minerals
		Geological formation (faults, folds etc.,)
		Ground Water Depth
8	Socioeconomic	Demographic distribution (age, sex, population density, male to female ratio)
		Education (number/percentage having primary/secondary/university education)
		Educational institutions—Schools and colleges in the project vicinity
		Infrastructure—Roads, railways, airports, ports/harbours, electricity, water distribution, sewage collection, industries, hospitals etc.
		Religious—temples, churches, mosques and other religious places
		Crime—murder, thefts, physical assault, pick pockets, communal riots, violation of traffic rules, violation of environmental laws

(continued)

Table 5.3 (continued)

Sl. No.	Aspect	Sub-aspect
		Income—number of earning members, number of dependents, income per person
		Occupation—primary, secondary, tertiary
		Settlements—number of villages, towns, cities etc.,
		Health—dominant commutable disease, non-commutable disease
9	Land use land classification	Forests
		Mangroves
		Waste land
		Built-up areas
		Agricultural land
		Mines
		Water bodies
10	Biological	Types of dominant flora—trees, shrubs, herbs, aquatic plants
		Types of dominant fauna—mammals, reptiles, birds, insects, arachnids, aquatic animals
		Distribution of flora and fauna
		Endangered and endemic species
11	Solid Waste	Municipal solid waste
		Biomedical waste
		E-Waste
		Hazardous Waste
12	Transportation	Road network
		Railway network
		Harbours/ports
		Airports
		Inland transportation

Biological setup includes density/distribution of existing flora/fauna in the project locality. The base line studies need to enlist major species in the area and highlight endangered/endemic species.

Climatic setup includes temperature, humidity, wind speed, cloud cover, precipitation (rainfall, snow fall, and hail), length of day/night. In addition to field measurement the study team also need to collect historic data from nearest meteorological centre.

The social setup in project site include population, sex ratio, employment patter, income pattern, age distribution, health, access to electricity, access to water/sanitation, crime, assets owned by people living in the area, education etc.

Apart from above the base line should also define ambient air quality, ground/surface water quality, noise levels, soil quality and land use pattern.

Once base line is defined impacts are predicted depending on the nature and magnitude of the project. Conventionally impact is predicted using following method—(1) Ad hoc, (2) Network, (3) Checklist, (4) Overlays, (5) Matrix, and (6) The Battelle Environmental Evaluation System.

In Ad hoc (Ad hoc is a Latin phrase which means "for this". It signifies a solution designed for a particular problem/task, non-general, and not anticipated to adapted to other purpose) method the assessing agency/person will just identify probable impacts due to proposed project based on past experience/literature.

In network method the impact is predicted by using network diagram of possible impact. The method may not provide magnitude of the impact, but it will ensure inclusion of all the possible impact making it easy for the reviewing authority to identify any missing impact. The impact network diagram for mining activity is given in Fig. 5.9.

Checklist (Table 5.4) method involves preparation of elaborate list so that every aspect is considered to predict probable impact to take prudent decisions.

Matrix (Table 5.5) method involves listing activity and environmental attribute in columns and rows to predict impact on different activity on identified environmental attributes. Table 5.6 shows ranking of alternatives.

The use of above methods will not quantify the magnitude of impact spatially. Hence overlay and mathematical models have been used over the year due to sophistication of graphic tools in information technology and improvement in computer hardware.

The overlay (Fig. 5.9) method is an effective visual aid, useful to make decision based on the impact projection before and after project. GIS technology comes in handy incorporating collection, storage, transformation and display of spatial Data.

A fairly scientific methodology is use of mathematical models to predict impact after the project. As shown in Fig. 5.10 the model is used to simulate the pollution level after the project by adding back ground concentration to predicted pollution levels. The end result is compared with national ambient air quality standards to know whether the project would affect the air quality beyond the standards. Figure 5.11 shows Output of mathematical model and concentrations after adding back ground.

Use of mathematical model is not fool proof as input data (wind direction, wind velocity, temperature, stabilisation class, stack emission, stack velocity, stack height, etc.,) can be manipulated by the consultants to show the concentration of pollutants will be within the limits. Other ways to manipulate data is changing the background concentration. The mega projects usually get speedy clearance without much cross verification due to eagerness to improve the economy or poor understanding of subject by experts evaluating EIA or political pressure.

The Battelle method (Dee et al. 1973) is being used for predicting environmental impact quantitatively by splitting environmental impacts is split into four categories: Ecology, Aesthetics Environmental contamination, and Human interest.

Apart from preparing EIA some consultants also help project proponent in speedy clearance by giving bribe to concerned officials.

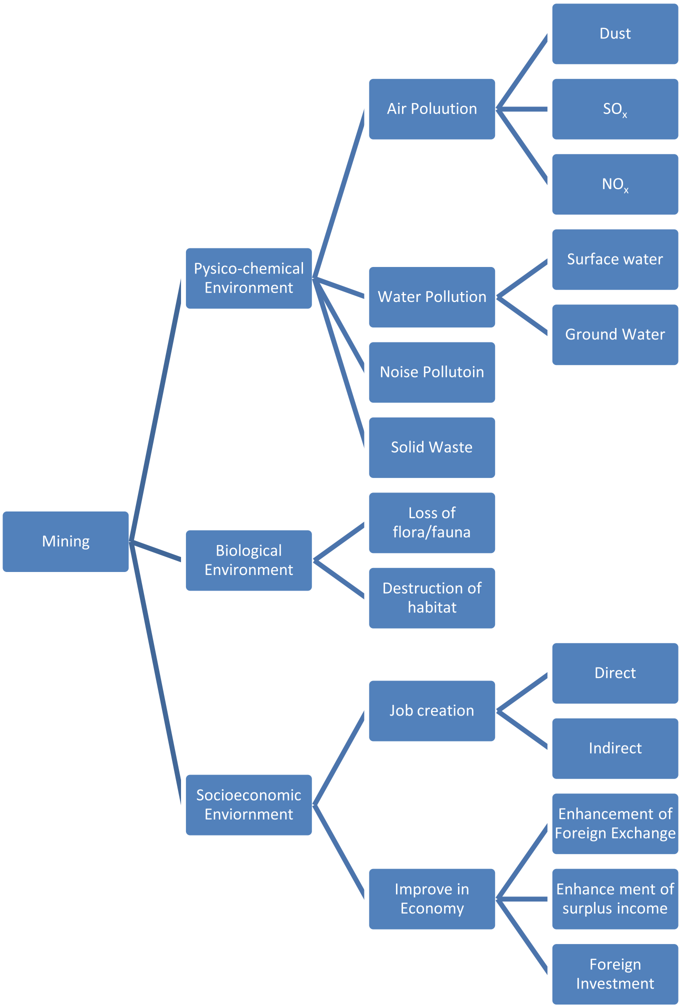


Fig. 5.9 Cause impact network analysis to predict environmental impact

5.6 Environmental Management System

Environmental Management System (EMS) is the management of an organization to improve environmental performance. Environment would be benefitted due to EMS when the programme is designed and implemented in a comprehensive, systematic and planned manner. The ISO 14000 family addresses many aspects of

Table 5.4 Sample check list for predicting impact for thermal power plant

Sl. No.	Activity	Nature of impact		Extent of impact	
		+ve	−ve	Temporary	Permanent
I *Construction*					
1.	Clearing the site		✓	✓	
2.	Earthwork		✓	✓	
3.	Transportation		✓	✓	
4.	Storage of raw material		✓	✓	
5.	Temporary shelter for labours		✓	✓	
6.	Planting new samplings	✓			✓
7.	Recruitment	✓		✓	
8.	Laying foundation		✓	✓	
9.	Scaffolding		✓	✓	
10.	Concrete mixing		✓	✓	
11.	Carpentry		✓	✓	
12.	Air conditioning		✓	✓	
13.	Painting		✓	✓	
14.	Installing machinery	✓		✓	
15.	Electrification	✓		✓	
II *Operation*					
1.	Coal receiving		✓		✓
2.	Water treatment and pumping		✓		✓
3.	Coal crushing/pulverising		✓		✓
4.	Coal feeding		✓		✓
5.	Steam generation		✓		✓
6.	Ash handling		✓		✓
7.	Wastewater treatment		✓		✓
8.	Recruitment	✓			✓
9.	Operation of turbine		✓		✓
10.	Feeding electricity to grid	✓			✓
11.	Economy of the area	✓			✓

environmental management. It offers practical tools for organizations to identify and control environmental impact in addition to constantly improve environmental performance.

EMS can be implemented without certification. But certification process will enhance commitment towards the EMS.

EMS in ISO 14001 certification is done by identifying significant aspects and a system is built involving top level management. A policy is formed based on

Table 5.5 Matrix method to predict impact of mining

		Physical Environment										Biological Environment						Social Environment										
		Landform	Nuisance	Climate	Pollution	Agricultural Soil	Ground Water	Surface Water	Sedimentation	Erosion/Land Stability	River Regime	Wetlands	Marine	Intertidal	Estuaries	Rivers	Lakes	Recreation	Landscape/Visual	Existing Land Uses	Historical/Cultural	Global economy	Risks and Anxieties	Local economy	Land Value	Human Settlement	Employment	Income
Construction	Top soil removal	-	-		-	-		-	-	-	-	-	-	-	-	-	-	-	-	-			-	+	-	-	+	+
	Preparation of area	-	-		-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	+	-	-	+	+
	wastes disposal	-	-		-	-		-	-	-	-	-	-	-	-	-	-	-	-	-			-	+	-	-	+	+
	waste water treatment	-	-		-	-		-	-	-	-	-	-	-	-	-	-	-	-	-			-	+	-	-	+	+
	Installation of campsites,	-	-		-	-		-	-	-	-	-	-	-	-	-	-	-	-	-			-	+	-	-	+	+
	Workshops storage facilities.	-	-		-	-		-	-	-	-	-	-	-	-	-	-	-	-	-			-	+	-	-	+	+
	Preparation of open pit area	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	+	-	-	+	+
Operation	Exploitation of open pits	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	+	-	-	+	+
	Mineral leaching		-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	+	-	-	+	+
	Transportation and disposal of materials in waste sites	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	+	-	-	+	+
	Mineral excavation	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	+	-	-	+	+
	Storage of mineral	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	+	-	-	+	+
	Process of mineral		-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	+	-	-	+	+
	Waste disposal	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	+	-	-	+	+
	Management of wastewater		-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	+	-	-	+	+
	Mineral trading																					+		+	+			
Closure and post closure	Closure of open pits	-	-							-													-	+			+	+
	Closure of solid waste piles	-	-							-													-	+			+	+
	Closure of heap leach pads	-	-					-		-													-	+			+	+
	Backfill waste dump sites	-	-					-		-													-	+			+	+
	Closure of storage sites	-	-					-		-													-	+			+	+
	Landreclamation	-	-					-		-								+	+				-	+			+	+
	Revegetation	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+			+	+

Table 5.6 Ranking of alternatives

Sl. No.	Parameters	No alternatives	Alternative I	Alternative II	Alternative III
Construction					
1.	Clearing the site	−3	−2	−1	−1
2.	Earthwork	−4	−3	−2	−2
3.	Transportation	−5	−4	−3	−1
4.	Storage of raw material	−1	−1	−1	−1
5.	Temporary shelter for labours	−2	−1	−1	−1
6.	Planting new samplings	+1	+1	+1	+1
7.	Recruitment	+4	+4	+3	+4
8.	Laying foundation	−4	−3	−2	−1
9.	Scaffolding	−2	−1	−1	−1
10.	Concrete mixing	−2	−1	−1	−1
11.	Carpentry	−2	−1	−2	−1
12.	Air conditioning	−2	−1	−1	−1
13.	Painting	−2	−2	−2	−1
14.	Installing machinery	−3	−2	−2	−2
15.	Electrification	−2	−2	−2	−2
Operation					
16.	Coal receiving	−4	−3	−2	−1
17.	Water treatment and pumping	−4	−3	−2	−1
18.	Coal crushing/Pulverising	−4	−3	−2	−2
19.	Coal feeding	−4	−3	−2	−1
20.	Steam generation	−5	−4	−3	−1
21.	Ash handling	−4	−3	−2	−1
22.	Wastewater treatment	−3	−3	−2	−1
23.	Recruitment	+4	+4	+4	+4
24.	Operation of turbine	−3	−2	−1	−1
25.	Feeding electricity to grid	−1	−1	−1	−1

significant aspects and manual and records are formulated by setting goals and targets set to achieve policy. The manual will be binding on all the decision including purchase, recruitment, choosing subcontractor, training, expenditure, and compliance to legislation etc. EMS is a significant tool to curtail environmental risks.

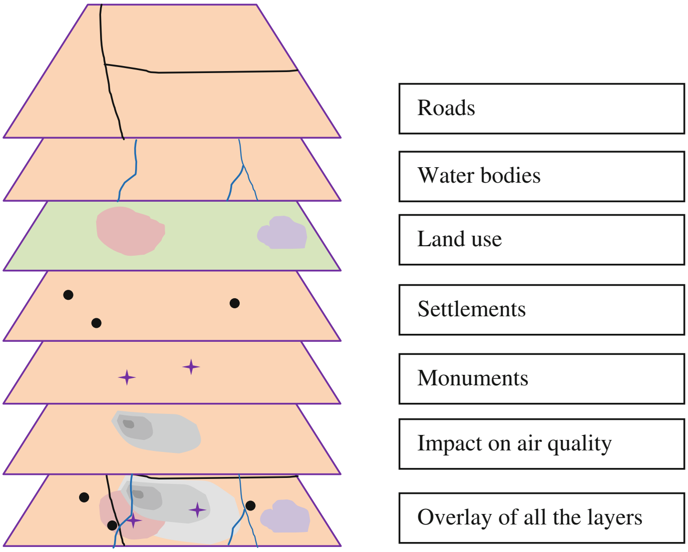


Fig. 5.10 Overlay concept

Identifying air pollution in a significantly air polluting industry can definitely benefit the society by curbing the air pollution.

5.7 Awareness

Awareness is something that can enhance the air quality to maximum extent. But effectiveness depends on target group to whom awareness is given.

Awareness should be designed to achieve reduction in pollution rather than just giving advertisement in few journal and magazines which does not have huge readership. Inclusion of topics in school curricula may improve the awareness among the future generation. The awareness among decision makers of government can result in procurement of only green products that pollutes less.

The general mode of awareness includes but not restricted to: (1) information on internet, (2) advertisement in television, radio, news papers and journals, (3) distribution of hand outs, (4) displaying posters and hoardings, (5) including the information to be dissipated in school syllabus, (6) displaying the message in sports events, movies, and TV shows, (7) printing on tickets bus/train and event show, (8) training, (9) conference, (10) sending messages through bulk SMS and emails, (11) message spreading through recorded message or call centres, (12) printing message on calendar, (13) using social websites like face book and twitter, and (14) organising events to promote idea/message. These modes of awareness can be used for controlling air pollution. Including pollution control and environment protection in political campaign can appeal to educated groups.

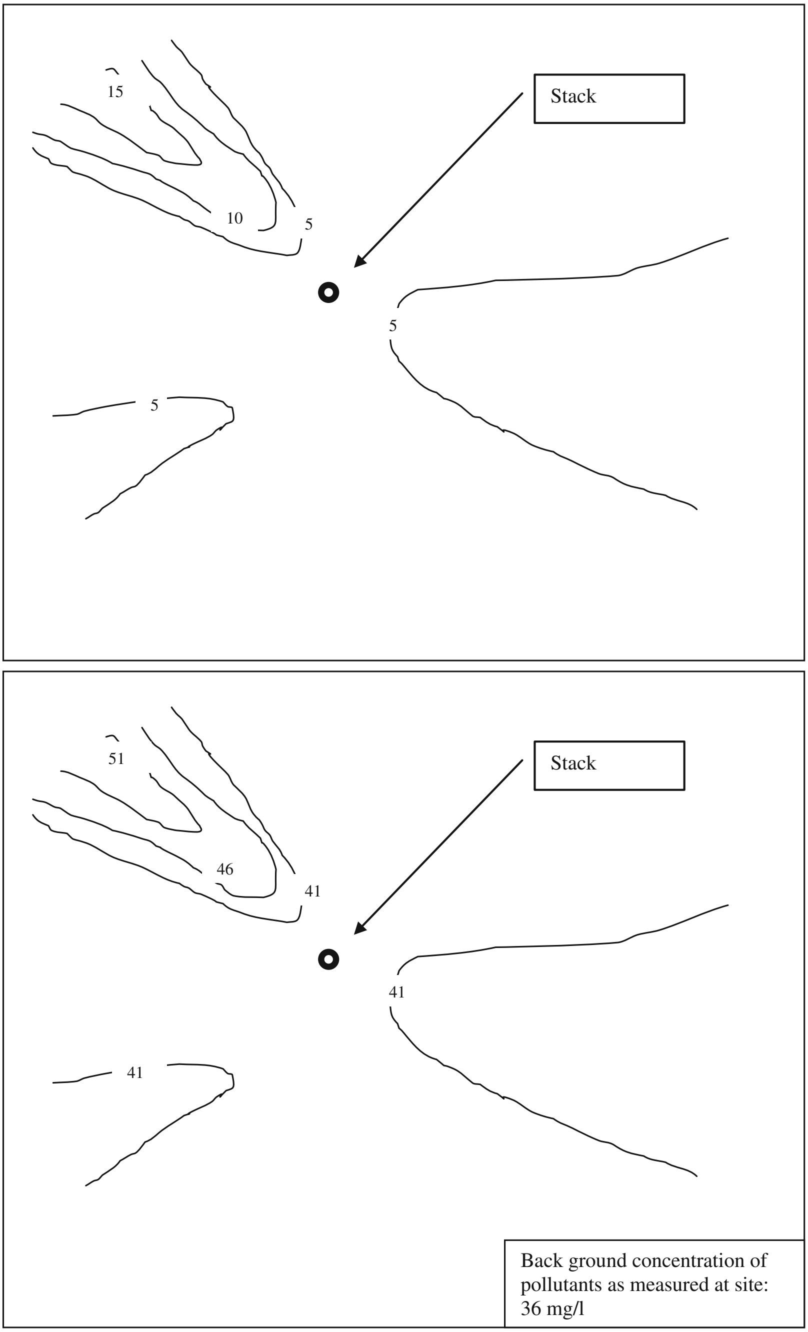


Fig. 5.11 Output of mathematical model and concentrations after adding back ground concentration

5.8 Incentives

Incentives are financial encouragement given to industries to achieve certain aim including reduction of air pollution. Incentives are provided in the form of waiver towards importing equipment/vehicle etc., or tax credits. Incentives can also be given in the form of subsidy where in partial investment is born by government. This incentive may be misused by investor due to unholy nexus between government and investor. Investment estimation may be boosted to get maximum subsidy. The estimations are made in such way that investor would get more financial assistance.

5.9 Enforcement

Enforcement is one of the oldest ways practiced by governments all over the world to ensure law and order. Enforcement may not always achieve full result as the system depends on humans and hence vulnerable to errors/corruption. But most of the people who comply would usually do so to avoid statutory risk and corporate dignity rather than efficient enforcement mechanism.

Enforcement mechanism includes making laws and verifying compliance to law. The law usually provides frame work which is further strengthened by series of notification, circulars, clarifications, guidelines, manuals, training and past judgments. But such circulars, guidelines and manuals may dilute the spirit of law in corrupt/ignorant institutions. In many institutions the circulars changes so often that employees and stake holders are confused to great extent.

International legislation often has great influence on national laws. The international conferences and treaties usually compel the representatives of participating nations to include in their local laws. But due to poor understanding of laws and lack of resources makes it difficult to enforcing staff to implement the same to fullest extent.

Other institutional weakness in enforcing agency include political pressure, threat from labour unions, incapability to comply with other laws, poor time management skills, and poor skilled manpower (Box 5.2).

Box 5.2 Pollution control and manpower

War on enemies cannot be fought with weak soldiers of inadequate number and war against pollution cannot be fought with sick employees who often go on leave or come to office late. There is huge difference between the numbers of employees among the organisation across the world. Many of the vacancies are not filled for numerous reasons. On the other hand poor quality of manpower among pollution control authorities across the world is also turning the colour of earth to grey. Nearly 50 % of moan power is lost due to late coming, early leaving, sick leave, meternity leave, peternity leave, holidays, and festivals.

Environment agency (environmental enforcing agency in England and Wales) has a staff strength of about 12,000 people across England (population: 53.01 million) and Wales (population: 3.064 million) (Epanet 2015). USEPA of USA(population: 313 million) employs about 17,000 people (USEPA 2015). Swedish Environment Protection Agency of Sweden (population: 9.593 million) has about 550 employees (Epanet 2015). Number of employees in central environment authority of Sri Lanka (population: 20.48 million) is about 670 (Central Environment Authority 2010). Umweltbundesamt (Environment Agency Austria) of Austria(8.474 million) has 479 employees (Epanet 2015). Environment Canada (2015) (Population: 35.16 million) has staff strength of about 6800. Agency of Environment and Forestry of Albania (2.774 million) has staff strength of about 47. Croatian Environment Agency has staff strength of about 40 (Epanet 2015). Finnish Environment Institute has staff strength of about 602 (Epanet 2015). Around 450 employees are employed in the Danish EPA (Epanet 2015). Umweltbundesamt (Federal Environment Agency) of Germany has about 1400 employees and PBL Netherlands Environmental Assessment Agency has about 220 staff members(Epanet 2015). The Federal Office for the Environment in Switzerland has staff of about 450 (Epanet 2015). Manpower hired by many developing countries is not easily available to researchers.

The Stockholm conference held in 1972 lead to passing environmental legislation all over the world. But lack of adequate skilled manpower in developing countries is affecting global environment very badly.

The manpower planning model published by USEPA (1975) is an excellent resource to calculate manpower requirements for each of 17 categories of non-federal air pollution control (APC) agencies in USA which can be adopted by developing countries which do not have any guidelines/law to calculate manpower. The projections were based on empirical information relating the manpower based on economic-demographic characteristics of the geographic region.

Consents, authorisation, registration and licences are usually made part of legislation so that people/organisation of interest would mandatorily provide details and obtain permits with conditions that are tailor made to the particular site and activity. Example of site/activity specific condition are emission standards, chimney height and pollution control equipments to be provided by the applicant.

The violators are usually brought to notice of judiciary system or issued with directions which are binding in nature. Statutory organisations may also demand guarantee money or bank guarantee so that the amount would be forfeited in case of violations.

Theoretically all the above provisions look great and can be found in environmental legislation all over the world. But enforcing agencies fail to curb pollution and protect environment for the following practical reasons:

- Accepting bribe from polluters and letting them to pollute;
- Absence of adequate manpower;
- Operation of industries in night and public holidays;
- Failure of system due to sudden death or conviction of important officer on whom the system depends heavily;
- Poor training/nurturing of staff;
- Politics in office;
- Political intervention in day to day administration for personal/political benefit;
- Recruitment of poor quality of manpower;
- Poor leadership;
- In ability to spend the available funds for the protection of environment;
- Too much dependency on individual staff/officer; and
- Poor administration/management of organisation.

In many instances a small and minor issues can weaken the enforcing system. Some of the recruitment process would be delayed due to stay orders obtained from un-recruited people. Honest officers may not be given responsible jobs due to political intervention. Too many correspondence, meeting, and visitors may also take away quality and productive time. Misplacement/theft of documents often introduces confusion in the system. Not initiating action against poor performers and nonperformers will also discourage hard working people to discharge their duties.

Increase in legislation and policy in the recent years due to ratification of international environmental legislation has increased work load of enforcing agencies. But inability to recruit adequate manpower often results in institutional failure.

In many countries pollution control/monitoring officer are used for other duties like election, census etc., and thereby hindering pollution control activities.

Slow decision and communication and inability to absorb advanced technology like remote sensing would also add to institutional failure.

5.9.1 Industries/Activities with High Particulate Emissions

Industries/activities that involve in crushing, pulverisation, handling of pulverised material are source of air pollution. The suppression of these particles involve collection of particle by series of hoods; spraying; covering material; good practices and end of pipe air pollution control system.

The major industries that emit particulate emissions are given in Table 5.7.

5.9.1.1 Mining

Mining is the extraction of geological materials from the earth. Mining of stone/metal has been done since prehistoric times. The mining processes create a negative impact on the environment during the mining operations and after the mine are closed.

Table 5.7 Major Activity emitting particulate matter

Sl. No.	Industry	Type	Major sources
1.	Brick kiln	Smoke	Kilns
2.	Carbon black plants (furnace process)	Carbon black	Generators
3.	Charcoal production plants	Smoke	Combustion
4.	Chemical process plants	Smoke	Processing
5.	Coal cleaning	Coal dust	Coal dryers
6.	Coal fired electric plants	Fly ash	Boiler
7.	Coke oven batteries	Coal and coke dusts, coal tars	Oven cells, quenching, material handling
8.	Fossil fuel boilers	Flyash, smoke	Combustion
9.	Fuel conversion plants	Smoke	Processing
10.	Glass manufacture	Dust	Melting furnace
11.	Glass furnace and glass fibre processing plants	Acid mist, dust, alkaline oxides, resin aerosols	Materials handling, glass furnaces, fiber forming and curing
12.	Hydrofluoric, sulphuric, phosphoric and nitric acid plants	Mist, dust	Grinding, handling, rock acidulating, absorption towers
13.	Incinerators	Smoke	Incineration
14.	Iron and Steel mill plants	Iron oxide dust, smoke	BFs, other steel making furnaces, sintering machines
15.	Kraft paper mills	Smoke	Boiler
16.	Lime plants	Dust	Kilns
17.	Mining	Dust	Drilling, blasting, excavation, material handling
18.	Ore processing plants	Dust	Processing
19.	Petroleum refineries	Catalyst dust, ash, acid mist, liquid aerosols	Catalyst regenerators, Acid treating, blow down
20.	Petroleum storage and transfer units	Smoke	Vehicular emission
21.	Phosphate rock processing plants	Dust	Pulverisation
22.	Portland cement plants	Alkali and cement dust	Kiln, Dryers, coolers, materials handling

(continued)

Table 5.7 (continued)

Sl. No.	Industry	Type	Major sources
23.	Primary aluminium ore reduction plants	Dust	Crushing and pulverisation
24.	Primary copper smelters	Fume, dust	Smelting
25.	Primary lead smelters	Fume, dust	Smelting
26.	Primary zinc smelters	Fume, dust	Smelting
27.	Puffed rice mills	Smoke	Frying
28.	Rice mills	Dust	Dehusking, Boilers
29.	Secondary brass and bronze melting process	Dust, metallic fumes, flyash, carbon, zinc, lead and other oxides	Kilns
30.	Secondary aluminium melting process	Aluminum chloride fumes, dust, chlorides, fluorides and oxides of metal	Kilns
31.	Secondary zinc melting process	Smoke or oily mist Zn and ZnO fumes, dust and ammonium chloride	Kilns
32.	Sintering plants	Dust	Sintering
33.	Solid waste management plants	Dust	Shredder, conveyors, manual handling
34.	Waste to energy	Smoke	Incinerator
35.	Gypsum processing	Dust	Calciner, dryer, grinding and materials handling
36.	Asphalt concrete batch plants	Dust	Dryer
37.	Foundries	Metal oxide dust, smoke, oil, grease, metal fumes	Furnace, sand conditioning, shakeout systems, core making, sand blasting, shot blasting
38.	Nonferrous smelter	Smoke, metal fumes, oil and grease	Smelting and melting furnace
39.	Pulp mills	Chemical dusts; Sodium carbonate, sodium sulphate, sodium sulphide, calcium oxide, calcium carbonate mists	Recovery furnace, dissolving tank, lime kiln
40.	Asphalt batch plants	Aggregate dusts	Dryers and materials handling
41.	Soap and detergent	Dust	Spray dryers, materials handling

(continued)

Table 5.7 (continued)

Sl. No.	Industry	Type	Major sources
42.	Coffee processing	Oil aerosols, coffee dust, ash	Roasters, dryers, coolers, waste heat boilers, conveying equipment
43.	Cotton ginning	Cotton fiber, dust and smoke	Gins, incineration
44.	Stone crushers	Dust	Crushing, screening, conveying

Fig. 5.12 Water being sprinkled in mine to control air pollution

In open cast mining, overburden will be removed to reach the mineral deposits. Mining may require excavators, transporters, loaders, conveyer belts etc.

Air pollution in mining is mainly due to localized dust storms. Effective methods to prevent these storms are to keep the dumps wet; and cultivation of shrubs and trees. Explosives used in mining produce oxides of nitrogen.

A commonly used explosive ammonium nitrate decomposes to form nitrous oxide and water

$$NH_4NO_3 \rightarrow N_2O + 2H_2O$$

The explosion not only generates emission due to combustion, it also includes dust due to suspension of fine material. The good practice in mining include water sprinkling in mining area (Fig. 5.12); pouring during boring (Fig. 5.13); spraying the mined material by water before crushing (Fig. 5.14); development of green belt.

The impact of dust depends on the material unearthed and handled at site. The asbestos mining will have impact of different magnitude compared to coal or graphite ore. The impact of bauxite will be different from that of iron ore or uranium ore.

Fig. 5.13 Water being sprinkled while drilling bore holes in mine to control air pollution

Fig. 5.14 Water being sprinkled on boulders in a mine to control air pollution

The destruction of forest above mine would expose top soil to atmosphere and enhances chances of re-suspension of dust (Table 5.8).

Fraction of methane produced during in the process of coal formation remains trapped under pressure in the coal seam as well as surrounding rock strata which is released during the mining process. Methane released during mining will escape into the atmosphere. The quantity of CH_4 released during mining of coal depends on coal rank (differences in the stages of coal formation), coal seam depth, as well as method of mining. As coal rank increases, the quantity of CH_4 produced also increases. Deeper coal seams normally contain more methane compared to shallow seams of the same rank. Methane can also be released from near surface coal seams from natural fractures.

Underground coal mining releases more methane compared to open-pit mining due to the higher gas content in deeper seams. Since methane is highly explosive in air concentrations from 5 to 15 % underground mine workings are provided with: (a) ventilation systems, and/or (b) degasification systems.

Table 5.8 Mineral and associated air pollutants emitted during mining

Sl. No.	Mineral/Material	Air pollutants emitted during mining
1.	Argentite (silver ore)	Dust
2.	Asbestos	Asbestos
3.	Barite (Barium ore)	Dust
4.	Bauxite (Alumium ore)	Dust
5.	Beryl (Type of gem stone)	Dust
6.	Bornite (copper ore)	Dust
7.	Cassiterite (tin ore)	Dust
8.	Chalcocite (copper ore)	Dust
9.	Chalcopyrite (copper ore)	Dust
10.	Chromite (Chromium ore)	Dust
11.	Chloragyrite (Silver ore)	Dust
12.	Cinnabar (Mercury ore)	Mercury
13.	Cobaltite (Cobalt ore)	Dust
14.	Columbite-Tantalite or Coltan (niobium and tantalum ore)	Dust
15.	Coal	Methane, coal dust, SO_2, NOx
16.	Diamond	Dust
17.	Galena(Lead ore)	Dust
18.	Native gold (Gold ore)	Dust, Mercury
19.	Hematite (Iron ore)	Dust
20.	Limestone (calcium ore)	Dust
21.	Pyrolusite (manganese ore)	Dust
22.	Sphalerite (Zinc Ore)	Dust
23.	Uraninite (Uranium ore)	Uranium
24.	Wolframite (Tungstone ore)	Dust

Ventilation systems, is used to reduce CH_4 concentrations to safe levels of less than one percent. Drainage or "degasification" systems extract CH_4 from the coal seams by means of bore holes. Methane emissions occur during post-mining period as well.

Mercury occurs naturally in some gold ore, which is released into the air at some stage in the ore-heating during gold extraction. Airborne mercury can travel long distances, finally settling in water bodies where it gets converted into methylmercury by bacterial action. The mercury will accumulate in fish by the process of bioaccumulation.

Mercury has been used in gold as well as silver mining since Roman times. With the invention of the "patio" process mercury released to the biosphere by this activity may have reached more than 260,000 t from 1550 to 1930. Hg-amalgamation was replaced by the cyanidation process.

Presently, Hg amalgamation is used as major technique for gold production in the South America, China, Southeast Asia as well as in some African nations.

Mercury emissions into the environment due to this activity might have reached up to 460 t/year. Gold mining is presently responsible for about 10 % of the global anthropogenic Hg emissions(Lacerda 1997).

Release of arsenic from sulphide minerals has increased due to weathering process during excavation.

5.9.1.2 Metal Beneficiating and Extraction

Ores mined from the mines are usually beneficiated to remove undesired components called gangue minerals to decrease the cost of transportation. The minerals are first released from the rock by crushing and grinding. The ground rock/mineral is then subjected to a separation process.

Flotation is a major beneficiation method wherein organic reagents are added to the mineral slurry that selectively make certain minerals un-wetted by water and hence can adhere to air bubbles during flotation. The mineral particles are removed as a concentrate in the froth. Presence of pyrite in tailings from beneficiation processes undergoes aqueous oxidation generating sulfuric acid.

$$FeS_2 + H_2O + 7/2O_2 \rightarrow FeSO_4 + H_2SO_4$$

5.9.1.3 Thermal Power Plants

Thermal power can be generated from variety of fuels that include coal, fuel oil, or natural gas. *Conventional steam-producing thermal power plants* produce electricity by converting water to high-pressure steam, which is used to drive a turbine.

In c*ombined-cycle units* exhaust gases are used to drive turbine and waste heat boilers are used for the production of steam from exhaust steam which drive another turbine.

The air pollution sources in thermal power plants are fuel handling, combustion and waste handling. The coal handling can emit dust when it is handled and transported with earth movement machines and conveyor belt. Water is sprinkled in each stage to suppress dust. The emission from pulverizing activity is reduced by passing emission through cyclones and bag filters.

The exhaust gases from combustion of fuel comprise of particulates SO_x, NO_x, CO_2 and VOCs.

The quantity of these pollutants in the exhaust gases depends on firing configuration, operating practices, as well as fuel composition. Gas-fired plants usually generate negligible quantities of particulates.

Exhaust gases may contain noteworthy levels of heavy metals as well as organic compounds. Fly ash in exhaust gases makes up 60–85 % of the ash residue in pulverized-coal boilers.

Coal fired thermal power plants are opposed in recent past due to the associated carbon emission. Compared to biomass burning (which emits atmospheric carbon trapped in biomass during carbon cycle) combustion of coal adds to carbon that was not originally present in atmosphere thereby increasing carbon dioxide concentration. Compared to petroleum coal has lesser calorific value but higher carbon content thereby emitting more CO_2 per unit quantity of fuel burnt.

The wide use of fossil fuels started during industrial development enhanced air pollution many folds. Coal is a main fuel for power stations in nearly 40 percent of the world's electricity. The environmental impact of power generation starts from coal mining which generates coal dust, methane, and particles associated with ore.

There are three major combustion systems in which coal as well as air is reacted: fixed bed, suspended bed and fluidized bed. Coal gasification promises clean systems of power generation since nitrogen compounds, sulfur, and particulates are removed prior to the fuel is burned. Coal gasification can achieve removal of 99 percent of its sulfur and ash as well as 90 percent of its nitrogen pollutants.

Pre-combustion cleaning is employed to decrease the mineral as well as ash content in coal. Desulfurization is an important step in the pre-combustion coal cleaning. Froth flotation is employed to remove pyrites (up to 30–50 %) by flotation.

Distillate oils contain negligible nitrogen/ash content with sulfur (less than 0.3percent by wait). Residual oils contain noteworthy quantities of nitrogen, metals, and sulfur. Mixing waste oil with a virgin fuel oil is often practiced. Waste oils from automobiles and industrial activity contains high levels of halogenated solvents that ultimately enters atmosphere after combustion.

Fugitive emissions at coal handling area, ESP hopper area, ash silo, and ash pond form main sources of the uncontrolled emissions (Goel and Yadav 2014). The various methods to control fugitive emissions are discussed in following paragraph.

Control of fugitive emission at coal unloading section is achieved by water spraying. The emissions form coal handling plant is controlled by water spraying or by extracting to cyclone separators and bag filter.

Belt conveyors are closed while conveying coal to different locations to avoid emissions.

Dust suppression from coal stacker is achieved by wetting with spray guns and paving pathways of coal yard. Accumulated dust should be removed frequently followed by water sprinkling.

Air pollution control during storage of flyash is achieved by: (1) transporting dry ash in closed tankers or bulkers, (2) pumping fly ash directly from tankers to silos pneumatically in closed loop, (3) storing dry fly ash in closed silos, (4) the silo vent should be provided with proper air pollution control equipment like bag filter, (5) care should be taken to avoid leakage while transferring ash from silo to truck.

Emission of SO_2 from coal combustion can be achieved by coal beneficiation, flue gas desulphurization, and sorbent injection.

Significant choice for decreasing the sulfur of fuel is called beneficiation. Nearly Up to 70 percent of the sulfur in high-sulfur coal will be not chemically bonded to the coal and will be in the pyretic or mineral sulfate form. Coal beneficiation can get rid of 50 % of pyretic sulfur as well as 20–30 % of total sulfur. Beneficiation can also remove ash which is responsible for particulate emissions.

Sorbent injection involves addition of alkali compound to the coal combustion gases. Normally lime and variants of lime and sodium-based compounds are used that can remove 30–60 % of sulfur oxide emissions.

Gasification of solid/liquid fuels is practised for generation of gases by catalytic or non-catalytic processes. Liquid fuels are sprayed into the combustor. Waste oils can be used in a variety of burning systems that include steel production BFs; cement/lime kilns; asphalt plants, etc.

The pollution control from combustion is achieved by the design of the combustion systems; pre-combustion treatment of the fuel; by direct involvement in the combustion reactions with suitable reagents; and by post-combustion treatment of emissions.

Incomplete combustion of fuel may occur due to insufficient oxygen availability; cold-wall flame quenching; poor fuel/air mixing; decreased combustion gas residence time; reduced combustion temperature; as well as load reduction.

NO_x are formed due to the fixation of nitrogen and oxygen in air. Sulfur oxide are formed due to oxidation of the sulfur present the fuel. Particulate matters are formed from non-combustible mineral constituents as well as hetero-cyclic compounds in the fuel; and PM formed due to pyrolysis of the fuel molecules. Soot formation occurs by synthesis reactions in the fuel-rich regions of the combustion chamber. Fuel substitution/alteration and post combustion controls are used to reduce PM emissions.

Flue gases from combustion of waste may contain chlorinated organic compounds. Some of these products are very toxic. Trace chemicals including radio-nuclides, are emitted during combustion of coal. Radiation doses from thermal power plant fueled by coal may be greater than that of nuclear plant.

NO_x emission from thermal power plant can be regulated by combustion process. The dominant flue gas desulfurization process used in thermal power plant is limestone scrubbing.

5.9.1.4 Surface Coating

Surface coating is done to increase life of an object by safeguarding components from atmospheric moisture/dust and enhance aesthetics.

There is variety of technologies available to coat surface. Examples of surface coating include (1) painting with brush, (2) physical vapor deposition, (3) thermal spray coating, (4) chemical vapor deposition, (5) electroplating, (6) powder coating, (7) spray painting, and (8) phosphating.

Electroplating is the procedure of depositing a protective layer to an object by passing electric current through a chemical in contact with the object. The operations can generate toxic emissions including heavy metals as well as cyanide. Degreasing and cleaning solutions can generate toxic pollutants and VOC that react in the air to form ozone. Emission reduction can be achieved by (1) using water-based cleaning chemicals and degreasing solvents with lower toxic/VOC content, (2) using less toxic chemicals, (3) covering containers as well as used shop towels, (4) installing ventilation hoods above plating baths and pass the fumes through air pollution control equipments, (5) mechanical cleaning, (6) changing to a water-based cleaning system, (7) cleaning parts with hot water with detergent at high pressures, (8) switching to less air polluting elctrocoating technology like physical vapor deposition, thermal spray coating, and chemical vapor deposition, and (9) using lowest concentration of chemicals in the bath.

Plating operations produce mists due to the development of oxygen and hydrogen gas. The gases formed rise to the surface in the form of bubbles and escape into the air carrying liquid in the form of mist. Air sparging also results in emissions due to cleaning and degreasing.

The techniques used to control emissions include chemical fume suppressants, add-on control devices; mist eliminators; and wet scrubbers. Chevron-blade and mesh-pad mist eliminators are used most frequently to control mist from electroplating containers. Fume suppressants include foam blankets, wetting agents or combinations of both wetting agent as well as foam blanket. Use of solid plastic balls (Fig. 5.15) on surface of plating tank solutions can reduce loss of heat and chemicals.

5.9.1.5 Drugs and Pharmaceuticals

Activities in the pharmaceutical industry involve extraction, processing, purification, mixing, and packaging of chemicals. Pharmaceutical manufacturing comprises of two major stages: (1) the production of the active ingredient, and (2) the conversion of the ingredients into products appropriate for administration (The process referred as drug formulation).

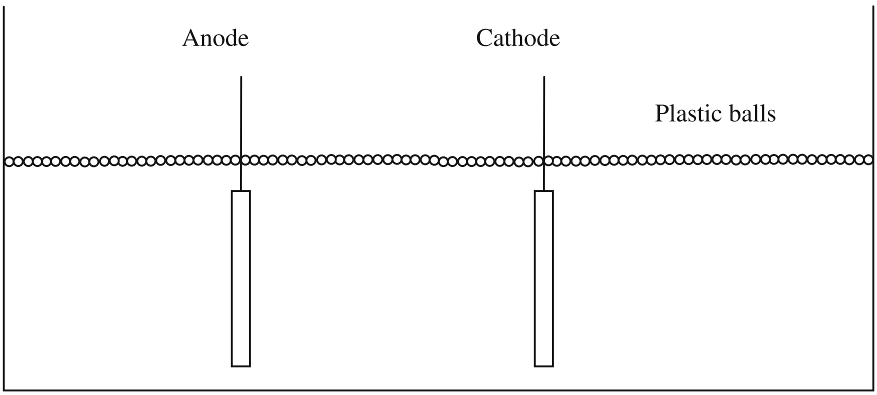


Fig. 5.15 Use of plastic balls to reduce evaporation of chemicals from electroplating process

The major manufacturing steps are: (a) preparation of intermediates; (b) fermentation; (c) introduction of functional groups; (d) coupling and esterification; (e) separation processes (like washing, stripping and extraction with organic solvents); (f) natural product extraction from natural sources (plants, and animal parts); (g) purification of the product; (h) crystallization; (i) drying; (j) tablet pressing, (k) printing, (l) coating; (m) filling; and (n) packaging.

The principal air pollutants from drugs and pharmaceutical industry are VOCs and PM. Effort should be made to replace toxic as well as persistent ingredients with degradable and less toxic substances. Other pollution prevention measures in this sector are as follows: (1) minimize wastage of active ingredients, (2) reuse by-products, (3) recover solvents, (4) prefer use of nonhalogenated solvents, (5) minimize spillage (6) use “closed” feed systems in batch reactors, (7) use dedicated dust collectors and recycle recovered materials, and (8) vent equipment through vapor recovery system.

Stack gas scrubbing, baghouses for particulate matter removal and carbon adsorption for toxic organics, are effective for minimizing air pollution from the sector. Biological filters are used to reduce emissions of organic substances and combustion technology is used for the destructing of toxic organics.

Fermentation is the most appropriate for production of antibiotics, amino acids steroids, and some food additives. The major processes involved in fermentation are inoculums, seed preparation, fermentation as well as downstream processing.

Fermentation emits VOCs with bad odor. The steam (for sterilisation, aerobic fermentation, evaporation) production in manufacturing units results in emissions of SO_x, NO_x, CO_2, and PM. The final step in pharmaceuticals production is compounding and formulating which are considerable source of VOCs and tablet dust.

Each pharmaceutical plant is unique. The dominant air pollutants are recovered by scrubbing, adsorption or condensation. Incineration is applied, when recovery is not possible (Beschkov 2006).

5.9.1.6 Cement Industries

Cement manufacturing involves mining, crushing, grinding, calcining, cooling, mixing the clinker with gypsum, milling, storing, and bagging. The process generates dust, which is captured for recycling. The dry process is preferred compared to the wet process as the energy consumption is about half of the requirement for the wet process. Certain solid waste from other industries like fly ash, slag, foundry sand, roasted pyrite residues, are used as additives.

Figure 5.16 shows cloth covered on soil to control air pollution. Figure 5.17 show conveyor belts with cover to control air pollution. Figure 5.18 shos view of cement industry. Raw materials are fed into the kiln as a dry meal or as wet slurry and then heated to a very high temperature to induce chemical reactions to get a fused material called clinker. The clinker is ground into a fine after mixing with gypsum to form the Portland cement.

Fig. 5.16 Cloth covered on soil to control air pollution

Fig. 5.17 Conveyor belts with cover to control air pollution

Fig. 5.18 View of Cement industry

The commonly used fuels are coal and gas, which are supplemented by waste such as tyres, waste oil, and solvents. An oxygen-rich atmosphere, high flame temperatures (>2000 °C) and long residence time in the kiln are required for the process.

About 10–20 % of the kiln feed are suspended in the kiln exhaust are captured and returned to the kiln. Clinker cooling, crushing, grinding, and materials-handling operations also generate substantial amount of dust which are filtered in bag filter and recycled. Conveyors are usually covered to avoid air pollution.

NOx and SOx are formed during combustion and oxidation of sulfur in the raw materials, but the alkaline conditions in the kiln absorb up to 90 % of the SO_x. Heavy metals present in the fuel and raw materials are released in kiln gases.

Dioxin are formed from combustion processes by: (1) formation from precursors, and (2) formation anew.

Dioxin may form precursor molecules, like chlorinated aromatic hydrocarbons which later react in the lower temperature. Temperature of 250–450 °C is necessary for dioxin formation. These critical temperatures occur when gases have cooled in heat exchangers, air pollution control equipment, flue ducts, or the stack.

Dioxins may also formed anew in locations where combustion gases have attained critical temperatures during cooling.

5.9.1.7 Stone Crusher

Stones have been used for variety of constructions. Many hills have vanished to build concrete infrastructure. The boulders from quarries and mines will be reduced to fines or course aggregate to enable them for easy transportation and mix with other ingredients of concrete.

Stone crushers have been used all over the world to crush boulders to reduce the size to desired size for construction of infrastructure as well as transfer the aggregate of minerals for further processing (like lime stone is crushed to suitable size before it was transferred to in cement plants).

Production capacity of small crushers usually range from 3 to 25 TPH. Typically, the units will have one Jaw type crusher along with one or two rotary screens. Medium type crushers will have a production capacity in the range of 25–100 TPH. Medium crushers will usually comprise of primary and secondary crushers along with vibratory screens. Large stone crushers are capable of crushing stone more than 100 TPH. Classification of crusher is given in Fig. 5.19.

Crushing will be usually followed by screening activity with rotary screen that would separate stones into different sizes prior to despatch. Screening is generally classified into two types—(i) Coarse screening, and (ii) fine screening. Course screening is achieved through grizzlies, vibratory Screens, revolving screens or shaking Screens. Fine screening is achieved through vibrating screens or shaking Screens.

Emission from stone crushing arises from mining/quarrying, crushing, screening, and handling.

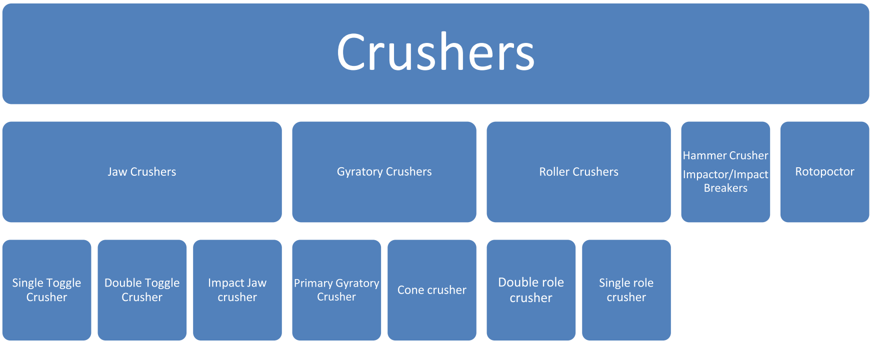


Fig. 5.19 Classification of crusher

Fugitive Emissions are generated during quarrying/mining activities due to drilling, blasting, excavation, breaking, transportation and material handling.

Emission for stone crusher varies from 0.25 to 3.0 kg/t crushed (CPCB 2009). Emission during and screening vary form 2.5 to 5.5 kg/t screened. The emission during material handling is around 1.0 kg/t of material handled.

The emissions from the crushing operations are controlled by wet dust suppression and dry collection. In wet dust suppression moisture is introduced into the material flow to hold back fine particulate matter from entering atmosphere. Dry collection involves enclosing dust producing points or hooding and exhausting emissions to a collection equipment (usually cyclone separator or bag filter). Sometimes combination of both methods is applied.

The location of crushers is also essentially away from residential area and sensitive area to avoid complaints due to nuisance.

5.9.1.8 Solid Waste Management

Solid waste includes waste from industries, house hold, and commercial activity. The waste can be classified into municipal solid waste, hazardous waste, E-waste, Biomedical waste, construction and demolition waste depending on nature and source of the waste. Management of solid waste include storage, transfer and transportation, reuse, recycle and disposal. Emission from solid waste management depends on fuel used and process adopted.

Municipal solid waste varies in composition depending on economy and culture of the citizens. The collection and storage practice varies widely. The uncontrolled waste burning practice followed in developing countries often cause of major pollution.

Figure 5.20 Plastic cover ingotmaking machine; Fig. 5.21 Hazardous waste processing unit; Fig. 5.22 Hazardous waste processing unit; and Fig. 5.23 Waste to energy plant. Incineration is the most widely used method used to dispose

Fig. 5.20 Plastic cover ingot making machine

Fig. 5.21 Hazardous waste processing unit

Fig. 5.22 Hazardous waste processing unit

combustible waste which results in air pollutants. As per Psomopoulos et al. (2009), the USA has more than over 1500 incinerators burning about 26.3 million tons of municipal solid waste.

In incineration waste is burnt in specialized engineered set up to: (1) reduce quantity of waste, (2) recover energy or (3) destroy infectious material or (4) convert combustible hazardous waste into nonhazardous material. Incineration can be done in: (1) multiple hearth incinerator, (2) fluidized bed incinerator, (3) recirculating fluidized bed incinerator, (4) liquid injection incinerator, (5) fume incinerator, (6) rotary kiln, (7) cement kiln, (8) large industrial boiler, (9) multiple chamber incinerator, (10) cyclonic incinerator, (11) auger combustor, (12) two stage combustor, (13) catalytic combustion, (14) oxygen enriched combustion, (15) molten salt combustor, and (16) moving belt combustor. The air from incinerators is passed through air-pollution control system to control pollution.

Combustion converts the waste into flue gas, ash, and heat. The air pollutants from flue gases must be controlled by with air pollution control equipment. In order to avoid formation of air pollutants like dioxins and furans, duel chamber incinerators are used for disposal of biomedical waste. The temperature in primary chamber is be maintained at $800 \pm 50\ ^{\circ}C$ from where the gases formed during combustion enter the secondary chamber maintained at $1050 \pm 50\ ^{\circ}C$.

Solid waste incinerators are categorized as: industrial; commercial; municipal; and sludge. Incineration of solid/liquid/gaseous wastes will generate emissions that require special treatment.

Optimum control emission is achieved in municipal solid waste incinerator by proper design/operation. Proper design of incinerator to control pollution include design of: (1) furnace/grate system suitable to the waste; (2) sufficient combustion gas velocity as well as detention time in the secondary combustion chamber; (3) suitable under fire as well as over-fire air system; and (4) optimum under-fire/over-fire air ratios.

Particulates may be controlled with settling chambers; mechanical collectors; after burners; as well as low efficiency scrubbers as pre-cleaners followed by an ESP or a high efficiency venturi/orifice scrubber. Fabric filters can be used if emission temperature is maintained lower than rating of fabric media being used by cooling of the gas stream.

Odor control can be achieved with after-burners located in the furnace at strategic location to oxidize the odor causing gases.

Fig. 5.23 Waste to energy plant

Air pollutants from hazardous waste sites can arise form:

- Fugitive dust resulting from wind erosion;
- Vehicular pollution arising from movement of vehicle in hazardous waste sites; and
- Emission from land fill site.

Industrial and commercial incinerators are designed considering composition of the waste to be incinerated. Commonly used primary collection devices for controlling PM are: after-burners; wetted baffles; mechanical collectors; and spray chambers. These equipments are followed by venturi or orifice-type scrubber; ESPs and fabric filter.

Odors as well as objectionable vapors from incinerator are controlled by Afterburners, vapour condenser, catalytic oxidation and absorbers.

Combustion of waste in cement kilns is gaining importance as favorite choice as it serves dual purpose of saving fuel for cements manufacturing and disposal of waste.

The waste heat boilers are used where the system is designed to recover heat. Such arrangement allows use of fabric filter, for particulate control. ESP is not suitable for hazardous waste incinerators. The induced draft fan is provided to avoid leaking of a gas from kiln system.

Composting is done to organic waste to convert into manure. Methane and VOCs are usually released to atmosphere during processing. The screening (Fig. 5.24) of the manure is source of particulate matter.

Radioactive wastes are also used in hospital (Figs. 5.25 and 5.26) and research activities in small quantities. Since escape of radioactive material into environment will lead to huge impact on environment, they are disposed causiously by supplier/manufacturer. The treatment methods followed before disposing radio active waste are: (1) Compaction and Super-Compaction, (2) Incineration, (3) Chemical and Thermochemical Decomposition, (4) Partitioning and Transmutation, (5) Conditioning, (6) Immobilization. The treated wastes are disposed through (1) Reinforced Concrete Trenches, (2) Tile Holes, and (3) Geological Disposal.

Fig. 5.24 Compost screening machine

Landfill is used for ultimate disposal of non-combustible waste. Municipal solid waste are compacted to form predetermined cell size and covered with cover of compressed soil. In case of hazardous waste different types of hazardous wastes are placed in mappable cells placing of incompatible substance adjacent to each other to avoid hazardous reactions. Drummed wastes are usually placed and covered with wastes which are compatible with drummed waste. Drums may be placed in single lifts or stacks. Land Fill Gas (LFG) is generated both in managed "landfill" as well as "open dump" sites due to un-aerobic decomposition of organic material present in the waste. LFG contains 50–60 % methane. The remaining and 30–40 % comprises of CO_2 and other gases.

Biodegradable waste decomposes in five stages.

Stage 1: Aerobic bacteria generate CO_2, water and heat.
Stage 2: Carbohydrates, proteins, and lipids are hydrolyzed to sugars by facultative bacteria.
Stage 3: Organic acids will be transformed into acetic acid, CO_2, H_2, H_2S.
Stage 4: Methanogenic microorganisms decompose the organic acids to CO-$_2$, CH_4, and H_2O.
Stage 5: CH_4 will be converted to CO_2 and H_2O. H_2S may also formed in this stage.

Fig. 5.25 Radioactive waste storage in health care establishment

Fig. 5.26 Inside of Radioactive waste pellets storage

LFG generation depends on: (1) the gas migration properties, (2) CH_4 oxidation ctivity, (3) gas collection efficiency, (4) pH, (5) temperature, (6) composition of waste, (7) water content, (8) compaction, (9) shredding, (10) meteorological condition (11) leachate recirculation, (Mohammed et al. 2009; Gurijala et al. 1997; Naranjo et al. 2004; Williams 2005; Chandrappa and Das 2012).

CH_4 move vertically as well as laterally. If the LFG is not vented out correctly it will accumulate beneath buildings or other spaces as specific gravity of methane is less than air. CO_2 is about 2.8 times denser than methane and 1.5 times denser than air and therefore it will move to the bottom of landfill lowering the pH and increasing hardness as well as mineral contents of the ground water.

LFG generated from a landfill (Fig. 2.27) are either collected for power generation or vented to the atmosphere As the generation of methane will begin immediately after waste placed in cell, "bio-trap" comprising of alternative layers of geotextile and geomembrane can be used to mitigate methane from open landfill cells by promoting uniform and greater methane oxidation in the cover layer. Figure 5.28 shows waste storage that would reduce emission at storage point (Fig. 5.27).

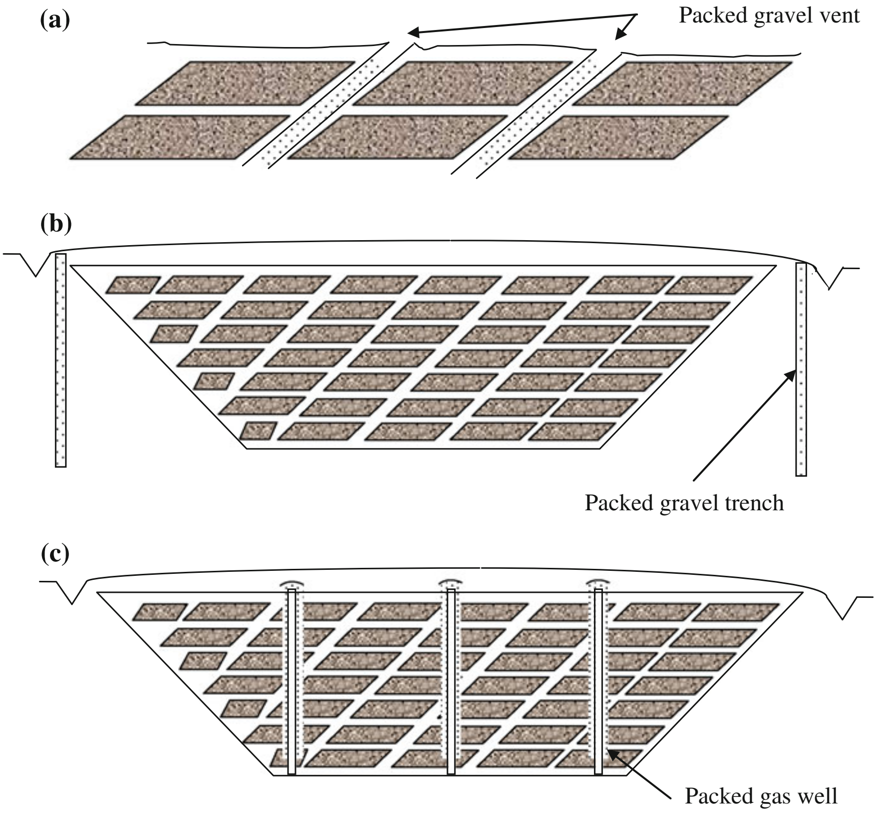


Fig. 5.27 Usual methods of venting landfill gases: **a** cell, **b** barrier, **c** well

Fig. 5.28 Waste storage

Combustion is commonly used for controlling and treating LFG by using flares, boilers, incinerators, gas turbines, and internal combustion engines. During combustion CH_4 is converted to CO_2.

Land fill fires are common during hot weather due to spontaneous combustion. Landfill gases (which includes methane, hydrogen sulfide, ammonia, non methane organic compound) migrate either below ground (groundwater, voids in soil) or above (atmosphere) contaminating soil, air, and groundwater. Accumulation of gas may create fire hazard or explode. Management plans for landfill fire include: (1) prohibition of smoking on site, (2) prohibition of deliberate burning, (3) inspection of incoming loads, (4) good compaction as well as cover, (5) control of deposition of waste, (6) maintenance of fire fighting extinguishers/equipment, (7) keeping protective clothing and breathing apparatus at landfill site, (8) maintenance of adequate water supply, (9) training of staff, and (10) preparation of comprehensive disaster management plan.

Figures 5.29, 5.30 and 5.31 shows E-waste or Waste from Electrical and Electronic Equipment (WEEE) which contains more than 1,000 different substances and disposal of this waste in organized or unorganized sector are likely to generate hazardous emission. The copper recoveries in E-waste using ammonia or acid are likely to emit fumes. The burning of E-waste to recover metal is common practice in many unorganized sector that emits toxic fumes which is dangerous to people in immediate vicinity.

The dismantling of refrigerator and air conditioner need elaborate arrangement to recover compressor gases. Cutting and crushing cathode ray tube generate dust that requires proper industrial ventilation followed by dust collectors.

5.9.1.9 Hot Mix Plant

Hot mix asphalt (HMA) a widely used paving material consists of a mixture of aggregate as well as liquid asphalt which are heated and mixed in known proportions. Hot mix plant can be batch or continuous. After mixing, the HMA is transferred to a storage bin/silo from where it is emptied into trucks for transporting to the job site.

The emission sources associated with production of HMA are the dryers, hot bins, as well as mixers. Pollutants from hot mix plans include particulate matter as

Fig. 5.29 E-waste dismantling unit

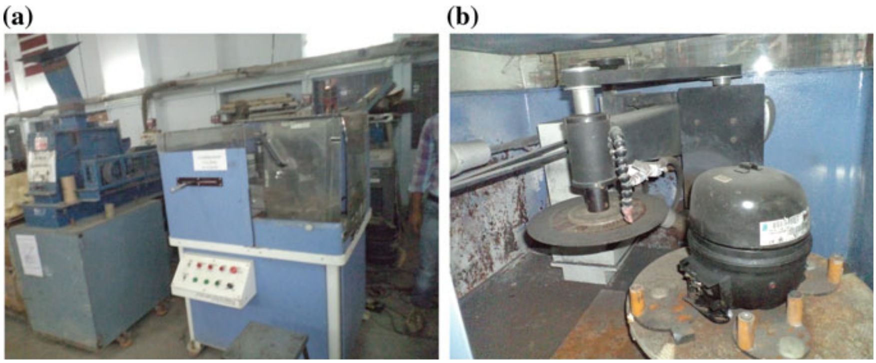


Fig. 5.30 Compressor cutting machine. **a** Outside view, **b** inside view

well as a variety of gaseous pollutants. The other air pollution sources at HMA plants are: storage silos; truck load-out operations; liquid asphalt storage tanks; yard emissions; hot oil heaters; vehicular traffic; aggregate storage/handling operations.

Fig. 5.31 Cathode ray cutting bench

The emissions from HMA production include PM emissions, HAP metals, HAP organic compounds, SO_2, NO_x, CO, and VOC.

At batch mix plants, apart from dryers other main process sources comprise the hot-side conveying, classifying, as well as mixing equipment, that are vented to either the primary dust collector or to a separate dust collection system. Emissions from aggregate handling/transfer usually are controlled with scrubbers or fabric filters. Mechanical collectors, scrubbers and fabric filters are usually used to control emissions from dryers. Large diameter cyclones as well as settling chambers are used in some plants for product recovery and is recycled back into the process (USEPA 2000).

5.9.1.10 Ready Mix Concrete

Ready-mix concrete (RMC) is manufactured in a factory by mixing ingredients of concrete. RMC preferred by some builders since it reduces work at site. RMC plants are established where there is huge demand for concrete like metropolitan cities where construction activities are high.

The activity is not significant from pollution as this is a wet process wherein emission of PM is very low. The manufacturing site normally contains raw material storage facility and mixer. The concrete ingredients are proportioned and fed into the mixer and final product is transported to construction sites.

5.9.1.11 Construction Sites

The ultimate aim of construction activity is to renovate, refurbish or construct structures for residential, commercial or industrial purposes on a piece of land suitably zoned for that purpose.

Construction sites vary in size as well as activities. Normally they include clearing of land, excavation/compaction, operation of heavy machinery, erection of structures, mechanical activities, metal joining, generation of solid wastes and debris, transport, movement of vehicles, and application of surface coatings.

Emissions from construction site include particulates, SO_x, NO_x, VOCs and odor. Emission from construction activities is are predominantly dust. Other emissions include those generated from vehicles and machinery. Applications of paints, sealants, waterproofing agents caulking compounds, and adhesives can generate odours due to release of VOCs. Hazardous materials (such as asbestos, lead based paints, PCBs in capacitors/transformers, halons and CFCs) may also be emitted from construction site.

Air pollution control at construction site is achived by: (1) proper housekeeping practices, (2) frequent auditing/supervision, (3) maintenance of vehicles, (4) rest/work balance to workers, (5) covering construction sites, and (6) training to construction personnel.

5.9.1.12 Entertainment

Not all entertainment is significant from air pollution. But many activities associated with entertainment are responsible for air pollution. Sports, film making, drama, live concerts, telecasting and broadcasting do involve transportation, diesel generator set, use of paints/crackers/chemicals. Many action scenes in movie involve fire and smoke which emits considerable air pollutants. Artificial snow making, water sports, processions of also involve many chemicals and fuel combustion activities.

Pollution control method is same as that of construction site discussed in Sect. 5.9.1.12.

5.9.1.13 Cracker/Explosive Manufacturing

In a fireworks industry, various chemicals like fuels, ignitor, oxidisers, and sand as well as special effect chemicals are mixed thoroughly (Rajathilagam et al. 2012) to get desired product. Mixing operations are usually done manually. Charcoal, other chemicals as well as water are prepared into paste and are applied on cotton wicks. The wicks are cut to required size after drying, and fitted suitably on the fireworks/crackers. The fuses are then inserted and allowed to dry. Dried fireworks are packed in small boxes manually. Dust accumulation as well as overheating may cause accidents during drying.

As per the studies conducted by Azhagurajan et al. (2014) crackers made of 100 % nano flash powder provide less quantity of sulphur dioxide when crackers are burnt there by reducing air pollution.

Figure 5.32 shows smoke released during burning of firecrackers. The use of firecrackers, has led to air/noise pollution and injuries. Hence, many governments/authorities have banned the sale/use of firecrackers. But use of crackers still persists during festivals, political gatherings, and many other occasions. Ignorance and lobby from cracker manufacturers make these fire crackers easily available to citizens.

5.9.1.14 Brick Kiln

Bricks are basic building material made from clay, fly ash, soft slate, shale, concrete, calcium silicate, or shaped from quarried stone. The process of making bricks from soft mud is summarised in Fig. 5.33.

Raw clay and 25–30 % sand is mixed with water to achieve desired consistency and moulded into desired shape with hand mould or table mould or hydraulic press or wire cut. The shaped clay is "burned" at 900–1000 °C to impart strength.

Prior to burning in the kiln, the unfired brick must be properly dried to prevent certain defects occurring when the brick heated in the kiln.

Fig. 5.32 Smoke released during burning of firecrackers

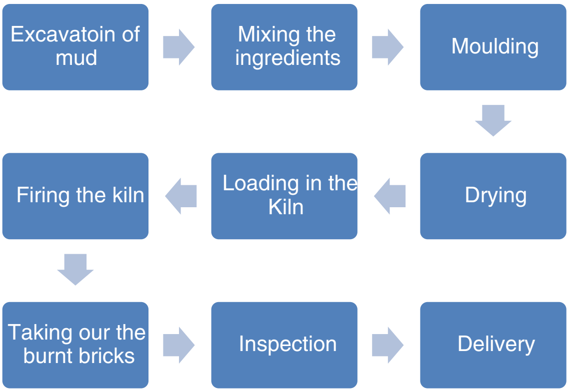


Fig. 5.33 Normal mud brick making process

Figure 5.34 shows classification of Brick Kilns and Fig. 5.35 shows view of brick kiln chimney. The following kilns are commonly used to make bricks:

Clamp Kiln: Generally built with brick walls like a room, where unburnt bricks are stacked inside. These kilns are used to burn bricks in batches. They are not efficient in fuel, and highly polluting.

Hoffman Kiln: These kilns have a large arched masonry with a tall masonry chimney. It is operated in continuous mode.

Bull's Trench Kiln: In this kiln movable metal chimneys are used that are moved as the fire moves in the kiln. The improved version of this kiln has a permanent stack. These kilns are operated in continuous mode. The kiln has no roof and cannot be used during rainy season.

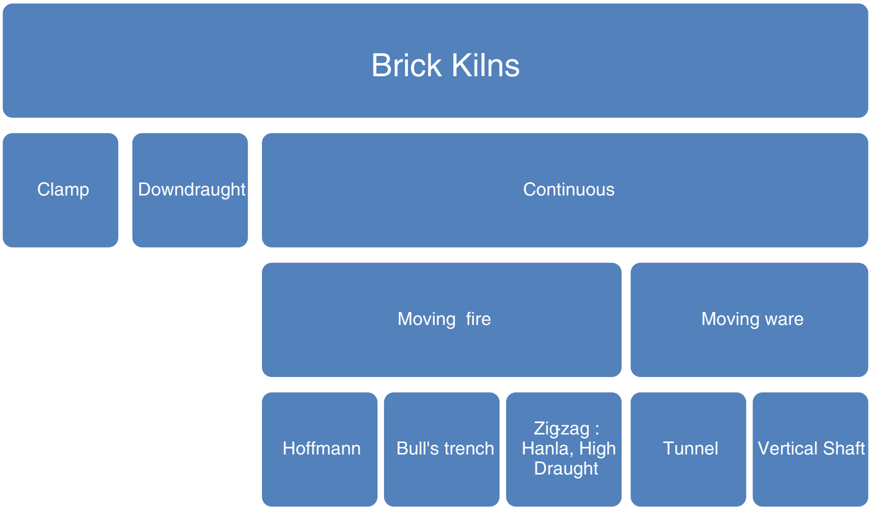


Fig. 5.34 Classification of brick kilns

Fig. 5.35 View of brick kiln chimney

Tunnel kiln: These kilns are highly automated and used for large brick production where bricks move through a long stationary fire zone. They need very high capital cost and operated in continuous mode. This kiln requires a guaranteed electricity supply.

Habla Kiln: It has a long fire zone with suction fan. This kiln consumes less fuel.

Vertical Shaft Kiln: In this kiln unburnt bricks are loaded into the shaft.

Biggest impact happens when bricks get fired and molded clay changes its condition chemically as well as physically. Problem of air pollution aggravates due to clustering of brick kilns.

The characteristics and extent of emission depends on type of kiln and fuel used. The flue gases mainly comprise of particulate matter, SO_2, CO_2, NO_X, CO. The brick kilns in developing countries usually do not fix air pollution equipments and combustion of fuel contributes heavy metal like mercury present in the fuel.

5.9.1.15 Rice Mill

The aim of rice milling is to obtain whole grain rice in their approximate original shape. Rice obtained by milling the pre-boiled rice is called as parboiled rice and the rice obtained by milling untreated paddy is called as white rice or raw rice.

The process employed in rice mill is shown in Figs. 5.36 and 5.37. The paddy is cleaned to remove impurities to protect the processing equipment as well as improve the quality of rice. The impurities include rice straw, bag strings, soil stones, panicles, iron parts, dust, sand, weed seeds, insects, soil particles, stones,

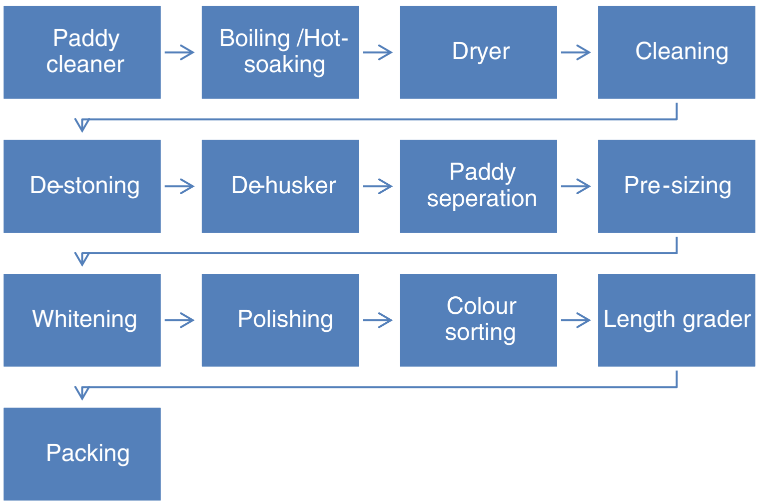


Fig. 5.36 Process flow diagram of production of parboiling rice

empty grains. In the cleaning process different equipments are employed to separate impurities based upon size/weight of foreign bodies. Small/large sized impurities are removed by sieving whereas lighter/heavier impurities are removed by gravity separation.

In parboiling the paddy is soaked heated/steamed and dried, prior to milling to minimize the breakage of rice as well as minimising the loss of nutrients during milling. Parboiling is done by single boiling, double boiling, hot soaking method, pressure parboiling method, modified pressure parboiling method as well as dry heat parboiling.

After parboiling, paddy contains high moisture (20–40 %) hence needs to be dried quickly to achieve around 14 % moisture for safe milling. Drying is done in the sun or by hot air.

The milling process consists of de-husking/hulling, separation of husk and whitening/polishing. Hulling/dehusking is done to take away the husk from the paddy with minimum of damage to bran layer and, without breaking rice grain. During whitening, the silver skin as well as the bran layer is removed and rice is polished to give it a shining.

As per CPCB (2008), sources of dust emissions in rice mill are: (1) unloading the paddy, (2) lifting and discharging of paddy through bucket elevator, (3) pre-cleaning, (4) paddy cleaning, (5) destining, (6) magnetic separator, (7) milling Section, (8) dehusking, (9) polishing, (10) grading, and (11) flue gas through boiler stack.

Cyclone separators are used in rice mill at all air pollution sources except boiler. Air pollution in boiler is controlled depending on fuel and type of boiler.

5.9.1.16 Puffed Rice

Puffed rice or *puri* is a type of puffed grain made from rice, commonly used in breakfast cereal or snack foods, and served as a popular street food in India. It is usually made by heating paddy in sand though the method of manufacture varies

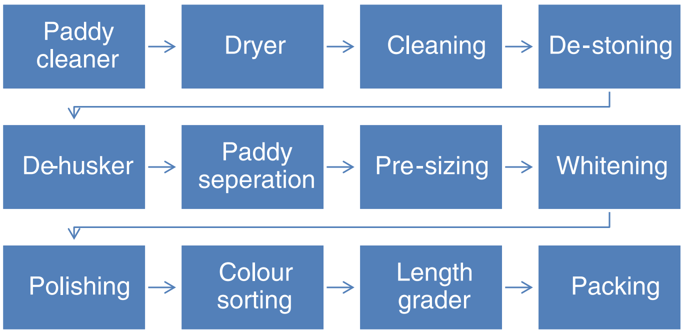


Fig. 5.37 Process flow diagram of production of white/raw rice

widely. The use of tyres, wood and agro waste has been adopted by puffed rice manufacturers in order to reduce manufacturing cost and compete in the market. Many of puffed rice manufacturing units are located in commercial and residential area in India resulting in series of complaints and conflicts. Most of the manufacturers are from informal sector and not registered with any of the government agencies.

The main pollutants are smoke due to combustion of fuel and paddy. Even though air pollution can be reduced by installing scrubbers, these equipments are not installed as it is low priority for manufacturers.

5.9.1.17 Diesel Generator

A diesel generator (often called as DG set, “generating set” or a “genset”) is the combination of an electric generator and diesel engine to produce electrical energy. A diesel CI engine usually is designed to run on diesel. Some generating set are designed to run on other fuels.

DG sets are used as emergency power-supply if the power grid fails or in locations without electric power supply. Ships often also employ DG Set.

DG Set sizes range from 8 to 2000 kW. The main pollutants emitted in DG Set are VOC, SO_x, and NO_x. Particulate matter in the form of un-burnt fuel is often visible at exhaust pipe. SO_x emission is controlled by feeding low sulfur fuel. The emission of NO_x and VOC is controlled by proper design of engines and use of catalytic convertors.

5.9.1.18 Boiler

Boilers are used to convert water into steam for various uses. The steam is used for (1) running turbine in thermal power plant; (2) to maintain the temperature of chemical reactors; and (3) cooking. Hence the boilers are widely used in chemical, pharmaceutical, food, and paper industries. The boiler uses variety of fuel: wood, solid waste, coal, charcoal, furnace oil, diesel and gaseous fuel. The emission from the fuel depends on fuel used. The respective quantities and chemical composition of pollutants are dependent upon variables within the combustion process.

Gaseous fuels burn readily as well as completely compared to other fuels. Solid and liquid fuels need more time for complete combustion since they are tired in droplet/particle form. Fluidized bed boilers cover a range of systems.

Emission control systems for boilers: The usual pollutants emitted from natural gas fired boilers are PM, SO_2, NO_x.

Natural gas fired power boiler: External devices are not normally needed. Pollution control is achieved by properly adjusted combustion controls, furnace designs, burner(s), as well as gas monitoring.

Although natural gas is a clean fuel, some emissions may occur from combustion reaction due to improper operating conditions, poor mixing as well as insufficient air.

Since a mercaptan containing sulfur is added to this fuel for detection proposes, minor quantity of sulfur oxides are produced in the combustion process.

NO_x are the major pollutants generated during burning natural gas. NO_x emissions depend on temperature in the combustion chamber as well as the cooling rate of the combustion products. NO_x emission levels normally vary with the type/size of unit s well as function of loading.

In some large boilers, many operating modifications have been adopted for controlling NO_x. In staged combustion, some burners are operated in fuel-lean condition, where as others in fuel-rich condition, while others supply only air. In two-staged burning, the burners are operated by introducing 80 to 95 % stoichiometric air with burning completed by injection of air above the flame zone through "NO_x-ports".

In staged combustion, emissions of oxides of nitrogen are decreased because most of the combustion happens under fuel-rich, reducing conditions.

Distillate oil fired power boilers: External Particulate emission control devices are not needed for boilers. NO_x can be controlled by using flue staged combustion; gas recirculation; limited excess-air firing; or combinations of these.

Pulverized coal-fired power boiler: Particulates are controlled by ESPs, fabric filters, venturi scrubber. Cyclone separator usually preceded ESPs/filters/scrubbers. SO2 emissions are controlled by wet scrubbing system. NO_x emissions are controlled by using proper burners and furnaces designed to reduce NO_x generation (by limiting excess air firing, staged combustion and flue-gas recirculation).

Residual oil fired power boilers: Particulates are controlled by cyclone separator followed by ESPs, fabric filters, venturi scrubber. SO_2 emissions are controlled by wet scrubbing system.

NO_x emissions are controlled by using proper burners as well as furnaces designed to reduce NO_x generation (by limiting excess air firing, staged combustion and flue-gas recirculation).

Wood waste and bark fired boilers: Wood-fired power boilers are normally found where wood is abundantly available. They are fired with sawdust, sander dust, bark, or process trim. Emissions in boilers using wood fires range between 0.057 and 1.626 gm per cubic meter of dry wood (Boubel et al. 1994a, b). Particulates are controlled by cyclone separator followed by ESPs, fabric filters, venturi scrubber. SO_2 emissions are controlled by wet scrubbing system.

NO_x emissions are controlled by using proper burners as well as furnaces designed to reduce NO_x generation.

Coal fired fluidized bed boilers: Particulates are controlled by cyclone separator followed by ESPs, fabric filters, venturi scrubber. SO_2 emissions are controlled by feeding limestone into fluidized bed of fuel. The low furnace temperatures maintained in fluidized bed boilers avoids the NOx formation during combustion hence no special controls are required for NOx control.

Municipal solid waste fired boilers: Particulates are controlled by cyclone separator followed by ESPs, fabric filters, venturi scrubber. SO_2 emissions are controlled by wet scrubbing system. NO_x emissions are controlled by using proper burners as well as furnaces designed to reduce NO_x generation.

5.9.1.19 Thermic Heaters

Thermic fluid heaters are widely used for indirect process heating employing petroleum—based fluids for transferring heat. The thermic fluid is heated up in the heater that is circulated through the user equipment. The heat is transferred in the process through a heat exchanger. The fluid is then returned to the heater for re heating.

The pollutants emitted in thermic heaters depend on the fuel used. In recent years suppliers and buyers of thermic heaters prefer diesel/furnace oil fired thermic fluid heaters. Emissions from thermic heater mainly contain SO_2, NO_x, PM, VOCs which are dispersed with adequate chimney height.

5.9.1.20 Tobacco Curing

Tobacco is an agricultural product. It is processed from the leaves of plants that belong to genus Nicotiana. It is commonly used as a leisure drug in the forms of chewing, smoking, snuffing, etc. 4.1 million hectares of land was under the cultivation of tobacco in 1985 (Simon and Wong 1990). Tobacco curing is one of the reasons of deforestation in many parts of the world. Wood shortage is alarming in Tanzania and Malawi due to deforestation (Simon and Wong 1990). Money used for purchase of tobacco causes malnutrition in poor families.

Cultivation as well as processing of tobacco creates jobs and lively hood for some people and cause of disease and death for consumers.

Curing tobacco is a process necessary to prepare the tobacco leaf for consumption. Curing and succeeding aging leads to slow oxidation as well as degradation of carotenoids present in the tobacco leaf resulting in compounds that give cured tobacco its aromatic flavor. The aging process extends for a period of months.

Tobacco curing is classified into: air cured, fire cured, flue cured, sun cured.

Air-cured tobacco is hung in ventilated barns and dried from four to eight weeks. *Fire-cured* tobacco is hung in barns and fires of hardwoods are used over a period of three to ten weeks. *Flue-cured* tobacco was initially strung onto tobacco sticks, and hung from tier-poles in curing sheds. These sheds have flues which run from externally fed fire boxes where in tobacco is heat-cured without exposing it to smoke for about a week. *Sun-cured* tobacco is obtained from drying in the sun. Wood requirement for curing tobacco is around 7.8 kg of wood for 1 kg of tobacco (WHO 2014). Curing flue-cured tobacco is a complex process. As per Boornlong et al. (1994), More than 200,000 t of firewood was used for tobacco curing in Thailand each year.The harvested leaves need to be kept alive during the yellowing so that required chemical as well as color changes can occur. When yellowing is accomplished the leaves will be wilted. After the leaves attain the desired yellow color, the temperature need to be raised to kill the tissue as well as stop further chemical/color changes.

Temporary curing boxes are now being used in many parts of the world instead of conventional curing structures.

5.9.1.21 Hotels and Restaurants

A hotel is a place for short stay. Restaurants provide food. A variety of hotels and restaurants are seen all over the world. A comfortable as well as healthy indoor environment is key factor to attract and retain premium guest. Hotels and restaurants are not considered as great threat to air pollution.

Pollution sources from restaurants include emissions from variety of ovens that include coal fired, wood fired and electrical. Emissions from kitchen include oil droplets and VOCs arising from deep fry and shallow frying. Modern kitchens are designed with proper ventilation that transports pollutants to air purifiers or directly into atmosphere. Common choice of air purifier includes air filters that are washable. Use of filter in hoods is also common in modular kitchen where in pollutants are captured at the point of generation by washable filters.

The most common hotel pollutants and their sources are listed below:

Personal care products, cleaners and pesticides used by inmates and hotel staff can increase the concentration of pollutants in indoor. Indoor CO_2 concentration in hotels increases due to overcrowd and inadequate ventilation. Carbon monoxide and nitrogen dioxide are released from car exhaust, gas stoves, smoke, heaters as well as fireplaces. Tobacco smoke is a complex mixture of more than 4000 chemical compounds emitted by guests. Formaldehyde emissions occur from furniture, cleaning fluids, adhesives, urea-formaldehyde foam insulation, carpets, etc. Lead from lead-based paint can become airborne when paint flakes off walls and renovation. Ozone can be generated by equipment that utilises UV light or equipments that causes ionisation of air which includes laser printers, photocopiers, as well as ionisers. Radon may enter building from natural sources and VOCs are emitted from cleaning agents, building materials, cosmetics, waxes, laser printers, photocopiers, carpets, furnishings, adhesives and paints.

Asbestos can be present in buildings and building installations in the form of asbestos spray, asbestos-textured paints, flexible joints in air handling units, insulation boards in electrical switch boxes, and brake linings in lift brake drums. Inhalation of asbestos fibres has been linked to asbestosis, lung cancer and mesothelioma (a cancer of the lining of the chest or abdominal cavity).

Biological contaminants include bacteria, fungi and microscopic allergens such as dust mites. Their growth may be accelerated by inadequate ventilation, dirty air filter or ventilation systems, inadequate maintenance and inadequate humidity control. They may cause sneezing, coughing, shortness of breath, dizziness and lethargy. Some of them may trigger allergic or asthmatic reactions.

Indoor air quality improvement is achieved by: (1) eliminating stagnant water accumulation, (2) carrying out routine cleaning/maintenance of the ventilation system, (3) ensuring location of the fresh air inlets far away from any pollution sources like trash storage place, car parks, kitchens and washrooms, (4) conduct daily vacuuming of carpets, (5) control oil emissions from kitchens by installing air pollution control devices like electrostatic precipitators or air filters, (6) maintain kitchens and canteens under slightly negative pressure, to reduce migration of the pollutants, (7) provide adequate or separate ventilation for pollutant-generating

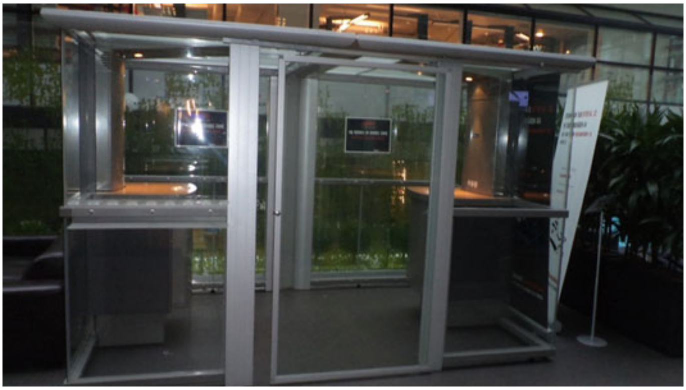


Fig. 5.38 Smoking chamber

office equipment such as copiers, printers and fax machines, (8) heavy-duty photocopying should be located away from densely occupied office space to decrease the impact of particles/ozone on the occupants. Choose furniture and materials with very low formaldehyde and VOCs, (10) avoiding use of chemicals with VOC for cleaning of the carpet, fittings, panels, windows, and flooring, (11) removing/ discarding mouldy carpets, (12) switch off engines of vehicles while waiting and (13) Installing smoking chamber (Fig. 5.38).

5.9.1.22 Food Industries

Eating habits vary hugely from country to country. It may also vary within the country. Sizes of this industry vary from small units in slums to sophisticated industry spread over huge area. Food industries includes slaughter house, processing of food grains, bakery, beverages, breweries, confectionaries, and ready to eat foods that varies from country to country.

Frying, baking, cooking would often require fuel even though electricity is commonly used in sophisticated industry.

Rearing animals result in obnoxious odors due to generation of large quantities of excreta.

Grain grinding and handling result is emissions of grain dust. Normally such emissions are controlled by baghouses following the cyclones in large setup shere it is controlled by having open smog at the outlet of flour mill (Fig. 5.39). Caution is required in places handling grain dust as it is combustible and can result in fires.

Odors can arise in slaughter house and ment processing units during rendering, cooking, smoking, as well as processing. The emissions from the meat/fish processing are controlled by afterburners in developing countries. But the practice in developing countries is very primitive and unhygienic without any attention for air pollution.

Fig. 5.39 Bags used at out let of flour mill controls dust

Cooking of fruits and vegetables can cause odors that are normally controlled by afterburners. Roasting of coffee emits smoke, odor as well as particulate matter. The particulate matter from coffee grinder is usually removed with a cyclone separator whereas smoke and odors require an afterburner.

5.9.1.23 Glass Industry

Manufacturing of glass involves preparation of glass melt from silica sand, dolomite, soda, lime, and cullet (broken glass). Other raw material like lead oxide, zinc oxide, potash, and other metal oxides are added to manufacture special and technical glass. Metal oxides as well as sulfides are used as coloring/decoloring agents. Refining agents include antimony oxide, arsenic trioxide, nitrates, as well as sulfates.

The emission from glass manufacturing originates from (1) combustion of fuel for operating the furnaces, and (2) the vaporization and recrystallization of substances in the melt. The main emissions from glass manufacturing are SOx, NOx, and particulates. Particles may contain heavy metals such as lead and arsenic. Manufacturing of certain specialty glasses may generate arsenic, hydrogen chloride, hydrogen fluoride, boron, and lead from raw materials.

Container pressing, as well as blowing operations generate a periodic mist. Cold-top electric furnaces, release very less particulate matter. The pollutants emitted depend on the type of fuel and the composition of the raw material. High input of sulfates and potassium nitrate will increase emissions of sulfur dioxide as well as nitrogen oxides, respectively (World Bank 1999).

Use of Oxygen-enriched and oxyfuel furnaces reduce emissions. Use of natural gas emits negligible sulfur dioxide emissions compared to other high-sulfur fuel oils. Other modes of emission control are improved burner design and firing patterns, preheating of raw material, and electric melting.

5.9.1.24 Crematoria

Air pollutants are emitted in the cremation processes due to incomplete combustion, and the volatilization of metals present the human body. Combustion results in particulate matter, hydrogen chloride, as well as other emissions that depend on chemicals in the body, dress/coffin. Incomplete combustion will produce carbon monoxide. The emission may also comprise of radioactive elements if the body belongs to patient treated with radioactive material. Other emissions may arise due to medicines used by dead person and contamination in the cloths.

HCl is generated when plastics with chlorine are burnt. NO_x reaction of oxygen and nitrogen in the body and air formed due to.

A human crematory comprises of one or more combustion chambers known as cremators. Polychlorinated dibenzo-p-dioxins and—furans (PCDD/F) emissions are formed due to combustion of chlorinated products such as plastic present as prosthetics (artificial appliance that replaces a lost body part) or as part of the container or in buttons/zip/ornaments/foot ware/clothing. The body and non-treated wood will have small quantity of chlorine (Mari and Domingo 2010).

Mercury is usually emitted during incineration (Llobet et al. 2002; Ferré-Huguet et al. 2007; Mari and Domingo 2010; Muenhor et al. 2009) of body having fillings made with dental amalgam.

5.9.1.25 Gas Turbine

Gas turbines (combustion turbines) are used in electric power generation, natural gas transmission, cogeneration, and various process applications. These turbines are available with power outputs from 300 hp to over 268,000 hp.

A gas turbine is an IC engine that operates with rotary motion. These turbines contain three main components: compressor, combustor, as well as power turbine.

Ambient air is drawn and compressed in the compressor section, and directed to the combustor section. In combustor section fuel is introduced, ignited, as well as burned.

The main pollutants from gas turbine engines are NO_X, CO, VOC and PM. Trace to low quantity of HAP and SO2 are also emitted. CO, VOC, HAP, and PM are formed due to the result of incomplete combustion.

Following are common types of emission controls used for gas turbines: (1) wet controls using steam; (2) water injection to decrease combustion temperatures; (3) advanced combustor design to reduce NO_X formation and/or promote CO burnout,(4) post-combustion catalytic control to reduce NO_X and/or oxidize CO emission.

5.9.2 Industries with Gaseous Pollutants

Many industries which involve reaction of gases and use of gases for combustion will have negligible PM or no PM. Hence use of air pollution control equipment system need not have PM control device.

5.9.2.1 Petroleum Refineries

The petroleum industry can be categorized into four sectors: (1) exploration and production of natural gas and crude oil; (2) transport; (3) refining; and (4) marketing and distribution. Refining involves fractioning of crude oil into liquefied petroleum gas, kerosene, aviation turbine fuel, diesel oil, naphtha, and residual fuel oil. Thermal cracking; catalytic cracking and reforming; and other processes are employed to achieve the required product specifications. Some refineries produce coke, feedstock for the manufacturing of bitumens and lubricating oils.

Major sources of air pollution from petroleum industry are given in Table 5.7. Major activities in exploration and production of crude oil as well as natural gas include exploration, site preparation, drilling, crude oil/gas production, enhanced recovery and on-site processing. Air pollutants from these activities are volatile hydrocarbons, and emissions from storage/manipulation, exhaust from compressors, pumps, drill engines, engines of servicing vehicles, gas flaring, water separated from the crude oil and natural gas.

A blowout (uncontrolled release of a formation fluid, usually gas, from a well being drilled, typically for petroleum production) results in wastage of gas and oil on a large scale. Wastewaters generated during drilling and crude oil/gas production operation are held in pits. VOCs and other compounds, such as hydrogen sulfide will escape from the theses wastewater pits into the atmosphere. These chemicals will then be transported through the air, into nearby neighborhoods. The odors associated during drilling and crude oil/gas production chemicals will vary, depending on the concentrations, volumes, as well as combinations of chemicals released.

Earthen pits are often used to store or evaporate produced water as well as wastewater from natural gas dehydration or oil/gas separation units. Further drilling wastes (muds and cements) and hydraulic fracturing (fracking) wastes are usually stored in earthen/metal pits that are open to the air.

Venting (release of gas to the atmosphere) occurs at a number of points in the oil and gas development process (well completion; well maintenance; pipeline maintenance; tank maintenance; etc.).

Gases generated from crude oil/gas production are allowed to escape into the atmosphere, or they are burned off (flared). Flares emit a numerous air pollutants, depending on the chemical composition of the gas being burned as well as the efficiency/temperature of the flare (Table 5.9).

Boilers, process heaters, as well as other process equipment in petroleum industry emit particulates, carbon monoxide, NOx, SOx, and CO_2. Catalyst

Table 5.9 Sources of air pollution in petroleum industry

Sl. No.	Source	Control method
1.	Site preparation	Maintenance of vehicle, spraying water on roads
2.	Drilling	Maintenance of vehicle, spraying water
3.	Crude oil/gas production	Floating roof tanks; Vapor recovery systems; pressure tanks; vapor balance; painting tanks white
4.	Enhanced recovery	Vapor recovery systems; pressure tanks; vapor balance; painting tanks white
5.	On-site processing	Floating roof tanks; Vapor recovery systems; pressure tanks; vapor balance; painting tanks white
6.	Ballast water from ships during transportation, leaking liquid from pipelines in petroleum facility	Inspection and maintenance
7.	Storage vessels	Floating roof tanks; Vapor recovery systems; pressure tanks; vapor balance; painting tanks white
8.	Catalyst regenerators	Install and operate cyclones; Precipitators; scrubber
9.	Accumulator vents	Vapor recovery vapor incineration
10.	Blowdown systems	Smokelss flares-gas recovery
11.	Pumps and compressors	Inspection and maintenance; Mechanical seals; vapor recovery; sealing glands by oil pressure;
12.	Vacuum jets	Vapor incineration
13.	Equipment valves	Inspection and maintenance
14.	Pressure relief valves	Inspection and maintenance
15.	Effluent waste disposal	Enclosing separators; liquid seals on drains; covering sewer boxes
16.	Bulk loading facilities	Submerged or bottom loading; Vapor collection with recovery or incineration;

(continued)

Table 5.9 (continued)

Sl. No.	Source	Control method
17.	Acid treating	Continuous-type agitators with mechanical mixing; stop sludge burning; replace with catalytic hydrogenation units; incinerate all vented cases;
18.	Acid sludge storage and shipping	Scrubbing; incineration, vapor return system
19.	Spent caustic handling	Incineration; scrubbing
20.	Doctor sweetening process (industrial chemical process for converting mercaptans in sour gasoline (petrol) into disulfides)	Steam strip spent doctor solution to hydrocarbon recovery before air regeneration; replace treating unit with other, less objectionable units
21.	Sour water treating	Use sour water oxidizers as well as gas incineration; conversion to ammonium sulfate
22.	Mercaptan disposal	Adding to catalytic cracking charge stock; Conversion to disulfides; incineration; using material in organic synthesis
23.	Asphalt blowing	Incineration; scrubbing
24.	Shutdowns, turnarounds	Depressure and purge to vapor recovery

Source Bela (1974), Boubel et al. (1994a, b), observation from authors

changeovers along with cokers release particulates. VOCs such as toluene, benzene, and xylene are emitted from product loading, storage and handling facilities; and oil-water separation systems. Fugitive emissions released from valves, flanges, seals, and drains also contribute to VOCs.

Each ton of crude processed, emits 0.8 kg particulate matter; 1.3 kg of Sulfur oxides; 0.3 kg of nitrogen oxides; and 2.5 g of Benzene, toluene and xylene. VOC emissions depend on the process techniques, equipment maintenance, emissions control techniques, and climate conditions. VOC emissions range from 0.5 to 6 kg/t of crude (World Bank 1999).

Sustainable air pollution control options include (1) reducing losses from petroleum product storage and transfer areas by double seals and vapor recovery systems, (2) reducing SOx emissions through desulfurization of fuels, or using of high-sulfur fuels in operations/process equipped with SO_x emissions controls, (3) recovering sulfur from tail gases, (4) recovering non-silica-based catalysts and reduce particulate emissions, (4) keeping fuel usage to a minimum, (5) using low-NO_x burners to lessen NO_x emissions, and (6) avoiding/limiting fugitive emissions by process design and maintenance,

Solution for elimination or reduction of pollution include capture and recycling/combustion of emissions from product transfer points, vents, storage tanks, as well as other handling equipment. Particulate matter controls are required for heaters, boilers, other combustion devices, cokers, as well as catalytic units. Use of carbon monoxide boiler is usually practiced in the fluidized catalytic cracking units to control emission of carbon monoxide. Steam injection in flaring stacks is practiced to reduce particulate matter emissions.

Hydrocarbons are main air emissions from storage/transportation of petroleum liquids. Ballast water from ships is major source of secondary emissions, as well as marine water pollution. Leaking liquids from pipelines also source of hydrocarbon emissions into atmosphere.

The most extensively used control technologies to control emissions from storage tanks include floating roofs from where vapors are collected.

Typical control techniques include flue gas heat recovery, new types of burners, manufacturing processes with lower energy consumption. Flaring is employed to remove gas, which cannot be used.

Fugitive emissions are controlled by proper inspection and maintenance. *Process emissions* generated in the process released from process vents. Gas streams from refinery processes are passed through gas treatment as well as sulfur recovery units to remove sulfur. Wet scrubbers are used for catalytic cracking units in order to remove catalyst fines.

Storm water drainage, sewer system, tanks, etc. are the main source of *secondary emissions is controlled by* closed systems.

5.9.2.2 Chemical Manufacturing

Chemical industry is a broad term that covers petrochemical industry, pharmaceutical productions, and fine chemicals production, etc. The chemical industry converts raw materials such as oil, natural gas, metals, air, water, as well as minerals into more than 70,000 products.

The majority of chemical manufacturing is related to the petrochemical industry, coal processing, coal tar distillation, fermentation, processing of metals etc., The major chemicals manufactured in terms of quantity are sulfuric acid, nitrogen, propylene, polyethylene, chlorine, lime, ammonia, ethylene, oxygen, phosphoric acid and diammonium phosphates.

There are four basic organic bulk chemicals that impose significant impact on environment as well as human health: benzene, ethylene, propylene, and vinyl chloride (Beschkov 2006).

The main use of ethylene is polyethylene synthesis. Even though Ethylene is not carcinogenic, some of its derivatives are carcinogens.

Propylene is the monomer used for synthesis poly-propylene; substrate for propylene oxide, iso-propanol, and acrylonitrile. The propylene oxide and acrylonitrile are carcinogenic.

Benzene is a product of oil processing used for production of ethyl-benzene, cumene, nitrobenzene, cyclohexane, and benzene chloride that are precursor for other products like dyestuffs, explosives, aniline, pharmaceuticals, etc. which are toxic and/or carcinogenic.

Vinyl chloride is a monomer emitted from PVC production which is carcinogenic.

Emissions from chemical manufacture occur from vents from hooding, reactors, distillation units, loading/unloading and storage tanks. Fugitive emissions from valves, pumps, pipe joints and mechanical seals are frequently emitted into atmosphere.

Basic chemicals, or "commodity chemicals" are chemical category including bulk petrochemicals and intermediates; polymers; inorganic chemicals; other derivatives and basic industrials; and fertilizers.

Polymers that includes plastics and man-made fibers are used in packaging, home construction, pipe, transportation, toys, containers, appliances and sports.

Polyethylene is the most used polymer mainly used in packaging films as well as other products such as containers, milk bottles, as well as pipe. Polyvinyl chloride (PVC) is mainly used in manufacturing pipe for packaging materials and construction markets. Polypropylene, is used in packaging, containers, appliances, clothing as well as carpeting. Polystyrene, is used mainly for appliances, packaging, toys and recreation. The main man-made fibers include polypropylene, polyester, nylon, and acrylics.

Bulk petrochemicals, are the principal raw materials for polymers. Bulk petrochemicals as well as intermediates are made from LPG, natural gas, as well as crude oil. Other derivatives in chemical industry include synthetic rubber, dyes, surfactants, pigments, turpentine, carbon black, resins, explosives, as well as rubber products. Inorganic chemicals manufactured in chemical industry include salt, caustic soda, soda ash, chlorine, acids (such as phosphoric acid, nitric acid, hydrochloric acid and sulfuric acid), hydrogen peroxide and titanium dioxide.

Fertilizers are the smallest category among chemical industry. It includes phosphates, ammonia, and potash chemicals.

Life sciences chemicals include differentiated chemical as well as biological substances, diagnostics, pharmaceuticals, animal health products, vitamins as well as pesticides.

Specialty chemicals include industrial gases, electronic chemicals, adhesives, sealants, coatings, industrial/institutional cleaning chemicals, as well as catalysts.

Chemical consumer products include soaps, detergents, cosmetics, plastics, cosmetics, paints, cleaning materials, coatings, automobiles, electronic gadgets, and construction materials, industrial Cleaners, flavours, fragrances, printing inks, water soluble polymers, speciality coatings, food additives, paper chemicals, oil field chemicals, adhesives and sealants, cosmetic chemicals, catalysts, textile chemicals, water management chemicals.

Apart from production emission from storage tanks (Fig. 5.40 and 5.41). The emission control is done by following good practices; proper operation; proper maintenance and using pollution control equipment at appropriate locations.

The emission of VOCs in laboratories is controlled by using chemical cans with vents fitted with absorbents (Fig. 5.42).

Fig. 5.40 Waste chemical storage tank and drums

Fig. 5.41 Waste chemical tank

5.9.2.3 Inorganic Chemical Manufacturing

Inorganic chemicals are widely used in agriculture, household and industrial activities. They have become essential part of day to day activities. Following paragraphs discuss some of the important chemicals significant from air pollution point of view.

Production of Sulfuric Acid

The most commonly used method for sulfuric acid production is catalytic oxidation of sulfur dioxide to sulfur trioxide followed by reaction with water.

$$2SO_2 + O_2 \rightarrow 2SO_3$$
$$SO_3 + H_2O \rightarrow H_2SO_4$$

Fig. 5.42 Chemical cans with vents fitted with absorbents

Formation of oxides of nitrogen is possible in the process. To avoid formation of mists of SO_3, the reacting gases are washed in dilute sulfuric acid.

SO_x is produced by burning elemental sulfur or metal sulfides. The main disadvantage of the using metal sulfides in manufacturing sulfuric acid is contamination of arsenic, and the associated problems with respect to environment protection.

Reduction of the SO_2 concentration in the exhaust gases is achieved by optimization of the ratio of SO_2 to O_2 in the gas inflowing to the catalytic converter and increasing residence time of the reactants. Intermediate cooling and absorption of SO_3 before the conversion in the fourth stage can also reduce emission of SO_2 into atmosphere.

Mist formed due to the existence of water vapor in the feed can be neutralized by washing inlet air with concentrated H_2SO_4. Washing with ammonium hydroxide or water in a scrubber can decrease the emissions in air. The mist removal is achieved by the Brinck's demistor in most of the manufacturing facility which contains fabrics of glass fiber.

Production of Nitrate-Containing Fertilizers

Main nitrate containing fertilizers are sodium, ammonium and potassium salts of nitric acid. Manufacturing involves two steps: ammonia synthesis followed by oxidation to nitric acid.

Catalytic synthesis of ammonia from hydrogen and nitrogen is accomplished at high temperature (450–500 °C) and high pressure (up to 900 bars). The nitrogen is produced by controlled combustion of fuels or by distillation of liquid air.

When nitrogen is produced by distillation of liquid air, the hydrogen essential for the synthesis is normally obtained from (1) electrolytic production of sodium hydroxide and chlorine, (2) petrochemical industry, (3) coal, (4) natural gas and water steam. Controlled combustion of the natural gas in presence of water steam followed by shortage of air produces a mixture of H_2, N_2 and CO_2:

$$CH_4 + H_2O \rightarrow CO + 3H_2$$
$$2CO + O_2 \rightarrow 2CO_2$$

The produced CO_2 can be removed by scrubbing followed by treatment with hydrogen to obtain CH_4 again.

Major air pollutants from production of Nitrate-Containing pollutants are: (1) SO_2 resulting from the burning of coke, natural gas or oil products, (2) NO_x from partial oxidation of atmospheric nitrogen and partial oxidation of the ammonia.

Reduction in NH_3 emission is achieved by better feeding as well as compressing of ammonia, removal from the exhaust gases; and improved control of evaporation.

The effectiveness in hydrogen utilization can be improved by: (1) reducing the ratio of steam to H_2 in the reforming step, and (2) by improving the system of separation of CO_2.

Production of Nitric Acid

Nitric acid is normally produced by catalytic oxidation of ammonia followed by absorption of NO_2 in water. NO formed during oxidation is oxidized to NO_2 which is absorbed in water. Multi-layer platinum net is usually used as catalyst.

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$
$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$$

The key air pollutants are NO_x, mainly NO_2 which is removed by catalytic reduction with methane/hydrogen or scrubbing with alkaline solutions.

Soda Production

Ernest Solvay developed the traditional soda production technology and its modern version explained by equation below involves saturation with gaseous ammonia, and carbon dioxide:

$$NaCl + NH_3 + CO_2 + H_2O \rightarrow NaHCO_3 + NH_4Cl$$

Sodium bicarbonate thus formed in is precipitated, filtered, dried and calcinated in a rotary kiln.

$$2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$

Recovery of ammonia from ammonium chloride can be achieved as follows:

$$2NH_4Cl + Ca(OH)_2 \rightarrow 2NH_3 + CaCl_2 + 2H_2O$$

Air pollutants in soda production are emitted from the lime kilns releasing PM and CO_2. The fly soda ash is emitted after calcination. The pollutants are captured using ESPs or bag house (Beschkov 2006).

5.9.2.4 Metal Industries

Metal or metallurgical industry generate large amount of air pollution as most of the metals are extracted from minerals by series of chemical reaction at high temperature. Coke used in steel industry manufactured from coal releases mixtures of air pollutants that remain incompletely characterised (Bhopal et al. 1994). The mining and metallurgical industries are source of toxic materials. The Romans, used to send prisoners to work in mercury mines as it was well-known that they will die soon due to air in the mine (Habashi 2011).

Metallurgical activities are broadly classified into Pyrometalurgy, Hydrometallurgy and Electrometallurgy (Fig. 5.43).

Pyrometallurgy consists of the thermal treatment of ores to bring about physical as well as chemical transformations. Elements extract by pyrometallurgy include the oxides of less reactive metals such as Iron, Copper, Zinc, Chromium, Tin, and Manganese. Pyrometallurgical processes are grouped into: (1) Calcining, (2) Roasting, (3) Smelting, and (4) Refining.

The energy for pyrometallurgical process is provided by fossil fuel combustion, or electrical heat or exothermic reaction of the material. When enough material is present within in the ore to sustain process without external energy source, the process is called autogenous.

Calcining is thermal decomposition. Examples include decomposition of ferric hydroxide to water vapor and ferric oxide. Another example is decomposition of calcium carbonate to carbon dioxide and calcium oxide. Calcination is carried out in furnaces, which include rotary kilns, shaft furnaces, and fluidized bed reactors.

Roasting is thermal gas-solid reactions. The process includes oxidation, chlorination, sulfation, reduction, and pyrohydrolysis. The common example of roasting is the oxidation of metal sulfide ores. The technology is a significant source of air pollution.

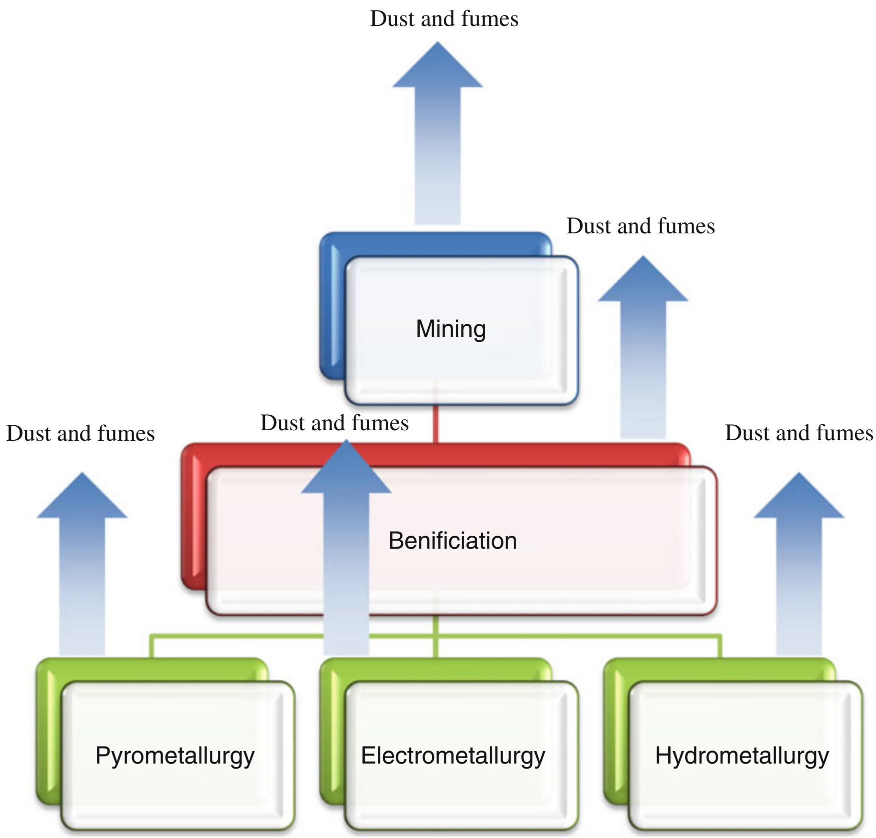


Fig. 5.43 Classification of metallurgy

During roasting, the sulfide is transformed to an oxide, and is released as SO_2, for chalcocite (Cu_2S) and sphalerite (ZnS), equations for the roasting are:

$$2Cu_2S + 3O_2 \rightarrow 2Cu_2O + 2SO_2$$
$$2ZnS + 3O_2 \rightarrow 2ZnO + 2SO_2$$

The Sulfur dioxide from roasting is often used to manufacture sulfuric acid. Most of the sulfide minerals contain components like arsenic that are released into the atmosphere.

Smelting is a process in which a metal is obtained, from its ore by raising temperature beyond the melting point. Smelting can be done in the presence of oxidizing agent like air or reducing agent like coke.

Refining is the process of removal of impurities by a thermal process of electrolytic processes in metals.

Table 5.10 Major sources of air pollution in metallurgical industry

Sl. No.	Type of metallurgical process	Product/Activity	Description of major air pollutants
1.	Pyrometallurgy	Iron and Steel; Processing of Sulphide ores (copper, lead, zinc Nickel); Ferro Alloy Production	*Nickel carbonyl*: Formed during nickel refining process when impure nickel reacts at high temperature and pressure with Carbon monoxide
			Mercury: Mercury vapours are emitted during combustion/processing of coal and minerals which will have mercury
			Arsenic oxide: Generated during the oxidation of arsenic-bearing sulfide minerals under restricted supply of air
			Nitrogen dioxide: This gas is formed during combustion process and reaction between nitric acid with minerals
			Sulfur dioxide: Sulfur dioxide is generated due to combustion of fuels with sulfur and melting of sulfur/suphide bearing ores.
			Cyanogen: This gas is formed when hot air contact carbon under reducing conditions (as in the iron Blast Furnace (BF))
			Carbon disulfide: It is formed in small quantity when SO_2 reacts with carbon at high temperature
			Nitric oxide: It is formed in trace amounts when a fuel is burnt with air and hence will be present flue gases
			Carbon monoxide: This is used as a reducing agent and is a major component of producer gas and BF gas
			Carbon dioxide: This is generated during combustion of carbonaceous fuels
			Acetylene: Acetylen is produced from calcium carbide or from petroleum fractions
			Phosphine: Calcium carbide (produced by heating lime with coke in an electric furnace) is used for manufacture of acetylene. Phosphine is formed in the process due to presence of traces of phosphorus in raw material
			Fluoride: Hydrogen fluoride, sodium fluorides and aluminium fluorides are produced in the aluminium smelting process

(continued)

Table 5.10 (continued)

Sl. No.	Type of metallurgical process	Product/Activity	Description of major air pollutants
2.	Electrometallurgy	Production/refining of Aluminium, Chromium, Copper, Steel	Metal oxides, PM, CO, Carbon tetrafluoride, hydrogen fluoride, hexafluorethane, hydrogen fluoride, SO_x: Formed during electrochemical reaction
3.	Hydrometallurgy	Production of Gold, Silver, Copper Zinc, Uranium, Thorium	*Arsine*: This gas is formed when hydrogen is generated in presence of arsenic-bearing solutions
			Phosgene: It is formed during the chlorination of metal oxides under certain conditions
			Chlorine: This gas which is heavier than air is used to form chlorides from ores as well as concentrates
			Hydrogen fluoride: This gas is used in the fluorination of oxides
			Hydrogen cyanide: This gas which is lighter than air may be formed during cyanidation process of gold ores
			Ammonia: Ammonia is used in hydrometallurgy for leaching sulfides of nickel, copper, and cobalt as ammonia forms the ammine complexes with these metals
			Sulfur chlorides: These chlorides are formed during the treatment of concentrates of sulfide with chlorine
			Hydrogen chloride: This gas may be formed accidentally in industry when gaseous chlorides leak and react with moisture in the air
			Hydrogen sulfide: The gas is used in hydrometallurgy for precipitation of copper, nickel, as well as cobalt from solution
			Fluorine: Fluorine is used mainly for uranium isotopic enrichment and to produce uranium hexafluoride from uranium tetrafluoride

Pyrometallurgical processing of ores generates dust, slag, and gases. The dust can be controlled by cyclone separator, scrubbers, and ESPs. The electrometallurgical operations are employed in aluminum industry, copper electrorefining and zinc electrowinning which emit gases and dust.

Major air pollutants significant in metallurgical industries are given in Table 5.10.

Metallurgical industry emits particles (size 1–150 µm), fumes (0.2–1µm), and smokes (less than 0.2 µm). Dust is formed due to mechanical attrition whereas fumes/smoke is formed due to chemical reaction. Aerosols formed due to condensation of vapours or mechanically when a gas escapes an aqueous solution. Oxygen is generated in the anode during electrowinning of zinc. Surface active agent or plastic balls on the top of the electrolyte allow escape of oxygen without acid droplets.

Explosions may occur in a metallurgical plant. Molten material like molten salts, mattes, slags, and metals are vulnerable to explode when handled improperly. Contact with water is the usually cause of explosion. Molten mattes react with water to formation of Hydrogen Sulphide which is explosive. Pouring molten slag/metal into water for cooling/granulation purposes is safe but the reverse is not true. Methane and natural gas are often a cause of explosion in underground coal mines. Aluminum/iron powders may explode or catch fire due to oxidation. Mines of sulfide minerals may catch fire when sulfides are accumulated in existence of humidity. Some microorganisms accelerate the oxidation reaction resulting in heat.

Iron and steel production

Iron and steel industry causes noteworthy impact on air quality. The major plants involved in iron and steel production are sintering (process of forming a solid mass of material by heat/pressure without melting it) plants, BF, direct reduction plants, steel works, rolling, scarfing(process which removes surface defects prior to shaping/rolling), pickling, ferroalloy production, iron and steel foundry, argon—oxygen decarburization, ladle metallurgy vacuum degassing. Coking plants are considered as part of this sector as coke is produced exclusively for the iron and steel manufacturing.

Sinter plants generate emissions from wind box exhaust, material handling, discharge end as well as cold screen. Emissions from sinter plants comprise mainly iron oxides, carbonaceous compounds, calcium oxides, sulfur oxides, hydrocarbons, and chlorides. Sintering Plant emits significant quantity of SO_2, PAH, NO_x, CO, H_2S, Organi Compound (such as such as Polychlorinated byphenyls (PCB) and PCDD/F), PM, Zn, heavy metals (Pb, Ni, As, Cd, Cu, Se, Hg, Cr, etc.,) HCl.

Following techniques are considered as Best Available technology (BAT) for sintering plant (European Commission 2001).

1. Use of Advanced ESP; *or* ESP and fabric filter; *or* pre-dedusting and high pressure wet scrubbing system.
2. Waste gas recirculation, by: Partial recirculation of the waste gas from the surface of the sinter strand; *or* sectional waste gas recirculation.

3. Minimising of PCDD/F emissions, by treatment of waste gas from sinter strand;
4. Application of waste gas recirculation;
5. Use of fine wet scrubbing systems;
6. Fabric filtration with addition of lignite coke powder;
7. Use of fine wet scrubbing systems or a bag filter with lime addition;
8. Exclusion of PM from last ESP field from recycling to the sinter strand.
9. Lowering the sulphur input by use of coke and/or iron ore with breeze with low sulphur content, Adopting wet waste gas desulphurization.
10. Minimisation of NOx emissions by: waste gas recirculation; waste gas denitrification, by regenerative activated carbon process or selective catalytic reduction.

Pelletisation is one more process to agglomerate iron-containing material. While sinter is produced at the steelworks site, pellets are produced at mine or its shipping port. Following techniques are considered as BAT for pelletisation plant (European Commission 2001).

1. Removal of PM, SO_2, HCl and HF from the by means of:
   - Scrubbing *or*
   - Semi-dry desulphurisation followed by de-dusting
2. Plant design should be optimised to generate low-NOx emissions from all firing sections

Significant emissions from BF comprise of magnesium oxide, iron oxides, and carbonaceous compounds. The significant air pollutants from the basic oxygen process are emitted at the time of the oxygen blow period. The emissions during oxygen blow period comprises of iron oxides, mostly heavy metals as well as fluorides.

The emissions from electric steelmaking process are: melting—iron oxide; refining—calcium oxide; and tapping steel–iron oxides as well as oxides from the fluxes. Emissions also occur during pouring of the molten steel into ingot molds as well as when semi finished steel is scarfed.

Open dust sources in iron and steel mill include vehicle traffic; wind erosion from storage pile; and raw material handling. Pollution control from iron and steel industry is achieved by cyclone cleaners, dry or wet ESPs, scrubbers, and bag houses.

Sintering in iron production converts fine-sized iron ore, coke breeze, lime stone, mill scale, and flue dust into sinter for charging into the BF. A burner hood, at the commencement of the sinter strand set fire to the coke in the mixture. The combustion provides heat (between 1300 and 1480 °C) to cause agglomeration of the mix.

Wind boxes below the sinter strand draw combusted air through the material bed. The fused sinter is crushed and screened at the end of the sinter strand which is cooled in open air with water sprays or mechanical fans. The cooled products are fed to the BFs.

Emissions form sinter plants are generated from wind box exhaust; handling of raw material; cooler and cold screen; and discharge. The wind box exhaust comprises of particulate emissions, containing iron oxides, carbonaceous compounds, sulfur oxides, aliphatic hydrocarbons as well as chlorides. Cyclone separators, ESP, wet scrubber, Rotary Vacuum Drum Filters (RVDF), and bag house are used to control air pollution from sinter strand and wind box emissions.

Sustainable practice for raw material handling often employs Dry Fog Dust Suppression (DFDS) systems at wagon tipplers, stock house and dust extraction systems at transfer points. Figure 5.44 shows Conventional and improved dust extraction system (b) Hood (b) Dog house or house in house Secondary emission are controlled by using ‘house in house’ or ‘dog house’ to reduce escape of pollutants.

Following techniques are considered as BAT for coke oven plant (European Commission 2001).

Extensive maintenance of oven doors and frame seals, oven chambers, charging holes, ascension pipes, and other equipment;

1. Sustain a free gas flow in the coke ovens;
2. Undisturbed, smooth, avoiding strong temperature fluctuations, coke oven operation;
3. Application of flexible-sealing spring-loaded doors or knife edged;
4. Use of desulphurized Coke Oven Gas (COG);
5. Prevention of leakage between heating chamber as well as oven chamber by regular coke oven operation;
6. Repair of leakage between oven chamber and heating chamber;

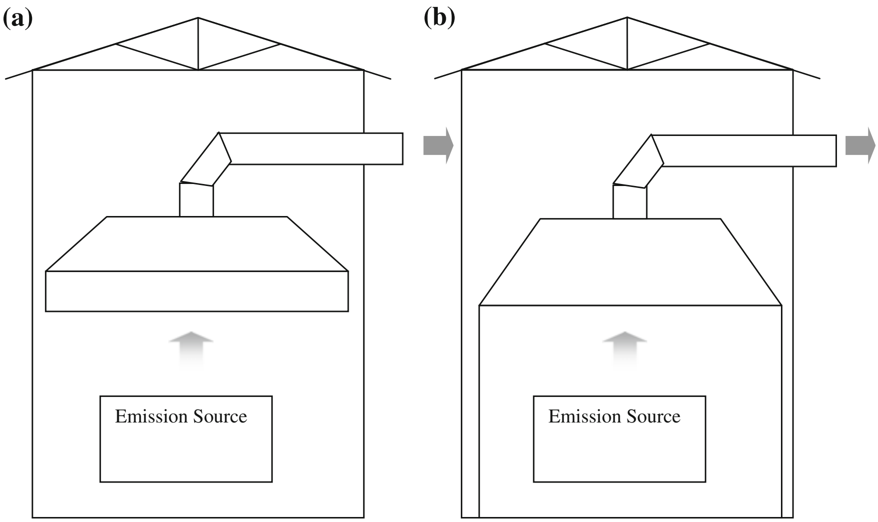


Fig. 5.44 Conventional and improved dust extraction system. **a** Hood, **b** dog house or house in house

7. Inclusion of low-NOx techniques while construction of new batteries;
8. Adopt coke dry quenching (CDQ);
9. Desulphurization COG by absorption systems or Oxidative desulphurization; and
10. Gas-tight operation of gas treatment plant.

Following techniques are considered as BAT for BF (European Commission 2001).

1. BF gas recovery;
2. Energy recovery of from BF gas;
3. Direct injection of reducing agents;
4. BF gas treatment with efficient de-dusting; and
5. Treatment of BF gas scrubbing wastewater.

The aim of oxygen steelmaking is to oxidise the unwanted impurities in the hot metal from BFs. Following techniques are considered as BAT for Oxygen steelmaking and casting (European Commission 2001).

1. Particulate matter reduction from hot metal pre-treatment by efficient evacuation and subsequent purification with ESP or fabric filtration.
2. BOF gas recovery for subsequent use as a fuel.
3. Secondary de-dusting, and fume suppression with inert gas for the period of reladling of hot metal from torpedo ladle (hot metal mixer) to charging ladle.

The following techniques are considered as BAT for electric steelmaking and casting,

1. Dust collection with a combination of direct off gas extraction and hood systems *Or* total building evacuation *or* dog-house (Fig. 5.43) and hood systems;
2. Waste gas de-dusting by well-designed fabric filter;
3. Minimising of organochlorine compounds emissions, by separate postcombustion chamber or suitable post-combustion within the off gas duct system with subsequent rapid quenching to avoid de novo synthesis (synthesis of complex molecules from simple molecules) *and/or* injecting of lignite powder into the duct prior to fabric filters; and
4. Scrap preheating to recover sensible heat from primary off gas.

Production of Aluminum

Aluminum production is done by electrolysis of molten alumina. The first step is preparation of alumina from bauxite by extraction with sodium hydroxide (the process is referred as

$$Al_2O_3 \cdot x(H_2O) + 2NaOH \rightarrow 2NaAlO_2 + (1 + x)(H_2O)$$

This process is done in digesters, under high pressure and temperatures. The alumina is separated from iron, silicon, calcium oxides and titanium as insoluble components.

Alumina is precipitated from sodium aluminate solution.

$$2NaAlO_2 + 4H_2O \rightarrow 2Al(OH)_3. + 2NaOH$$

The slurry containing tri-hydrate crystals is separated according to the crystal size. Excess sodium hydroxide is removed by washing, and dewatered on vacuum filters. Dewatered crystals are sent to calcination. The finer crystals are recycled to the precipitator to act as seed for providing nucleation sites.

Calcination of alumina is accomplished in fluidized-bed furnaces or rotary kilns at about 1000 °C. Calcination is followed by electrolysis of the molten alumina in a semi-batch way in large rectangular electrolytic cells.

Electrolysis during manufacture of aluminium involves several complex electrode reactions which can be represented by following equation (Beschkov 2004).

$$Al_2O_3 + 3/2C \rightarrow 2Al + 3/2CO_2$$

Emissions of particulate matter take place during bauxite preparation by crushing and grinding in ball mills; and drying in rotary kilns. Usual air pollution control equipment used are cyclone separators followed by scrubbers or ESPs.

The flue gases resulting from calcination are controlled by cyclone separators followed by ESPs.

Main gaseous emissions emitted during the electrolysis are carbon dioxide hydrogen fluoride, carbon monoxide, sulfur dioxide, carbon tetrafluoride and hexafluorethane. Particulate matters of fluoride are emitted due to vaporization of fluorine compounds from the molten bath as well as succeeding condensation in the cooler zone of the pot. SO_2 comes from the sulfur present in the coke as well as the coal tar pitch binder in the anodes. Material handling and transportation also emit particulate matter. Aluminium manufacture also emits carbon disulfide, carbonyl sulfide, and aromatic hydrocarbons that needs to be controlled in a scrubber or combusted.

Emissions from electrolysis cells is controlled by liquid scrubbing followed by ESP or absorption columns with sieve trays. Fluorides can also be trapped using alumina as adsorbent using fluidized-bed or injection in zone of high gas velocity/turbulence.

Production of Copper

Copper can be produced by two methods pyrometallurgy and hydrometallurgy.

In Pyrometullurgy, the concentrate obtained after mining and flotation is subjected to roasting in multi-stage furnace or fluidized bed reactor at 650–800 °C to generate calcine. Heating is accomplished with oil/gas. Sulfuric acid is manufactured as by-product.

Roasting is followed by smelting in smelting furnaces using silica as flux. In reverberatory furnaces coal, oil or natural gas, are used for smelting. In electric arc furnaces electric current through carbon electrodes submerged in the slag layer of the molten bath generate heat.

Converting last stage in copper smelting that includes air blasting of the molten matte (an impure fused material comprising metal sulphides formed during the smelting of a sulphide ore). The product will be porous, due to presence of sulfur dioxide and is called blister copper.

Final stage in pyrometullurgy involves refining wherein blister coppers as well as flux are placed into a fire furnace and air is blown through the molten mixture to oxidize the impurities. This is followed by electrolytic refining in sulfuric acid medium

Pyrometullurgy processes of crushing of ores and concentrates and the fine grinding are the major sources of emissions of particulate in the preparation steps. If wet methods are applied, these emissions could be reduced.

The main air pollutants in pyrometallurgical processes are SO_2 and PM. PM emitted in these processes contain oxides of antimony, lead, zinc arsenic, and their sulphates. Particulate emission removed by gravity settlers, ESPs, wet scrubbers, baghouses.

Evaporation of arsenic hydride, during refining stage can be captured with lime.

Hydrometallurgical methods for copper production are normally used in following cases: (1) low copper content present in the raw material; (2) oxides based raw material; and (3)to avoid the emissions of SO_2.

In this process ores are leached by 5–10 % solution of sulfuric acid. Then copper is recovered by adding iron filings to the solution or electrolytic process.

Recently, organic solvents are used for formation of complexes of copper. This is followed by re-extraction with dilute sulfuric acid.

The emissions of air pollutants are lesser than pyrometallurgical process. Ammonia may be released in some processes which are removed by passing through a packed-bed absorber.

Lead Production

Lead is produced by primary lead production (from mineral ores) and secondary lead production, (from scrap, lead batteries, etc.)

Primary lead production follows five main steps.

1. Production of ore concentrate—crushing, grinding and flotation
2. Sintering process—roasting the lead concentrates to convert the sulfides into sulfur dioxide or chemically bound sulfates in slag. In this process Iron, limestone, silica, is added as a flux. Further coke, pyrite ash, soda, zinc and caustic, and some dust, collected in bathhouse filters are also added. The process is carried out by blasting of hot air.
3. Smelting—sintered mass is subject to heat in a BF along with limestone (as flux) and coke (fuel and reducing agent).
4. Refining—lead melt from smelting process is refined in cast iron kettles.
5. Casting—the pure lead is cast to ingots.

Main sources of air pollutants during production of lead are sulfur and metal fumes (like cadmium, lead, arsenic, etc.), Particulate matter (lead oxide, pyrite, quartz, limestone, iron silicates, etc.).

Sulfur dioxide in the sintering step is directed to the sulfuric acid production.

Secondary lead smelting involves smelting of used lead articles. Used car batteries are the major sources of recycled lead. Sweating operations are generally carried out in reverberatory-type furnaces/tubes. Lead scrap, oxides, drosses, battery plates, etc. are charged to a reverberatory furnace which is heated to 1200 °C by gas, oil, or both. Sulfur dioxide and sulfur trioxide will be present in the emissions along with fumes of metal oxides, smoke, sulfides and sulfates of arsenic, copper, lead, tin, and antimony.

Baghouses are used as final collectors preceded by gas-cooling systems as well as settling chambers.

The lead BF (or cupola) is similar to those in the ferrous industry. The typical charge consists of scrap cast iron, rerun slag from previous runs, coke, drosses, limestone, oxides and reverberatory slag.

Emissions from these operations consist of oxides of metals, smoke, coke and other impurities present in the charge. All of these contaminants are passed through a baghouse.

Zinc Production

Zinc production can happen by primary or secondary methods. In primary zinc production, zinc concentrates are separated from inert mass of rocks minerals. Separation in this method is achieved by crushing and flotation followed by recovery zinc from the concentrates. Recovery can be achieved by electro-winning method or pyrometallurgy method. Electro-winning process is widely used for zinc production which is preceded by calcination, leaching, and purification.

Calcining is carried in multiple-hearth or fluidized bed roaster to remove sulfide sulfur as sulfur dioxide and produce zinc oxide. In multiple-hearth process zinc concentrate mixed with coal is roasted at 700 °C wherein part of the zinc oxide evaporates which is captured in bag filters. In fluidized bed roasters, material is ground finely to facilitate more complete conversion. In fluidized bed roasters no additional fuel is required after ignition as autogenic roasting takes place. SO_2 from roasters is directed to sulfuric acid plant.

The leaching is carried out to obtain zinc sulfate in two stages by sulfuric acid—a dilute as well as a more concentrated one.

Purification is achieved by adding zinc powder to the solution in two or three stages to eliminate the detrimental elements by precipitation and filtration. Purification is carried out in huge agitation tanks at higher pressure (about 2.5 bars) and moderate temperatures. Electro-winning carried out in baths with silver/lead alloy as anode and aluminum as cathodes. zinc is stripped mechanically at intervals of 24–28 h from the cathodes which is melted and cast into ingots.

The raw materials in secondary zinc production are generally scrap die castings. Pre-treatment in secondary zinc production involves processing in sweating furnaces (typically unlined rotary furnace, or refractory-lined furnace) wherein zinc is separated in liquid state. The separated zinc is melted in kettles, crucibles, reverberatory as well as electric induction furnaces wherein flux traps all of the impurities. The zinc is further purified by leaching with hydrochloric acid followed by neutralization by sodium carbonate. Zinc hydroxide thus obtained is dried and calcined to get crude zinc oxide that is recycled in primary zinc smelters.

Distillation to reclaim zinc from alloys is carried out in bottle retorts by heating till most of the zinc is evaporated and Zinc is collected as dust/liquid.

Emissions in zinc production consist of metals, fumes, and smokes. Afterburners and fabrics filters are used to control air pollution.

Foundry

Foundry operation converts metal into desired shapes. The process involves melting of metal, mould preparation, pouring, degating, heat treatment, cleaning, and packing. The metal is melted in furnaces. Induction furnace is used widely due to its efficiency and easy handling. But cupola furnaces still exists in large number in developing countries. Other types of furnace include electric arc furnaces, reverberatory, and crucible furnaces.

Emission during melting depends on raw material and type of furnace. Virgin material and scrap is used to charge the furnace. If the charge material contains impurity, it evaporates into air or becomes part of product/slag. Certain fluxes are used to separate the metal from slag/dross. Degassers are added to remove dissolved gas from metals.

A degassing step is normally necessary for foundry operations of aluminium alloys, to reduce the hydrogen dissolved in the liquid metal. Too high hydrogen concentration in the melt results in porous casting as the hydrogen comes out of solution during cooling. Porosity affects mechanical properties of the metal. Hence hydrogen from the melt is removed by bubbling argon or nitrogen through the melt.

Molds are usually prepared with sand/ceramic using pattern made up of wood/wax/plastic/metal. Sand moulds are prepared with sand by mixing sand with resins. Molten metal is poured into these molds and solidified metal component is removed. This is flowed by degating where in the heads, runners, gates, as well as risers from the casting is removed. Heat treating is done if required to add specific quality to metal components. Pouring is done in shop floor which leads to emission that is removed by industrial ventilation.

Surface cleaning of solidified metal component is done using a blasting process by propelling granular media against the surface of the casting. Surface cleaning is done in chamber designed for the purpose. The emission from cleaning mainly contains particulate matter which is usually removed by bag filter. Cyclone separator may precede the bag filter to reduce the load on bag filter. Finally components are finished by grinding/sanding/machining the component.

5.9.2.5 Paper Industries

The usual substrate for production of paper is slurry of cellulose in water. Figure 5.45 shows paper manufacturing process. The key steps in paper manufacturing are wood debarking as well as chip making, pulp manufacturing, pulp

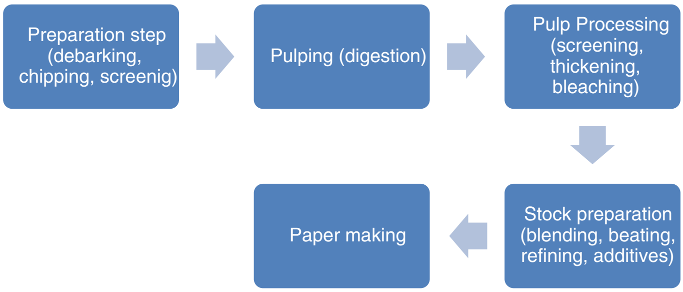


Fig. 5.45 Paper manufacturing process

bleaching, paper manufacturing, and fiber recycling. Pulp manufacturing starts with debarking, chipping, and other processes like depithing when bagasse is used as the raw material. The wood contains lignin and hemicelluloses. Lignin easily oxidizes and darkens during production of pulp from wood.

Cellulosic pulp is produced by chemical, mechanical and thermal methods or combination these methods.

In mechanical pulping mills, disintegrators are used to make slurry from wooden chips. In thermal process grinding is preceded by thermal treatment with steam at 120–130 °C. Advantage of mechanical and thermal pulp is that they are chemical free. In Chemical method release cellulose fibre is released by destroying bonds (like lignin) that bonds cellulose by chemicals.

Advantage of chemical method is that it can be used for broad range of woods. In chemico mechanical pulping hot solution of sodium hydroxide is used. Some amount of SO_2 can be used to avoid darkening of broth. Semi-chemical pulping uses aqueous solution of sodium sulfite and sodium carbonate. Sodium sulfite is produced by combustion of elemental sulfur.

Emissions from kraft pulsing process include hydrogen sulfide, dimethyl sulfide, methyl mercaptan, and dimethyl disulfide, typically at a rate of 0.3–3 kg/t of air-dried pulp (ADP). Usual generation rates for other pollutants are:

1. Particulate Matter: 75–150 kg/t;
2. Sulfur Oxides: 0.5–30 kg/t;
3. Nitrogen Oxides: 1–3 kg/t; and
4. VOCs: 15 kg/t

In the sulfite pulping process, normal sulfur oxides emission rates vary from 15 kg/t to over 30 kg/t.

Mechanical and thermomechanical methods, generate lower quantities of air emissions. Steam- and electricity-generating units emit fly ash, sulfur oxides, and nitrogen oxides.

Conventional bleaching using elemental chlorine generates large quantity of chlorinated organic compounds, including dioxins.

In modern mills, oxygen is usually used in the first stage of bleaching to avoid the use of chlorine chemicals. Total chlorine-free (TCF) bleaching do not use chlorine and its compound. Elemental chlorine-free (ECF) processes use chlorine dioxide, for bleaching certain grades of pulp.

Best practices followed to reduce air pollution in paper industry are: (1) combustion control, (2) collection and incineration of malodorous gases with SO_2 control, (3) reduction of SO_2 emissions from recovery and auxiliary boilers, (4) use of low sulfur fuel or scrubber to control sulfur emissions, (5) use of ESPs to reduce dust emissions, (6) reduction of NO_x emissions by controlling fire conditions and proper design; (7) adopting chlorine free bleaching.

Best practice to attain energy efficiency are: (1) phasing out of fossil fuels, (2) installing recovery boiler as well as auxiliary boilers, (3) drying of bark in order to increase energy efficiency, (4) delivery of waste heat to district heat system, and (5) increasing of internal electricity production,

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Chapter 6
Sustainable Air Pollution Management in Transportation Sector

Abstract Transportation sector has transformed dramatically over the years. Here as the demand for vehicles has reached saturation level in developed countries, other countries have become market heavens for vehicle manufacturers. Land, air and water transportation has increased many folds for shifting both passengers and cargo from one place to other. This chapter discuss major issues and solution with respect to transportation which includes shifting to green fuel, improving mass transportation, ensuring good quality fuel, eco friendly engines and fuel, vehicular emission standard.

Locomotion is key characteristic of humans. Humans travel across the globe in variety of vehicles. Apart from fuel combustion, air pollution is also caused due to re-suspension of soil particles in case of road transport and for some extent in takeoff/landing operations in aviation operation.

People travel for many purpose that include (1) tourism and recreation, (2) education, (3) exploration, (4) job, (5) movement of goods, (6) to avail service, (7) to meet people, (8) rescue operation during emergency, (9) to perform crime, and (10) the investigate/interrogate/arrest criminals. The major reasons that influence transport trends are travel time budgets, costs, increased personal income, as well as social/cultural factors (Schäfer 2011).

About 10 % of the worldwide population account for 80 % of motorized passenger-kilometres (p-km) with OECD nations dominating GHG transport emissions even though most recent growth has taken place in Asia (Sims et al. 2014)

The mode of transportation include space, air, water (surface and subsurface), and land transportation. Some of the solutions sustainable air pollution management in transport sectors are

- Use of electrically driven vehicles;
- Use of fuel cells and battery driven electric vehicles;
- Use of eco friendly fuel like natural gas and hydrogen;
- Increasing fuel efficiency;
- Changing to less carbon-intensive fuel;
- Reducing emissions from vehicle exhausts;

R. Chandrappa and U. Chandra Kulshrestha, *Sustainable Air Pollution Management*, Environmental Science and Engineering,
DOI 10.1007/978-3-319-21596-9_6

- Reducing weight of vehicles;
- Intelligent traffic management to avoid unnecessary traffic jams and to many signals; and
- Restriction of private vehicle ownership.

All the solutions may not be acceptable to all the people. Rich people who travel for fun may recommend fuel efficiency instead of stopping travelling. All public will not avail public transport even when it is available. Many public transport vehicles in developing countries are overcrowded resulting in suffocation. These vehicles are also known for frequent pickpockets. The public transportation in some cities are characterized by lack of adherence to schedule, sexual harassment, impolite staff, inefficient/infrequent service, non availability of service during night as well as riots (Chandrappa et al. 2011).

Transportation sector represents around one-quarter of energy consumption worldwide (Clark and Kelly 2004). Over 53 % of world wide primary oil consumption in 2010 was used to satisfy 94 % of the total transport energy demand, with natural gas and other fuels 3 %, biofuels contributing approximately 2 % and electricity 1 % (IEA 2012). The transport sector is predominantly fueled by petroleum products. This huge demand puts a large stress on global reserves, and results in environmental degradation. The efficiency can be increased by: (1) improving engine/vehicle designs; (2) increasing the load factor; (3) ensuring traffic/usage patterns are optimal (by adopting practices like efficient routing, and avoiding empty back hauls); (4) switching over from less to more efficient transportation modes; (5) reducing the need for transport; and (6) changing over to eco friendly fuels.

Sustainable transport refers to an acceptable level of social cost associated with the movement of goods or people. Transport plays an important role in a country's environmental performance and the sustainability of its development. Mobility and infrastructure have many effects on the ecological system and the spatial organization of economic activities. The demand for transport leads to a large pressure on the sustainability of the living environment. Technological development is often seen as one of the ways to increase sustainability of transport. Despite potential, there are some barriers to technological implementation that hinder short-term viability. Policy intervention can also steer transport development toward sustainability. A wide range of measures are available to policy makers, ranging from transport demand measures to spatial planning interventions.

Sustainable transport is a distant reality in many countries where transportation itself is a luxury. Sustainable transportation means transportation at an acceptable level of social cost connected with the movement of people or goods. Social costs include impact on environmental quality, injury/fatality.

Transport which is wheel of economy is also responsible for injury/death, resource depletion, air/noise pollution, source of some of the hazardous waste, and threat to biodiversity. While road/railways affect terrestrial ecosystem sea/inland waterway pollute ecologically sensitive coastal waters. Pollution form motor vehicles generates around one-fifth of the incremental CO_2 in the atmosphere (Nijkamp et al. 2003).

Transport sector degrades environment during creation of infrastructure and later by its use. The roads and railways are often causing for fragmentation of terrestrial ecosystem.

Alternative vehicle fuel include CNG, hybrid-electric, LPG, ethanol and methanol. Ethanol is produced from grains or sugar. Electric vehicles (EV) use an electric energy. The mode of electric generation decides sustainability and quantum of air pollutants released into atmosphere. Solar, hydel, hydro, wind energy generation promises good air quality compared to energy generated from thermal power plants.

Hybrid electric vehicles comprise of the electric motor that can be powered either by a battery or fuel. These vehicles provide environmental benefits over conventional vehicles.

Vehicles powered by fuel cells combine hydrogen and oxygen to produce the electricity. The emissions from fuel cell vehicles depends on the primary fuel used, as well as where the fuel is reformed that is whether hydrogen is produced from solar, wind, thermal or hydropower. *Battery-electric vehicles* include two wheelers, three wheelers, cars, buses and trains. The primary advantages of such vehicles are that there will be zero emission at the path of their use.

Synthetic fuels include bio-diesels, Fischer-Tröpsch diesel, as well as di-methyl ether (DME). Bio-diesel can be manufactured from vegetable oils. Diesel fuel synthetically produced from coal or natural gas or through a process called Fischer-Tröpsch is known as Fischer-Tröpsch diesel. DME is a synthetic fuel produced from methanol or renewable raw materials or, natural gas.

6.1 Air Transport

Increase in aviation activities both military and civil aviation contribute to air pollution. The emission from aviation activity would contribute to climate change through emissions CO_2, VOC, NO_x, water vapor, SO_2, soot and other particles to environment (Brasseur et al. 1996). A large fraction of these emissions occurs at roughly 9–11 km from surface of earth. Hence, many studies have concentrated on the resulting climate change of aviation emissions in the lower stratosphere and upper troposphere (Brasseur et al. 1998; Hendricks et al. 2000; Morris et al. 2003). Piston aircraft Engines use similar fuels and have the same characteristics as gasoline(petrol)-powered automobile engines. The sources as well as pollutants are hence similar to emission from motor vehicles (John 1977). Gas turbine engine (jet) emissions as well as fuel are similar to diesel engines.

Emissions from aircraft gas turbine engines differ from that of motor vehicles with respect to “fuel-venting emission.” Every time a turbine engine is shut down or started up, some fuel previously present in the system is drained to a dump. Normally dumping fuel is carried out after takeoff (John 1977).

Emissions from aircraft occur on the ground during idle, start-up, taxi, and shut-down operations. Emissions also occur from engine during repair.

Aircraft engines usually combust fuel efficiently, and exhausts from jet have very less smoke emissions. Pollutant emissions in and around airports are more due to aircraft movements, surface traffic and airport operations. Particular emission from jet will be mostly in $P_{2.5}$ fraction. The International Civil Aviation Organization (ICAO) has set international standards for emission from aircrafts. It also restricts the venting of fuels from aircrafts. Technologies such as selective catalytic reduction as well as exhaust gas recirculation have been employed in aircrafts to reduce air pollution.

Emission from landing and take-off (LTO) emissions will have less impact than non-LTO due to relatively large quantity of non-LTO emissions (Lee et al. 2013). As per studies by Barrett et al. (2010) non-LTO aviation emissions may adversely affect local air quality particularly with respect to particulate matter. Barrett et al. (2010) concluded that secondary aerosols like sulfate-ammonium-nitrate formed by SO_x and NO_x emissions from aircraft can be increase premature deaths worldwide.

Optimized profile descent (OPD) Continuous or descent approach (CDA) (Fig. 6.1) has been used in many airports to reduce noise and air pollution. In this a method, aircraft approach airports in a smooth, constant-angle descent during landing instead of a stairstep fashion requesting permission to move down to each new altitude.

Total reactive nitrogen(or odd nitrogen), the collective name for oxidized forms of nitrogen in the atmosphere such as NO_2, NO_3, HNO_2, HONO, HNO_3, HO_2NO_2, $2N_2O_5$, PAN, other organic nitrate and aerosol nitrate is usually designated by NOy.

$$NO_y = NO_z + NO_x$$
$$NO_x = NO + NO_2$$
$$NO_z = HNO_3 + HONO + N_2O_5 + HNO_2 + HO_2NO_2 + PAN + NO_3 + \text{Organic Nitrates}$$

An understanding of contributions of NO_x (NO and NO_2) and total reactive nitrogen NO_y(NO) distribution is essential because NO_y emitted into the upper troposphere is longer-lived compared to odd nitrogen emitted into the boundary

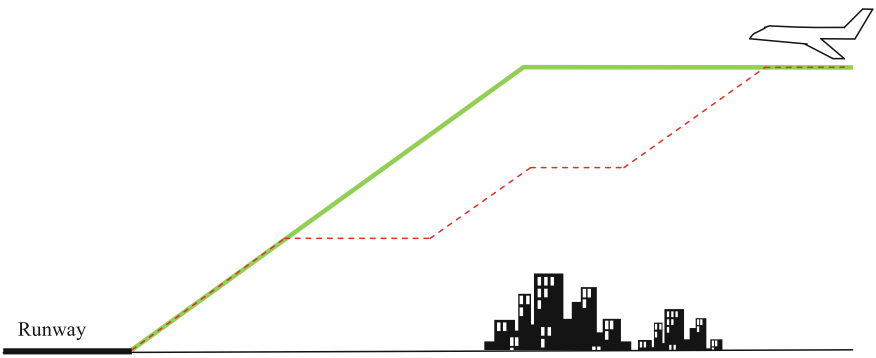

Fig. 6.1 Schematic descent profile of a CDA (*green*) and a conventional approach (*red*)

layer. Also NO_y is responsible for producing more O_3 (Lee et al. 1987; Hauglustaine et al. 1994).

Emissions during landing as well as take-off are responsible for most of the NO_y, ozone (O_3) and aerosol perturbations near the ground. Aviation-induced perturbations have an insignificant effect on air quality (Lee et al. 2013).

In-flight operations cover climb-out to about 914 m above ground and descend from 914 m to ground. The 914 m elevation is assumed to be the top of the temperature inversion below which atmosphere dispersion would be poor. Pollutants below this level would most likely affect the community near the airport, whereas above 914 m the pollutants are dispersed more thoroughly (John 1977).

6.2 Water Transport

Even though air pollution from water transportation (Fig. 6.2) is not gained much importance in developing country, it has gained attention in developed countries. The sustainable management for air pollution from water transport are:

- Replacing smaller vessels by larger vessels with better shipping energy;
- Traffic control;
- Selective catalytic reduction (SCR);
- Direct water injection (DWI);
- Humid air Motors(HAM); and
- Sulphur reduction

In SCR urea/water solution is injected into exhaust stream over a catalyst to reduce nitrogen oxides to nitrogen gas. In DWI, fresh water is mixed with the fuel and injected with high pressure into the combustion chamber. The water vapour

Fig. 6.2 Smoke from ship

reduces the combustion temperature reducing formation of nitrogen oxides. In HAM, sea water is vaporised by waste heat from the engine's cooling system as well as turbo-chargers and mixed prior to the combustion chamber reducing combustion temperature thereby reducing the nitrogen oxides. Sulphur reduction in emissions from shipping is achieved by using low sulfur fuel and installing scrubber (Swedish Maritime Administration 2007).

Apart from above technology the sector in developed countries is active in emission trading to bring down overall emission at global level from the sector.

The International Convention for the Prevention of Pollution from Ships [MARPOL (short from for Marine Pollution)] is the most important international convention for prevention of marine pollution by ships. MARPOL has been updated by amendments over the years. It was adopted on 2 November 1973 at IMO. It covers pollution by oil, harmful substances in packaged form, chemicals, sewage and garbage.

MARPOL has VI annexes and a state must accept Annex I and II to become a party to MARPOL. Annexes III–VI are voluntary annexes listed below (ECG 2014).

Annex I: Regulations for the Prevention of Pollution by Oil
Annex II: Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk
Annex III: Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form
Annex IV: Prevention of Pollution by Sewage from Ships
Annex V: Prevention of Pollution by Garbage from Ships
Annex VI: Prevention of Air Pollution from Ships

Annex VI of MARPOL was entered into force 19th May 2005 and it was ratified by 75 States/Parties. This annex set limits on PM, NO_x and SO_x emissions from ship exhausts. This annex prohibit deliberate emissions of ODS.

6.3 Land Transport

Land transportation is done to move people, animals and goods on land from one place to other. Poor urban planning, improper use of fuel/energy, inability to acquire new technology, attitude of people have been key reasons for air pollution from land transport. The emission can be controlled by combination of following:

- Motor vehicle restraints
  - Auto-free zones
  - Selective vehicle entry permits
  - Ban of heavy duty vehicles
  - Restriction on delivery times
  - Regulation of office/business timings

  - Regulation of school timings
  - Encourage non motorised transport (animal driven, bicycle, walking, push/pull cart)

- Control of fuel
  - Increasing cost of fuels
  - Ensure zero fuel adulteration
  - Reduce sulfur content from fuel
  - Sell un-lead fuel

- Motor vehicle emission reduction
  - Inspection and maintenance
  - Idling limitations
  - Gasoline(petrol) vapor control
  - Changing or improving technology

- Improvement of mass transportation
  - Bus lanes on city streets as well freeways
  - One way streets to buses only
  - Reducing cost of public transportation
  - Improving service of pubic transportation

- Regulation
  - Urban planning
  - Parking policy
  - Road user tax
  - Parking surcharge
  - Bicycle lines
  - Land-use/urban planning
  - Banning old vehicles

- Voluntary approaches
  - Use of video conferencing rather than physical meeting
  - Car pooling
  - Car-pooling and ride-sharing

- Traffic flow improvements
  - One way street operation
  - Loading regulation
  - Parking restriction

Approaches to reduce the emissions from land transport can be theoretically achieved by intervening with the vehicles and the fuels (Gorham 2002). But in practice the narrow roads/streets with high rise building on both sides of roads/streets still exists posing hindrance to movement of air pollutants.

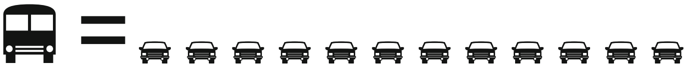

Fig. 6.3 Pictorial representation of capacity of *Bus* and *car*

Fig. 6.4 Narrow roads and permission to build high rise building often case hindrance to dispersion of air pollutants

To be sustainable human transportation solution should aim to transport people rather than vehicles. Figure 6.4 show Narrow roads and permission to build high rise building often case hindrance to dispersion of air pollutants. A bus can transport as many people as 8–12 cars (Fig. 6.3). Hence efficient use of public bus would decrease emission.

6.3.1 Shifting to Green Fuel

Confronted with rising oil prices, and to protect environment biofuel production has been encouraged in many parts of the globe. Agricultural food produce has been used to manufacture “green” fuels apart from nonagricultural sources. Some of the bio fuels are ethanol, biodiesel, methanol, biobutanol. In many countries 10–15 % ethanol is normally added to gasoline(petrol). Major factors considered in use of biodiesel are cost, availability, as well as food supply.

6.3.2 Improving Mass Transportation

Movement of people and goods in bulk plays an important role in a country’s economic and environmental performance. Sustainable transport is a perception that refers to a satisfactory level of social cost connected with the movement of goods and people. These social costs include degradation of environmental quality, fatality due to accidents, or traffic congestion.

Fig. 6.5 Traffic on Asian road

Public transportation system includes buses, light rail, rapid transit system, tram, personal rapid transit.

Rapid transit is a high-capacity public transport in urban areas. Rapid transit systems operate on an exclusive right-of-way. It helps to transport large numbers of people swiftly over short distances with minute use of land. Variations of rapid transit include people movers, small-scale light metro, as well as the commuter rail hybrid.

Personal rapid transit (PRT), which is also called podcar, employs small automated vehicles operating on a network of built guide ways. PRT typically carries not more than 3–6 passengers per vehicle.

Inappropriately designed transport systems will damage the environment. More than half a million people die every year due to road accidents (Nijkamp et al. 2003).

Figure 6.5 shows traffic on Asian road. Failure of government to provide proper mass transportation has resulted in uncomfortable journey.

6.3.3 Ensuring Good Quality Fuel

Most of the current ICEs are designed and run with the traditional liquid fuels as well as lubricants obtained from crude oil. There are many advantages making fuel options for decreasing emissions from ICE:

- Fuel options can be targeted to non-achievement regions/seasons.
- Fuel refining as well as distribution is highly centralized, therefore modifications are easy to negotiate as well as enforce.
- Fuel modifications may require low investment than modification of engine and can be applied to a larger range of engines.

6.3.4 Eco Friendly Engines and Fuel

Transport and economic development are linked. Transportation essentially enables and catalyses development. Demand for passenger as well as freight transport in developing countries will increase rapidly in coming decades. Developing countries need to avoid the 'lock-in' of unsustainable transport that accompanied growth of economy in developed countries.

The most graceful invention that ever had a larger impact on the economy, society, as well as the environment is the reciprocating IC engines (Haworth and El 1998; John 1988). At present there is a need to develop sophisticated combustion engines that make best use of the engine efficiency and totally lessen the exhaust emissions (Kumar and Kumar 2011). IC engines generate work using the combustion products as the working fluid. Combustion is carried out in a way that produces high-pressure burning products that are expanded through a turbine/piston. These high pressure systems introduce a numerous features that influence the pollutant formation.

In recent years the scientific as well as public awareness on environmental/energy issues has brought in significant interests to invent efficient IC engines. As the energy consumption is proportional to the economic development, global energy demand is likely to rise in future. The motorised movement of goods and people increased more than a 100 fold over the 20th century while the human population increased by four fold (UNEP 1999; AAMA 1998). In 2008, more than 50 % of the world's population lived in urban region (Dalkmann and Huizenga 2014) and by 2050 it is expected that ¾ of global population will live in urban areas (IEA 2008). The process of urbanisation has resulted in more vehicles and air pollutants. Collectively cities are expected to account for 71 % of global GHG emissions and 67 % of worldwide energy related CO_2 emissions (Dalkmann and Huizenga 2014). Such scenario attracts need for sustainable transport that allows the basic access and needs of citizens safely, cheaply and with least impact on environment.

Electric vehicles (Fig. 6.6) and vehicles with low emission (Fig. 6.7) have been replaced many vehicles in developed countries to curb air pollution.

6.3.5 Vehicular Emission Standard

Vehicular emission standards vary worldwide and over a period of time. The prominent among the emission standards are European Emission Standards which is adopted with slight or no modification by different countries.

European emission standards stipulate the acceptable limits for emissions from vehicle exhaust of new vehicles sold in European Union (EU) member states. These standards are defined in a number of European Union directives. These standards aim progressive introduction of progressively more stringent standards.

Fig. 6.6 Electric goods carrier

Fig. 6.7 Boat with lower emission

Currently, emissions of NO_x, total hydrocarbon (THC), NMHC, CO and PM are regulated for most vehicle types excluding seagoing ships as well as aeroplanes. Different standards apply for different vehicle type. Vehicles that do not comply with EU emission standards cannot be sold in the EU, but these new standards are not applicable to vehicles already on the roads. Compliance is determined by operating the engine at a standardised test cycle. No use of specific technologies is compelled to meet the standards.

The stages of EU emission standards are typically referred to as Euro 1, Euro 2, Euro 3, Euro 4 and Euro 5 for Light Duty Vehicle standards and the standards are refereed as Euro I, Euro II, EURO III etc., for Heavy Duty Vehicles (Roman numbers are used rather than Arabic numerals for Heavy Duty Vehicles).

The summary of the standards of EU directives is given in Fig. 6.8.

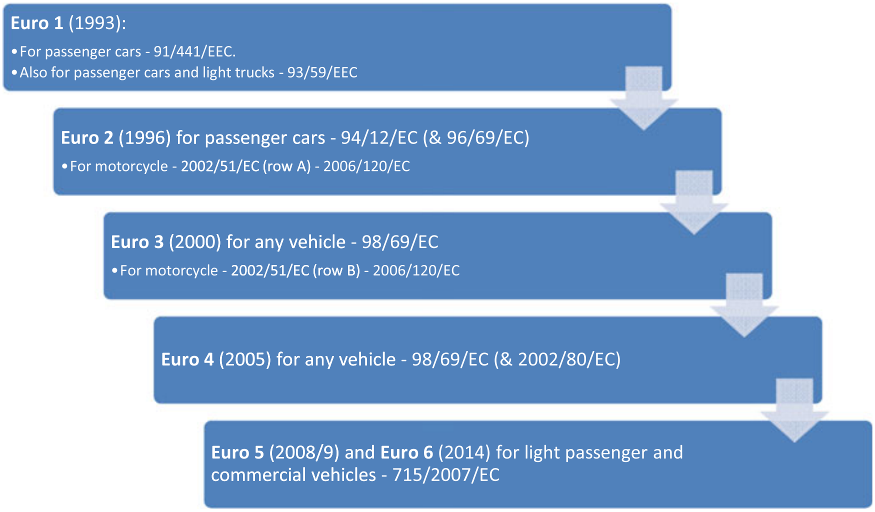

Fig. 6.8 Summary of the standards of EU directives for controlling vehicular emission

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Chapter 7
Sustainable Fuel Management

Abstract Combustion fuel is one of the major sources of air pollution. Many solutions adopted over the year have paid high dividends though out the world. But still the issues like adulteration low efficiency persist in developing world. This chapter discusses many issues pertaining to sustainable fuel management.

Fuels are any substance that store potential energy and used for heat energy. A fuel is a gives heat energy on combustion. A fuel contains carbon and hydrogen as main combustible elements. Heat is released due to reaction with oxygen in air. Fuel should contain one or several of the combustible elements: hydrogen, carbon, sulphur, etc. During combustion, the chemical energy of fuel is converted into heat energy.

Fuels can be divided into following main categories

(a) Solid fuels
(b) Liquid fuels
(c) Gaseous fuels
(d) Nuclear fuels (Radioactive fuel)

Main impurities in fuels are:

- Getero-elements (e.g. sulfur, nitrogen, Chlorine, Bromine, Fluorine) in gaseous and liquid fuel; and
- Fuel ash, in heavy oils and solid fuels.

Solid fuels leave some ash/residue after combustion. Most of the liquid fuels are the hydrocarbons that exist in the liquid form at room temperature. Gaseous fuels exist naturally at room.

Solid fuels are can be classified into two categories,—natural and anthropogenic (Table 7.1). They are widely used for cooking, recreation, and industrial purpose. The advantages and disadvantages of solid fuels are:

Advantages

(a) Easy to transportation;
(b) Convenient to store;
(c) Lower production cost; and
(d) Possess moderate ignition temperature.

R. Chandrappa and U. Chandra Kulshrestha, *Sustainable Air Pollution Management*, Environmental Science and Engineering,
DOI 10.1007/978-3-319-21596-9_7

Table 7.1 Examples of fuel

Sl. No.	Type of fuel	Example	
		Natural	Anthropogenic
1	Solid	Wood, coal, oil shale, dried cow dung	Tanbark, bagasse, straw, charcoal, coke, briquettes, agricultural waste, refuse derived fuel
2	Liquid	Petroleum	Oils from distillation of petroleum (Fig. 7.1), coal tar, shale-oil, alcohols
3	Gas	Natural gas	Coal gas, producer gas, water gas, hydrogen acetylene, BF gas, oil gas
4	Radioactive	Uranium	–

Disadvantages

(a) Possess high ash content;
(b) Large proportion of heat is wasted;
(c) Form clinker;
(d) Combustion operation cannot be controlled easily;
(e) High handling cost; and
(f) Lower calorific value (Table 7.2).

Solid fuels are freely available as byproduct of agricultural activity and hence widely used in rural area. Many people in the vicinity of forest are collect dry twigs for sale or own use. Wood is also converted to charcoal for further use as the process reduces moisture content and other impurities.

Table 7.2 Calorific values of various fuels

	Calorific value (J/kg)	Carbon content (%)	CO_2 emission (g/MJ)
Hydrogen	121×10^6	0	0
Petrol (gasoline)	$44–46 \times 10^6$	87	72.8
Diesel fuel	45×10^6	86	72.6
Crude oil	$42–44 \times 10^6$	89	70–73
Methanol	20×10^6	37	75.3
Liquefied petroleum gas (LPG)	46×10^6	81	59
Firewood (dry)	16×10^6	42	94
Natural uranium, in LWR (normal reactor)	500×10^9	0	0
Natural uranium, in LWR with U & Pu recycle	650×10^9	0	0
Natural uranium, in FNR	$28{,}000 \times 10^9$	0	0
Uranium enriched to 3.5 %, in LWR	3900×10^9	0	0
Hard coal	29×10^6	75	115
Natural gas	42×10^6	85	87

LWR Light Water Reactor, *FNR* Fast Neutron Reactor
Source Based on information in Biomass Energy Centre (2015), World Nuclear Association (2010)

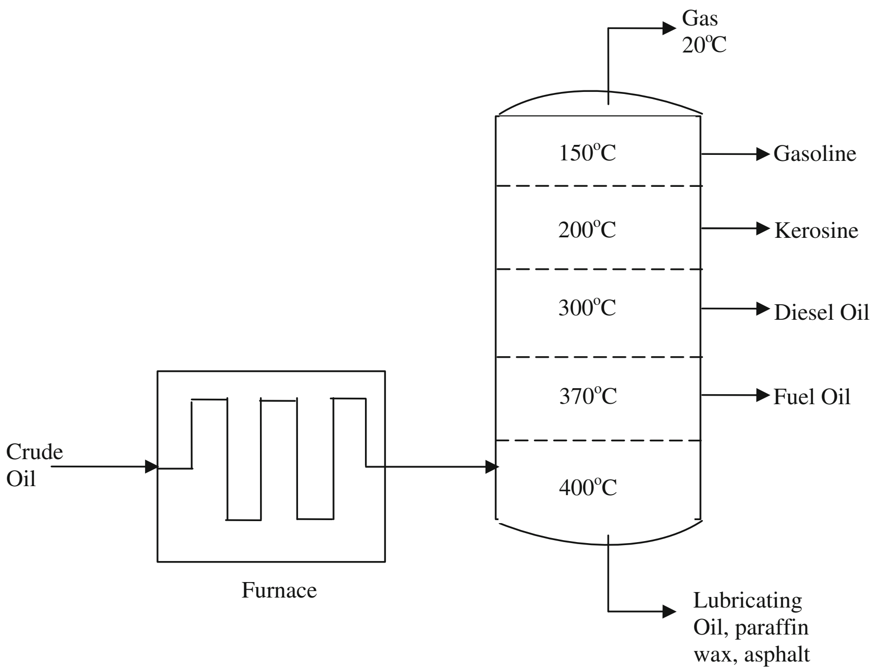

Fig. 7.1 Scematic diagram of a distillation tower showing products produced from petroleum

The first known fuel use was wood used first time about two million years ago. Charcoal, has been used since around at least 6000 BCE. Coal was used first as a fuel about 1000 BCE in China. After invention of steam engine in 1769, coal was used commonly as a power source. Gas extracted from coal was used for street lighting by the 19th century. Coal became major fuel to in 20th century to generate electricity.

Man first used coal as an energy source in Les Canalettes, southern France, about 73,500 years ago (Thery et al. 1995, 1996). Later coal was used for cremation pyres in the Bronze Age in southern Wales. Underground coal layers have burned in China for centuries (Stracher and Taylor 2004) and use of coal was recorded sometime during 200 B.C. to A.D. 220 (Cassidy 1973; Raymond 1986). Coal was also used by the ancient Greeks (Agricola 1950, p. 34) and in USA by the Hopi tribe for firing pottery during A.D. 1100 (Hodge 1904; Hack 1942). "sea-coale" was observed on the beaches of England led to widespread coal use.

Advanced coal technology can remove 99 % of the tiny particles, and more than 95 % of the acid rain pollutants.

CO_2 emissions from fossil combustion of fuel and industrial processes contributed around 78 % of the total GHG emission increase between 1970 and 2010 (IPCC 2014).

Fuel management at national level at user level plays important role in air pollution management. The loss of fuel during storage and transportation and inefficient use ultimately results in pollution which includes air pollution.

The energy efficiency and type of fuel used varies widely depending on technology used and knowledge of person/organization using the fuel. The factors affecting fuel consumption in road transportation depends on fuel, people, roads, vehicles, load weather and seasonality.

It is not possible to clean the air. Fuel management can greatly help reduce air pollution. The first law regarding fuel specifications was adopted in the U.S. and Japan in the 1970s. These law restricted use of lead in some fuels.

The liquid fuels can be classified as: (a) Natural liquid fuel, and (b) Artificial liquid fuel.

The advantages and disadvantages of liquid fuels are:

Advantages

(a) Posses higher calorific value compared to solid fuels;
(b) Burn without dust, ash, and clinkers;
(c) Starting and stopping fire is easier compared to solid fuel;
(d) Easy to transport through pipes;
(e) Can be stored for long period without any loss;
(f) Clean in use and economic to handle;
(g) Loss of heat in chimney is very low;
(h) Need less excess air for complete combustion; and
(i) Need less furnace space for combustion.

Disadvantages

(a) Costlier compared to solid fuel;
(b) Costly special storage tanks are required;
(c) Greater risk of fire hazards, s;
(d) Specially constructed burners as well as spraying apparatus are required.

Properties of fuels used in transportation, are selected so as to suit best the specific type of engine. Changes in one fuel property may reduce emissions of one pollutant but will have negative effects on others and different type of engines may respond differently to modifications of fuel.

The fuel for SI engines should evaporate at relatively low temperatures in order to ignite by the spark. Hence gasoline(petrol) is produced from crude oil fractions with boiling points from 30 to 200 ^{o}C.

In CI engines, the fuel—air mixture is ignited following compression at high temperatures. Hence *diesel fuels* are normally produced from distillate crude oil fractions boiling at normal pressure from 180 to 360 ^{o}C.

Aviation gas turbine fuels work in conditions, which need distillate crude oil fractions with boiling points from 140 to 280 ^{o}C for their production.

Gas turbines used in ships, trains, etc. usually use heavier and cheaper crude oil fractions, with boiling points above 360 ^{o}C.

Rockets as well as some of the specialized air/space vehicles may use petroleum fractions, ammonia, alcohol, liquid hydrogen, etc., and oxidants such as liquid oxygen, nitric acid, hydrogen peroxide, etc.

Petroleum lubricating oils are manufactured from refined distillate fractions with boiling point between 350 and 500 °C with residual components boiling over 500 °C. Crankcase oils may comprise more than 20 % different additives.

Commercial gasoline(petrol) is a mixture of about 300 types of hydrocarbons. Important properties of gasoline (petrol) in combustion are the volatility, anti-detonation (knock resistance) rating, and chemical composition.

Anti-detonation properties of gasoline(petrol) are defined by its octane number. High-octane fuels are more resistant to detonation. Fuels with higher octane fuel allow higher compression ratios. The engine octane requirements changes with altitude spark advance, humidity, engine deposits, cooling jacket temperature, etc.

The octane number depends on proportion of composition of the gasoline(petrol). It is high for compounds with higher chemical stability. It can be enhanced by compounding the gasoline (petrol) from high-octane hydrocarbon produced by particular refinery processes such as catalytic reforming, alkylation, catalytic cracking, isomerization, etc.

The cheapest method to increase the octane number is addition of tetra ethyl lead, which is being banned due to its adverse effects. Instead of tetra ethyl lead oxygenates are used for improving octane rating.

Volatility of gasoline(petrol) is measured in a test known as Reid's bomb test. It is defined by the "Reid Vapor Pressure" (RVP). Gasoline(petrol) volatility is identified by chemical composition and is controlled in limits, related to geography as well as season. Lower RVP obstructs the cold start of the engine and enhances cold start emissions. Higher RVP enhances evaporative property and may compromise fuel supply.

Important standard distillation properties of gasoline(petrol) are—T10 the temperature at which 10 % gasoline (petrol) is evaporated, T50 the temperature at which 50 % is evaporated, and T90 the temperature at which 90 % is evaporated. The T10 influences cold start as well as correct fuel supply. T50 is related to warm-up, short trip fuel economy, and cool weather drive ability. T90 is related to the formation of deposits as well as oil dilution.

The chemical composition of gasoline(petrol) can influence storage stability as well as toxic emissions. Alkenes and arenes increases octane number, hence the control of alkenes in gasoline (petrol) decreases the emissions of 1, 3—butadiene, as well as the ozone reactivity of emissions. Presence of benzene in gasoline (petrol) reduces emission of arenes and butadiene.

Oxygenates can be used as alternative fuels or as components of gasoline(petrol). Typical compounds include methanol as well as ethanol, tertiary amyl methyl ether, methyl or ethyl tertiary butyl ether, isopropyl ether, etc. The presence of oxygenates in gasoline (petrol) is normally expressed as oxygen content. Gasoline(petrol) blends contain up to 10–15 % oxygenate. Benefits of oxygenates are summarized below:

1. Oxygenates have high octane numbers. They replace tetra ethyl lead as well as a proportional quantity of arenes in unleaded gasoline(petrol). Changing to unleaded gasoline (petrol) significantly prolongs engine life and reduces maintenance costs.
2. CO and hydrocarbon emissions are increasingly reduced with raising the content of oxygenates.
3. Driving capability of vehicles with fuel injection systems will be improved.
4. Methanol as well as ethanol can be generated from different resources like biomass.

Oxygenates following negative features:

1. Emissions of NO_x may increase, particularly for gasoline(petrol) with less content of arenes.
2. Oxygenates are normally more toxic compared to their hydrocarbon counterparts. They have comparatively low normal boiling points. Exhaust emissions of aldehydes are augmented in the presence of oxygenates. They form azeothropic mixtures with hydrocarbons, encouraging evaporative emissions.
3. Oxygenates are more soluble in water and hence creates problems with corrosion as well as leaks from storage tanks because of which Methyl tert-butyl ether (MTBE) has been detected in drinking and underground water. Methanol—hydrocarbon blends need to be stabilized against reduction in the presence of water.
4. Oxygenates diminish the calorific value of gasoline(petrol) and hence influence fuel economy.
5. Oxygenates have bad cold start properties than hydrocarbons, resulting in augmented emissions if not corrected.
6. Oxygenates may corrode exhaust pipes, valve materials, filters, and result in fouling spark plugs. These effects increase emissions.

Reformulated gasoline(petrol) will have positive properties imparted due to oxygenates. Reformulation may affect, volatility, chemical composition, etc.

Content of arenes and sulfur affect the fuel characteristics of Diesel. *The cetane number* is the capacity of the fuel to ignite instinctively in the combustion chamber. Cetane number is determined by comparing the ignition quality of the fuel under standard conditions with a mix of alkane n-cetane and alpha methyl naphthalene.

Cetane numbers in diesel specifications are typically vary from 40 to 57. Higher cetane numbers (but <57) normally reduce emissions as well as improve fuel efficiency, but values above 57 may influence negatively towards engine performance as well as emissions.

Sulfur in diesel normally vary from 0.1 to 0.5 per cent. It is emitted as SO_2, metal sulfates and sulfuric acid. Hence developed nations have limited sulfur content to 0.05 % and aim to reduce further by 0.03 %.

Arenes in diesel fuels are normally about 30 %.

Diesel fuel additives include detergents; cetane and pour point improvers; anti-oxidants, etc. Barium as well as other metal containing smoke suppressants have been encouraged but not accepted due to own or generated toxicity as well as contradictory effects on emissions. New ashless anti-smoke additives need more experimentation.

Gaseous fuels occur in nature, and manufactured from solid/liquid fuels. Hence the gaseous fuels can be classified as: (a) Natural gaseous fuel, and (b) Artificial gaseous fuel.

The advantages and disadvantages of gaseous fuels are:

Advantages

(a) Can be transported easily through pipelines;
(b) Poses higher calorific value compared to liquid and solid fuel;
(c) Can be pre-heated by hot waste gases, and achieve economy in heat;
(d) Combustion can readily by controlled;
(e) Clean in use compared to liquid and solid fuel;
(f) Burn without any shoot/smoke/ashes; and
(g) Free from impurities found in solid/liquid fuels.

Disadvantages

(a) Require very large storage tanks; and
(b) Chances of fire hazards due to use of gaseous fuel is higher compared to liquid and solid fuel.

Alternative fuels

Strategies for reducing air pollution must be implemented by improving efficiency of machine and fuel quality. Changing the composition of certain ingredients in gasoline(petrol)/diesel can reduce emissions from vehicles. Reducing the lead in gasoline (petrol) will decrease the lead emission in the air. Alternative fuel such as methanol; ethanol; other alcohols; natural gas; mixtures of ethanol, methanol, and other alcohols with gasoline (petrol); LPG, liquid fuel extracted from coal, hydrogen gas, non-alcohol biological fuel and electricity can reduce air pollution.

The major alternative fuel are pure oxygenates, hydrocarbon gases, *Fuel alcohols, Liquefied natural gas, liquefied petroleum gas*.

Alternative fuels have great potential to reduce or eliminate air pollution. In many parts of the world natural gas and LPG are replacing gasoline(petrol) and diesel due to economic and environmental perspective. Ethanol, methanol, and hydrogen are yet to make their use economical. *Methanol* is dispensed from fuel pumps similar to gasoline (petrol). The main drawback of methanol is its cost and the variability of pricing.

Methanol is one more sustainable fuel which can be synthesized from natural gas, wood, coal, and organic rubbish. It can also be synthesized by electrolyzing water to produce hydrogen and combining with CO_2.

Ethanol produced by processing crops like sugar cane or corn but it is more expensive compared to methanol. When ethanol is blended with gasoline(petrol) in proportions up to 22 %, the resulting mixture is called gasohol, and may be used in ordinary spark-ignition automobiles. Ethanol is used as a blendstock for gasoline (petrol) in many countries. Ethanol can be synthesized from grains, and other plants like sugarcane or beet sugar. Research is focusing to use methyl ether as substitute to diesel. Hydrogen is also an ideal clean fuel.

Natural Gas which is 85–99 % methane is known for clean-burning, cheapness, and abundance in many parts of the world. It already plays a significant role in Argentina, Canada, New Zealand, Russia, Italy, and the United States. LPG is used by millions vehicles in several countries across the globe. The main ingredient of natural gas is CH_4 and usually the 50 % cheaper than gasoline(petrol) and has high ignition point which is more volatile than gasoline (petrol). It does not contain dangerous substances such as benzene, lead, and aromatic hydrocarbons. The ignition point of natural gas is 1.7–5 times higher than gasoline (petrol). Emissions of pollutants from use of natural gas are less than those from gasoline (petrol)/diesel as combustion of natural gas generates same amount of CO_2 and twice the H_2O compared to conventional fuel. Natural gas vehicles are of two types: liquefied natural gas (LNG) vehicles and compressed natural gas (CNG) vehicles. The pressure of compressed natural gas is typically 20–30 MPa, where as pressure of liquefied natural gas is typically in the range of 0.05–0.5 MPa. CNG vehicles are the more common compared to LNG vehicles.

LPG is mixture of several gases with major fraction comprising of propane, and butane. LPG also consists of minor quantities of propene, various butenes, iso-butane, and small quantities of of ethane (C_2H_6). In countries with colder climates, higher proportion of propane and propene is maintained in LPG in order to provide adequate vapor pressure in winter. Warmer countries LPG consists more butane and butenes. LPG composition may also be varied by supplier according to season. LPG is a by-product during the production of oil and oil gas (Kebin and Hong 2005). It can also be synthesized from natural gas. The main ingredients of LPG are propylene (C_3H_6), butane (C_4H_{10}), propane (C_3H_8), and butylenes (C_4H_8). Its cetane number is 103–105. It has good antiknock properties. The ignition temperature of LPG is 441–550 °C.

Biodiesel are nothing but vegetable oils used as substitutes for diesel fuel. These oils can be produced from a many sources including rape, peanut, soya, coconut, sunflower, sesame, cotton, and oil palm. Their high viscosity (around 20 times that of diesel), results in poor fuel atomization, ring stickings, fuel injector blockage, and contamination of lubricating oil, makes them used as blends with diesel fuels in proportion of up to 50 %. When used in blends, vegetable oils generates higher emissions of PM, CO, and HC, as compared to pure diesel fuels (OECD 1995; Vermon and Jones (1993).

Biodiesel additives are ethyl or methyl esters of fatty acids manufactured from vegetable oils Their most important positive effects might consist of lower hydrocarbon, CO as well as PM emissions, fast biodegradation of spills, better lubricating properties. Addition of biodiesel to petroleum derived fuel reduces the quantity of sulfur as well as arenes and therefore—emissions. The major negative effects are lower calorific value, increased NO_x emissions, increased water solubility, incomplete combustion, higher aldehyde emissions, etc.

Three important factors that affect negatively the manufacture of biodiesel additives are—high costs, limited vegetable oil availability and the pollution characteristics of the conventional transesterification (the process used to convert vegetable oils to Biodiesel) technology.

Combustion characteristics of biodiesel are comparable to diesel fuel, but the potassium and sodium atoms in biodiesel can deposit in the combustion chamber. These deposits can affect combustion characteristics, influencing engine performance and operability resulting in increase in exhaust emissions. Substantial deposit build-up can also degrade engine durability. Biodiesel tends to dilute engine oil requiring more frequent oil changes.

Even though hydrogen has the potential to become clean fuel, it has many properties that restrains using it. Hydrogen suffers major problems with respect to production and storage is not found in huge quantities in nature. Manufacture process of hydrogen includes reforming natural gas; electrolysis of water; partial oxidation and steam reforming of other fossil fuels. The most economical way of hydrogen production is from reforming natural gas.

Electric and Hybrid-Electric Vehicles even though eco friendly in terms of noise and air emission, they have high operating and capital costs compared with diesel-fueled vehicles. Electric vehicles in the form of trolley buses are used in some countries. But its use is limited due to the need of overhead wires and hence is replaced by other vehicles.

Sustainable fuel management in industries can be achieved by energy efficiency, material efficiency in production, material efficiency in product design, using products more intensively, and decreasing overall demand for product/services.

Nitrogen occurs in coal and some crude oils. It is partly removed by hydrodesulfurisation. Organic wastes (leather, proteins, nylon, wool, leaves) contain considerable amounts of nitrogen.

Solid waste contains chlorine in municipal solid waste in PVC, kitchen salt. Brominated fire retardants are part of E-waste. Bromine usually represents 1 % of chlorine in natural sources. Fluorine will be present in CFCs present in spray cans, thermally insulating foams, refrigerator circuits. Burning of such elements in combustion chamber of incinerator will form complex toxic chemicals. Ash up to half of some coal and can be partly eliminated by washing. Fuel oil residues will contain catalytic metals such as Vanadium and Nickel with a potential to oxidize SO_2 to SO_3. Coal ash will contain mainly SiO_2, TiO_2, Al_2O_3, CaO, Fe_2O_3, Hg, Pb, Cu. Some coal and lignite will contain lime that neutralizes SO_2. Wood ash is rich in K_2O, reducing the melting point of many minerals thus contributing to boiler fouling.

Mainly SO_2 leaving the stack slowly converts to SO_3 in the environment. Non-stoichiometric vanadium oxides present in heavy fuel ash, platinum, iron oxides and nitrogen oxides act as catalyst.

Any chlorine in organic compounds is converted to HCl during combustion. HCl is less toxic than Cl_2 and easier to remove by wet scrubber. The consecutive oxidation may lead to formation of toxic chemicals and can be is avoided by:

- Using steam as an atomizing agent and operating at low excess of oxygen;
- Rapid quenching of flue gases, by water curtain or spray.

NO, formed by combustion, spontaneously oxidizes to NO_2, whereas NO_2 may reduced back to NO reacting with VOCs or CO. Important factors in formation of NO_x are excess of air, temperature, and the presence of compounds of organic nitrogen in the fuel.

NO_x can be part of fuel (NO_{fuel}) or formed due to thermal reaction(NO_{th}). The higher the flame temperature leads to formation of more NO_{th}.

NO_{th} can be reduced by :

- Increasing air during combustion.
- Using low NO_x burners in furnaces.
- Staged combustion, (decreasing the air supply and assuming sub-stoichiometric ratios. This makes Nitrogen molecules compete for Oxygen in fuel molecules. The resulting gases, are post-combusted at a comparatively low temperature, adding supplemental air).

Prompt NO_x is also formed in hydrocarbon-rich mixtures, due to reactions of nitrogen molecules from the air with flame-generated free radicals (Buekens 2005).

7.1 Sulphur Control at the Point of Fuel Manufacturing

Natural solid and liquid fuel as well as derivatives of natural fuel contains sulfur resulting in SO_x during combustion. Sulfur is a problem in residual as well as heavy fuel oil. LPG, Natural gas, gasoline(petrol) and distillates are desulfurized during manufacturing before selling to consumers.

Coal contains organic sulphur and inorganic sulphur. Removal of organic sulphur almost not possible to remove selectively, whereas inorganic sulfur (marcassite, pyrite,) can be partly removed by fine milling and ore beneficiation methods. Coal can be gasified and the flammable gas obtained can be scrubbed free of Carbony Sulfide (COS) and H_2S.

As per Vernon and Jones (1993) global anthropogenic SO_2 emissions resulted into 70–80 million tonnes per year. Due to associated impact on environment and health it is important to control the emission of SO_x from anthropogenic activity.

Coals are sedimentary rocks containing incombustible matter, combustible matters and water. Coal comes in numerous composition and energy. Lignite has less than 50 % carbon and an energy density lower than wood. Anthracite has more than 90 % carbon, and bituminous coals have carbon content between 70 and 75 %. If improperly fired, bituminous coal will emit excess smoke and soot. Anthracite coal creates a steady and clean flame. Coal has impurities like sulfur, nitrogen, and minerals. Sulfur makes up, usually, around 2 % of bitumen coals.

Legislation worldwide is required lower the sulphur in gasoline(petrol). With few exceptions, the tendency across the world appears to be production of a sulphur-free gasoline (petrol) (Brown and Evans 2007). New technologies for desulfurizing gasoline (petrol) are hydrogenation and adsorption.

Low-sulfur fuels are the solution to decrease emissions from combustion. Sulfur naturally occurs in crude oil and hence is found in both diesel and gasoline(petrol). When these fuels undergo combustion, sulfur is emitted as SO_2 or sulfate particulate matter. Any decrease in fuel sulfur reduces emission of sulfur compounds.

Reduced sulfur fuel ($\sim$150 ppm) reduces emissions of HC, CO, as well as NO_x from catalyst-equipped gasoline(petrol) vehicles. Reduced sulfur fuel fuel also reduces PM emissions from diesel vehicles, with/without oxidation catalysts.

Low sulfur fuel ($\sim$50 ppm) allows further benefit. Selective catalytic reduction may be used for more than 80 % control of NO_x emissions. Near-zero sulfur fuel ($\sim$10 ppm) increases NO_x control in NO_x Adsorbers to over 90 % in both diesel/gasoline(petrol) vehicles. Particulate filters attain the greatest efficiency with near-zero sulfur fuels, attaining 100 % control of PM.

In developing countries, high-sulfur fuels continue to be used and restrain the introduction of new engine technologies. These countries can dispel the air pollution and associated impacts by reducing sulfur content in fuel.

7.2 Use of Green Fuel

Green fuel, also known as biofuel, is distilled from plants/animal materials. Critics argue that the term “green fuel” is a misnomer, as the production of biofuel generates considerable pollution. Production of bio-fuel is mainly derived form sugar/starch producing and oil producing plants. Sugar/starch producing crops, such as corn or sugar cane are used to produce ethanol by fermentation. Oil from plants is processed to become biodiesel. Figure 7.2 shows bus fuelled by Biogas generated from organic solid waste and sewage sludge. Figure 7.3 shows Fuel station of biogas generated from organic solid and sewage sludge for public transport buses.

Recent technological innovations focus on non-food sources (algae, wood, inedible plant parts) and waste for energy. Algae have high oil content that can be processed to manufacture green fuel. Green fuel may emit formaldehyde, ozone, as well as other carcinogenic substances when used.

Fig. 7.2 Bus fuelled by biogas generated from organic solid waste and sewage sludge in Stockholm, Sweden

Fig. 7.3 Fuel station of biogas generated from organic solid and sewage sludge for public transport buses in Stockholm, Sweden

7.3 Mitigation of Fuel Adulteration

Adulteration liquid fuel is common practice in developing world wherein huge population depend on liquid fuel for cooking and transportation. The pricing of different fuels often motivates staff/agencies responsible for transportation/storage/sale to mix cheap fuel with costly fuel. The cost of fuel depends on purity, flash point, viscosity, calorific value, tendency to emit soot and other properties. In the absence of proper checks and involvement of government officials as well as politicians in adulteration mafia leads to considerable pollution in developing world.

Diesel, Gasoline(petrol) and Kerosene are liquid fraction obtained from crude oil. They differ in carbon numbers. Since Kerosene is used mainly for domestic purpose for cooking, lighting etc., it is available through public distribution scheme with at subsidy in developing countries. The Diesel/Gasoline (petrol) are mainly used as fuel and priced high. Hence Diesel is mixed with Gasoline (petrol)/Diesel to make profit. Adulteration of gasoline(petrol) and diesel with kerosene increases the harmful emissions from vehicles (Osueke 2011).

7.4 Improving Combustion Efficiency

Combustion is a group of chemical reactions, involving fuels and oxygen that liberats heat. Combustion Products

The main combustion products are CO_2 and water vapour. The quantity of CO_2 is proportionate to the quantity of carbon burned. The amount of CO formed, varies between 6 and 15 % of CO_2. The moisture content in flue gas depends on (1) moisture content of the fuel fired, (2) chemically formed water during combustion, (3) moisture in combustion air, (4) water evaporated during quenching operation of flue gas by water injection.

Smoke emitted from combustion process is a conglomerate of aerosols, grit, soot as well as adsorbed compounds. Pollutants from combustion are generated by: (1) The dispersion of the fuel, (2) Products of Incomplete Combustion (PICs), and (3) Fuel impurities.

Soot is formed in fuel-rich combustion, due to carbonization of fuel droplets/volatiles, or by an untimely quenching of flames.

The loss of fuel due to leaks, spills, evaporation losses will contribute to air pollution. In each bulk handling operation about 0.2–0.5 % of the materials handled is lost, or blown by the wind.

At flame temperatures combustion is completed within milliseconds and remains incomplete, if one of the three T's is not adequate (Buekens 2005):

- T (temperature)
- T (time) period
- T (turbulence), (mixing of fuel and air).

Combustion is usually very fast process and its completion is not restricted to thermodynamic equilibrium. But at flame temperatures stable combustion products, like CO_2 and H_2O start dissociating noticeably and unstable species, like free radicals and ions attain prominent concentrations. Usually such situations do not continue during the cooling of flue gas, except these are exposed to sudden quench. Chemical combustion rates are high between 800 and 1200 °C. Below this range combustion rates rapidly fall off and surviving products of incomplete combustion will escape as pollutants.

If air is more than optimal quantity required then combustion is fuel-lean. If fuel is more than optimal quantity then condition is termed as fuel-rich condition. A fuel-rich flame leads to incomplete combustion releasing unburned fuel and products of incomplete combustion (PIC). Ignition starts from local heating of fuel and air-parcel. Gaseous fuels are easily ignited, at concentration between Lower Explosion Limit (LEL) and Upper Explosion Limit (UEL). In case liquid fuels flash point and flame point are important to engineer a system. If the flame point is above ambient temperature ignition is not an easy process. If liquid fuels are atomized, they perform as if their vapor pressure elevated.

When solid combustibles are heated, they decompose thermally, generating flammable gases as well as vapors. Active combustion starts when these fuel gases are evolved and vapors are available in adequate quantity and ignited.

Ignition spreads from the source to adjacent gas/vapour propagating into the surroundings provided that some necessary conditions are being met. Combustion theoretically ends when thermodynamic equilibrium is achieved. In practice, a fire extinguishes before reaching equilibrium

Physical processes that transfer mass as well as energy are also important in combustion and closely associated with chemical change. Diffusion of flames depends on diffusion of reactants and combustion products and depends on concentrations, temperatures, pressure, as well as diffusion coefficients. Convection is responsible for the transport of mass as well as energy, and comprises buoyant external forces, and turbulent eddy motions. Rates of heat and mass transfer depends on:

- The Reynolds Number,
- The Prandtl and Schmidt Numbers,
- The Nusselt and Sherwood Numbers,

Flames are composed of a reacting mixture of air as well as flammable gas/vapor generating heat and light. Flames are characterized by geometry, form as well as position of the flame axis, buoyancy, stability, and radiant heat loss.

For safety reasons diffusion flames are preferred over premixed flames. Hence Gas burners usually feature a central duct and gas exit velocity of 50–200 m/s for natural gas. Combustion air is supplied at lower velocity through an annular opening surrounding the first. The major flame features are length, stability, angle, as well as radiant properties which depend on the methods used for mixing air with gas. Mixing rate and combustion rate are kept same to attain efficient burning.

In industrial burners, geometry of a single gas flame depends on the size in addition to form of the orifice, the amount and swirl of air, and the outlet velocity. Flame position as well as shape are adapted by changing the angle or position of injection, combining many burners in-line.

The maximum combustion rate is achieved at about 1/3rd of the flame length which can be decreased by partial pre-mixing of air and fuel, increasing the swirl, preheating the combustion air or feeding fuel with air under an angle. The flame is lengthened by rising the momentum of the fuel injected, diluting the stream to be fired and adding re-circulated flue gas,

Flame propagation is explained by theories based on diffusion of reactive species and heat conduction. Combustion spread from the flame front, into the area where active burning occurs, to the unburned mixture of air and fuel. In the first theory heat flows to the inner core, whereas in second theory molecules generated in the reactive flame diffuse into the inner cone thereby igniting the mixture. Actually in reality, both the phenomena always occur in combination.

Laminar flame velocity of most hydrocarbons will be in the order of 0.5 m/s. Reactive species, oxygen enrichment, as well as high flame temperatures augment this flame velocity. The influence of pressure is very complex. The adiabatic flame temperature should attain ca. 1700 K to set fire to the surroundings.

Flame spreading is stopped in the presence of cold surfaces, absorbing heat as well as radicals. Flames may be extinguished by too much cooling and numerous other causes, such as strain, or extreme turbulence.

Burners
A burner has following functions:

- Mixing fuel as well as air in proper proportions,
- Providing a properly shaped section for flow of fuel as well as air,
- Act as a heat sink to limit erratic movements of flame.

Lighting Flames
Emission of light whether flaming or glowing is a normal effect of burning. Formation of **soot** will occur in almost all hydrocarbon flames. Soot-forming tendency of fuels makes the flame luminous as well as non-transparent.

Explosions and Detonations
An explosion is a rapid combustion reaction, along with pressure rise. Explosive combustion can be caused by:

- rise in the number of free radicals (referred as branched-chain explosion),
- rise in temperature (refereed as thermal explosion) or

The thermal explosion occurs when the rate of heat released by the reaction surpasses the rate of heat lost from the burning area to the surroundings. The second type usually accompanies the first.

Solid fuels burn evolving volatiles with visible flames, and glowing residues. Solid fuels are converted into 'fixed carbon' as well as 'volatile matter' upon burning. These volatiles vary in quantity and quality, depending on the temperature, turbulence and time. Upon ignition, volatiles maintain a flaming combustion and burn with visible diffusion flames surrounded by air. The remaining residue, burns slowly by glowing combustion. The time required for a complete combustion of this residue depends on whether fuel is pulverized, periodically poked/ agitated.

For safety reasons industrial flames are maintained as turbulent diffusion type. Diffusion flames are formed wherever reactants are not properly mixed before entering into the combustion zone. Molecular/turbulent diffusion is responsible for further mixing.

Premixed flames are very fast, almost instantaneous combustion of the premixed fuel/air-mix. The combustion reactions happen within few micrometers of the flame front.

The combustion of fuel and pure oxygen reach temperatures of up to three thousand degrees. Dilution of this mixture with nitrogen results in gradual decrease in flame temperature.

Fig. 7.4 Two chambered incinerator

Addition of excess air will further reduce the temperature. Great quantity of added air or nitrogen can extinguish the flame.

Furnace is a heat-resistant enclosure that fulfils several functions:

- Providing mechanical or pneumatic fuel feeding and ash removal facilities.
- Providing appropriate ports for primary as well as secondary air.
- Limiting the heat losses to the surroundings,
- Offering sufficiently long combustion.

The combustion of unburned volatiles can be completed in a secondary combustion chamber (Fig. 7.4). Separate, secondary combustion chamber, provides proper postcombustion of volatiles. The quality of primary and secondary combustion is affected by the mixing features of the furnace, which include throughput, geometry, primary and secondary air, flow organization of fuel, and flue gas.

Since parallel flows of air and fuel result in poor mixing leading to incomplete combustion, better mixing is achieved by impacting fuel with air by tangential or radial injection of combustion air. Secondary chambers offer less residence time as low as two seconds. A fairly homogeneous temperature is achieved by proper selection of the furnace dimensions.

Less excess air (LEA)

Excess air flow for combustion is associated to the amount of NO_x generated. Hence limiting the net excess air flow to less than 2 % can reduce NO_x content of flue gas. Even though there are fuel-rich as well as fuel-lean zones in the combustion region, the net excess air is limited by using this approach.

Burners out of service (BOOS)

Burners out of service (not feeding fuel, but supplying air or flue gas) in multiple-burner equipment allows the burners around them to supply fuel/air to air/flue gas flowing from the BOOS resulting in combustion by stages. Thus, thermal NO_x is lower. The quantity of NO_x generation depends upon the spatial relationship of the burners.

Over fire air (OFA)
Utilization of OFA completes the combustion when primary combustion utilizes a fuel-rich mixture. This is usually not a excessive amount of air.

Low NO_x burners (LNB)
A LNB provides a stable flame with several zones—(1) primary combustion, (2) fuel Reburning (where fuel is added to chemically reduce NO_x, and (3) final combustion.

Flue gas recirculation (FGR)
Recirculation of cooled flue gas decreases temperature by diluting the oxygen in combustion air. This reduction of temperature reduces the NO_x concentration that is generated.

Water or steam injection
Injection of water/steam changes the stoichiometry of the mixture to dilute calories generated by combustion to reduce temperature to an extent where thermal NO_x will not be produced in as great a concentration.

Reduced air preheat
In many facilities air is preheated while cooling the flue gases to reduce the heat losses in order to improve efficiency. Since this can form more NO_x during combustion, air preheat, is lowered to an extent where NO_x formation is suppressed.

Fuel reburning (FR)
Recirculation of cooled flue gas along with added fuel causes dilution of calories and the of added fuel chemically reduces recently formed NO_x to molecular nitrogen.

Combustion optimization
Combustion optimization refers to control of combustion to reduce air pollution. In a natural gas fired boiler, by reducing combustion efficiency from 100 to 99 %, generation of NO_x will be reduced to acceptable level. 20–60 % reduction in NO_x can be expected in coal-fired boilers. This technique requires finding optimum combustion efficiency as well as controlling combustion at that efficiency.

Air staging
In this method combustion air is split into two streams. The first stream is blended with fuel in a ratio that generates a reducing flame. The other stream is injected to downstream of the flame to achieve reduced emission.

Fuel staging
In this method fuel is split into two streams. The first stream is fed into primary combustion which operates in a reduced fuel to air ratio. The second stream is injected downstream of primary combustion, to achieve reduced emission.

Catalytic combustoin
Use of a catalyst to achieve combustion below NO formation temperatures can reduce emission of oxides of nitrogen.

Ultra-low nitrogen fuels
These fuels can avoid NO_x formation during combustion as results of presence of nitrogen contained in conventional fuels.

Selective catalytic reduction (SCR)
SCR is used to reduce injected ammonia to NO_x with the help of catalyst (usually precious metals or zeolite).

Selective non-catalytic reduction (SNCR)
In SNCR ammonia/urea is injected within a boiler or in region of ducts with temperature range of 900–1100 ^{o}C where temperature ionizing the ammonia/urea will reduce NO_x up to a 70 %.

Sorption
Adsorbants and absorbents are injected to control NO_x. There are many absorbents/adsorbents available. Spraying limestone in slurry or powder form into the flue gas reacts with both sulfuric acid and nitric acid. In-duct injection of dry sorbents can reduce pollutants at three places: (1) combustion chamber, (2) flue gas duct leading to the baghouse, and (3) flue gas duct leading to the electrostatic precipitator. Injection of carbon into the air flow to would finish the capture of NO_x. The carbon is later captured in baghouse/ESP just like other sorbents.

Combined technology approaches
Very rarely is only one method/principle used alone to control air pollution. Depending upon energy conversion device, type of combustion system and type of fuel used technologies are combined to get the maximum NO_x reduction.

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Chapter 8
Air Pollution and Disasters

Abstract Many disasters lead to air pollution and vice versa. This chapter elaborates major air pollution issues due to earthquake, tsunami, volcanic eruption, epidemics, extreme temperature, insect infestation, mass movement, wars, and fire accidents.

A disaster is a hazard resulting in significant physical damage, loss of life, or impact to the environment. In modern academia, disasters are considered as the consequence of improper risk management. Hazards that strike areas with low vulnerability area or uninhabited region will never become disasters. Developing nations suffer the greatest impact in terms of life, economic loss, and environmental degradation. Disasters can be natural or anthropogenic and could be sudden onset (as in case of flash flood, cloud burst or explosion in industry) or prolonged onset (like drought or civil conflict). Air pollution may subsidies or enhance due to disasters. Disasters like earth quake, war and volcanic eruption add to air pollution. Disaster disturbs the air quality within airsheds. Disasters disturb the air quality for a long or short period. The exposure of life to large concentration of pollutants within short period may result in unpredicted impact as witnessed in release of toxic gases in industrial accidents.

As per Gribble (2002) 3700 naturally occurring organo-halogens are known to exist as on date. The presence of many fluoro-alkanes in geothermal emissions is well documented, even though how these compounds are formed remains a mystery.

Air quality management during disaster depends on preparedness of the community and external aid. Air pollution can lead to disasters and disasters can result in air pollution. In either the case human health or environment will be affected. The notable among the air pollution episodes are Meuse Valley episode in 1930, episode in Donora in Pennsylvania of USA, London episode in 1952, Bhopal episode in India that occurred in 1984, Chernobyl episode in 1986, southeast Asian haze of 1997, and Fukushima Daiichi nuclear disaster of 2011.

Quantity of emissions released during disaster is difficult to assess hence following equations are used to estimate quantity of pollutants emitted.

$$Q_i = M_i / C_i$$

R. Chandrappa and U. Chandra Kulshrestha, *Sustainable Air Pollution Management*, Environmental Science and Engineering,
DOI 10.1007/978-3-319-21596-9_8

where,

Q_i release rate of pollutants into atmosphere
M_i measured air concentration of pollutants
C_i dilution factor (calculated under assumption of unit release rate)

Total release of pollutant is calculated using following equation

$$S_i = \sum \left[Q_{i,j} \times T_j\right]$$

where

$Q_{i,j}$ release rate of pollutant i at time j
T_j Duration of release

A temperature inversion in Meuse valley of Belgium lead to increase concentration of pollutants emitted from industries along narrow valley of Meuse river resulting in death of about 60 and sickness of 6000 people in valley. The temperature inversion in Donora of Pennsylvania, USA killed 20 people and sickened 7000 people in 1948 due to air pollutants emitted from industries located in the valley of Monongahela River.

Most of the natural disasters in urban area trigger technological accidents. Such incidents/accidents that lead to technological accidents due to natural disasters are called "Natech" (Campedel 2008) or natural-technologic or *na-tech* events (Young et al. 2004). Several effects could take place in industries and in the storage sites, resulting in damage of pipelines, storage tanks, and process equipment resulting in the release of hazardous materials. Examples of Natech include flood in 2002 at the Samir refinery in Mohammedia, Morocco; Kocaeli earthquake that occurred in 1999 in Turkey; nuclear disaster in the year 2011 at the Fukushima Nuclear Power Plant in Japan.

Natural disasters are prominent mechanisms of hazardous material (*hazmat*) releases. Na-tech releases may be small (e.g.: paints, solvents, and other chemicals stored in household) or large (e.g.: explosion of fuel storage tank). Disaster-related hazardous material releases may affect large areas and people. Smoke from Indonesian wildfires spread to Kuala Lumpur and Singapore (Swinbanks 1997), where outpatient attendance for haze-related conditions increased by 30 % (Emmanuel 2000).

Figure 8.1 Air pollutants released from disaster. Table 8.1 shows scale of disaster due to air pollution. Disaster-related hazardous substance releases can have an effect on large geographic areas and people (Young et al. 2004). Many na-tech releases from inadequate building structure, poor storage well (Whitman 1986).

Pollutants released to the environment cycles between air, land, as well as water until it is finally removed from the system through burial in lake sediments or deep ocean sediments and through entrapment in secure mineral compounds. Disasters can increase the release of the pollutants accumulated in living/non-living things. While the wild fires release the chemicals entrapped in biomass, volcano/tsunami/earthquake can release the elements/compounds present in earth/seabed.

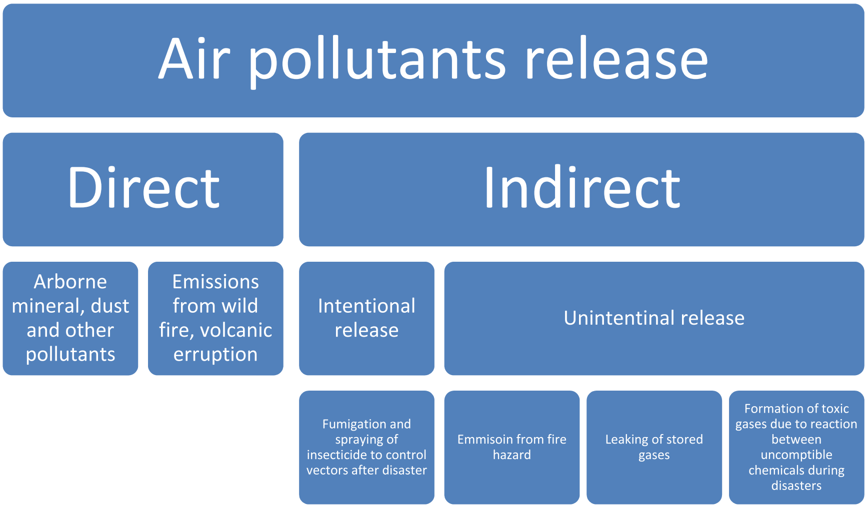

Fig. 8.1 Air pollutants released from disaster

Table 8.1 Scale of disasters due to air pollution

Environmental issue	Global	Regional to continental	Local to regional	Local
Climate change	x			
Ozone depletion	x			
Tropospheric ozone	x	x	x	
Acidification	x	x	x	
Corrosion		x	x	x
Urban air quality			x	x
Industrial emissions			x	x
Nuclear emergencies		x	x	x
Chemical emergencies		x	x	x
Food poisoning epidemics				x

Methylmercury, the most toxic substance is mainly formed in aquatic environments by natural microbial processes. Subsequently mercury escape to air and washed into water bodies. A geothermal activity emits mercury to the atmosphere as well as releases it to the deep oceans (UNEP 2013).

Figure 8.2 shows biogeocycle of pollutants that are disturbed during disasters there by releasing air pollutants. Air pollution during disasters are not researched and documented because monitoring of air pollution is not a priority activity during disaster and lack of funds towards research with respect to air pollution during disasters. Further even if the monitoring devices exist in disaster prone area, the devices will get affected and stop functioning due to damage or power cut.

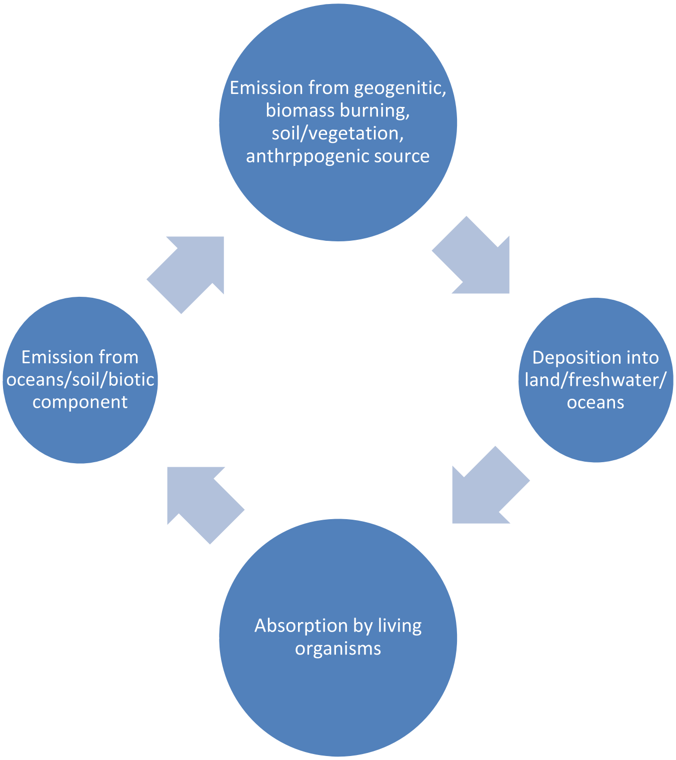

Fig. 8.2 Biogeocycle of pollutants

Land use planning should evade hazard zones such as 100-year flood plains and fault lines for locating landfills, waste lagoons, chemical storage facility as well as industrial facilities. Using special designs for pipeline supports and tanks can improve structures' capacity to withstand the disaster (Selvaduray 1986). Release of petroleum during the Northridge earthquake as well as ammonia releases during flooding in Brazil might have been prevented by proper engineering design and location of facilities. Nuclear power stations and industrial facilities that have been particularly designed to withstand natural catastroph.

8.1 Floods

Floods usually occur due to rain, destruction of dams, overflow of water bodies, and cloud burst. It is usually assumed the flood will not lead to air pollution. But the pollutants like methane and hydrogen sulphide may be released during flood due to purification of organic matter. Presence of pyrite in flooded area may undergo aqueous oxidation generating sulfuric acid which could be released to air. Many dimensions of air pollution and flood are shown in Fig. 8.3.

A water-reactive substance like alkali metals, iron sulfide, uranium, lithium, sodium, potassium, rubidium, calcium, phosphorous, caesium, sulphuric trioxide and oleum release air pollutants due to reaction. Some chemicals are also pyrophoric and will ignite releasing air pollutant.

Standing water due to flood will become breeding ground for microbes and can become airborne and be inhaled resulting in lung disease. The contaminants and microorganisms left behind after flood pose health risk. Due to the time spent in emergency camps may increase the risk of infectious diseases. Damp buildings as well as furniture promote the growth of dust mites, microorganisms, mold and

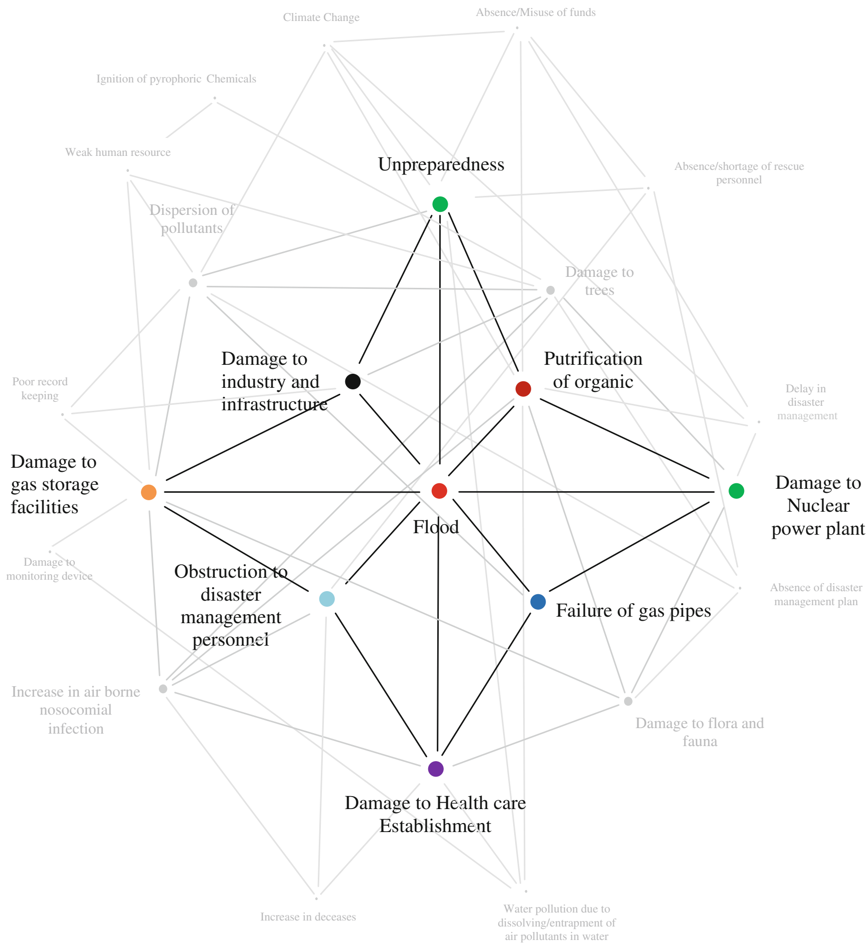

Fig. 8.3 Many dimensions of air pollution and flood

cockroaches that can aggravate asthma, allergies, wheeze, cough and hypersensitivity pneumonitis.

Leakage of variety of gas both in residences and industry can lead to health as well environmental hazard. The geothermal water from underneath the glacier may lead to release of hydrogen sulphide when exposed to air during flood which may include glacial outburst flood. A flood can expose people to lead from contaminated soil, deteriorating paint, and dust from chipping or peeling paint. Further asbestos in flood debris can also contribute to air pollution.

8.2 Drought

Drought is affecting millions of people, especially poor as well as underprivileged. Their vulnerability is increased by ongoing environmental degradation as well as inefficiency of governance. Drought are classified into three types: meteorological, agricultural, and hydrological.

Meteorological drought is shortage of precipitation from "normal rainfall". Agricultural drought is shortage in water to crop. Hydrological drought is shortage in surface/subsurface water supplies, resulting in shortage of water to meet normal water requirements.

1930s witnessed drought followed by infamous dust storms (Schubert et al. 2004). The drought and dust storms created major environmental catastrophes in USA and led to the popular description of most of the southern Great Plains as the dust bowl (Worser 1979).

The Dust Bowl, during the 1930s is also popularly phrased as dirty thirties. Severe drought and unanchored soil lead to formation of dust clouds that sometimes blackened the sky. These billows of dust often referred as "black blizzards" or "black rollers" reached Washington, D.C. as well as New York city and reduced visibility to a meter or less. Extended drought in 1930 resulted in exposure of ploughed field to wind erosion.

Emissions of isoprene as well as terpenes from vegetation which has a significant impact on ozone as well as fine particle formation will be reduced due to drought. The overall pollution will increase as gross leaf areas in the vicinity of drought prone area will decrease and so as scrubbing effect due to absence of precipitation. Dry, clear skies influence light available for enhancing photochemical reactions. Changes in soil moisture will change height to which pollutants in the air can mix in the atmosphere.

Climate change brings numerous economic activities with it. Increase in heat enhances demand for cool drinks, ice cream, sunburn creams, and electricity demand towards air-conditioning/refrigeration which may increase electricity demand and associated emissions.

Several years of drought resulted in desiccation of Old Wives Lake, in southern Saskatchewan. The wind generated airborne silt, sodium sulfate, and clay due to which residents reported nasal, respiratory and eye irritation (Gomez et al. 1992).

8.3 Wild Fire

Wild fire is fire in an area of combustible vegetation in the wilderness area that include forest and grass land. Wildfire occur due to lightning, spontaneous combustion, sparks from rock falls, volcanic eruption, coal seam fires, cooking in forests, sparks from equipment discarded cigarettes, intentional fire by terrorist, shooting by poachers, preparation of forest land for agriculture by firing, and power line arcs. During wild fire, burning logs can roll downhill igniting dried vegetation in lower elevation. Dry climbers become fire ladders and burns trees. Methane formed due to litter decomposition catches fire easily thereby spreading fire. Lower precipitation, higher temperature, drop in humidity increases spread of fire.

Millions of hectares of the forests are destroyed by wild fires every year resulting in air pollution. Annually fires burn about 500 million hectares of open forests, woodland, tropical as well as sub-tropical savannahs; 20–40 million hectares of tropical forests; and 10–15 million hectares of boreal as well as temperate forest (Goldammer 1995).

Air quality of thousands of km is affected by wildfires (Sapkota et al. 2005). Apart from smoke comprising of unburnt carbon particle, the emission from wild fire comprises carbon monoxide, ash participles, methyl chloride, methyl bromide, polynuclear aromatic hydrocarbons, aldehydes, VOCs.

Due to intervention of anthropogenic activity, forests have become dump yards for waste that include hazardous waste. Fires in such area contribute to toxic air pollutants. The pollutant concentration and type depends on the nature of substance burnt and hence it is highly difficult to characterise emissions.

The notable massive forest fires often occur at Southeast Asia. The 1997 Southeast Asian haze caused mainly due to slash and burn agricultural practice was worsened by quasi-periodic El Nino drought. Large area of southeast Asia were affected by emissions of 45,600 km^2 of vegetation burnt on Indonesian islands of Kaliman and Sumatra resulting in concentration of total suspended solids of more than 2000 $\mu g/m^3$ in locations close to extensive fire activity. The resulting haze covered more than 3 million km^2 affecting Indonesia, Singapore, Thailand, Brunei and Malaysia. The haze also occurred 2005, 2006 and 2013 affecting life in south East Asia. Local sources of pollution due to industries increased toxicity. Urbanised as well as industrialised Klang Valley of Malaysia increased pollution aggravating the situation. The problems due to haze lead to ASEAN (Association of South East Asian Nations) Agreement on Transboundary Haze Pollution signed in 2002 by ASEAN nations to decrease haze pollution in Southeast Asia.

Wild fires can significantly contribute to illnesses of the respiratory system (WHO 2002; Bowman and Johnston 2005; Moore et al. 2006). 1997 Indonesia fires increased cardiovascular and respiratory diseases, and affected living in South-East Asia (Sastry 2002; Frankenberg et al. 2005; Mott et al. 2005). Smoke containing ozone, sulfur dioxide, nitrogen dioxide, carbon dioxide as well as particulate matter resulted in hospital admissions of at least 8000 in Malaysia during the Indonesian forest fires in 1997 (Swinbanks 1997). Fatalities due to too much carbon monoxide concentrations only or along with other pollutants were reported during wild fires in Côte d'Ivoire (1982–1983), China (1987) and Australia (1983) (Schwela et al. 1999).

Wild fire not only destroys wild life habitats that include nests and burrows, it affects healthy wild life as well in. The young and weak animals/birds are easily get killed due to wildfire.

Wildfire suppression can be as simple as beating the fire with sticks or throwing sand. Advanced suppression methods include use of Silver iodide to encourage snow fall, dropping fire retardants and water by unmanned aerial vehicles. Fire retardant may also be applied prior to wildfires as a precautionary measure. The secondary impact of the application of aerial fire retardants includes impact on land, water and vegetation.

Spreading of smoke in hilly terrain depends on the narrowness of valleys and may get stagnated for many days thereby forcing displacement of large animal and birds. Small animals may die to exposure due to small lung size and large quantity of polluted air.

8.4 Earthquake

Earthquake is shaking of land due to seismic waves. The majority earthquakes occur along the boundaries of the tectonic plates. Nations around the Pacific Ocean frequently experience earthquakes as they are situated in boundary of the Pacific plate. About 80 % of the world's major earthquakes are felt along a belt around the Pacific Ocean. Hence this belt often refered as 'Ring of Fire'.

Earthquake, in Taiwan on September 21, 1999 and March 31, 2002 was preceded by abrupt increase in SO_2 concentrations several hours prior to the earthquake possibly due to seismic triggered degassing (Hsu et al. 2010). Air pollution in the affected areas due to the Great Hanshin Earthquake in Hyogo, Japan on 17th January 1995 resulted in maximum TSP concentration of 150 $\mu g/m^3$ at five locations (Gotoh et al. 2002). After earthquake in Kobe City, Japan in 1995, dust and irritants generated during demolition work were considered as a factor in the worsening condition of asthma patients (Nukushina 1995). Hazardous substance (like asbestos; fiberglass; mercury; chemicals from leaking transformers and broken chemical containers etc.,) exposures accounted for 20 % of after-earthquake work-related injuries after Loma Prieta earthquake in the year 1989 near Santa Cruz, California (Durkin et al. 1991; Nathan et al. 1992).

Impact on air quality of earthquake prone area depends on activities and infrastructure in the area. An area with atomic power plant or nuclear research centre will result in emission of radioactive material during earthquake. Damage to petroleum storage area and subsequent smoke during earthquake will result in emission of pollutants due to combustion of petroleum product. The damage to industry may result in emission of stored chemicals.

On 11th March 2011, earthquake in the northeastern coast of Japan and tsunamis occurred over the east coast of the Tohoku Region (Nagamatsu et al. 2011) that resulted emissions from failure at the Fukushima Nuclear Power plant.

The Whittier Narrows quake in October 1987 resulted in at least two hazardous material incidents: (1) the release of 2/3 of a 1-ton chlorine container at a facility in Santa Fe Springs; and (2) chemical spills, a major fire and asbestos contamination in California State University, Los Angeles (Tierney 1989). Tipping of 1-gallon container storing sodium metal during the quake resulted in fire. Water leaking from ruptured safety shower reacted with the sodium generating hydrogen gas that ignited and spread, vaporizing mercury as well as exposing asbestos (Lindell and Perry 1996).

Earthquake in Northridge, California in USA resulted in nine petroleum pipeline ruptures, 752 natural gas line breaks, 60 emergency hazmat incidents that included release of sulphuric acid during train derailment (Lindell and Perry 1997, 1998).

Hazardous releases were reported from about 200 laboratories, 100 industrial facilities and commercial activities (like drug stores, hair salons as well as restaurants) and residences after the Loma Prieta quake 1989 at California. Three of the largest releases associated this quake were between 5000 and 20,000 pounds of ammonia from a food processing plant, 50,000 gallons of aqueous solution from a semiconductor facility, and 15,000 $yard^3$ of fuel from underground storage containers (Young et al. 2004).

8.5 Tsunami

Tsunami is series of water waves due to displacement of a large quantity of water in water body. Air contaminants released during tsunami depends on the development and activities of the tsunami affected area. The flooding of sea/lake water over land is likely to emit pollutants associated with flood already discussed in Sect. 8.1.

The nuclear disaster at the Fukushima Nuclear Power Plant in Japan on 11 March 2011, lead to meltdown of three of the plant's nuclear reactors when the plant was hit by the tsunami activated by the Tōhoku earthquake. The disaster resulted in release of substantial quantities of radioactive materials becoming the largest nuclear after Chernobyl. The disaster caused the month-long emission of radioactive substance into the atmosphere (Chino et al. 2011).

Severe pneumonia known as 'tsunami lung', was reported in region affected by the Indian Ocean tsunami (Chierakul et al. 2005; Allworth 2005; Athan et al. 2005) a disease that occur due to inhalation of salt-water contaminated with bacteria and mud.

8.6 Volcanic Eruption

A volcano is a hole on the crust of a planetary mass such as the Earth, which allows volcanic ash, gases and hot lava to escape from below the surface. Earth's volcanoes occur as the planet's crust is made up of 17 major, rigid tectonic plates that float on magma. Erupting volcanoes can pose threat to aircraft, as ash particles can be melted in engine and then adhere to the turbine blades disrupting the functioning of the turbine. Large eruptions can obscure entry of solar rays and cool the troposphere; but they also absorb heat released from the Earth, resulting in warming of stratosphere. Historically, volcanic winters have resulted in catastrophic famines (Texsor et al. 2004).

Volcanic activity is linked to the active zones of plate tectonics. The emission from volcano depends on the pressure, temperature and chemical composition of magma type. Most of the magma erupted is of basaltic composition and erupt commonly along mid-oceanic ridges in deep sea water. In some locations, such as in Iceland and the Azores these volcanoes erupt into the atmosphere. Such eruptions into atmosphere are called subaerial eruptions.

The composition of volcanic gases is generally controlled by the equilibrium among exsolved gas at the top as well as the silicate melt in the magma (Symonds et al. 1994). The composition varies widely between volcanoes and depends on volcano's state of activity.

There are three common types of magma: Andesitic, Basaltic and Rhyolitic. Andesitic magma erupts explosively since it tends to have high gas content. It is viscous and hence traps gas, and explosively erupts due to pressure built by gases. High viscosity in Andesitic magmais related to high silica content. Basaltic lava flows easily due to low viscosity (due to low silica content) and low gas content. Rhyolitic magma erupts catastrophically since it has high gas content. It is viscous (due to presence of high silica content) and traps gas, builds pressure resulting in explosive eruption.

As per Baxter et al. (1990) and Bernstein et al. (1986) CO_2, CO, H_2S, radon, hydrogen fluoride, silica as well as halogenated hydrocarbons are released during volcanic events. 50 and 90 % of volcanic emission comprises water vapor and 1–40 % comprises of carbon dioxide by volume. Sulfur gases in volcanic emission vary typically from 2 to 35 % by volume. Hydrogen chloride forms with 1–10 % of emissions from volcano. Hydrogen bromide will be in the range of 10^{-6} parts per volume and Hydrogen fluoride forms less than 1 ppm of volcanic emission (Texsor et al. 2004).

Stratospheric aerosols generated by short lived volcanic eruption will have small to moderate volume impact compared to moderate (10–20 km^3) volume basaltic flood lava eruption. Iceland is the only place on the earth where eruption of this scale is occurring releasing 5–9 megatons of SO_2 per km^3 of magma erupted (Thordarson and Self 2003). Lakiflood lava eruption in the year 1783–1784 at Iceland emitted 122 megatons of SO_2 and maintained a sulfuric aerosol mask over the Northern Hemisphere for more than five months. The volcano resulted in release of 95 megatons of SO_2 into the lower stratosphere/upper troposphere with eruption columns extending 9–13 km (Thondarson and Self 2003).

Quiet escape of hot sulphur-rich gases from new volcanic bodies known as Solfataric activity have been studied by Isidorov et al. (1990, 1991; Isidorov 1990) at Kamchatka volcanoes located in the Siberian peninsula, identified several organofluorines in the volcanic solfataric gases.

Volcanoes also emit mercury when they erupt. Geothermal activities also emit mercury present in the underground to the atmosphere as well as discharge it to the deep oceans. As per UNEP (2013) some recent studies suggest that natural sources account for around 10 % of the about 5500–8900 tonnes of mercury presently being emitted/re-emitted from all sources to the atmosphere.

8.7 Epidemics

Not all epidemics pose same importance with respect to air pollution. The transportation of pollutants that is biologically active like microbes are responsible for Swine flue, avian flue and Severe acute respiratory syndrome (SARS) may not change the air quality beyond the legal ambient air quality limits but harm human and animal life to great extent. SARS caused by the SARS coronavirus caused an eventual 8096 cases and 775 deaths between November 2002 and July 2003. Within weeks, SARS spread to in 37 countries in early 2003. Influenza A (H1N1) a human-to-human transmission disease is transmitted by direct body contact or respiratory droplets.

8.8 Extreme Temperature

Heat and cold waves (also referred extreme heat and cold temperature) cause human discomfort and ailments. A heat wave is a prolonged time of excessively hot weather. A heat wave is measured comparative to the normal weather in the area. Old wave or cold snap or deep freeze is weather phenomena distinguished by cooling of air over al large area.

Rising temperatures can result in smog pollution and increase rate of formation of secondary pollutants like Ozone. Higher temperature can increase pollen production plants and enhance wildfire risks. On the other hand Cold wave reduces dispersion of pollutants and traps pollutants. As per AIRPARIF (2013), an intense cold wave in February and an average high temperature in March are favorable to pollution of particulate matter.

But people with asthma, allergies, and other respiratory diseases face the most serious threats, since exposure to increased pollution heightens sensitivity to allergens.

8.9 Insect Infestation

Insect infestation is pervasive influx as well as development of insects affecting humans/animals/crops/material. Locusts and grasshoppers are main economic pests of crops as well as grasslands all over the world's dry zones. Chemical pesticides have been used for controlling locusts and grasshoppers for decades. The main classes of chemical pesticides used to control desert locust are organochlorines, organophosphates, carbamates, synthetic pyrethroids, phenyl pyrazoles, and biological pesticides (Wiktelius et al. 2003). Biological pesticides which comprises of spore of microorganism capable of killing target insects are used to avoid impact of chemical insecticide on environment.

Aerial spraying with aircraft is widely used to control insect infestation. The pesticide is usually applied as an Ultra Low Volume (ULV) formulation, with drop size ranging between 40 and 20 μm. Desert locust control is emergency operations and hence it is difficult to get trained personnel and pesticides with least environmental impact. Aerial spraying often cover large surfaces of unpolluted areas and often take place over different ecosystems and landscapes affecting flora and fauna.

Birds feeding on locusts may be enormously vulnerable to aerial spraying of pesticide (Mineau 2002). The birds will get affected due to shortage of food due to death of insects and toxic food due to chemicals that may present on food the birds ultimately feed on. These compounds are harmful for humans (Reichhardt 1998), aquatic organisms, honeybees as well as other insects (Mullié and Keith 1993; Krall 1995). A reduction in insect availability may lead to shortage of food to resident predatory species that consume locusts during the outbreaks (Culmsee 2002).

8.10 Mass Movement

Mass movement disasters include dry land movement and wet land movement. Mass movement include landslide and avalanches. A landslide or landslip is the outward and downward movement of soil/rock material on slopes.

Mass movement depends on slope angle, slope orientation, weather, snowfall, terrain, snow pack conditions and vegetation. Mass movement can be triggered by both natural as well as anthropogenic causes.

Mass movement is triggered due to ground movement like deep failure of slopes, rock falls, and flow of shallow debris in sloppy terrain. Landslides may occur due to natural or artificial causes.

One or more of following condition can lead to land slide: (1) jointed rocks, (2) steep slope, (3) fine-grained permeable rock or sediment, (4) large quantity of water, (5) clay or shale layers subject to lubrication and (6) volcanic activity.

Even though landslides usually occur in mountainous areas, they can also occur in roadway and building excavations, lateral spreading landslides, river buff failures, collapse of mine-waste piles, collapse in open-pit mines and quarries.

Airborne arthrospores dislodged from soil during landslides at Northridge, USA, in the year 1994 (Schneider et al. 1997).

8.11 Air Pollution Due to Anthropogenic Disasters

Anthropogenic disasters are hazards caused due to human intent; error; negligence; or involving a failure of anthropogenic system. This includes social hazards (such as wars and conflicts) and technological hazards (like fire accidents, structural collapse).

The notable industrial disaster at Bhopal in occurred in 1984 at the Union Carbide India Limited, India exposed more than 500,000 people to methyl isocyanate (MIC). The major wars in the history of mankind have severely caused air pollution and so as act of terrorism and mutiny. The terror attack on twin towers in USA on September 11, 2001 resulted in thousands of tons of toxic debris comprising more than 2500 contaminants spread across Lower Manhattan (Anita 2006). About 18,000 people developed illnesses due to toxic dust (Shukman 2011).

8.11.1 Wars and Conflicts

Wars and conflicts are part of civilisation since beginning of the civilisation. Invention of fire and weapons are used for self protection followed by defence and attack. The Wars and conflict occur for innumerable reasons but end up with loss of lives and property. War and conflict restricted to land in old days was extended to water and air. People built forts to protect themselves. This was followed by naval and air force.

It is essential to know the ongoing conflicts and possible air pollution as the pollutants gradually move to neighbouring countries and beyond. The failure of nuclear plants or testing of nuclear weapons are usually kept secret. But the ill effect will spread beyond boundaries and affect own cities as well as that of neighbouring countries.

Emission from war and conflicts include emission from use/manufacture of ammunition, fuel use in transportation, manufacturing of ammunition, destruction of infrastructure. Urban settlements, fuel storage, power station, military camps, roads, bridges, airports, ports are main targets of wars to weaken the opponents.

Mutiny and terrorism will aim haphazard use of explosives due to absence of planning, training and information.

The use of chemical, biological and nuclear weapons will have different impacts on environment. The emissions from these weapons vary depending on constituents of the weapon. Biological warfare also known as germ warfare use of biological toxins or agents like microbes to kill or incapacitate people, animals or plants as an act of war. A chemical weapon uses chemicals formulated to impose death or injure human beings. A nuclear weapon is made up of radioactive material used for mass destruction.

Conflict in Kuwait in January 1991 ended up in the discharge of about 6–8 million barrels of oil, followed by the fire of more than 600 oil wells and destruction of sewage treatment plants. The total estimated crude oil burned during Gulf war was 52.5 million metric tons generating smoke of 29.2 t/d/well resulting in 1.2 million metric tons of SO_2 and 0.3 million metric tons of NO_x (Khordagui and Al-Ajmi 1993). Oiling and petroleum hydrocarbon pollution was restricted largely to the northwestern region of the Gulf, while air pollution from the burning oil wells were more widespread (Price et al. 1994).

8.11.2 Fire Accident

Fire accident can occur at homes, commercial establishments, industries or forests. It can occur due to many reasons. The accidents can occur due to natural disasters or due to negligence of people. The accident can be associated with explosion. The duration of fuel and pollutants released depends on the availability of fuel and substance present at the place of accident.

The Chernobyl disaster that occurred on 26th April 1986 at the Chernobyl Nuclear Power Plant, Ukraine due to fire and explosion, resulted in release of radioactive material into the atmosphere that spread over western USSR and Europe. The quantity of radioactive material released was 400 times more than the quantity of radioactive material released during the atomic bombing of Hiroshima. *Chernobyl nuclear accident led to contamination higher than in the previous two decades in the human environment of Republic of Croatia* (Lokobauer et al. 1998). Releases and succeeding transfers of radionuclides through foods, air, and water exposed people to radiation who continued to live in the regions and those evacuated from nearby settlement (Bennett et al. 2006). Even though in 1986 the ^{137}Cs levels in the environment were higher than those of ^{90}Sr, ^{90}Sr transfer to the food chain from soil is considerably more than for ^{137}Cs, in the following years (Lokobauer et al. 1998).

Fire accident at Indian Oil Corporation Limited (IOCL) located at Sitapur, India on 29th October 2009 resulted in a very high fire flames resulting in emission of black plumes resulting in death and injury of people. Air quality in Jaipur as well as nearby area of Sitapur Increased values of SPM, RSPM NO_x and SO_2 (Sharma and Mishra 2013).

Coal fires associated with inactive/abandoned mines are reported from mining areas across the world (Glenn et al. 2011; Prakash and Gupta 1999; Stracher and Taylor 2004) and surface expressions of underground coal fires include areas of dead vegetation, baked rocks, land subsidence, gas vents and fissures (Glenn et al. 2011; Stracher 2007). Coal fires in abandoned mines, unmined outcrops as well as waste banks, constitute safety and environmental hazards. Such fires cause subsidence and air pollution. Coal fire started in 1765, was active until at least 1846 in the Pittsburgh seam in Pennsylvania (Eavenson 1938, 1942). Lewis and Clark, in their exploration in 1805, reported that burning coal ridges were visible in the bluffs along the Missouri River (Lavender 1988). Outcrop fire that was burning since around 400–600 years in southeastern Montana, has affected a 500 acres (Shellenberger and Donner 1979). Hundreds of coal-bed fires are on fire in the Powder River Basin (PRB) in the USA and studies have shown that such fires have been occurring since thousands of years in the area (Heffren et al. 2007).

Coal fires can be extinguished by (1) physically separating coal from the burning mass; or (2) oxygen removal by introduction of an inert gas; or (3) isolation of the fire zone from fresh air; or (4) heat removal by moving a heat-absorbing agent such as inert gas or H_2O.

Usually the chance of reignition is small if temperature is below 100 °C (Kim and Chaiken 1993). Fuel-removal by excavation is the most successful fire-control techniques (Chaiken 1984) wherein burning is removed and cooled to extinguish the fire by spraying with water or by spreading it out on the ground to cool in air.

The reappearance of excavated fires is normally due the failure to completely excavate or lower the temperature past the reignition point (Kim and Chaiken 1993).

Inundation methods for extinguishing coal fires involve the use of water to reduce the temperature of the burning matter. To increase the water level, dams are constructed. The Water level must cover burning coal and overlying heated rock. This method is used for small fires that are fairly accessible and near the water table. Another method provides use of water by continuous pumping or by gravity flow.

Apart from water, underground fire zone is extinguished by fine, noncombustible solids like sand, red dog, crushed limestone, silt, and fly ash. Air or water is normally used to carry the material through a borehole.

Grout slurries can also be pumped underground burning area to form fire control barriers. Cement slurry solidifies to form a seal. Grout slurries can be added with foaming agents as well as incombustible materials, such as sand/soil.

Surface sealing is a comparatively cheaper method of controlling fires in abandoned mine. It is planned to slow down ventilation of the fire zone. If the seal is maintained while all the heat in mine dissipates, the fire may ultimately be extinguished. Normally most surface seals fail within one to three years after construction due to settling, drying, shrinkage, or increased fire activity.

In western USA 85 % of fire abatement projects were surface seals due to the topography of the area, the relatively low cost, and the lack of water needed to employ other methods (Shellenberger and Donner 1979). If the seals are maintained for about 10–20 years, the fire may be put off.

Surface seals sufficiently inhibit unsightly venting, control subsidence, and limit the emission of harmful fumes. Surface seals with regular as well as periodic maintenance provide a sufficient control method (Kim and Chaiken 1993).

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Chapter 9
Safety Issues in Sustainable Air Pollution Management

Abstract All human activities bear some risk of injury to people and so as air pollution and its management. People who erect, operate, inspect, and monitor are exposed to air pollutants. Apart from those who are involved in air pollution management business, other citizens are also exposed to injury due to unsafe practice. Safety is the condition of being protected against social, spiritual, physical, financial, political, emotional, psychological, occupational, educational or any other consequences of failure, damage, accidents, harm error, or any other event considered non-desirable. Safety is also control of recognized hazards to attain an acceptable level of risk. To be safe, professionals should plan well to cope with possible hazards. Coping with hazards involves recognizing, evaluating, and control hazards. Air pollution management need not be at the cost of health and safety of people who control them. This chapter elaborates major air pollution issues due to earthquake, tsunami, volcanic eruption, epidemics, extreme temperature, insect infestation, mass movement, wars, and fire accidents.

All human activities bear some risk of injury to people and so as air pollution and its management. People who erect, operate, inspect, and monitor are exposed to air pollutants. Apart from those who are involved in air pollution management business, other citizens are also exposed to injury due to unsafe practice.

Safety is the condition of being protected against social, spiritual, physical, financial, political, emotional, psychological, occupational, educational or any other consequences of failure, damage, accidents, harm error, or any other event considered non-desirable. Safety is also control of recognized hazards to attain an acceptable level of risk.

To be safe, professionals should plan well to cope with possible hazards. Coping with hazards involves recognizing, evaluating, and control hazards. Air pollution management need not be at the cost of health and safety of people who control them.

Safety is affected by internal as well as external influences. Internal influence that affect safety include: finance, production target, trade unions, organisational goals and culture. External influences on Safety include enforcement agencies, insurance companies, contracts/contractors/clients/trade unions, public opinion,

R. Chandrappa and U. Chandra Kulshrestha, *Sustainable Air Pollution Management*, Environmental Science and Engineering,
DOI 10.1007/978-3-319-21596-9_9

legislation, and courts/tribunals. At very basic level people in an organisation come to work for money. Apart from earning money there will be other shared interest. Further people will also have interest and goals which are not common that could lead to conflict. Every organisation will have informal structure and arrangement based on—how they behave towards each other and how they react to management instructions. The instructions from the top management are adjusted in accordance with personal relationships to achieve goals. This makes the distinction between formal and informal setup which is blurred at the edges between them.

Organisational chart cannot identify all the interactions and quality of relationships determines how communications flow within an organisation. Figure 9.1 shows informal structure. Formal organisation structure is represented by organisation structure of an organisation. Informal relation is represented by group behaviour. An awareness of this informal relationship is essential breakdown resistance to new measures including safety issues.

The safety of plant personnel involved in operation and maintenance of air pollution control equipment is important and areas of concern include confined area entry, electrical shock hazard, chemical burns, injury, etc. With proper planning, established procedures, and safety equipment, personnel can be protected without risk of injury.

Safety issues in air pollution management include

1. Unsafe air pollution equipment installation;
2. Unsafe operation;

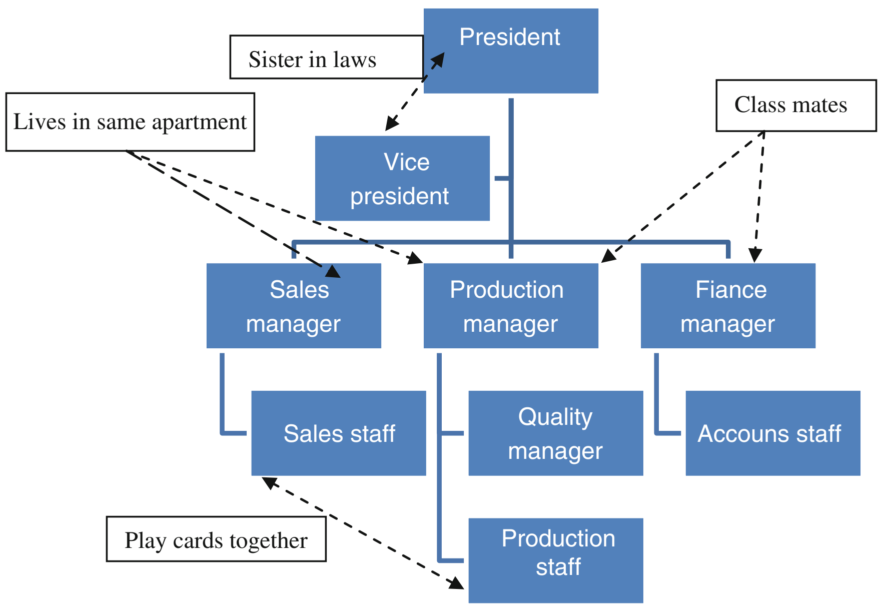

Fig. 9.1 Formal structure and informal relationship within an organisation

3. Unsafe maintenance;
4. Unsafe monitoring; and
5. Road hazards due to air pollution.

Hazard can happen to people working in industry or a common citizen not responsible for air pollution or its control. The Bhopal gas tragedy is one such episode which is already discussed wherein unsafe act lead to death of hundreds of people. Visibility impairment due to air pollution while travelling can lead to road accidents.

In addition to the training as well as awareness proper work practices, controls and equipments can help reduce the number of accidents.

Safety could be normative, substantive, or perceived. Normative safety is achieved when a product/design meets appropriate standards and practices. Substantive or objective safety occurs when the real-world safety history is favorable, whether or not standards are met. Perceived or subjective safety refers to the comfort at the users' level. Traffic signals are perceived as safe, but in reality they can increase traffic crashes. Similarly air pollution control equipment though seems safe it could turn out be disastrous if not properly operated or maintained.

Hence in order to achieve safety the product should be designed in such a way that it will not lead to hazard. If it fails the designer should make arrangement to either (1) *divert pollution without harming people*; or (2) stop emission by stopping the production/activity.

In order to manage accidents facility should be prepared for the administration of first aid. The personnel at site should be trained in medical emergency procedures.

At the top of the hierarchy of hazard control (Fig. 9.2) is elimination and substitution (replace the hazard with a safer option). If elimination or substitution

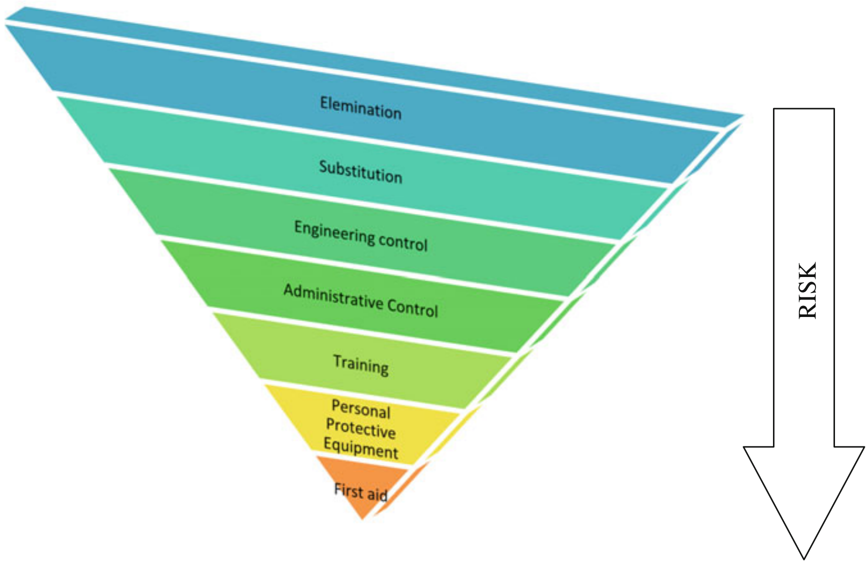

Fig. 9.2 Hierarchy of hazard control

cannot apply, engineering controls as well as administrative controls, that seeks to design safer mechanisms and train personnel. Personal Protective Equipment ranks last in the hierarchy of controls.

Frick and Wren (2000) distinguish three types of Occupational Health and Safety Management Systems (OHSMS)—voluntary, mandatory and hybrid. Voluntary systems are adopted without compulsion where as mandatory systems are followed due to enforcement. Hybrid methods involve a mixture of voluntary motives as well as legislative requirements. An effective OHSMS is requiring integration into workplace management systems. The need for such integrated systems has been supported by numerous authorities (Quinlan and Bohle 1991; Rahimi 1995).

The principles safety has been discussed by IAEA (2006) elaborately with respect radiation safety. But he principles can be used with respect to activity involving non radioactive also. The principles disused are:

Principle 1: Responsibility for safety

The main responsibility for safety must be vested with the person or organization responsible for facilities as well as activities that give rise to risks. Gone are the days where in individuals are responsible for their own safety. But modern laws insist that action be initiated against person who is responsible for day to day affairs within the organization. This ensures allocation funds, training, first aid, auditing, treatment and other responsibility associated to ensure safety of people and environment.

Principle 2: Role of government

An effective governmental is responsible for safety, including formation of an independent regulatory body to look after safety issue. A corrupt government would often fail to ensure safety of its citizens.

Principle 3: Leadership and management for safety

Effective leadership as well as management for safety should be established as well as sustained in organizations concerned with.

Principle 4: Justification of facilities and activities

Facilities as well as activities that give rise to risks must justify an overall benefit.

Principle 5: Optimization of protection

Protection must be optimized to offer the highest level of safety that can be achieved reasonably.

Principle 6: Limitation of risks to individuals

Measures for controlling risks should make sure that no individual tolerate an unacceptable risk of harm.

Principle 7: Protection of present and future generations

People and environment, present as well as future, must be protected against risks.

Principle 8: Prevention of accidents

All practical efforts should be made to prevent as well as mitigate accidents.

Principle 9: Emergency preparedness and response
Arrangements should be made for emergency preparedness as well as response for unsafe incidents. Most of the mega projects which is likely result in huge disaster should prepare disaster management plan with elaborate emergency preparedness and response. Such document will elaborate possible scenario that would lead to disaster and response plan including evacuation of people and seeking external aid. The document should have information about authority to be informed, contact details of hospital, disaster management authority, media, etc.

Principle 10: Protective actions to decrease existing or unregulated radiation risks
Protective actions to decrease existing or unregulated risks should be justified and optimized.

Not all the principles are applicable to the circumstances of air pollution. Action against forest department is not initiated due to air pollution arising due to wild fire. Accident due to injury to eyes because of air pollution from vehicles would not lead to action on all the vehicles moving in particular road.

In addition to the training as well as awareness, general safety principles like proper work practices, equipments, as well as controls can help bring down accidents in work place. The concerned persons at work place should understand the hazards associated with the work and know how to reduce the risk associated.

9.1 Health, Safety and Sustainability

Sustainability of air pollution management cannot be isolated with health and safety issued. Air pollution control equipments can be exploded in industries that handle combustible dusts due to inadequate safeguard measures. Since the powder in dry dust collectors is the finest and dry, it enhances ignition sensitivity as well as explosion severity of the dust.

Electricity, impact, friction, sparks and accumulation of thermally unstable powders can induce ignition over time. Transfer of smoldering or burning material into air pollution control equipment can also ignite the dust in the dust collector. Further sparks/hot surfaces within air pollution equipment can also induce ignition.

The explosion in an unprotected dust collector can lead to destruction of the vessel as well as generation of a pressure wave, fireball, as well as flying fragments.

To overcome ignition hazards some of the solution in practice is: (1) inert gas blanketing, (2) use of explosion resistant equipment, (3) use explosion pressure relief venting, (4) explosion suppression by injection of a suppressant to quench the flame.

Many incomputable chemicals react violently when mixed intentionally/accidentally. Some major incompatible chemicals are: (1) ammonia with hypochlorite bleach, (2) nitric acid with sulphuric acid, (3) n-butyl amine with copper as well as copper alloys, (4) ethyl acetate with strong alkalies, (5) ethylene glycol with sulphuric acid, (6) nitric acid with acetic acid, (7) 1-butanol with strong mineral acids, and (8) ethylene dichloride with oxidizing materials.

The impact of nuclear accidents has been concern since the first nuclear reactor was constructed in 1954. All nuclear accidents have resulted in Air pollution resulting loss of life.

Safety in olden days was considered as individual's responsibility which is still practiced in many developing countries. In the wrong concept the employer has no responsibility for safety of the employee and the employee or person affected during performing a task is expected to take precautions on his own.

But as the time changed the concept of safety and responsibility of employer has changed. The prime responsibility for safety lies with organization and top management responsible for facilities. Government shall take responsibility framework for safety, and it shall be responsibility of government to establish independent regulatory body to safeguard safety of employees and citizens. The organization and top management shall take all precautions to prevent and mitigate accidents.

Personnel in industries should have sound health in order to protect themselves during emergency and act during emergencies. Poor health status of employees in disastrous industry or activity would affect them as well other. Hence it is essential that all personnel are subject to preemployment health checkup including to their sensitivity to allergy.

Analysis of the effectiveness of OHSMS needs reliable measures of system. James (1993) noted considerable margin for error in the method of claims reporting as well as acceptance. Quinlan and Bohle (1991) observed the omission of short-term injuries/illnesses as well as particular work-related illnesses from claims statistics. Some organizations exclude self-employed, subcontractors, from reporting procedure. Studies by Division of Workplace Health and Safety (1994) revealed alarming levels of under-reporting.

Co-operation and communication play key role maintaining positive health and safety. Hence consultation of employee plays major role in developing co-operation and communication. The benefits of consultation are:

- Better employer—employee relation
- Increase in confidence among Employee
- Creates good safety culture.

Behaviour of employees affects individual and organisational safety. Organisational factors that influence behavior are:

- Managers and supervisors
- Work Colleagues
- Training
- Job Design
- Work equipment.

Indicators of safety culture within an organization include:

- Wearing o PPE
- Quality of risk assessment
- House keeping
- The presence of warning notices in the work place
- Staff relationships
- Accident and occupational health statistics
- Statement made by employees.

9.2 Safety Issues During Fabrication and Erection of Air Pollution Equipment

All air pollution equipments are fabricated using basic materials. Safety while manufacturing is achieved by best manufacturing practices within the manufacturing facility. Larger equipment like Electrostatic precipitator needs control during fabrication at manufacturing facility as well as during erecting at place where air pollution has to be achieved.

Chimneys can be as high as 500 m in case of power plants. Construction of such tall structures should consider safe construction practices which include use of nets and scaffolding.

Erecting tall steel chimney needs services of skilled people and special equipments. Further the chimney need to be designed to withstand wind, snow, humidity and rain. Tall metal chimneys are conveniently fabricated and shifted to site and erected using crane (Fig. 9.3).

Some times the chimney is held in position by guy-wires (tensioned cable used to add stability to free-standing structure) or steel structure (Fig. 9.4).

Not all tasks are carried out by employees of organization. Some special tasks are out sources to outside contractors. The contractor at work place shall implement Behavior Based Safety (BBS) programme which include: (a) conducting a Safety Culture Survey, (b) training of management staff, workers, site supervisory staff, as well as the appointed observers, (c) assigning observers to carry out observations of safe as well as unsafe behaviors.

It is normal practice to deploy one observer to 50 workers. Each Observer shall conduct 20 min observations at least twice a week.

Working on chimney (for maintenance or air pollution monitoring) needs special safety precaution that includes wearing PPE.

Fig. 9.3 Erecting chimney using crane

Fig. 9.4 Tall structures and pipes demands special safety precaution

9.3 Safety Issues During Operation

Operation of air pollution equipment requires considerable safety precautions especially with respect to ESP which require high voltage of operation.

Many injuries can result because of improper storing as well as handling of materials. Bending, twisting, turning, tumbling of improperly stacked materials, falling objects, are the more common cause injuries at work place. Workers at work place should know following:

- Bruises and fractures caused while handling waste;
- Strains/sprains by carrying objects that are too large/heavy; and
- Cuts and bruises due to falling of improperly stored objects.

All air pollution control system must be operated and maintained as per the manufacturer's recommendations. Operator of these equipments must be properly trained to perform their duty with confidence and efficiency.

Electrical shock is the furthermost concern in the operation of an ESP. Similarly exposure to scrubbing fluid is of concern in case of operation and maintenance of scrubbers.

All section of the electrical system exterior of the ESP shell must be isolated or insulated or from potential contact. Every access points to the electrical distribution system in air pollution control equipment should be closed as well as bolted or key-interlocked to avoid inadvertent access to the system.

A clear, legible sign should be clearly displayed to each component indicating the nature of the hazard.

But there are exceptions in small scale installation where in air pollution control equipment is not interlocked. Interlocking is done invariably to ESP for to safe guard personnel. Key interlocks are used to make sure that the precipitator has been deenergized before personnel enter the precipitator or electrical distribution system. To prevent shock to personnel, the ground strap in ESPs should be linked to the plate system as well as discharge electrode system.

Ground straps of air pollution control equipments should be checked routinely to ensure their continuity and safety. If exposed to weather, insulation of handles can deteriorate and can become conductive. Precautions should be taken to use such handles.

To prevent the closure of the air pollution control equipment with personnel inside, central operation should be notified before anyone enters the equipment. Tags should be placed on the main breaker, switches, and entry door informing men are working inside. Entry should not be made alone without proper tagging of the access door and proper notification.

Air pollution control equipment may contain toxic substance which may pose adverse health effect to personnel through inhalation, ingestion, or skin contact. Hence Personal Protective Equipment (PPE) must be made before anyone is allowed to enter the equipment.

Each facility must have a confined-space entry policy to safeguard personnel who are entering confined space in air pollution control equipments.

Improper startup and shutdown can lead to damage of the equipment and injure health of the personnel.

Startup of an ESP involves heating components such as hoppers and support insulators. The internal arcing of the ESP can lead to fire or an explosion. When ESPs are used to control pollution from oil-burning boilers, the boiler should be started with #2 fuel oil or gas. Heavy oil (#6 fuel oil) emits tarry particulate emissions that coats collection plates which is difficult to remove. When an ESP is used in a coal-fired boiler, it should not be started till coal firing can be verified in order to prevent accumulation of combustible gases leading to explosive conditions.

During temporary shutdown of industrial process, the ESP system should be de-energized to save energy.

De-energizing the ESP fields should be done starting with the inlet field to maintain proper opacity levels from the stack. All hoppers should be emptied before bringing the ESP back on line.

ESP units are usually entered twice annually during maintenance. The units are cleaned, inspected and repairs are made. Particulate matter collected in ESP contains significant concentrations of heavy metals which need to be handled with precaution using PPE.

PPE refers to protective equipments designed to protect the wearer's body from hazards. PPE itself is not the solution to the entire safety problem. It is only final barrier against hazard.

Respirators serve to protect the respiratory track of user from contaminants in the air. Proper clothing to cover entire skin acts as PPE. Gloves are an essential PPE in providing skin protection as lot of work is done by hands. Gloves include cut-resistant gloves, chainsaw gloves, rubber gloves, and heat-resistant gloves.

Eye injuries occur when solid particles or irritant gas enter eyes. Goggles and face shield are used to protect eye from injury. Earplugs and earmuffs are used to protect ear.

Some of the commonly used PPEs are

- Aluminized gloves
- Aprons
- Barrier creams
- Belts and climbing hooks
- Boots
- Bump caps
- Chemical resistant gloves/aprons/clothing
- Coats
- Cold weather gloves
- Dust mask/respirators
- Ear muffs
- Ear plugs
- Encapsulating chemical protective suits

- Face shields
- Fall protection
- Fire proximity suits
- Gloves
- Goggles
- Hard hat
- Hearing protection
- Helmet
- Lab coats
- Ladder safety device belts
- Laser safety goggles
- Lineman's boots
- Logging boots
- Long pants
- Long sleeve shirts
- Mesh cut proof gloves, mesh or leather aprons
- Metatarsal foot protection
- Ordinary rain gear
- Parkas
- Personal flotation devices (life jackets)
- Prescription eyewear inserts/lenses for full face respirators
- Prescription eyewear inserts/lenses for welding and diving helmets
- Reflective work vests
- Respiratory protection
- Rubber boots with steel toes
- Rubber insulating gloves
- Rubber sleeves
- Shoe covers
- Steel-toe shoes/boots
- Sturdy work shoes
- Sunglasses/sunscreen
- Window cleaners' safety straps
- Winter boots

Some important safety precautions while working with air pollution equipments are:

1. Ensure all air pollution control equipments are leak proof.
2. In case of ESPs Double-check that field wiring between controls as well as devices prior to startup is correct, complete, and labeled properly (Bibbo 1982).
3. Never touch exposed internal parts of control system.
4. Provide proper cover to all rotating equipment like, blowers, fans and pumps to avoid hazards.
5. Make sure access to air pollution control equipment are clear, clean and not slippery.

6. Ensure that personnel are out of the air pollution control equipment, flues, or controls prior to start up.
7. Never bypass/tamper the safety key interlock system.
8. The ESP can hold a high static charge (up to 15 kV) after it is de-energized. Use grounding chains whenever entering the ESP, Transformer-Rectifier switch enclosure, or bus ducts.
9. Do not open a hopper door unless the level of dust positively below the door. Hot dust can flow and severely burn/kill a person below the door.
10. Wear protective clothing while working with air pollution control equipment.
11. Check the metal temperatures prior to touching.
12. Ozone is created when discharge electrodes are energized. Hence wear an air-line mask while entering the precipitator, flues/stack when ozone may be present.
13. Do not poke hoppers with an un-insulated metal bar (Bibbo 1982).

Fire/Explosion

As discussed before a fuel and oxygen must exist in certain proportions with an ignition source for fire/explosion to occur. The ratio of fuel and oxygen required varies with each combustible gas/vapor. Below LEL, the mixture is too “lean” to burn and above UEL, the mixture is too “rich” to burn. The range between the LEL and UEL is called as the flammable range. Risk of fire or explosion exists in many ESPs, mainly because CO concentration can reach the critical level in cement plants, waste incinerators, boilers when burning procedure is not appropriate. Hence ESPs are provided with self shutdown mechanism as so as CO concentration exceeds safe limits (LEL for CO: 12.5 % v/v and UEL for CO: 74.0 % v/v).

1. Boiler malfunction could result in entry of carbon and/or volatile gases in ESP. In such scenario shut down all transformer-rectifier sets.
2. *Do not open ESP access doors until the ESP has cooled below 52 °C (125 °F) as* inrush of air may cause spontaneous combustion.

Typically fire is classified into five types:

- Class A: Fires due to burning of solids other than combustible metals.
- Class B: Fires involving combustible or flammable liquids.
- Class C: Fires involving energized electrical equipment.
- Class D: Fires involving combustible metals.
- Class K: Kitchen fires.

Fire is put out by Passive Fire Protection (PFP) or Active Fire Protection (AFP). PFP is achieved by compartmentalization and AFP is achieved by fire extinguishers.

The major types of fire extinguishers are:

- **Water extinguishers**: Water is suitable for extinguishing class A fires. It is not suitable for class B, C and D fires.
- **Carbon dioxide extinguishers**: Carbon dioxide are used for class B and C fires.

- **Dry chemical extinguishers**: These are suitable for either class BC or class ABC fires. They leave a layer of non-flammable substance on the extinguished substance. ‘Class BC’ fire extinguishers comprises of potassium or sodium bicarbonate. ‘Class ABC’ fire extinguishers comprises of ammonium phosphate.
- **Sand/metal/metallic salt extinguishers**: These extinguishers are used for class D fires. The major chemicals used in this types of extinguishers are Sodium chloride magnesium, sodium potassium, uranium, powdered aluminium, and powdered copper metal.
- **Graphite based powders**: Used for lithium fires.
- **Sodium bicarbonate based dry agents**: These are suitable for fires with most metal alkyls and pyrophoric liquids that ignite on contact with air.
- **Sodium carbonate based dry powders**: These are suitable for generally for Class D fires.
- **Halotron I extinguishers**: Used for fire accidents involving telecommunications equipment, computer rooms, and electronics.
- **Water mist extinguishers**: Used for Class A fires where a possible Class C hazard exists.
- **Non-magnetic fire extinguishers**: These are suitable for Magnetic Resonance Imaging (MRI) and Nuclear Magnetic Resonance Spectrometers (NMRS) machines.

Housekeeping is essential and integral part of safety in all work places including air pollution management. Poor house keeping practice is shown in Figs. 9.5, 9.6 and 9.7. Good example for house keeping is shown in Fig. 9.8. Further it is also essential that personal protective equipment should be made mandatory while working with air pollution control equipment as many of the gas and dust may harm eye, lungs, skin and ultimately get into blood stream or digestive system thereby reaching all parts of body.

Typical manufacturing, mining as well as material handling may be quite toxic. Dust suppression is achieved by spraying liquid. Special chemicals capable of reducing surface tension are added to water so that the liquid coating is spread over a greater surface area. The dust would then attached to the pieces there by suppressing dust generation.

The contaminant in shop floor is contained by putting hoods or enclosures around the dust generating machines. The hood is then ventilated and cleaned by a dust collector.

Particles of ten settle in horizontal duct. Hence horizontal duct runs will be provided with cleanout doors at frequent intervals.

The flammable dusts need more attention as they may cause hazard in dust collectors. Sparks may be transported in the ducts casing substantial damage to property and people. To guard against such incidents an in-line spark suppressor along with a duct cleaner—booster need to be installed. These suppressor devices will cool the spark below the ignition temperature.

There are instances where the rotary feeders located at the bottom of a collection hopper fails and dust builds up in the hopper which may ignite and burn. Shutting

Fig. 9.5 Haphazardly distributed material near air pollution control equipment

down the section of the collector to allow it to burn depriving it from getting oxygen will extinguish the fire. Spraying in water can lead to explosion as the water displaces the dust with steam.

Confined Space

A confined space is a place which is considerably enclosed, and where serious injury can occur due to hazardous substances/conditions within the space/nearby.

Confined spaces with respect to air pollution control comprise of chimney and air pollution control equipments. The authorised manager for such confined space shall issue a confined space entry permit into for work in the confined space after confirming: (a) the level of oxygen is in the range of 19.5–23.5 % by volume; (b) the flammable gas or vapour is less than 10 % of its lower explosive limit; (c) the toxic substances in the confined space do not exceed the permissible exposure; (d) the confined space is sufficiently ventilated; (e) steps have been taken to prevent ingress of dangerous gases/vapours; and (f) precautions have been taken to make sure safety and health of persons entering the confined space.

Work permit system

Work permit system is a system within an organization that provides identification, control as well as review of hazards within work environment. Eg.: (1) entry to a

Fig. 9.6 Slippery floor near air pollution control equipment

confined space, (3) working at heights, (2) work in or around confined spaces, (4) excavation, and (5) hot work.

The advantages of using permit to work system are: (1) ensures appropriate people are authorised, (2) provides clearness about the hazard, (3) specifies the safety measures, (4) ensures the supervisor in direct charge of the facility about the work under progress, (5) provides a system of uninterrupted control, and (6) provides formal handover as well as hand back procedure.

Before issuing a work permit, the issuer/recipient should consider all possible hazards. The work permit should also mention the precautions, like: (1) isolation, (2) working in confined spaces, (3) hot work, (4) decontamination, (5) working at heights, (6) excavation as well as building work, (8) PPE, (7) work on high voltage equipment, (9) provision to notify relevant persons when work starts/ends, and (10) any other special precautions.

Safety education and training

Organizations where air pollution equipment are installed are responsible for ensuring training personnel. In addition to general Environment, Health and Safety (EHS) training, all employees, should receive job-specific training regarding the following topics:

Fig. 9.7 Poorly managed storage tanks

Fig. 9.8 Good example of housekeeping

- Location as well as content of the safety manual;
- Physical, biological, chemical, laser as well as radiation hazards in the work area;
- Location of references describing hazards as well as safety of chemicals handling;
- Protective measures employees should take in order to avoid exposure or injury;
- Procedures for responding to emergencies;
- Procedures for obtaining medical care in case of exposure/injury;
- Proper waste management as well as disposal procedures; and
- Proper record keeping.

Departments as well as supervisors should maintain safety training records for all employees.

First aid
In order to manage accidents it is necessary that the facilities should be prepared for the administration of first aid for people working near air pollution control equipment. First aid is care given for sudden illness/injury before medical treatment. The first-aid provider must be trained in medical emergency procedures. The usual work related injury/illness include exposure to chemicals, electric current, fire, fall from height and physical injury during handling material.

Safety auditing
Safety auditing is nothing but auditing of safety performance. It is done in construction site, industries, hospitals, laboratories etc., to identify noncompliance's to safety regulation and risks. The safety auditing is done by members of organizations as well as outside agency. The outcome of auditing is used for improving the existing system by taking corrective action.

The auditing of air pollution equipment is usually performed while auditing entire plant. The auditors prepares a check and verifies records/equipment during the plants. The auditor may also questions the personnel involved in day to day activity to know any lacunas in the system.

Accident reporting
Accident reporting is done to record the information pertaining to accident. Accident reporting is required for statutory purpose and taking corrective action. Report by manager concerned with safety issues prepares it for the purpose of documentation to take corrective action and fulfil legal obligation.

A typical accident report should have following information:

- Location of accident;
- Time and date of accident;
- Details of person at the location of accident;
- Duration of accident;
- Number of people injured during the accident;
- Details of personnel/injury;
- The disaster response activities carried out during accident;

- First aid provided;
- Details of hospital admitted and treatment;
- Quantum of loss in terms of amount, manpower, loss of income due to shut down activity;
- Chemical/equipment associated with accident;
- The personnel protective equipment used by personnel during the accident; and
- The maintenance details of equipment.

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Annexure I

Sample table for inventory of air pollutants

Sl. No.	Activity	Pollutants				
1 A	**POWER AND TRANSPORTATION**					
1 A 1	Power	PM	SO_x	NO_x	Pb	…
1 A 1 a	Public electricity and heat production					
1 A 1 b	Petroleum refining					
1 A 1 c	Manufacture of solid fuels and other energy industries					
1 A 2	Manufacturing industries and construction					
1 A 2 a	Iron and steel					
1 A 2 b	Non-ferrous metals					
1 A 2 c	Chemicals					
1 A 2 d	Pulp, paper and print					
1 A 2 e	Food processing, beverages and tobacco					
1 A 2 f	Saw mills					
1 A 2 h	Construction and demolition					
1 A 2 g	Other (please specify)					
1 A 3	Transportation					
1 A 3 a i	Aviation					
1 A 3 a i (i)	International Aviation (LTO)					
1 A 3 a i (ii)	International Aviation (Cruise)					
1 A 3 d i (i)	International Maritime Navigation					
1 A 3 d i (ii)	International inland waterways (Included in NEC totals only)					
1 A 3 b	Road transportation					
1 A 3 b i	Passenger cars					
1 A 3 b ii	Light duty vehicles					
1 A 3 b iii	Heavy duty vehicles					

(continued)

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DOI 10.1007/978-3-319-21596-9

(continued)

Sl. No.	Activity	Pollutants				
1 A 3 b iv	Mopeds and motorcycles					
1 A 3 b v	Gasoline evaporation					
1 A 3 b vi	Automobile tyre and brake wear					
1 A 3 b vii	Automobile road abrasion					
1 A 3 c	Railways					
1 A 3 d	Water transportation					
1 A 3 e	Other (please specify)					
1 A 3 e i	Pipeline compressors					
1 A 3 e ii	Other mobile sources and machinery					
1 A 4	Commercial institutional and residential					
1 A 4 a	Commercial/institutional					
1 A 4 b	Residential					
1 A 4 b i	Residential plants					
1 A 4 b ii	Household and gardening (mobile)					
1 A 4 c	Agriculture/forestry/fishing					
1 A 4 c i	Stationary					
1 A 4 c ii	Off-road vehicles and other machinery					
1A 4 c iii	National fishing					
1 A 5	Others					
1 A 5 a	Other, stationary (including military)					
1 A 5 b	Other, mobile (including military)					
1B1	Fugitive emissions from solid fuels					
1 B 1 a	Coal mining and handling					
1 B 1 b	Solid fuel transformation					
1 B 1 c	Charcoal, refuse derived fuels, wood					
1 B 1 d	Other (please specify)					
1 B 2	Oil and natural gas					
1 B 2 a	Oil					
1 B 2 a i	Exploration production, transport					
1 B 2 a iv	Refining/storage					
1 B 2 a v	Distribution of oil products					
1 B 2 a vi	Other					
1 B 2 b	Natural gas					
1 B 2 c	Venting and flaring					
2 A	**MINERAL PRODUCTS**					
2 A 1	Cement production					
2 A 2	Lime production					
2 A 3	Limestone and dolomite use					
2 A 4	Soda ash production and use					

(continued)

(continued)

Sl. No.	Activity	Pollutants				
2 A 5	Asphalt roofing					
2 A 6	Road paving with asphalt					
2 A 7	Stone crusher					
2 A 9	Brick manufacturing					
2 A 10	Other including non fuel mining and construction (please specify)					
2 B	**CHEMICAL INDUSTRY**					
2 B 1	Ammonia production					
2 B 2	Nitric acid production					
2 B 3	Adipic acid production					
2 B 4	Carbide production					
2 B 5	Other (please specify in a covering note)					
2 C	**METAL PRODUCTION**					
2 D	**OTHER PRODUCTION**					
2 D 1	Pulp and paper					
2 D 2	Food and drink					
2 D 3	Restaurants					
2 G	**OTHER (please specify)**					
3 A	**PAINT APPLICATION**					
3 B	**DEGREASING AND DRY CLEANING**					
3 C	**CHEMICAL PRODUCTS, MANUFACTURE AND PROCESSING**					
3 D	**OTHER INCLUDING PRODUCTS CONTAINING HMs and POPs (please specify)**					
4 B	**MANURE MANAGEMENT**					
4 B 1	Cattle					
4 B 1 a	Dairy					
4 B 1 b	Non-dairy					
4 B 2	Buffalo					
4 B 3	Sheep					
4 B 4	Goats					
4 B 5	Camels and llamas					
4 B 6	Horses					
4 B 7	Mules and asses					
4 B 8	Swine					
4 B 9	Poultry					
4 B 13	Other					

(continued)

(continued)

Sl. No.	Activity	Pollutants				
4 C	**RICE CULTIVATION**					
4 D	**DIRECT SOLID SOLUTIONS**					
4 F	**FIELD BURNING OF AGRICULTURAL WASTES**					
4 G	**OTHER**					
5 A	**FOREST AND GRASSLAND CONVERSION**					
6 A	**SOLID WASTE DISPOSAL ON LAND**					
6 B	**WASTE-WATER HANDLING**					
6 C	**WASTE INCINERATION (e)**					
6 D	**OTHER WASTE (f)**					
7	**OTHER**					
X	Volcanoes					
Y	Disasters (please specify)					

Glossary

Abrasiveness Material used for grinding, polishing

Absorbant Capable of absorbing a liquid/gas

Absorbate Material capable of being absorbed

Absorption The process by which one thing absorbed or absorbs another

Acid deposition Precipitation of acidic compounds from the atmosphere which include, rain, snow, and fog

Acid rain Precipitation of rain with low pH

Activated carbon Form of carbon processed to have minute, pores that enhances the surface area

Activation energy Initial energy required to initiate the chemical reaction

Acute exposure One/series of short-term exposures normally lasting less than 24 h

Acute health effect A health effect that occurs over comparatively short period of time

Add-on control device An air pollution control device such that reduces the pollution in exhaust gas

Adiabatic lapse rate Rate at which atmospheric temperature reduces with increase in altitude

Adiabatic process A process during which no heat is transferred between initial and final states

Adsorbate Molecules adsorbing to adsorbent

Adsorbent Material used to adsorb chemical

Adsorber Equipments that adsorbs chemicals

Adsorption Adhesion of atoms/ions/molecules from a liquid/gas, or dissolved solid to a surface

R. Chandrappa and U. Chandra Kulshrestha, *Sustainable Air Pollution Management*, Environmental Science and Engineering,
DOI 10.1007/978-3-319-21596-9

Advection Advection is a transport mechanism of a conserved property (such as heat/cold) or substance by a fluid due to the fluid's bulk motion

Adverse health effect A health effect from exposure to air contaminants that may range from relatively mild temporary conditions such as eye or throat irritation, shortness of breath, or headaches to permanent and serious conditions, such as birth defects, cancer or damage to lungs, nerves, liver, heart, or other organs

Aerosol Fine solid particles or liquid droplets, in gas

Afterburner An air pollution control equipment that removes undesirable organic gases by incineration from polluted air stream

Agglomeration The act or process of congregation into a mass

Agglutination clumping of particles

Agricultural burning The intentional use of fire for management of crops

Air basin A land area with normally similar meteorological/geographic conditions throughout

Air monitoring Sampling and measuring of pollutants in the atmosphere

Air pollutant Substance in the air that can have undesirable effects on humans/ecosystem

Air pollution Harmful substance in the atmosphere that is detrimental to health of living beings and environment

Air quality index (AQI) It is a number indicating the air quality at a specific time in a specific area

Air quality A measure of the air pollution in the atmosphere

Air shed A subset of air basin—area that shares the same air because of meteorology, topography, and climate

Air toxics Harmful chemical or group of chemicals present in the air

Albedo It is the portion of solar radiation reflected by a surface/object

Algae Simple plants without distinguishable tissues

Algal blooms Sudden spurts of algal growth

Alkali rain Precipitation with high pH

Allergen Substance that causes an allergic reaction due to individual's sensitivity to the substance

Alumina Aluminum trioxide

Ambient air quality Quality of outdoor air in the environment

Anthropogenic source of air pollutants Pollutants originated due to activities of people

Atmosphere Layers of gases surrounding a celestial body

Bag filter Air pollution equipment which uses bags made up of fabric

Bauxite Aluminum ore

Biofilter Filter with biomass attached on the filter-media

Biofuels Liquid fuels made from biomass

Biogas Biogas means a gas produced by the anaerobic digestion or fermentation of organic matter

Bioreactors Manufactured/engineered device or system that supports a biologically active environment

Blasting Strong air injection in smelting furnaces

Bleedthrough Dust penetration through fabric filters

Blinding (in the context of bag filter) The flow constraint that occurs in fabric filter bags when dust becomes stuck in the bag startup or overcleaning

Blowpipe Pipe used in a Pulse Jet bag-house to directs air jets into the tops of the baghouse

Burners A device that burns a fluid fuel into a flame in a controlled manner

Cage (in the context of bag house) A wire structure used for supporting fabric filter

Calorific value of fuel The quantity of heat liberated in Kilocalorie/Kilojoules by the complete combustion of 1 kg of fuel

Calcination Heating to high temperatures

Calcine Product of calcinations

Cancer Growth of abnormal cells in a body

Car sharing Initiative to reduce use of car by individuals by sharing a car who will travel in to same or nearby destination

Carbon dioxide (CO_2) A colorless, odorless gas

Carbon monoxide (CO) A odourless, colorless gas resulting from the incomplete burning of hydrocarbon fuels

Carcinogenesis The production of cancer

Carpooling Same as car sharing

Catalyst Chemical substance which influence the rate of chemical reaction by decreasing its activation energy

Cell plate (tubesheet) Plate on which fabric filter bags are seated and separates polluted air from clean gas plenums

Cetane number Capacity of the fuel to ignite instinctively in the combustion chamber

Chemisorption Adsorption due to chemical interaction between the molecule

Chimney Structure which provides ventilation for polluted gas

Climate Climate is defined as the 'average weather'. As per World Meteorological Organization (WMO) the classical period of time is 30 years, as per

Chlorofluorocarbons (CFCs) Substances consisting of chlorine, fluorine, as well as carbon. CFCs are used for foam packaging, refrigeration, solvents, and propellants

Coal A type of solid fossil fuel mined from the earth

Coating A layer of any substance applied over a surface for protection

Cold wave Lengthy period of extremely cold weather over a large area

Combustion The act or instance of burning

Condensation The conversion of the water vapor in the air into liquid water on cool surfaces

Continuous emission monitor (CEM) Air emission monitoring system installed to operate continuously in a emission source

Converter Apparatus for metal production with oxide reduction

Cowl Covering used to increase the draft of a chimney as well as prevent backflow

Criteria air pollutant An air pollutant for which an ambient air quality standard has been set. Eg: ozone, CO, NO_x, SO_x, PM_{10} and $PM_{2.5}$

Cryogenics It is the study of the production as well as behaviour of materials at very low temperatures

Cryolite Aluminum containing mineral with molecular formula Na_3AlF_6

Cyclone separator A type of equipment used to separate particles from air-particle stream by centrifugal force

De novo synthesis Synthesis of complex molecules from simple molecules

Dedusting To remove excessively fine particles

Developed country A nation that has high levels of economic activity, education, and health care

Developing world Nations with low per-capita income, a small middle class, and little infrastructure

Dewpoint The threshold temperature at which condensables start to change to a liquid state

Diffusion flames Flames arising when fuel burns freely in ambient air, without premixing

Disaster Occurrence of an extreme hazard event causing significant disruption, damage, and casualties

Dispersion (in the context of air pollution) Spreading of air pollutants in the atmosphere

Drought Phenomenon that occur when precipitation is considerably below normal levels

Dustcake filter drag The resistance to flow caused due to accumulation of dust on the bags

Earthquake Earthquake is shaking of ground due to seismic waves

Ekman layer It is the layer in a fluid where force balance between pressure gradient force, turbulent drag and coriolis force are balanced

Electro static precipitator Air pollution control equipment which uses electrostatic force to remove particulate matter

Emission factors Quantity of pollutant emitted per unit of production, or per input unit (raw material), or per kilometer driven, or per fuel unit

Emission standards Legal requirements with respect to air pollutants released into the atmosphere

Enteric fermentation Digestive process by which carbohydrates are converted into simple molecules by mircroorganism for absorption into the bloodstream of an animal

Environmental impact assessment (or environmental assessment) Assessment of impact due to proposed activity

Epidemics Rapid spread of infectious illness to a huge number of people in a given population within a short period

Exosphere It is the outermost region of the atmosphere located after 500 km altitude wherein gas molecules with enough energy can escape gravitation force of atmosphere

Fabric filter Air pollution equipment made up of fabric

Flame velocity (laminar burning velocity) It is the distinctive rate at which a flame advance into the unburned mixture of fuel as well as oxidizer. It depends on fuel type, pressure, air equivalence ratio, and initial temperature

Flash point It is the lowest temperature at which a substance can vaporize to form an ignitable mixture in air

Flood Significant increase of water level in a surface water body flow

Fluidized bed A two-phase flow pattern with a chaotic motion of the solid phase (solid particles)

Free atmosphere It is the layer above Ekman layer in which the effect of the surface friction on the air motion is negligible

Fuel Adulteration Blending cheap low grade material with good quality fuel

Gasohol Blend of ethanol with gasoline(petrol) in proportions up to 22 % which can be used for SI engines

Global warming Increase in the average global temperature

Green fuel Also called as biofuel. A biofuel is fuel whose energy is obtained by a process of biological carbon fixation

Green house effect is the rise in temperature of the Earth due to the existence of Green House Gases in atmosphere

Green liquor Dissolved smelt of sodium carbonate, sodium sulfide as well as other compounds from the recovery boiler in the kraft process

Green technology is the use of the environmental science/technology for the development as well as application of equipment, products and systems to preserve the natural resources and environment and to reduce the negative impacts on the environment

Greenhouse gas Gases capable of absorbing solar heat there by warming the atmosphere

Guy-wires Tensioned cable used to add stability to free-standing structure

Hazard is the threatening incident within an area and a given time period and

Haze Group of solid as well as liquid particles in the air that poses visual restriction

Hearth Stone-lined fireplace

Heat wave A heat wave is a prolonged period of excessively hot weather relative to normal climate patterns in a given region

Hopper baffle (in the context of bag house) Baffle located in the bag house hopper to distribute the air as well as dust flow into the bags

Impingement The act of particulate striking as well as attaching to fabric filter bags

Incinerator A furnace used to burn waste at very high temperatures

Inside collection The collection of particulate matter on the interior side of the bag of bag filter

Internal combustion engine Engine in which combustion of the fuel takes place in a confined space, generating expanding gases that are used to provide mechanical power

Interstices The open voids in the cloth of fabric filter where air passes through

Inversion Deviation from the usual change of an atmospheric property with altitude

Ionosphere It is a region of the atmosphere between stratosphere and thermosphere where ions are produced by photo ionization

Jet baghouse Baghouse wherein jet of air is used for cleaning accumulated dust

Kyoto protocol An international agreement to reduce greenhouse gas emissions

Laminar sublayer It is also called the viscous sublayer, is the region in which the flow is laminar. With respect atmosphere it is usually less a centimetre

Lifecycle The duration of time a bag is in service

Manometer A liquid filled "U"-shaped gauge used to measure differential pressure

Matte An intermediate product of pyrometallurgy, containing metal and its oxide

Mesosphere It is the layer above stratosphere which extends up to 80–90 km where temperature decreases with altitude

Mixing depth Vertical distance from ground to the altitude up to which pollutants are mixed by turbulence due to vertical shear or convective currents in the horizontal wind

Mixing height is the height to which the lower atmosphere will be nearly homogeneous air mass due to mechanical or turbulent mixing

Montreal protocol This is a protocol on production as well as consumption of chlorine as well as bromine-containing chemicals that destroy stratospheric ozone. This protocol was adopted in Montreal in 1987, and amended in London (1990), Copenhagen (1992), Vienna (1995), Montreal (1997) and Beijing (1999)

Mullen burst test An rupture test for determining the strength of filter bag material

Natech (or natural-technologic or na-tech) event Incidents/accidents that lead to technological accidents due to natural disasters

Natural gas It is a type of fossil fuel comprising mostly methane

Null period Period during offline cleaning of bag filter, when filter bags are permitted to rest without any cleaning energy applied

Outside collection The collection of particulate matter on the exterior of filter surface

Particulate matter Solid/liquid (except pure water) substance with size larger than a molecule but less than microscopic/submicroscopic size (about 500 μ)

Passive sampling method based on the free flow of pollutant molecules from the sampled media to a receiving phase

Perturbation Mathematical approximation for solutions to problems which cannot be solved exactly

Plenum The baghouse housing area above/below the tubesheet

Polycyclic organic matter It is class of compounds that includes the polycyclic aromatic hydrocarbons, of which benzo[a]pyrene is a member

Poppet valve An efficient sealing valve on the outlet side of a baghouse to separate the gas

Premixed flames Flames arising during fast, instantaneous combustion of the premixed fuel/air-mix

Pressure drop (in the context of air pollution equipment) The resistance to flow across any air pollution equipment

Pulse duration The time a diaphragm valve is open for the period of the cleaning of a Pulse Jet baghouse

Pyrolysis Thermochemical decomposition of organic substance in the absence of oxygen at elevated temperatures

Radiation A form of energy transmitted in waves, rays or particles

Radioactive A material capable of emitting radiation

Radon A radioactive gas emitted from soils and rock

Reactivity the rate at which a chemical material tends to undergo a chemical reaction

Recycle To use waste components to re-make the original/new items

Reforestation The practice of planting trees in forest lands to replace trees that have been cut down

Respirable particulate matter Particles less than 10 microns diameter

Roasting High temperature oxidation of metal sulfides

Ruminants Mammal that digests food by softening in one of the four chambers and then regurgitating the semi-digested mass followed by chewing

Scarfing Process which removes surface defects prior to shaping/rolling

Scrubber Pollution control devices that use liquid/solid to remove unwanted pollutants from a gas stream. Devices that use liquid is called dry scrubber where as devices that use solid material is called dry scrubber

Sintering Process of forming a solid mass of material by heat/pressure without melting it

Solenoid valve An electromagnetic pilot valve used for activating a diaphragm valve on a Pulse

Solid waste Solid substance that does not have immediate use for a generator

Speiss The lightest fraction in lead smelting

Stoichiometric The quantitative relationship among constituents in a chemical substance

Stratosphere It is positioned on the stratosphere that extends from 45 to 55 km, wherein temperature increases with altitude and characterised by low vertical mixing

Subsidy Form of financial support extended with the aim of promoting economic/social policy

Surface failure (in the context of bag filter) Failure of bag filter

Surface layer It extends from ≤30 to 50 m. The heat and vertical turbulent fluxes in this layer are constant

Sustainable transport Transportation with acceptable level of social costs such as impact on environment quality, accident and traffic congestion

Temperature gradient It is a physical quantity that explain direction and rate of change of temperature in a particular location

Temperature inversion A thin layer of the atmosphere in which the normal decrease in temperature with height changes to the temperature rising with height

Thermosphere The region of the atmosphere where temperature raise continuously with altitude

Toxicity is the extent to which a matter can damage an organism

Troposphere Which is the lowermost layer of atmosphere extends from earth's atmosphere to 10–15 km altitude depending on time of the year and latitude.

Tsunami Series of water waves due to displacement of a large quantity of water in water body

Ultra-low nitrogen fuels Fuel with less nitrogen

Vehicle miles traveled The miles traveled by vehicles in a specified length of time

Visibility reducing particles Particles in the atmosphere that obstruct visibility

Venturi (in the context of pulse jet bagfilter) A cone-shaped device positioned in the top of a Pulse Jet bag to facilitate concentrate the high pressure cleaning air jet

Volatile Substance that evaporates readily

Volatile organic compound Organic chemicals with high vapor pressure at room temperature

Volcanic eruption Outbreak of volcano

Volcano It is a crack on the crust of a planetary mass which allows hot volcanic ash, lava, and gases to run off from below the surface of planet

Vortex Region within a fluid where the flow is spinning around some axis line

Wild fire Uncontrolled fire of combustible vegetation that occurs in a wilderness area

Zero emission vehicle Vehicles which do not generate air pollutants from the on-board source of power (e.g., electric vehicle)

Zoning atlas Atlas prepared for zoning different land use classes.

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DOI 10.1007/978-3-319-21596-9