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BP Process Safety Series

Hazards of Trapped Pressure and Vacuum

A collection of booklets describing hazards and how to manage them

Institution of Chemical Engineers

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Published by
Institution of Chemical Engineers (IChemE)
Davis Building
165–189 Railway Terrace
Rugby, CV21 3HQ, UK

IChemE is a Registered Charity in England and Wales and a charity registered in Scotland (SC 039661)
Offices in Rugby (UK), London (UK), Melbourne (Australia) and
Kuala Lumpar (Malaysia)

ISBN 978 0 85295 541 3

First edition 2003; Second edition 2005; Reprinted 2006; Third edition 2009

Typeset by Techset Composition Limited, Salisbury, UK
Printed by Henry Ling, Dorchester, UK

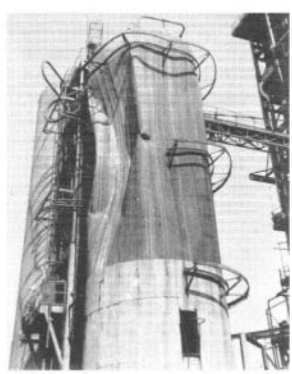
Contents

1

Introduction

Each and every day we come across pressure and vacuum. We come into contact with pressure and vacuum both at work on process plants and in life outside work. On the process plant, we see gauges which remind us that the equipment is being subjected to various degrees of pressure and vacuum. We use the words absolute pressure, gauge pressure and backpressure. We must understand what the basic phenomenon of pressure and vacuum is and how it must be considered during operations and maintenance of plant and equipment, to prevent the danger of trapped pressure or unexpected vacuum that could lead to an accident. This booklet is intended for those operators, engineers and technicians working on process plant so that they are aware of the possibility of trapped pressure or how vacuum could be unexpectedly generated, and can adopt safer designs and practices to avoid the occurrence of such incidents.

A storage tank damaged by trapped pressure.

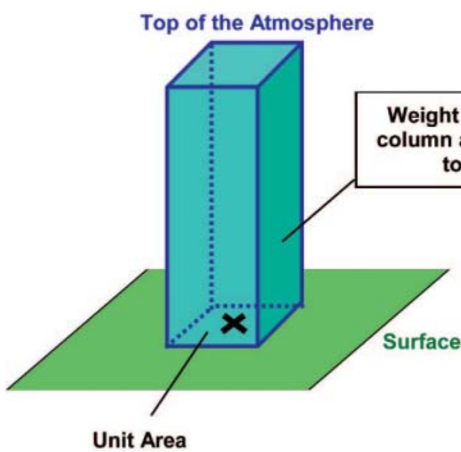


Too much vacuum ruined this catalyst storage drum.

These incidents are commonplace. But you can avoid them in your plant by knowing how to identify and eliminate trapped pressure and vacuum, through training and education, good engineering design or control and safe practices shared in this booklet.

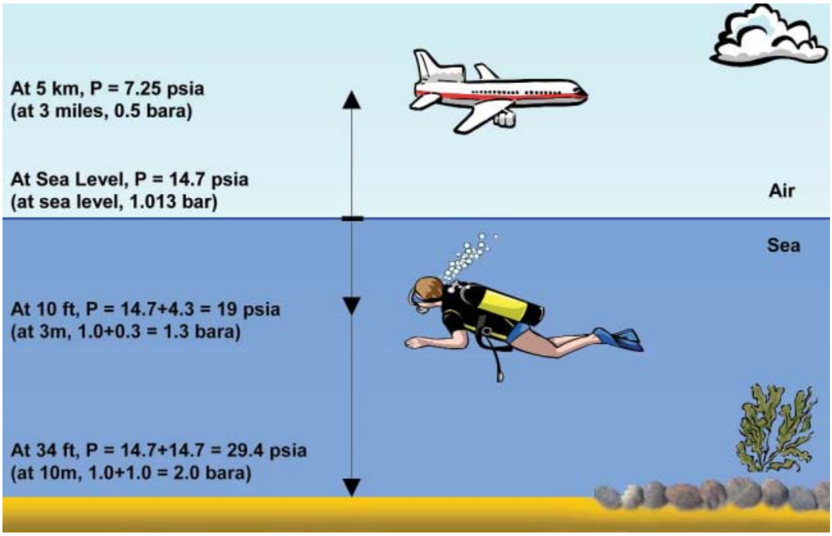
1.1 Theory of pressure and vacuum

Did you know that you are constantly pressurized by the air around and above you? The truth is that miles and miles of air molecules are stacked up on the earth exerting pressure due to the force of gravity. This is what we call 'atmospheric pressure'. Atmospheric pressure is defined as the force per unit area exerted against a surface by the weight of the air molecules above that surface. As an example, let us consider a 'unit area' to be one square inch. At sea level, on average, the weight of the air above this unit area would weigh 14.7 lb! Similarly, if we consider a 'unit area' to be one square centimetre, the weight of the air above this unit area would weigh 1.03 kg at sea level. Hence, we are constantly living our lives under pressure; and this pressure is equivalent to a height of 34 ft (10 m) of water!



As you climb a mountain, the atmospheric pressure decreases. This is because at higher elevations, there are fewer air molecules above a given surface than at lower levels. For example, there are fewer air molecules at a level 3 miles (5 km) above the earth than are found at sea level, which explains why the pressure is less at this high level. In outer space, there is a nearly complete vacuum so the pressure is zero.

So what happens then when you go below sea level and swim under water? Water molecules are much heavier than air molecules, so the pressure will be higher. Each foot (30 cm) of water creates water pressure of 0.43 psi (0.03 kg/cm^2). So if you swim 10 ft (3 m) beneath the water, the water pressure is 4.3 psi (0.30 kg/cm^2). Add to that the air pressure of 14.7 psi (1.03 kg/cm^2) above the water surface, and the total pressure at the bottom of the deep end of a swimming pool is 19 psi (1.33 kg/cm^2)!



While atmospheric pressure exists around us, it is usually harmless and does not cause discomfort. However, in the oil and chemical industries, liquids and gases are often pressurized to significant levels (for example, many times the atmospheric pressure) for various purposes. For instance, pumps are a common sight in our plants as they are frequently used to transfer liquids from one location to another, over a long distance or to a higher level. Compressors are used to accomplish the same purpose for gases.

Pressure is a source of energy and as such presents the potential to be a hazard. This safety booklet aims to present the hazards associated with trapped pressure and vacuum, and to recommend safeguards and safe work practices to overcome such hazards. Examples of typical accidents are used in this booklet to illustrate these hazards.

1.2 Definitions

Pressure is defined as the force exerted by an object per unit area. It can be presented in the following equations.

Pressure = Force/Area, $P = F/A$

Liquid Pressure = Depth (h) x Density (ρ), $P = h\rho$

Pressure = Force/Area

Liquid Pressure = Depth × Density

1.3 Different units of pressure

Pressure is measured in many different units. Needless to say, the confusion of units and their incorrect conversion has been the cause of some major incidents. Hence, it is very important to specify the correct measurement unit when dealing with pressure. The following table shows the units of pressure commonly used in the oil and chemical industries.

		kPa	psi	bar	kgf/cm^2	inch H_2O
1 kPa	=	1	0.1450	0.0100	0.0102	4.0146
1 psi	=	6.8948	1	0.0689	0.0703	27.6799
1 bar	=	100	14.5038	1	1.0197	401.4631
1 kgf/cm^2	=	98.0665	14.2233	0.9807	1	393.7008
1 inch H_2O	=	0.2491	0.0361	0.002491	0.00254	1

When expressing pressure as a height, say in inches (or feet, metres, etc.), it is also necessary to identify the type of liquid. There really is no such thing as an inch of pressure. Instead, it is inches of a particular liquid, generally water or mercury. Thus, one correct expression is '*inches of a water column*' (written as 'in. w.c.' or 'in. H_2O').

1 atm = 101.3 kPa
= 1.013 bar
= 14.7 psi
= 760 mm of mercury (30 in. of mercury)
= 10 m of water (34 ft of water)

Note: As mercury is much heavier than water, it takes less height of mercury than water for an equivalent pressure (760 mm of mercury versus 10,000 mm, or 10 m, of water).

1.4 Absolute pressure vs. gauge pressure

There are two main ways of expressing a pressure, 'gauge' or 'absolute', e.g.

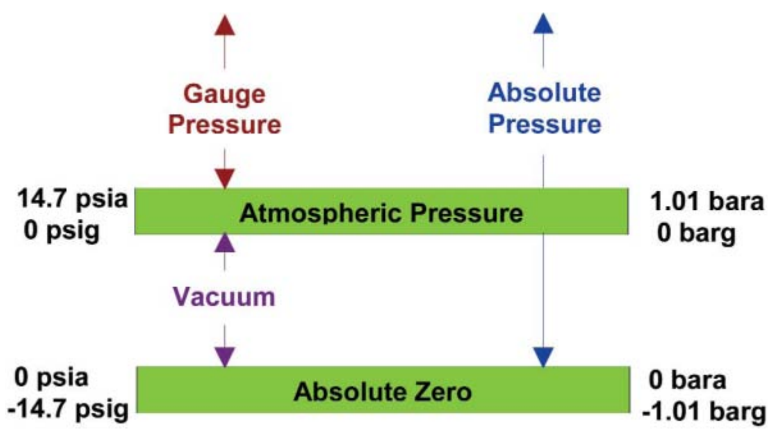
psia .... pounds per square inch absolute; bara …. bar absolute;
psig .... pounds per square inch gauge; barg …. bar gauge;

The relationship between the two is simple:

Absolute Pressure = Gauge Pressure + Atmospheric Pressure

e.g. psia = psig + atmospheric pressure
e.g. bara = barg + atmospheric pressure

Pressure can be expressed with respect to either of these two reference points—a perfect vacuum or atmospheric pressure. When a pressure is referenced to that of a perfect vacuum as zero pressure, it is called *absolute pressure.* When a pressure is referenced to that of the atmosphere as zero pressure, it is called *gauge pressure*. The relation between absolute and gauge pressure is illustrated in the following figure.



Absolute pressure uses a perfect vacuum as the zero point. We call pressures relative to zero pressure *absolute* pressure.

A pressure gauge

Gauge pressure uses the actual atmospheric pressure as the zero point and is so called because it is the pressure you normally read on a gauge. Pressures measured relative to atmospheric pressure are called *gauge* pressures. The pressure measured by the most common type of pressure measuring instrument is a gauge pressure since this instrument indicates the pressure relative to atmospheric pressure. A tyre gauge, for instance, measures the pressure in a tyre over and above the local atmospheric pressure.

A *vacuum* is any pressure lower than the ambient atmospheric pressure. The greatest vacuum possible, called a *perfect vacuum*, is zero absolute pressure (0 psia or –14.7 psig [0 bara or –1.01 barg]).

A vacuum is any pressure lower than the ambient atmospheric pressure.

1.5 The behaviour of gas

Ideal gas law

Gases have neither fixed volume nor shape. They are moulded entirely by the container in which they are held. The magnitude of gas pressure inside a confined vessel is affected by the temperature, the volume of the vessel and the quantity of gas in the tank. Their relationship is depicted by the Ideal Gas Law, which can be expressed in the following equation.

$$PV = nRT$$

Where
P = gas pressure
V = gas volume
n = moles of gas (or simply, the quantity of gas)
T = gas temperature
R = the universal gas law constant = 0.0821 litre-atm/(gmole.K)
= 8.314472 Pa.m^3/(gmole.K)
= 1.9859 Btu/(lbmole.°R)

Bringing V to the right side of the equation, we get

$$P = \frac{nRT}{V}$$

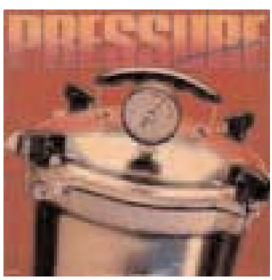
From this rearranged equation, it is clear to see that:

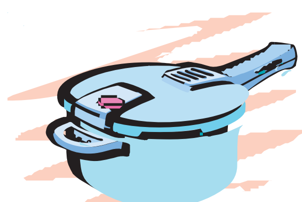
$P \propto n$: P is directly proportional to n, when T and V are constant.
$P \propto T$: P is directly proportional to T, when n and V are constant.
$P \propto 1/V$: P is inversely proportional to V, when n and T are constant.
(R is a constant number and it does not change under any condition)

This shows that there are three ways to increase the gas pressure within a vessel, container or system:

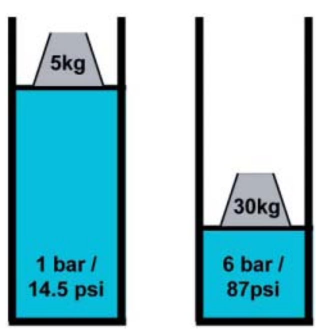
- *Put more gas in the container.* For example, pumping air into a car tyre. As you pump more air molecules into a fixed volume, the greater the pressure these molecules exert on the sides of the tyre.

- *Raise the temperature inside the container.* For example, a pressure cooker. As more heat is injected into the cooker, the liquid boils and generates more vapour. The vapour gets hotter and exerts a greater pressure on the sides of the cooker. Sometimes, the pressure increases due to a phase change, usually from liquid to vapour (boiling), such as in this case.





- *Reduce the volume of the container.* For example, a bicycle pump or piston pump. Packing a fixed amount of gas into a smaller container increases the number of collisions of gas molecules and the pressure they exert on the sides of the bicycle pump increases.



In the same way, there are three ways to decrease the gas pressure, and even create a vacuum, within a vessel or system:

- Reduce gas quantity.
- Reduce the temperature.
- Increase the volume.

Pascal's law

This law states that the pressure on a confined fluid is transmitted in all directions. For an enclosed vessel, the gas pressure inside the vessel is constant everywhere, provided there are no isolated pockets or blockages within the vessel.

When gas is under pressure, it exerts a given force against each unit of exposed area. For example, gas at a pressure of 10 psi pushes with a force of 10 pounds against each square inch of surface exposed to the gas.

If a pressure is small, does it mean that the force exerted by it is also small? No! It all depends on the *area* of contact. A good example of this can be illustrated by the next incident, where a large plug was ejected violently by low pressure nitrogen and killed a worker.

ACCIDENT

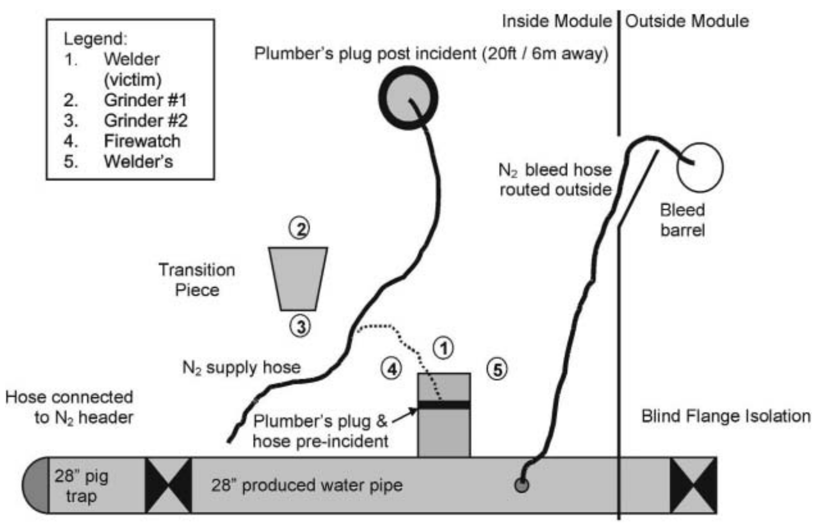
Small pressure generates big force behind plumber's plug!

A mechanical plug installed inside a pipe to isolate hot work from process fluids released suddenly, striking and killing the welder. The work in this incident involved a welding operation on a 28 inch (71 cm) water line that had residual water and hydrocarbons in it. A non-pressure containing mechanical plug (also known as 'plumber's plug') had been installed about 12 inch (30 cm) inside the pipe as a barrier against process fluids. The pipe area behind the plug was blinded at both ends, and was being purged with plant nitrogen to carry away potential hydrocarbon vapours. Nitrogen at 30 psig (2.07 barg) was introduced by a ¾ inch (2 cm) hose through a connection at the centre of the plug, and was being vented by a separate ¾ inch (2 cm) hose coming from the top of the pipe. The vent line ran out of the module through a door, to prevent the build-up of nitrogen in the atmosphere inside the module. The nitrogen absorbed residual water in the pipe and the water condensed and froze inside the nitrogen vent line when exposed to the cold temperatures outside, approximately 0ºF (–18ºC). The frozen water blocked the nitrogen vent line, causing pressure to build behind the 63 lb (29 kg) plug and blow it off.

A Job Safety Analysis (JSA) recognized the potential hazard of the purge line freezing. To mitigate the risk, the line was checked periodically for flow by placing a hand at the end of the vent hose, which proved to be inadequate. There was no pressure gauge, regulator, or secondary relief on the purge to allow pressure to be checked or to prevent pressure build-up.

Continued

When purging systems using such plugs, procedures should address the size of inlet and vent hoses, placement of vent hoses, use of regulators to control flow, use of secondary pressure relief to prevent overpressure, positioning of workers away from the plug, and work crew training and hazard awareness. Where possible, the best option is to design tie-ins so that isolation plugs between hot work and hydrocarbons are not needed. Alternatively, evaluate the use of better plug types, including double-sealing hydraulic plugs (Car-Ber type) and pressure-rated plugs (Thaxton) that have the potential to be used with or without purging.



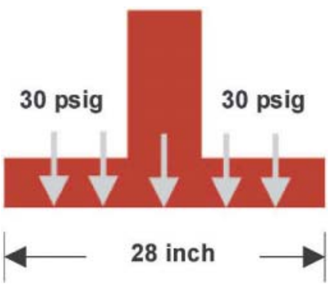
Module layout

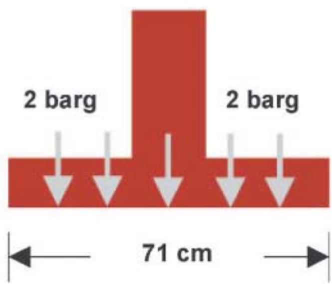
View of the 28 inch (71 cm) pipe

View of mechanical plug

1.6 Pressure-force relationship

Force is simply a push or a pull. It is measured in pounds (or kilograms), such as ‘x’ pounds (or kilograms) of pushing force or pulling force. Pressure is used to create a total force. The figure below shows the relationship between pressure, area and force, as illustrated in the previous incident. The diameter of the plug is 28 inch (71 cm) and thus the effective area of the plug is 616 in^2 (3,960 cm^2). Applying 30 psig (2.07 barg) of pressure to the area can generate a force of great magnitude





Surface Area = $\frac{\pi d^2}{4}$

$= \frac{3.14 \times (28)^2}{4}$

$= 616 \text{ in}^2$.

Force = Area × Pressure
= 616 in^2 × 30 psig
= 18,480 pounds!

Surface Area = $\frac{\pi d^2}{4}$

$= \frac{3.14 \times (71)^2}{4}$

$= 3960 \text{ cm}^2$.

2.07 barg = 2.11 kg/cm^2

Force = Area × Pressure
= 3,960 cm^2 × 2.11 kg/cm^2
= 8,356 kilograms!

Thus, it does not take much pressure (30 psig or 2 barg, for example) to develop a large total force (18,480 pounds or 8,356 kilograms)! It is a matter of the *area* that the *pressure* acts on.

1.7 Compressed air

[Abstracted from the book *What Went Wrong* by Trevor Kletz]

ACCIDENT Residual compressed air not vented!

Compressed air is often used to empty tank trucks and cars. Plastic pellets are one type of the load that is blown out of tank trucks. When the tank is empty the driver vents the tank and then looks through the manhole to check that the tank compartment is empty. One day a driver who was not regularly employed on this job started to open the manhole before releasing the residual pressure. When he had opened two out of five quick-release fastenings on the lid, the manhole blew open. The driver was blown off the tank top and killed.

Either the driver forgot to vent the tank or thought it would be safe to let the pressure (a gauge pressure of 10 psig or 0.7 barg) blow off through the manhole. After the accident the manhole covers were replaced by a different type in which two movements are needed to release the fastenings. The first movement allows the cover to be raised about ¼ inch (5 mm) while still capable of carrying the full pressure. If the pressure has not been blown off it is immediately apparent and the cover can be resealed or the pressure allowed to blow off. Such designs remove the possibility for human error.

In addition, the vent valve was repositioned at the foot of the ladder.

Many of those concerned were surprised that a pressure of ‘only 10 pounds’ could cause a man to be blown off the top of the tank. They forgot that 10 psi is not a small pressure. It is 10 pounds force on every square inch.

ACCIDENT Hazards of compressed air!

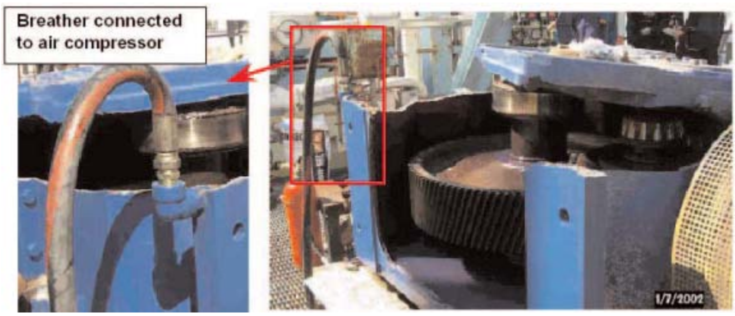
Many operators find it hard to grasp the power of compressed air. An incident took place where the end was blown off a pressure vessel, killing two men, because the *vent was choked*. Compressed air was being blown into the vessel to prove that the inlet line was clear. It was estimated that the gauge pressure reached 20 psig (1.3 barg) when the vessel burst. The operators found it hard to believe that a pressure of ‘only 20 pounds’ could do so much damage. Explosion experts had to be brought in to convince them that a chemical explosion had not occurred.

Unfortunately, operators often confuse a force (such as 20 pounds) with a pressure (such as 20 pounds per square inch) and forget to multiply the 20 pounds by the number of square inches on the end of the vessel.

Because we do not always appreciate the power of compressed air, it has sometimes been used to remove dust from work-benches or clothing. Consequently, dust and metal splinters have been blown into people's eyes or into cuts in the skin. Worse still, compressed air has been used in ‘horseplay’ and resulted in fatalities.

ACCIDENT **Emptying of a gear box!**

To speed up the removal of 250 litres of oil from a gear-box, the gauge hole was plugged and the breather was connected to the 6 barg (87 psig) air network. The gear box exploded and threw missiles around, seriously damaging surrounding piping and structure. Fortunately there was no injury.



1.8 Hydraulic and pneumatic systems

There are many ways that pressure is created, such as production from a gas or oil reservoir, gas compressor, liquid pump, etc. This energy can come from a naturally occurring phenomenon, such as oil under pressure in substrata formation, from expanding or evaporation of fluids by heat in a closed vessel, the weight of a water column, or from machines such as pumps and compressors.

Pressure is stored in liquids as well as gases but is very unlikely in solids, simply because most solids are not compressible. Pressure found in liquids is known as *hydraulic* pressure and in gases as *pneumatic* pressure.

Pressure and vacuum must be released to a safe level prior to the maintenance of process plant (for example, before breaking containment) and prior to opening vessels (for example, in the operation of pig launchers and receivers). Pressure and vacuum must never exceed the stipulated design limits for the plant or equipment and hazard analysis techniques must be used to verify this during the process design phase.

Many incidents presented in the following sections are examples of trapped pressure or unexpected vacuum that occurred in oil and chemical plants around the world. Sad to say that, unless we learn from these incidents and take necessary precautions, they will occur again.

Hydraulic pressure—Danger!
Pneumatic pressure—Danger!

Compressed air—Danger!
Compressed liquid—Danger!

1.9 Identification of trapped pressure and unexpected vacuum hazards

There are many operations in the oil and chemical plants that present the potential hazard of trapped pressure and unexpected vacuum. Below are some common operations that require special attention and actions to avoid the occurrence of pressure mishaps.

Maintenance:

- breaking of containment and equipment under pressure;
- leak or pressure proof tests to prove the integrity of equipment.

Operations:

- storage tank operations;
- pig launchers and receivers;
- sampling;
- overfilling;
- connecting and disconnecting of hoses to process systems.

Start-ups and shutdowns:

- steaming out equipment;
- hydrostatic or pneumatic tests of new/modified equipment;
- commissioning.

1.10 Sources of trapped pressure and vacuum

Beware of the possibility of trapped pressure and vacuum. The most common reasons have been:

- passing isolation valves;
- vents and drains blocked/choked by particles, ice or wax;
- other obstructions to vents and drains (e.g. pig/sphere stuck in a receiver preventing depressurization);
- plugged/choked pipelines, strainers or a valve body;
- hydrostatic head of liquid;
- formation of ice or hydrate in equipment or pipes;
- failed or incomplete heat tracing creating blockages;
- thermal expansion from trapped liquids;
- steam pressure generated from water by heat;
- passing non-return valves;
- production from a gas/oil reservoir;
- steam condensation causing a vacuum;
- vapour dissolving in the water phase creating a vacuum.

Nature is always trying to achieve a balance or equilibrium. Fluids in areas of high pressure will flow to areas of low pressure, and eventually the pressure in the two areas equalize.

The higher the pressure difference between the two areas, the greater is the driving force that causes the fluids to move, and the more dangerous the consequences. When high pressure is suddenly released to atmospheric pressure, the force can be extensive and can cause serious harm to both man and property.

Also remember the Joule-Thompson (auto-refrigeration) effects—most gases cool on expansion, such as when compressed gas is released through a throttle or leak to a lower pressure area. At lower enough temperatures this can create the condition for a brittle failure. The only exception is hydrogen gas. Hydrogen heats up when it is released from a higher to a lower pressure. With elevated temperature and its tendency to generate static charges, hydrogen gas will ignite spontaneously, giving rise to fire and explosion hazards.

2

Hazards of trapped pressure

2.1 Breaking containment under pressure

[Abstracted from the book *What Went Wrong* by Trevor Kletz]

Even though equipment is isolated by slip-plates/blinds and the pressure has been released through valves or by cracking a joint, pressure may still be trapped elsewhere in the equipment, as the following incidents show.

ACCIDENT This incident occurred on an all-welded line. The valves were welded in. To clear a blockage, a fitter removed the bonnet and the inside of a valve. He saw that the seat was choked with solid and started to chip it away. As he did so, a jet of corrosive chemical came out under pressure from behind the solid, hit him in the face, pushed his goggles aside, and entered his eye.

ACCIDENT An old acid line was being dismantled. The first joint was opened without trouble. But when the second joint was opened, acid came out under pressure and splashed the fitter and his assistant in their faces. Acid had attacked the pipe, building up gas pressure in some parts and blocking it with sludge in others.

ACCIDENT A joint on an acid line, known to be choked, was carefully broken, but only a trickle of acid came out. More bolts were removed and the joint pulled apart, but no more acid came. When the last bolt was removed and the joint pulled wide apart, a sudden burst of pressure blew acid into the fitter's face.

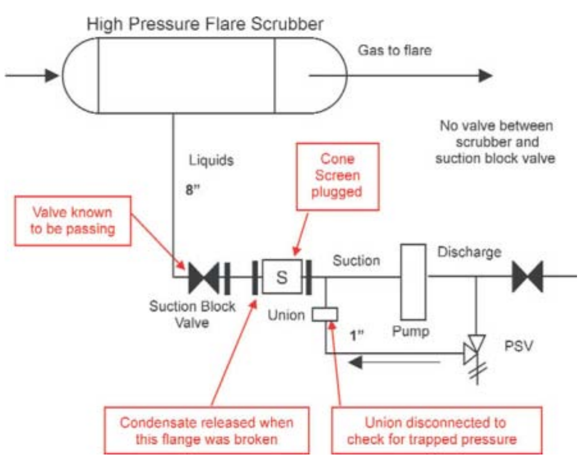
In all three cases the pipelines were correctly isolated from the operating equipment. Work permits specified that goggles should be worn, and stated 'Beware of trapped pressure.'

To avoid injuries of this sort we should always use the correct protective hoods and eye protection when breaking joints on lines that could have some residual corrosive liquids trapped under pressure, either because the pressure cannot be released through a valve or because lines may still contain hidden residual pressure behind solid deposits.

ACCIDENT Gas condensate release at exploration gas plant!

Gas condensate under pressure was released to atmosphere when a spool piece on the suction side of a pump was being removed to install an additional valve. The spool piece contained a cone screen that was plugged with wood fragments. This had prevented the upstream section of the pipe from being depressurized and vented.

Two workers from the approved contractor were assigned to install an additional valve downstream of a leaking 8 inch (20 cm) gate valve on the suction side of the high pressure condensate pump. The pump and associated pipework had been blocked in, locked out and tagged. The upstream gate valve was known to be 'problematic' and passing. Double blocking was not possible since there was no other valve in the drain line from the flare scrubber and the only other alternative was to shut down the process train. The effectiveness of the 'single' block valve was tested by breaking a 1 inch (2.5 cm) union on the PSV discharge line back to the suction line. This was undertaken to ensure that the line was completely depressured (see the following figure).



The contract workers unbolted the first flange downstream of the screen and removed the gasket/joint. They then unbolted the other end of the spool pipe upstream of the screen and immediately downstream of the leaking valve. As soon as the last bolt had been loosened, the spool piece became free and

Continued

condensate and wood fragments blew out of the open end between the screen and the suction valve. The contract workers were sprayed with condensate from the knees down. A 2×4 inch (5×10 cm) wood board was found smashed inside the 8 inch (20 cm) suction gate valve.

The immediate cause of the incident was identified as the complete unbolting of the flange when this section of pipe contained trapped high pressure condensate due to a downstream blocked cone strainer.

Always assume that the pipe may still contain liquid and/or pressure when breaking a flange. Take appropriate precautions as stipulated on the Work Permit.

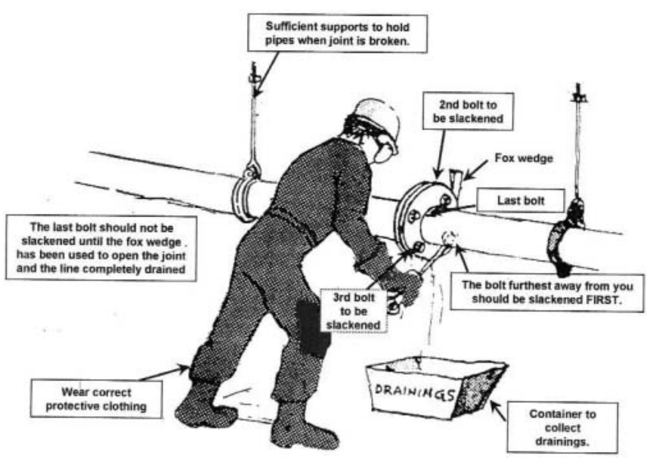
ACCIDENT **Two died while breaking flange!**

Two maintenance technicians died when almost all of the bolts from the 30 inch (76 cm) flare line were removed before breaking the flange. The result was an uncontrollable release of LPG-type material and a fire which burned for 40 hours.

The correct way to break a flange joint:

- Break a flange by loosening first the bolt furthest away from the technician.
- If liquid emerges or gas under pressure emerges, tighten up the flange immediately and report the incident to the supervisor.
- *Do not undo and remove all the bolts and then break the flange.*

The correct sequence is shown in the sketch below.



The correct way of breaking a flange

Always break a flange in the correct manner.

Every day, in every plant, equipment which has been under pressure is opened up. This is normally done under a work permit. One man prepares the job and another opens up the vessel. And it is normally done by slackening bolts so that any pressure present will be detected before it can cause any damage—provided the joint is broken in the correct way (see previous page).

Several fatal or serious accidents have occurred when one man has carried out the whole job—preparation and opening up—and has used a quick-release fastening instead of nuts and bolts.

ACCIDENT **Fatality due to pressure filter!**

A suspended catalyst was removed from a process stream in a pressure filter. After filtration was complete, the remaining liquid was blown out of the filter with steam at a gauge pressure of 30 psig (2 barg). The pressure in the filter was blown off through a vent valve and the fall in pressure was observed on a pressure gauge. The operator then opened the filter for cleaning. The filter door was held closed by eight radial bars which fitted into U-bolts on the filter body. The bars were withdrawn from the U-bolts by turning a large wheel fixed to the door. The door could then be withdrawn.

One day an operator started to open the door before blowing off the pressure. As soon as he opened it a little it blew open, and he was crushed between the door and part of the structure and was killed instantly.

In situations such as this it is inevitable that sooner or later an operator will forget that he has not blown off the pressure and will attempt to open up the equipment while it is still under pressure. On this occasion the operator was at the end of his last shift before starting his vacation.

It is too simple to say that the above accident was due to the operator's error. The accident was the result of a situation that made it almost inevitable.

Whenever an operator has to open up equipment that has been under pressure:

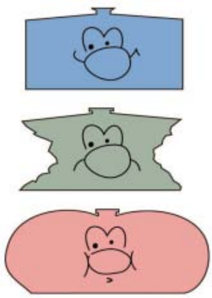
- The design of the door or cover should allow it to be opened about ¼ inch (6 mm) while still being capable of carrying the full pressure, and a separate operation should be required to release the cover fully. If the cover is released while the vessel is under pressure then this is immediately apparent and the pressure can blow off through the gap or the cover can be resealed.
- If possible, interlocks should be provided so that the vessel cannot be opened up until the source of pressure has been isolated and the vent valve has been fully opened.
- The pressure gauge and vent valve should be visible to the operator when he is about to open the door or cover.

Also, the design should be such that the vessel cannot be pressurized until the door is properly closed.

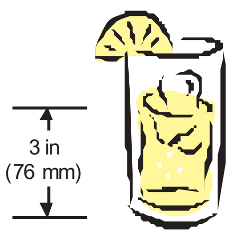
Vessels that have to be opened up as part of normal operating procedures (for example, pig launchers/receivers) should be fitted with an interlock arrangement to remove any possibility of the door being opened prior to the vessel being completely depressurized.

2.2 Storage tanks are fragile vessels

Large storage tanks are fragile due to their low strength and huge surface area. Let us examine how strong, or weak, an atmospheric storage tank is.



Is a storage tank as strong as it looks?



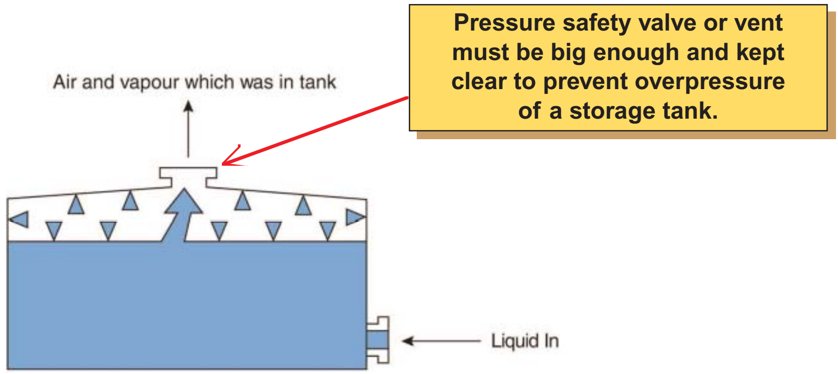
3 inch (76 mm) water gauge is the pressure at the bottom of a glass of water (1/10 psig, 0.007 barg).

1 inch (25 mm) water gauge is the pressure at the bottom of a small bottle of cologne (1/30 psig, 0.002 barg).

Atmospheric fixed roof tanks may only:

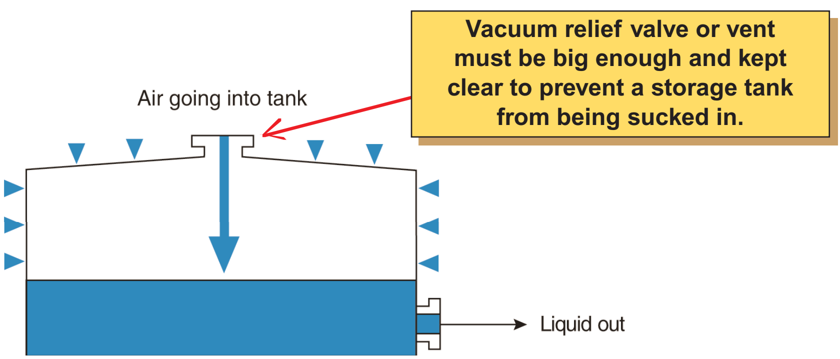
- withstand an overpressure of 7.5 mbar (3 inch or 76 mm of water);
- withstand a vacuum of 2.5 mbar (1 inch or 25 mm of water);
- have weak shell-to-roof welds that open (fish mouth) to minimize damage in the event of overpressure.

For more details on storage tank design and incidents, refer to BP Process Safety book *Safe tank farms and (un)loading operations*.



For liquid to get in, air and vapour must be pushed out:

- the pressure in the tank must be slightly above atmospheric pressure;
- the tank may only be designed to withstand a pressure of 3 inches w.g. (7.5 mbar).



For liquid to get out, air and vapour must be sucked in:

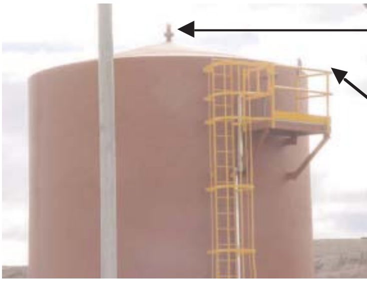
- the pressure in the tank must be slightly below atmospheric pressure;
- the tank may only be designed to withstand a vacuum of 1 inch w.g. (2.5 mbar).

ACCIDENT **Trapped air blows roof off tank!**

Operators were filling a new tank with water, from a fire hydrant via a 2 inch (50 mm) fire hose, to undertake a hydrotest on the tank. An operator had just climbed up the tank to check that the air was relieving through the vent on the roof. After inspection, while he was stepping off the bottom of the ladder, an explosion was heard and felt. The roof had completely blown off this tank! (see pictures on page 21)

The immediate cause of this incident was that the vent did not release the trapped air fast enough at the volume flow rate of water being added to the tank.

Continued



Atmospheric vent not big enough to release air displaced by filling rate of water

Operator had been here only seconds before the roof was blown off.

Tank before roof blew off.

Note missing platform and top of ladder.

Tank after roof blew off.

Tank roof—clean break. Note: Tank roof seal welds are designed to fail before the bottom floor seal (to protect the tank and spillage of contents).

The tank roof and its associated structure on the ground.

Lesson learned

- Filling something with water is a common activity we do at home and at work all the time—do not be complacent, think through the potential hazards.
- Are our procedures for tank hydrotesting good enough to significantly reduce the probability that an 'uninformed individual' might do something like this to one of our tanks during hydrotesting?
- Twenty years ago, a vacuum truck driver was killed when he was standing on top of a tank that blew its roof in a similar incident. Do you check whether it is completely safe to go up on a tank that is being hydrotested? Does everyone involved in tank hydrotesting know enough to ensure that venting will be sufficient during emptying as well as filling?

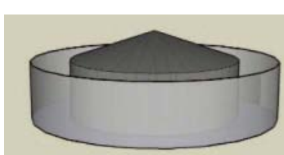
- Do you know what can happen when emptying water out of a vessel or tank after hydrotesting? A vacuum can easily be generated and can easily destroy a tank! Ensure vents are adequately sized and are fully open.
- Tank filling for hydrotesting takes a lot of time. This can give rise to an urgency that might cause people to cut corners to speed up the test. Would you recognize such a situation and make sure that the hydrotest was done safely in spite of the urgency?
- Would you have thought that air would not get out of a tank as fast as water can be pumped in?
- Tank roof welds are only designed for a few inches of water gauge pressure. This weak seam is intentionally designed to fail before other welds on the tank to protect the structural integrity of the tank. (Refer to API guidelines 2000 and 650.)
  - API 2000 *Venting Atmospheric and Low-Pressure Storage Tanks*
  - API 650 *Welded Steel Tanks for Oil Storage*

ACCIDENT **Bottom weld rupture!**

This slops tank ruptured at the bottom weld when it was overpressured by nitrogen leaking from an attached pipeline that was being purged. Once released, the product overtopped the bund wall.

ACCIDENT **Water stronger than steel!**

During summer, neighbours complained of bad smell vapours coming out of a storage tank vent. This tank was within a steel bund with an annular space (open at the top) between the tank and the bund wall (see simplified diagram below). To limit vaporisation by cooling the tank, operators turned on the cooling water deluge system which was fixed to the shell of the tank inside the annular space.



Continued

Unfortunately, the amount of water that could be drained by the bund pump was less than the amount of water that was used by the cooling water deluge system. Therefore, the water level started to go up in the annular space. Due to the fact that the tank was only one third full the hydrostatic pressure on the inner tank walls increased, until they were distorted as shown in the photograph.

Another incident where a storage tank fails at shell-to-roof seam (fish mouth) due to overpressure.

ACCIDENT **Blowdown trailer failure!**

In preparation for realligning a pumping unit, a blowdown trailer was used to bleed pressure from an oil production well at two different locations. On the second job, the employee intended to remove the screwed top lid on the tank prior to actual job commencement in order to provide a large venting area, but was distracted by other ongoing tasks and left the location. The contractor crew connected the hose from the wellhead to the trailer and began the venting process by opening the tubing vent valve. Unable to relieve pressure through the *closed lid*, the blowdown tank ruptured violently. A contractor injured his left wrist when struck by a tank fragment.

Continued

Apparently there was little well pressure during the first job. During the second job, the contractor crew went through the same procedure, but there was apparently sufficient pressure at this well to rupture the tank. The crew held on-site pre-job safety meetings before both jobs. They had recognized gas venting from the tank as a potential overpressure hazard, but presumed that the tank lid had sufficient internal relief capacity, since the equipment was used previously with the lid in place.

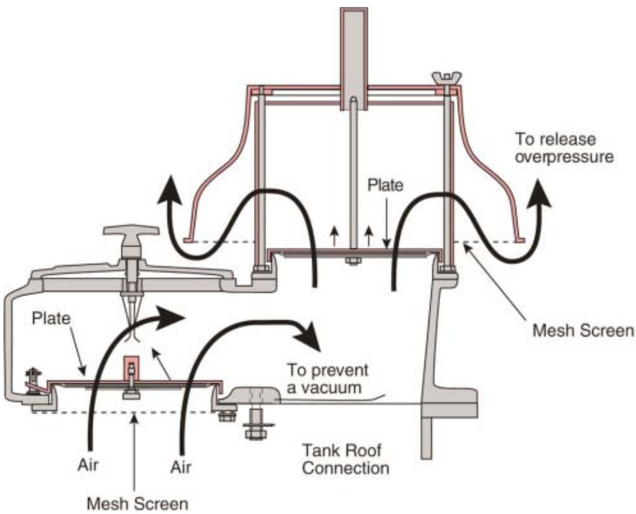
The ruptured blowdown tank.

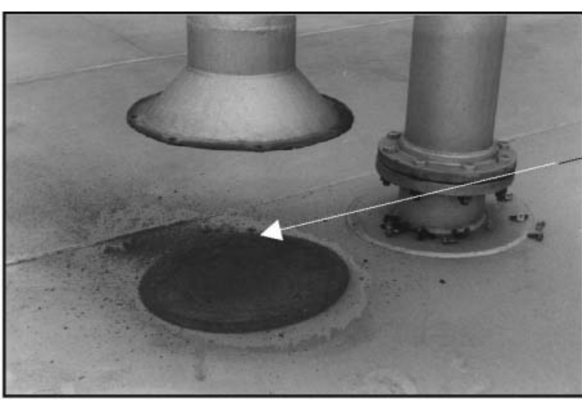
Do not use temporary equipment for venting or draining unless the job has been vetted through a Management of Change (MOC) procedure and Job Safety Analysis (JSA)

2.3 Blocked/choked/isolated safety valves, vents and drains

Pressure/vacuum safety valve

A pressure/vacuum safety valve (PVSV) is an important device. It has two functions—to relieve overpressure and to eliminate vacuum, thus preventing damage to the vessel or storage tank. It must be kept *clear* at all times. Typical examples of blocking items include rust, ice, wax, bitumen (asphalt) or hydrocarbon residue, and bird nest.





Rust partialy blocks a screen mesh on a fixed roof tank's open vent.

Ensure screens on pressure/vacuum safety devices are equipped with the correctly sized opening and remain clear.

ACCIDENT **Chemical tank overpressurized during water flushing!**

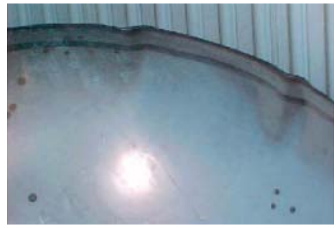
An atmospheric storage tank used to contain boiler treatment chemicals in the hydrogen plant was being washed in preparation for inspection. The vent on the tank was removed and a flanged water supply installed in its place. As a result of the suppression of the vent, air was compressed in the vapour space as the tank was filled with water. The atmospheric tank overpressured, blowing off the end cap completely and fracturing the concrete supports around the mounting studs.

The insulated flat-head horizontal cylinder failed due to overpressure.

ACCIDENT **Roof of heavy fuel oil tank sucked in!**

A fixed roof tank containing heavy fuel oil was sucked in during a pumping out operation and vacuum was generated inside the tank due to partially choked vents. The tank roof (43 m/140 ft in diameter) was equipped with three breathing vents, each fitted with a coarse expanded metal mesh screen to prevent birds from nesting underneath the weather cover. A waxy deposit had virtually sealed the screens. The tank, constructed in 1972 was fitted with internal steam heating coils and the roof and shell were fully insulated. After the tank was repaired, the refinery decided to remove the mesh screens from the vents.

ACCIDENT Truck's tank compartment ruptures due to use of unregulated compressed air!



Damaged tank compartment joint

While offloading product from a contracted road tanker at a customer's facility, the pressure relief valve on the compartment malfunctioned, possibly seizing open due to extreme cold and icing. The tank truck compartment was rated for 35 psig (2.4 barg). Since the tank truck trailer was not able to hold air pressure, the customer's employee applied an unregulated air pressure to the truck to offload the product. This resulted in pressure building up in the tank to the point where structural integrity was compromized and the tank bulkhead was pushed into the adjacent void. This caused 20 gallons of hot (>212°F/100ºC) product to be released from a drain hole in the void space.

Equipment must not be used if any safety device is malfunctioning.

Any proposed departure from the Standard Operating Procedures must be subject to a 'Management of Change' procedure.

ACCIDENT LNG plant explosion due to closed block valve!

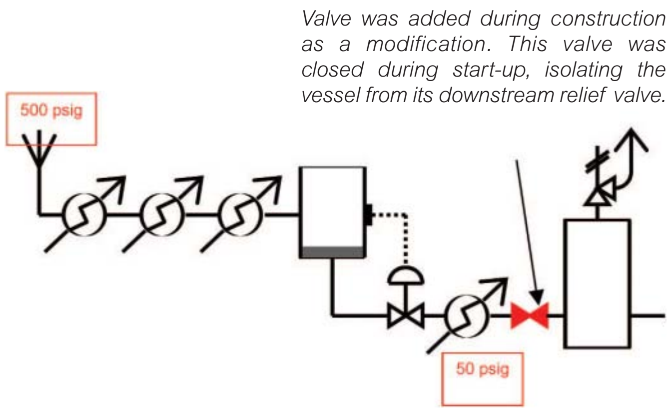
A block valve between the shell side of the main cryogenic heat exchanger and the blowdown system had not been opened by the plant operators after the tie-ins for a new production train were completed. This isolated the shell side of the heat exchanger from its relief system. As part of the start-up procedure, defrosting gas (dry methane) was introduced into the shell side of the cryogenic exchanger, with the exit to the blowdown system blocked! Hence, pressure built up inside the exchanger until it disintegrated into several main sections and many small pieces. The ensuing missiles and fireball destroyed plant equipment, killed three people and injured another thirty-two.

ACCIDENT Late modification on ethylene plant start-up!

Attention is drawn to a similar incident that occurred during the commissioning of a 'cold box' on an ethylene plant in 1973. The commissioning team had an extra valve fitted during construction as a late modification. During start-up this valve was closed and the whole train of exchangers was subjected to the full upstream pressure. When the pressure in the last exchanger reached

Continued

400 psig (27.5 bar), the exchanger, which was only designed for 50 psig (3.5 bar), burst. There was a major fire and a big delay in the start-up.



Ensure all proposed changes/modifications however small and cheap on process units are vetted through a HAZOP as part of the Management of Change procedure.

Importance of rupture disks

A rupture disk is a device that is designed to relieve excessive pressure in a process. When the pressure on one side of the disk exceeds the design limit, which is based on a designated difference in pressures on opposite sides of the disk, the disk bursts or opens to relieve the pressure. Once a rupture disk opens, it cannot reclose.

A common design strategy uses rupture disks in combination with relief valves to prevent damage to the relief valve from exposure to process fluid during normal operation. If the system pressure on the process side of the disk rises above the rupture disk burst point, the rupture disk will open, exposing the relief valve to the system overpressure. The relief valve will then open to relieve the system pressure. For this design strategy to work properly, the rupture disk must not leak or fail prior to the increase in system pressure. In a well-designed and maintained system, the space between the rupture disk and the relief valve is normally at atmospheric pressure.

A rupture disk can fail in a number of ways. For example, it can experience a pinhole leak, or it can prematurely burst. If the rupture disk bursts, the relief valve will still operate as long as the process fluid against which it was being protected does not degrade the integrity or operation of the relief valve. On the other hand, if the rupture disk experiences a pinhole leak, the pressure in the space between the rupture disk and the relief valve can equalize with the system pressure. In this situation, the rupture disk will not burst at the system pressure at which it was designed to burst because the rupture disk relies upon the difference in pressures on its opposite sides. If the pressure on both sides is the same because of a small leak, the rupture disk will open only at a pressure much higher than the designed system relief pressure. As a result, the system/vessel may be exposed to a much higher pressure than intended, thereby creating a potentially serious process safety hazard.

For these reasons, it is important to monitor the pressure in the space between the rupture disk and the relief valve to determine whether the rupture disk has failed prematurely. It is a recognized good industry practice to continuously monitor and alarm or frequently monitor and log the pressure of the rupture disk/relief valve space. If refinery staff detects a higher than intended pressure in the space between the rupture disk and the relief valve, the situation can be investigated, evaluated, and remedied.

On this picture, because there is nearly 50 psig (3.5 barg) pressure on the downstream side of this rupture disk, if the pressure was caused by a pinhole leak, the rupture disc will not burst until the pressure in the vessel is equal to the rupture disk design pressure plus 50 psi (3.5 bar). If this is a 100 psi disk, it will not burst until the vessel pressure is above 150 psig (10.3 barg).

Condensate downstream of relief valves

The potential dangers of condensate build-up downstream of relief valves discharging to atmosphere include not only a risk of potential seizure but can also result in:

- increased back pressure from the static column of condensate;
- scalds when a steam relief valve lifts.

It is well recognized that steam relief valves must have a drain—sometimes it is manifolded into a tundish—but often it is a nominal 0.5 inch or 0.375 inch (1.27 cm or 0.95 cm) hole drilled in the horizontal section of the tail-pipe to drain rain water and any condensate. Unfortunately, as appears to have occurred in past incidents, the drain becomes choked with rust formed by the reaction of air (oxygen) and steel allowing liquid to collect.

ACCIDENT Back pressure 1!

During a site tour, steam condensate was found dripping from the relief valve's tail-pipe flange. The drain hole at the bottom of the tail-pipe was plugged. The tail-pipe—10 m (33 ft) high—was virtually flooded. As the relief valve set pressure was 3 barg (44 psig) the true lift pressure would be nearer 4 barg (58 psig) and a slug of about 0.5 ton of hot water could have been discharged.

ACCIDENT **Back pressure 2!**

During a safety audit it was noted that the drain hole on an atmospheric discharge pipe from a de-ethanizer relief valve (at –30°C/–22°F) was choked. Steam was bled as an inert purge into the tail-pipe to prevent ignition at the tip during electrical storms. (The lessons from the rupture of a refrigerated LPG tank due to the freezing of steam in 1965 had not been learned.) In the case of the de-ethanizer, there was no evidence of icing. When the hole was rodded out, only hot condensate was discharged. The back pressure potential was only about 10% of the relief pressure but a 1-ton slug of condensate could have caused scalds.

Keep drain holes at the base of atmospheric tail pipes fitted to pressure safety valves clear.

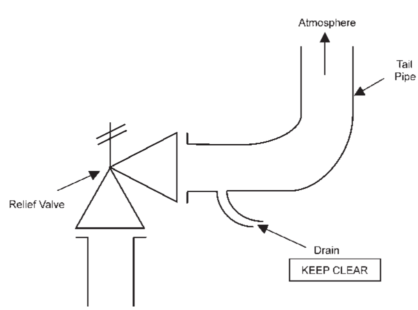
ACCIDENT **Geysers!**

The long tail-pipe, some 20 m (66 ft) high, from a steam relief valve suddenly discharged a slug of condensate. No one was hurt and no one believed the operator who reported it. When it happened again it was investigated in more detail. It was found that the relief valve was weeping and the drain was choked with rust. The steam weep kept the column of condensate hot but the 20 m (66 ft) vertical column of water imposed a 2 barg (29 psig) back pressure, suppressing boiling until the column was disturbed initiating the flashing at the bottom of the column.

It is now recognized that relief valve inlets and exits must be checked clear during schedule inspections and testing of pressure safety valves—though no one seems to treat the tail-pipe drains with the same seriousness.

Lessons learned

- Relief (pressure safety) valve tail pipes are a potential hazard.
- The drain point at the bottom of the tail pipe is not currently considered to be a critical safety item.
- Process or steam relief valve tail pipe drains should be confirmed as clear by rodding as part of routine inspection checks.



Tail pipe of relief valve must be kept clear.

Choked vents and drains

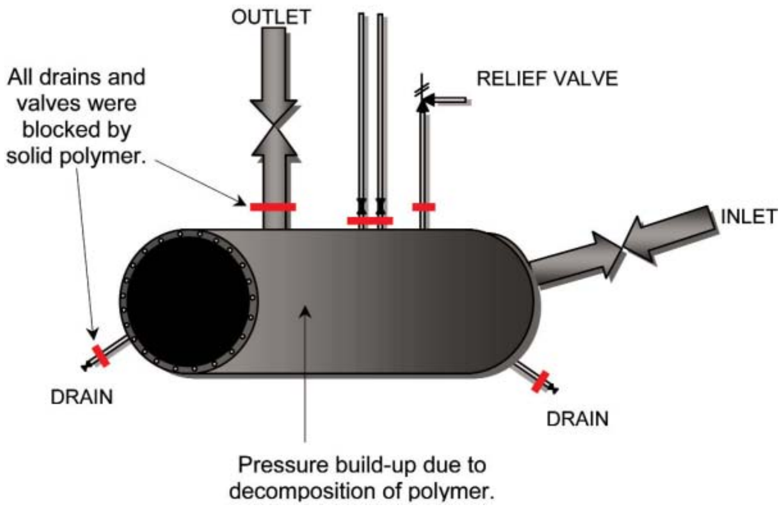
ACCIDENT **All vents and drains choked by polymer!**

Three employees were killed during the unbolting of a cover plate on a vessel in preparation for cleaning out deposited polymer. They were unaware of the accumulated pressure inside the vessel as a result of the release of volatile decomposition material and blocked nozzles (vent, drain, PSV and pressure gauge) from the build up of solid polymer. After approximately half of the bolts had been removed on one side of the cover plate, the internal pressure was sufficient to eject the plate and the vessel internals as missiles.

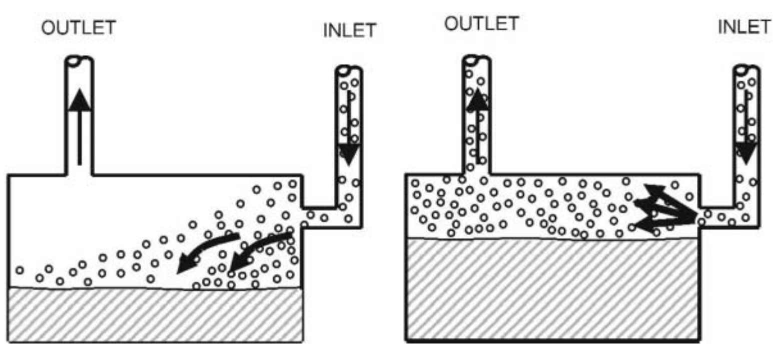
Polymer catch tank after the incident. Its cover was blown a few feet away.

(Left) Polymer plugging the polymer catch tank vent nozzle. (Right) Vent line obstructed by solid polymer.

Continued



Pressure was trapped inside the polymer catch tank.



(Left) Normal operation. (Right) Vessel filled beyond working capacity — particles entrained in vent polymer.

ACCIDENT **Runaway reaction in deadleg causes overpressure!**

A butadiene vapour cloud was released from a 1 m (39 inch) split rupture on the overhead pipe from the reboiler on the final purification tower. A large quantity of popcorn polymer was noticed in the area local to the leak substantiating the fact that the split was caused by the tremendous forces created during its formation. Fortunately, the released hydrocarbon vapour cloud did not ignite and no fatalities or injuries were recorded.

The causes of the pipe rupture were:

- Popcorn polymer formation (1,3 butadiene monomers polymerize at their active free radical ends and create crosslinkings. This reaction is extremely exothermic and can provide enough heat to expand and overpressure pipes, resulting in rupture).
- The safety valve line which was a deadleg line and ‘live’ to the process was found not sloped as originally specified, possibly allowing liquid butadiene to pool in the pipe.

A similar incident killed two operators and injured four others when a vessel was overpressured by a popcorn type reaction.

Pipe ruptured due to overpressure.

Clearing choked lines or plugged drains

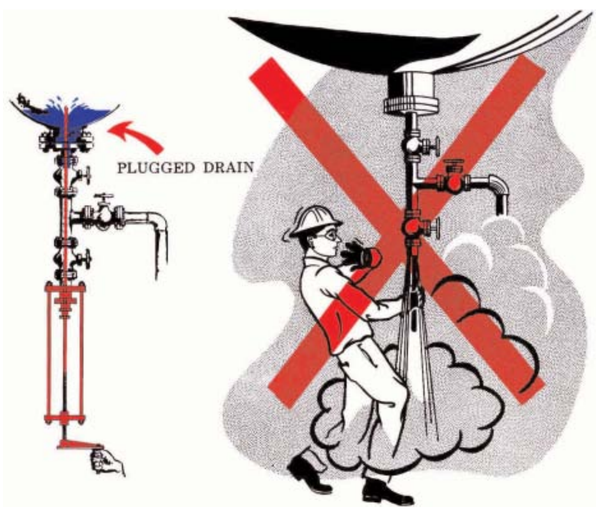
As many past incidents have shown, the clearing of blocked drains is a hazardous operation for which we really do not have a satisfactory and totally practicable answer. In the past, a number of techniques have been considered, but often the safest advice was to close the system down when it was not possible to safely clear a drain and prove it to be so. This could, unfortunately, sometimes be difficult when the blocked drain played an important part of the shutdown/draining system.

Next Page

There have been many instances of sudden release of trapped pressure and loss of containment while attempting to unblock a plugged drain.

Though there are several devices designed to overcome this potential hazard, certain criteria must be considered before adopting them:

- Will they effectively clear the whole or a substantial part of the bore of a drain connection?
- Will the device itself stand up to the pressure in the system so it will not blow out?
- Is there any chance that the threaded bar or similar part of the device could penetrate the drain connection wall, resulting in a blow out?
- Can the device itself be disconnected without the chance of a sudden release of pressure? For example, as it is removed from the drain connection, the valve, which may not be properly shut (scale under the seat), may blow clear.
- If ‘force’ pumps are used, these must not be capable of exceeding the pressure rating of the pipeline.



All plugged drains and bleeders must be opened safely.

3

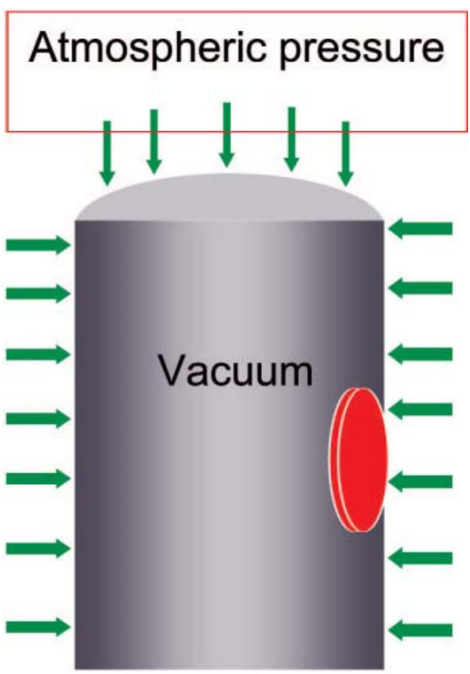
Hazards of vacuum

3.1 Ignorance of hazards of ambient pressure

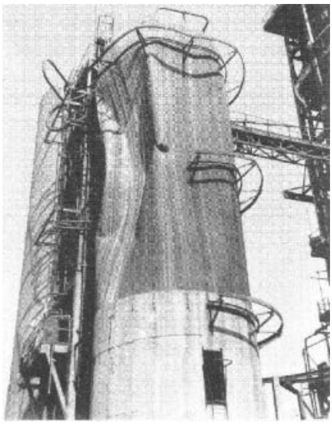
The same concepts for pressure apply to vacuum. However, in vacuum systems the pressure is pushing inward, not outward.

The pressure comes from the atmosphere — we don't feel it but a tank does when you pull vacuum on it.

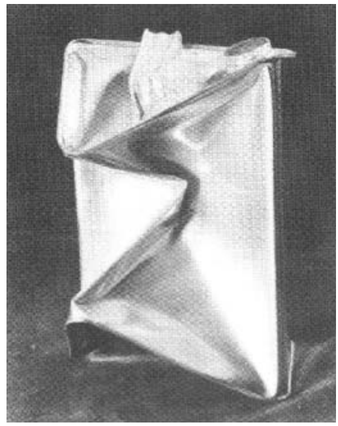
If a tank is not designed for vacuum, it will likely be damaged if placed under vacuum.



Storage tanks and railcars are particularly susceptible to damage, but it can also happen to process vessels that are only rated for low pressures or very large pipes.



Too much vacuum damaged this catalyst storage drum.



Result of condensation. This can was filled with steam and then closed. The steam condensed, and the resulting vacuum caused the damage shown.

A number of incidents occurred due to ignorance of the most elementary properties of materials and equipment. For example, an operator had to empty some tank trucks by gravity. He had been instructed to:

- open the valve on top of the tank;
- open the drain valve;
- when the tank was empty, close the valve on top of the tank.

He had to climb onto the top of the tank twice. He therefore decided to close the vent before emptying the tank. To his surprise, the tank was sucked in.

3.2 Blocked/choked/isolated vents and drains

The following incidents relate to the failure of vessels from unexpected vacuum. It is believed that the equipments' designers and operators just did not expect such problems. There were multiple causes for each failure, including modification to vent piping, insufficient monitoring of pressure and human error. Despite the fact that all of the vessels were designed for substantial internal pressures, they failed under vacuum conditions and ended up as scrap metal.

ACCIDENT **Vent blocked by wax!**

A very small overfill sent hot liquid paraffin on the mesh of the vent of that tank. The paraffin solidified when cooled. The tank collapsed while being pumped out!

ACCIDENT Similar incident on another tank.

Can you think of all the other possible causes of blockages in vents or flame-arresters? Here are some real life examples—bird nests, ice, rust, wax, tissue…

This kind of incident is not new but unfortunately happens too often. These mistakes demonstrate the importance of Job Safety Analysis and regular inspections before any job is carried out at any facility.

ACCIDENT

Vessel collapsed due to fouled equipment and poor pressure tapping location!

During routine plant checks, the polymer cyclofilter vessel, part of the powder product pneumatic conveying system, was found to be partially collapsed. The failure was due to the fouling of a blower after-cooler, which was 95% blocked with powder. The pressure sensing point was not located in a position that would protect this cyclofilter from vacuum.

Design inputs from multiple disciplines can reduce the chance of weak design like the location of the pressure switch close to the make-up line inlet point. A good HAZOP would have identified this deficiency.

Damaged cyclofilter being removed for repairs.

ACCIDENT

Plastic wrapped over vent 1!

Some workers were painting a tank and covered the conservation vent with some plastic to prevent vapour emitting from the tank. With the pressure/ vacuum valve covered by a plastic bag, the tank was sucked in when material was pumped out of the tank during a product transfer.

Pressure/vacuum safety valve of the tank was covered with a plastic bag during painting, causing the tank to be sucked in during a product transfer.

ACCIDENT Plastic wrapped over vent 2!

A pressure relief valve was removed for maintenance and the flanges were covered with plastic bags. 400 tons of acetic acid leaked in the bund following the tank failure when the tank was vacuumed during a pumpout.

Plastic wrap

ACCIDENT Cars sucked in 1!

Full vacuum rated railcars were changed to pressure rated discharge road tankers for the delivery of catalyst to the plant. When the plant's ejector system was used to discharge the catalyst from the road tanker, a vacuum was created and the vessel was sucked in.

ACCIDENT **Car sucked in 2!**

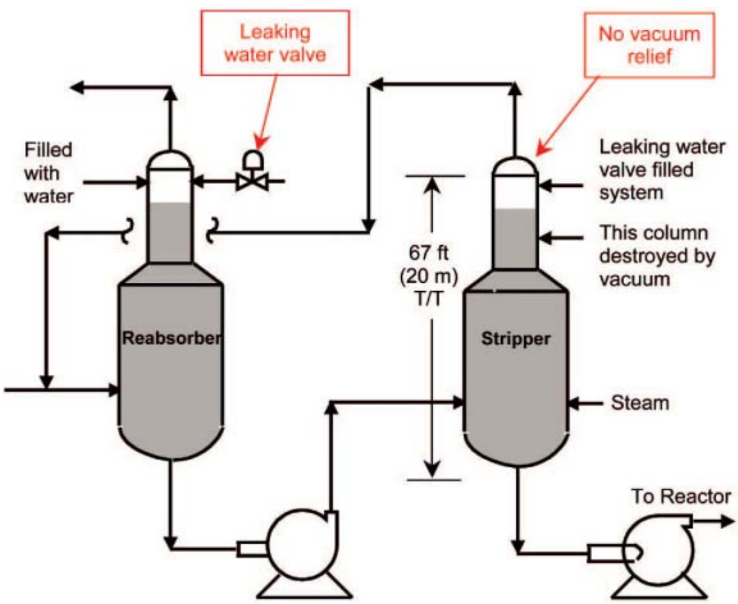
A truck arrived to unload chemicals at a chemical plant. After connecting the unloading arm, the operator started the pump before the driver opened the top man-holes. Air could not replace the displaced liquid in the tank. The road tanker was so badly damaged that some wheels didn't even touch the ground anymore!

ACCIDENT **Column collapsed during start-up!**

During a simulation of plant operation by circulating water in the system, a recycle water valve had leaked and filled both reabsorber and stripper columns with water. The vent line from the stripper was connected to the feed line of the reabsorber, which has an atmospheric valve. The vent line from the stripper could not provide vacuum relief because it was not in the normal gas service but flooded. The stripper was designed to operate at 5 psig (0.34 barg) and had a mechanical rating of 25 psig (1.72 barg).

The crew decided to open the drain valves on the suction lines from the reabsorber and stripper bottom pumps. When the level in the reabsorber dropped to about 75 percent, the crew stopped draining from the suction drains and started the stripper bottom pump, creating an even greater partial vacuum within the stripper as the water was routed to the reactor. About ten minutes later, the stripper collapsed.

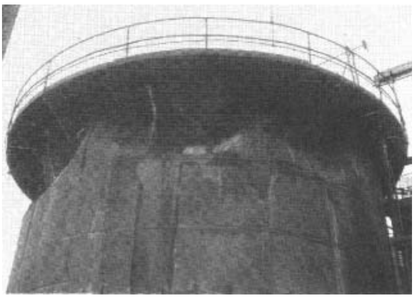
After this incident, vacuum breakers were installed on all of the vessels in this process that were not designed for full vacuum. In addition, the stripper vent line was rerouted.



Design of the reabsorber/stripper system.

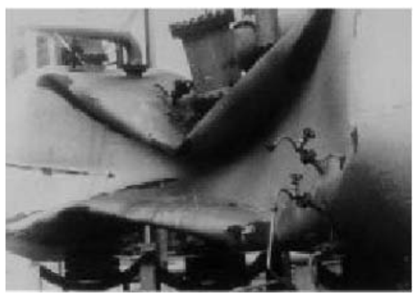
3.3 Steam condensation

ACCIDENT



A vacuum vent and one open hatchway were not enough to prevent damage when steam condensed and pulled in the top two courses of this 35 ft (11 m) diameter by 21 ft (6 m) high wash tank.

ACCIDENT Before a shut-down, steam was introduced in the blowdown system of a combined crude-vacuum distillation unit to gas free it. After several hours of steaming, the blowdown vessel was isolated with hot steam inside, by closing valves. When the steam condensed, the vessel collapsed dramatically.



ACCIDENT

A rail tank car was being steamed for cleaning and gas freeing before inspection. Again, valves were closed while hot steam was still inside the system.

Operators within their training and re-training programmes should be aware of how low pressures can be generated in process plant, tanks and lines, along with the design conditions for such equipment.

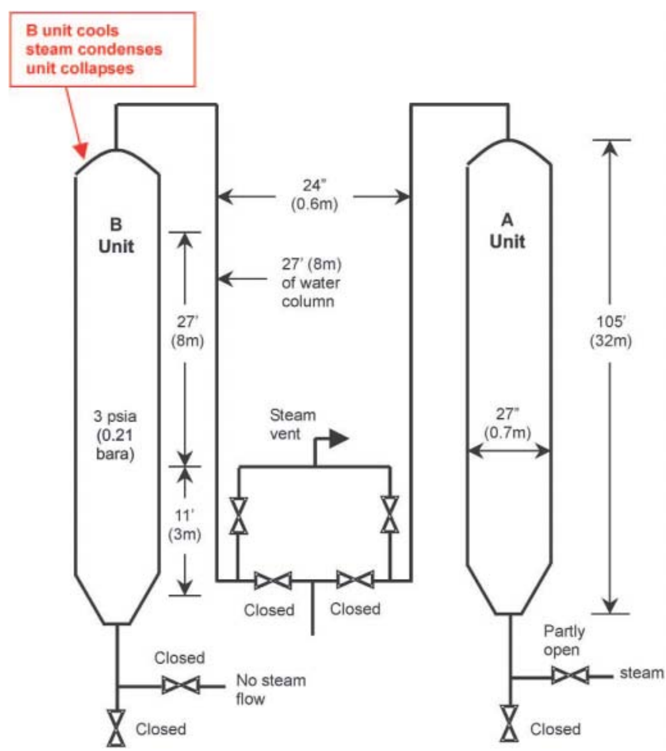
For more details on water or steam, refer to BP Process Safety Booklets *Hazards of Water* and *Hazards of Steam*.

ACCIDENT A coke drum is destroyed during commissioning!

A steam test was employed to check for system leaks in two new gigantic coker drums and to displace any oxygen prior to start-up. The 'A Unit' and the 'B Unit' cokers shared a common temporary 8 inch (20 cm) vent line to the atmosphere. The 'B Unit' was steamed out first and vented through the steam vent piping. Then, the steam was shut off to the 'B Unit' and the process was repeated for 'A Unit'. The steam in the 'B Unit' continued to condense as the unit cooled while steam continued into the 'A Unit' for an additional two days. Unfortunately, the design of the piping modification created a loop that could collect water as the steam condensed.

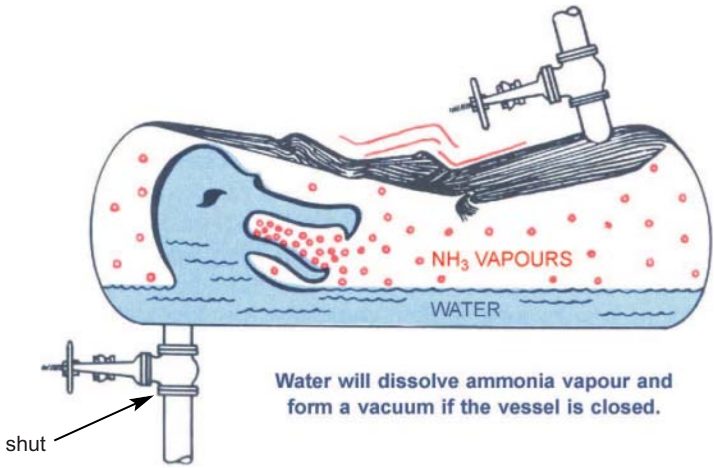
Separated from atmosphere by a column of water, vacuum was created in 'B Unit' as the steam cooled further. The range on the coker pressure instrument was 0 to 60 psig (4 barg), hence unable to indicate a negative pressure. The coker crushed inwards like an aluminium beer can, squeezed in the middle and distorted beyond salvage.

It was recommended that the vent line be modified to eliminate any possibility of a trap in the vent line, and that a low pressure (vacuum) alarm be installed to alert the control room operator of low pressure (vacuum) conditions within the coker drums.



Pre-start-up failure of the coker drum.

3.4 Ammonia dissolved in water



Ammonia both as liquid and vapour has a tremendous affinity for water. For example, if water is put into a vessel containing ammonia vapour at atmospheric pressure, the ammonia will rapidly dissolve in the water and form a vacuum in the vessel. Vessels have collapsed in this way. This phenomenon can happen to any vessels containing chemicals with a high affinity for water or other solvents.

3.5 Management of change

ACCIDENT Gasoline storage sphere collapses due to vacuum!

A sphere that normally stores high vapour pressure light straight run gasoline was used instead to receive natural gasoline from a barge because of insufficient room in the storage. Light straight run gasoline has a Reid Vapour Pressure (RVP) of 17.0 while natural gasoline is only 10.5. However, it appears that everyone thought that the two types of gasoline had the same RVP.

The sphere was filled at a much faster rate from the dock at 3,300 bbls/hr as opposed to 250 bbls/hr from the saturation gas unit. This resulted in the pressure safety valve lifting. This was followed by an increased pumping out rate of 1,100 bbls/hr instead of 400 bbls/hr. A loud roar was heard. The chief operator noticed that the top of sphere was collapsing and immediately stopped the blending operations.

After investigation, several problems were revealed:

- inadequate pressure instrumentation, control and alarms;
- insufficient monitoring of pressure/vacuum and flowrates;
- Management of Change (MOC) procedure was not followed before using the non-vacuum rated sphere for storing low RVP natural gasoline.

3.6 Can your vessels deal with vacuum?

In each of the cases described, the systems were not designed to handle the destructive forces created by ambient pressure. It is hoped that this review of 'victims of vacuum' will encourage plant personnel to review existing vacuum protection thoroughly, to encourage reviews of any modifications made to vent systems, and to ensure that vacuum protective systems are well maintained.

- Never underestimate the potential of vacuum condition to cause damage. Equipment that can support tens of bars of pressure are often unable to sustain a vacuum.
- Follow procedures, do not take shortcuts.
- Do not trap steam that will cool and condense in closed systems.
- Inspect and ensure vents/flame arresters remain clear.
- Do not wrap vent valves with plastic bags.

Vessels designed for a low pressure may not withstand a vacuum.

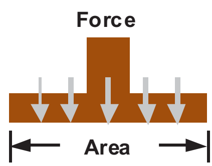
Vacuum may be created by a number of factors including a high pumping out rate, lower ambient temperature, lower vapour pressure of the liquid in the vessel.

The Management of Change (MOC) procedure should examine all types of changes including changes in the composition of feedstocks or products.

4

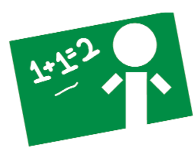
Points to remember

1. Pressure = Force/Area.



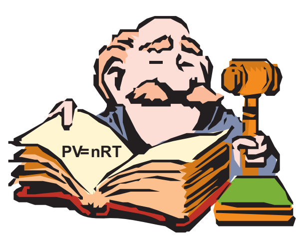
2. Liquid Pressure = Depth x Density.

3. Absolute Pressure = Gauge Pressure + Atmospheric Pressure



4. A vacuum is any pressure lower than the ambient atmospheric pressure.

5. Gas Law states that PV = nRT, where P = gas pressure, V = gas volume, n = mass of gas, T = gas temperature and R = the universal gas law constant.



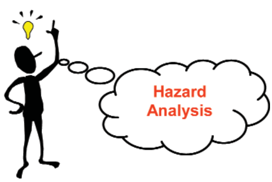
6. Hydraulic pressure—Danger!
Pneumatic pressure—Danger!

7. Compressed Air—Danger!
Compressed Liquid—Danger!

8. Always assume that the pipe may still contain liquid and/or pressure when breaking a flange. Take appropriate precautions as stipulated on the Work Permit.

Always break a flange joint in the correct manner.

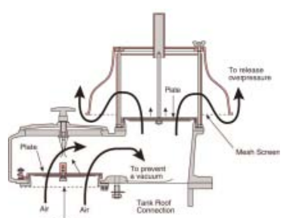
9. Vessels that have to be opened up as part of normal operating procedures (for example, pig launchers/receivers) should be fitted with an interlock arrangement to remove any possibility of the door being opened prior to the vessel being completely depressurized.

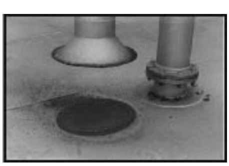


10. Do not use temporary equipment for venting or draining unless the job has been vetted through a Management of Change procedure and Job Safety Analysis.

11. Pressure Safety Valve or Vent must be big enough and kept clear to prevent overpressure of a storage tank.

Vacuum Relief Valve or Vent must be big enough and kept clear to prevent a storage tank from being sucked in.



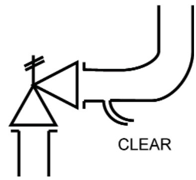


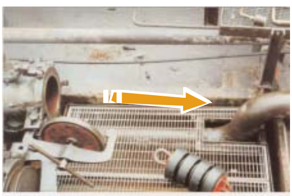
12. Ensure screens on pressure/vacuum safety devices are equipped with the correctly sized opening and remain CLEAR.

13. Equipment must not be used if any safety device is malfunctioning.

14. Any proposed departure from the Standard Operating Procedures must be subject to a 'Management of Change' procedure.

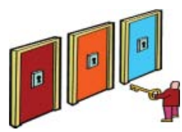
15. Keep drain holes at the base of atmospheric tail pipes fitted to pressure safety valves CLEAR.





16. All pig launchers and receivers should be subject to a process hazard analysis to ensure that the design has adequate safety features and that procedures/interlocks are sufficient to prevent operators from following an incorrect sequence of tasks.

17. Prepare written procedures for the proper closing and tightening of pig trap and launcher doors.

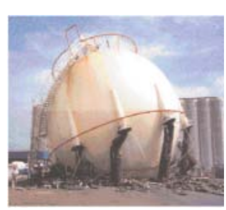


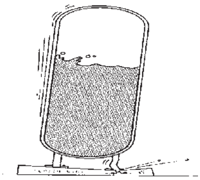
18. When not in use, traps and launchers should be isolated from pressurized pipelines to prevent unnecessary loading that may weaken their mechanical integrity.

19. The specification of safety critical items should be reviewed at periodic intervals to ensure that the best available materials for the particular service have been identified and used.

20. Ensure pig launcher/receiver step-by-step tasks are subjected to a procedural HAZOP or Job Safety Analysis.

21. The vessel itself, support legs and foundations must be able to support the weight of water during a hydraulic test.





22. Remember the density of liquid hydrocarbon is much less than that of water at 1.0. Are the structures designed to withstand the equipment becoming full with water?

23. HAZOPs must check the need for thermal relief under the deviation ‘higher temperature’. All possible causes for higher temperatures must be identified and studied.

24. Do not overfill tanks and vessels. Liquid expansion may cause relief valves to lift, or cause the equipment to rupture.

25. Energy stored in a pneumatic test is far greater than for a hydraulic test and therefore a hydraulic test is always the safer option.

26. Pressure = Stored Energy. When pressure acts upon an area, a force is generated.

27. Although hydraulic testing is always preferred, it can also provide sufficient stored energy to eject missiles.

28. Ensure all proposed changes/modifications, however small and cheap, on process units are vetted through a HAZOP as part of the Management of Change procedure.

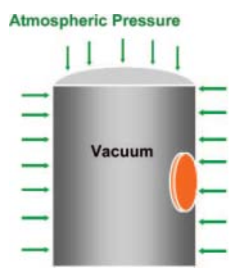
29. All areas of vessel containing pressure must be kept cool with water spray in a fire.

30. Appropriate assurance processes must be in place so that any component being installed in a pressurized application is inspected, tested, certified and/or verified as suitable for its intended service prior to installation.

31. Ensure all potential remaining hazards that include the possibilities for trapped pressure are discussed during the jobsite visit by the Permit Issuing Authority with those who are going to do the job.

32. Vessels designed for a low pressure may not withstand a vacuum.

33. Vacuum may be created by a number of factors including a high pumping out rate, lower ambient temperature, lower vapour pressure of the liquid in the vessel.



34. The Management of Change (MOC) procedure should examine all types of changes including changes in the composition of feedstocks or products.

Acronyms and abbreviations

CDU	Crude Distillation Unit
CO	Carbon Monoxide
CO_2	Carbon Dioxide
FCCU	Fluid Catalytic Cracker Unit
GPM	Gallon Per Minute
LPG	Liquefied Petroleum Gas (Propane – Butane)
N_2	Nitrogen
O_2	Oxygen
SO_2	Sulphur Dioxide
VDU	Vacuum Distillation Unit

Test yourself!

1. Pressure is defined as the force exerted by an object per unit area, i.e. P = F/A.

   True ☐ **False** ☐

2. Pressure can be expressed as absolute pressure or gauge pressure.

   True ☐ **False** ☐

3. Unit of measurement (e.g. bar, psi, pascal, inches water column) must be specified when measuring or using a pressure gauge.

   True ☐ **False** ☐

4. Air can be compressed to increase its density and pressure.

   True ☐ **False** ☐

5. Pressure inside a closed vessel can be raised by heating from steam jacket around the vessel.

   True ☐ **False** ☐

6. A small pressure is not a concern even when the surface area is large because the force is small.

   True ☐ **False** ☐

7. An atmospheric storage tank is delicate due to its large surface area.

   True ☐ **False** ☐

8. It is alright to have pressure vacuum valves of storage tanks blocked by bird nests, rust and debris.

   True ☐ **False** ☐

9. PSV of storage tanks must be kept clear at all times.

   True ☐ **False** ☐

10. It is safe to temporarily wrap tarpaulin sheet over vent valves of a storage tank to prevent odour emission from the vent.

    True ☐ **False** ☐

11. It is alright to pressurize a vessel which is non-rated or whose pressure rating is unknown to 100 barg (1450 psig) for the purpose of pneumatic testing.

    True ☐ **False** ☐

12. A pressure vessel rated for 50 barg is good for use at 200 barg, because it is alright to operate a vessel beyond its pressure rating.

    True ☐ **False** ☐

13. The possibility of trapped pressure or air entering a system under vacuum must be considered when issuing a work permit in preparation for maintenance.

    True ☐ **False** ☐

14. It is safe to break containment under high pressure without first venting or draining.

    True ☐ **False** ☐

15. Pig launching and receiving are common on-stream operations that can be done without risk assessment or safety toolbox meeting.

    True ☐ **False** ☐

16. Water trapped in closed piping or equipment can freeze during winter and break the piping.

    True ☐ **False** ☐

17. Ice and hydrate formation in the process plant can be prevented through proper winterization procedures, including draining, tracing, etc.

    True ☐ **False** ☐

18. Full vacuum means zero pressure.

    True ☐ **False** ☐

19. Damage from a vacuum is due to ambient pressure.

    True ☐ **False** ☐

20. 8 psia (0.6 bara) is a vacuum.

    True ☐ **False** ☐

21. 8 psig (0.6 barg) is a vacuum.

    True ☐ **False** ☐

22. After steam sweeping and isolating a container, steam will cool and condense eventually, creating a vacuum within the container.

    True ☐ **False** ☐

23. If water is put into a vessel containing ammonia vapour at atmospheric pressure, the ammonia will rapidly dissolve in the water and form a vacuum in the vessel.

    True ☐ **False** ☐

24. The length of pipeline carrying liquid which can be trapped between isolation valves does not require thermal relief valves.

    True ☐ **False** ☐

25. No safeguards are required when carrying out a hydraulic/pneumatic test because no air will be present.

True ☐ **False** ☐

26. Relief valve tail pipes can cause an overpressure if they become full of liquid.

True ☐ **False** ☐

27. It is alright for operations personnel to assume that maintenance personnel know the remaining hazards of a particular system when breaking containment.

True ☐ **False** ☐

28. A vessel designed to 60 psig (4 barg) will definitely withstand a full vacuum.

True ☐ **False** ☐

29. Do not trap steam that will cool and condense in closed systems.

True ☐ **False** ☐

30. Good practice to prevent the hazards of trapped pressure and vacuum includes inspecting and maintaining vents/flame arresters, and checking valves/manholes position.

True ☐ **False** ☐

ANSWERS
1T/2T/3T/4T/5T/6F/7T/8F/9T/10F
11F/12F/13F/14F/15F/16T/17T
18F/19T/20T/21F/22T/23T/24F
25F/26T/27F/28F/29T/30T

Short bibliography for regulations and norms

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- API 510, Pressure Vessel Inspection Code: Maintenance Inspection, Rating, Repair, and Alteration.
- API 572, Inspection of Pressure Vessels.
- API 920, Prevention of Brittle Fracture of Pressure Vessels.
- API 910, Digest of State Boiler, Pressure Vessel, Piping & Aboveground Storage Tank Rules and Regulations.
- API 620, Design and Construction of Large, Welded, Low-Pressure Storage Tanks.
- API 941, Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants.
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- 1926.152, Flammable and combustible liquids.
- 1926.153, Liquefied petroleum gas.
- 1926.306, Air receivers.

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