
safety

sharing the experience

improving the way lessons are learned
through people, process and technology

BP Process Safety Series

Hazards of Trapped Pressure and Vacuum

**A collection of booklets
describing hazards and
how to manage them**



This booklet is intended as a safety supplement to operator training courses, operating manuals, and operating procedures. It is provided to help the reader better understand the 'why' of safe operating practices and procedures in our plants. Important engineering design features are included. However, technical advances and other changes made after its publication, while generally not affecting principles, could affect some suggestions made herein. The reader is encouraged to examine such advances and changes when selecting and implementing practices and procedures at his/her facility.

While the information in this booklet is intended to increase the store-house of knowledge in safe operations, it is important for the reader to recognize that this material is generic in nature, that it is not unit specific, and, accordingly, that its contents may not be subject to literal application. Instead, as noted above, it is supplemental information for use in already established training programmes; and it should not be treated as a substitute for otherwise applicable operator training courses, operating manuals or operating procedures. The advice in this booklet is a matter of opinion only and should not be construed as a representation or statement of any kind as to the effect of following such advice and no responsibility for the use of it can be assumed by BP.

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Foreword

Why discuss hazards of trapped pressure/vacuum in the chemical or oil industries? The subject may seem quite simple to the experienced operator, however, every year we see incidents related to overpressurization or vacuuming of equipment. As an example, pig traps have been the source of major gas leaks and/or fatal incidents despite the fact that the equipment is simple in design and operation when compared to other more sophisticated hardware in the same plants.

This booklet was created to help share knowledge and improve the understanding on the basic principles for safe use of process equipment to avoid the hazards of trapped pressure/vacuum.

I strongly recommend you take the time to read this book carefully. The usefulness of this booklet is not limited to operating people; there are many useful applications for the maintenance, design and construction of facilities.

Please feel free to share your experience with others since this is one of the most effective means of communicating lessons learned and avoiding safety incidents in the future.



Frederic Gil, Process Safety and Fire Engineering Advisor

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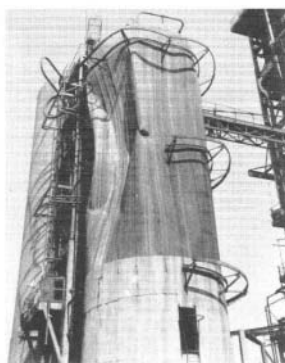
Introduction

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.

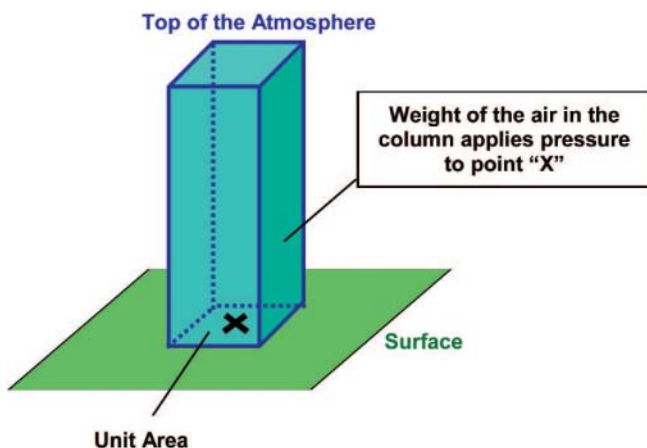
Too much vacuum ruined this catalyst storage drum.



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.

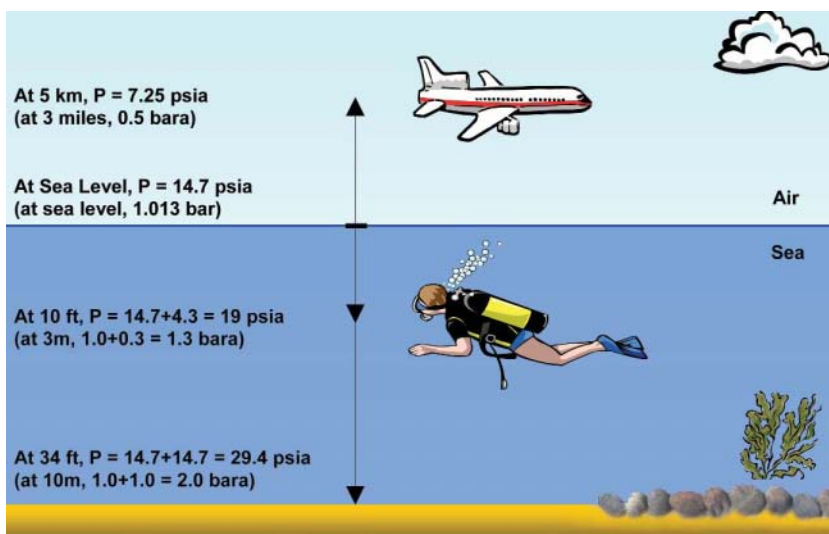
1.1 Theory of pressure and vacuum

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/cm²). So if you swim 10 ft (3 m) beneath the water, the water pressure is 4.3 psi (0.30 kg/cm²). Add to that the air pressure of 14.7 psi (1.03 kg/cm²) 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/cm²)!



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 ₂ O
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 ₂ O	=	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. H₂O').

**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;

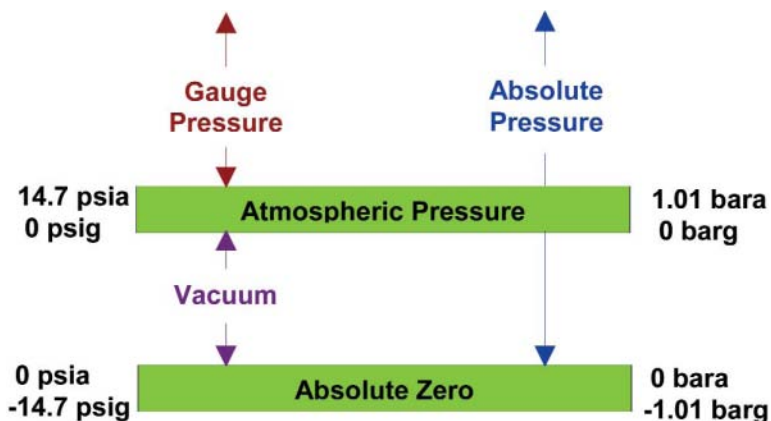
The relationship between the two is simple:

$$\text{Absolute Pressure} = \text{Gauge Pressure} + \text{Atmospheric Pressure}$$

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.m³/(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.

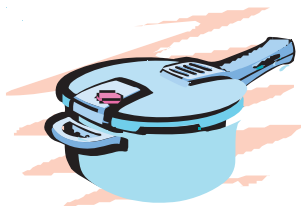
(R is a constant number and it does not change under any condition)

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

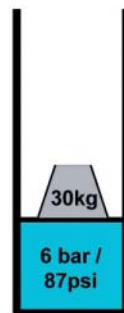
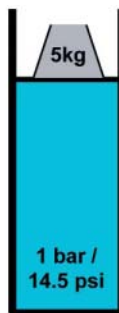
- *Put more gas in the container.* For example, pumping air into a car tyre. As you pump more air molecules into a fixed volume, the greater the pressure these molecules exert on the sides of the tyre.



- *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

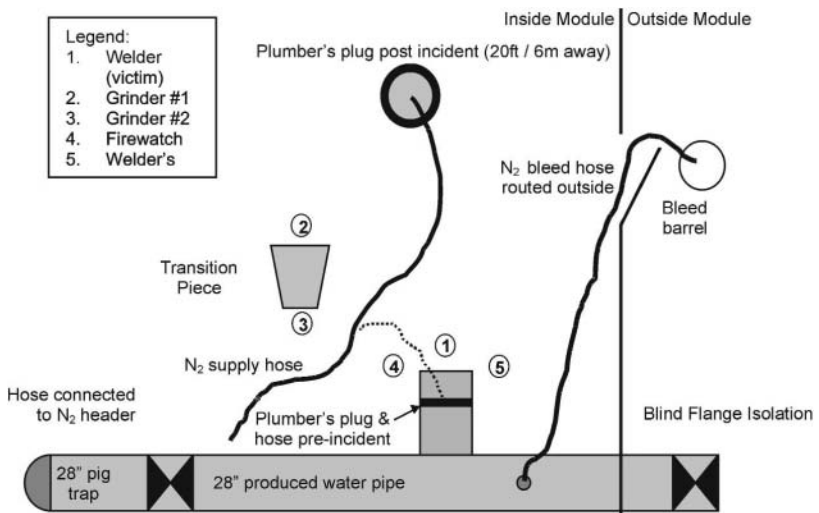
Small pressure generates big force behind plumber's plug!

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 0°F (–18°C). 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



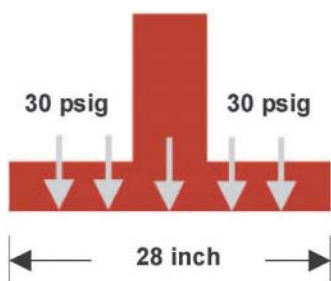
View of the 28 inch (71 cm) pipe



View of mechanical plug

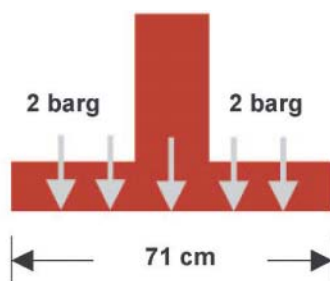
1.6 Pressure-force relationship

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 in² (3,960 cm²). Applying 30 psig (2.07 barg) of pressure to the area can generate a force of great magnitude



$$\begin{aligned}\text{Surface Area} &= \frac{\pi d^2}{4} \\ &= \frac{3.14 \times (28)^2}{4} \\ &= 616 \text{ in}^2.\end{aligned}$$

$$\begin{aligned}\text{Force} &= \text{Area} \times \text{Pressure} \\ &= 616 \text{ in}^2 \times 30 \text{ psig} \\ &= 18,480 \text{ pounds!}\end{aligned}$$



$$\begin{aligned}\text{Surface Area} &= \frac{\pi d^2}{4} \\ &= \frac{3.14 \times (71)^2}{4} \\ &= 3960 \text{ cm}^2.\end{aligned}$$

$$2.07 \text{ barg} = 2.11 \text{ kg/cm}^2$$

$$\begin{aligned}\text{Force} &= \text{Area} \times \text{Pressure} \\ &= 3,960 \text{ cm}^2 \times 2.11 \text{ kg/cm}^2 \\ &= 8,356 \text{ kilograms!}\end{aligned}$$

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 $\frac{1}{4}$ 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!

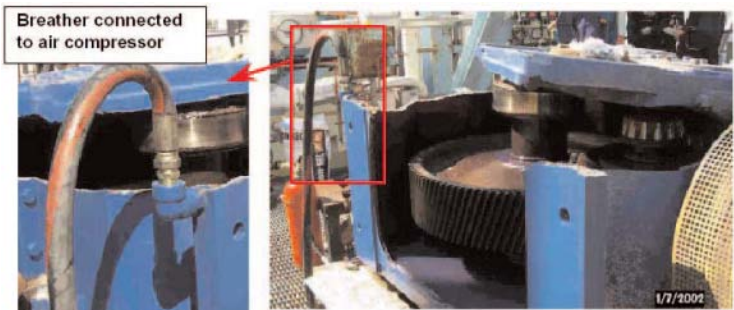
Many operators find it hard to grasp the power of compressed air. An incident took place where the end was blown off a pressure vessel, killing two men, because the *vent was choked*. Compressed air was being blown into the vessel to prove that the inlet line was clear. It was estimated that the gauge 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.'

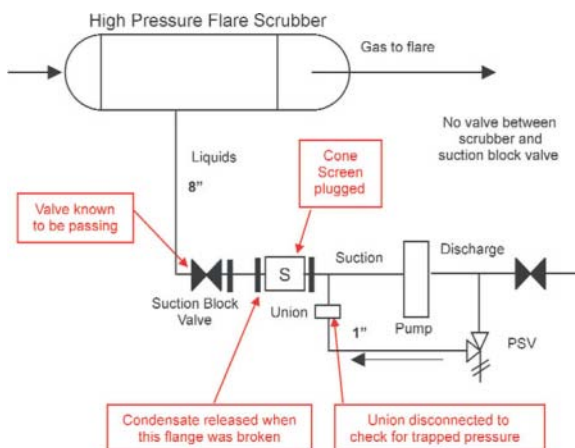
To avoid injuries of this sort we should always use the correct protective hoods and eye protection when breaking joints on lines that could have some residual corrosive liquids trapped under pressure, either because the pressure cannot be released through a valve or because lines may still contain hidden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

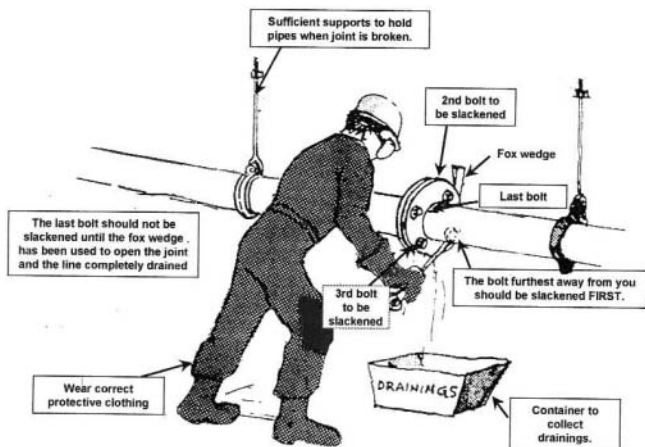
ACCIDENT Two died while breaking flange!

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:

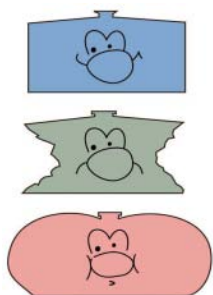
- The design of the door or cover should allow it to be opened about ¼ inch (6 mm) while still being capable of carrying the full pressure, and a separate operation should be required to release the cover fully. If the cover is released while the vessel is under pressure then this is immediately apparent 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.

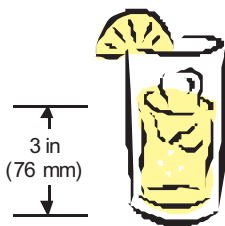
Vessels that have to be opened up as part of normal operating procedures (for example, pig launchers/receivers) should be fitted with an interlock arrangement to remove any possibility of the door being opened prior to the vessel being completely depressurized.

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).

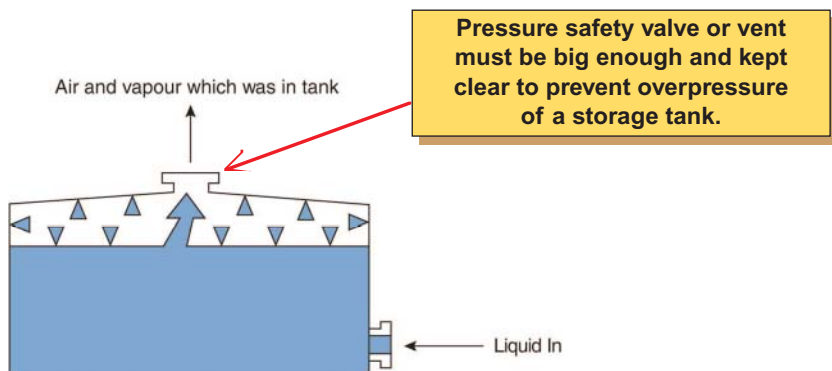


1 inch (25 mm) water gauge is the pressure at the bottom of a small bottle of cologne (1/30 psig, 0.002 barg).

Atmospheric fixed roof tanks may only:

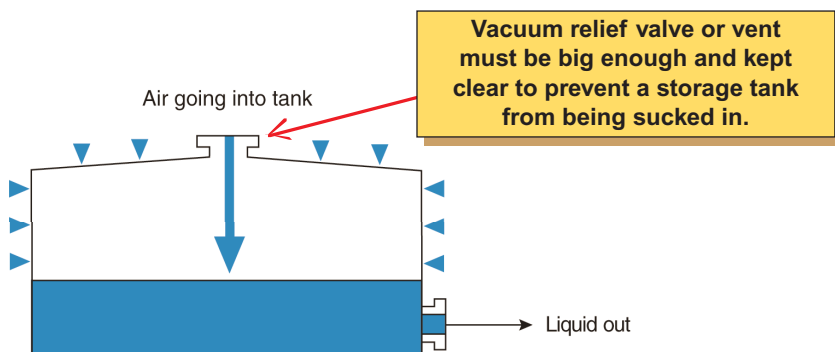
- withstand an overpressure of 7.5 mbar (3 inch or 76 mm of water);
- withstand a vacuum of 2.5 mbar (1 inch or 25 mm of water);
- have weak shell-to-roof welds that open (fish mouth) to minimize damage in the event of overpressure.

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*

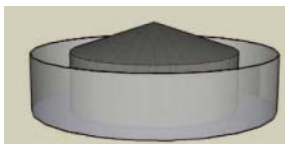
ACCIDENT Bottom weld rupture!

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 realigning 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.



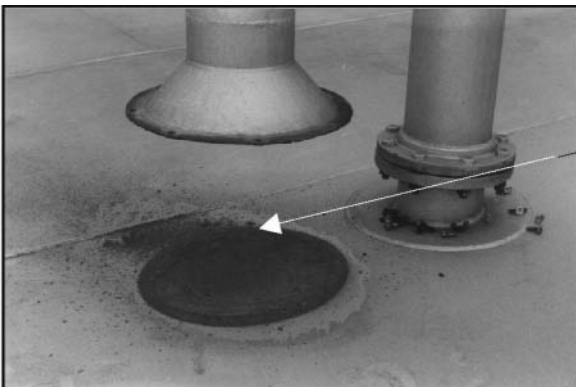
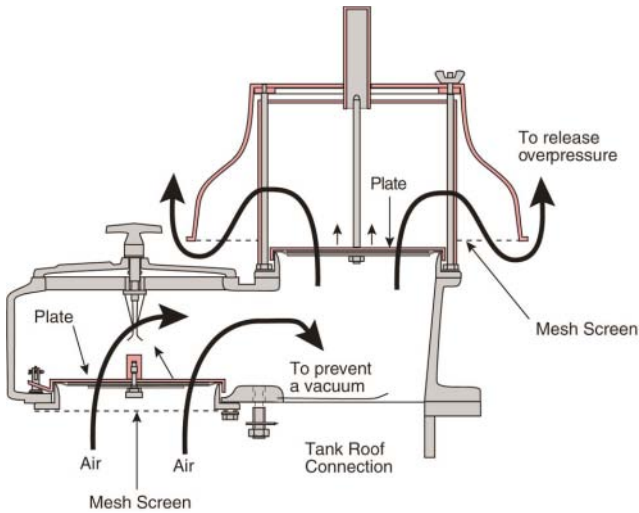
The ruptured blowdown tank.

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 partially 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 overpressurized, 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!

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 compromised and the tank bulkhead was pushed into the adjacent void. This caused 20 gallons of hot ($>212^{\circ}\text{F}/100^{\circ}\text{C}$) product to be released from a drain hole in the void space.



Damaged tank compartment joint

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.

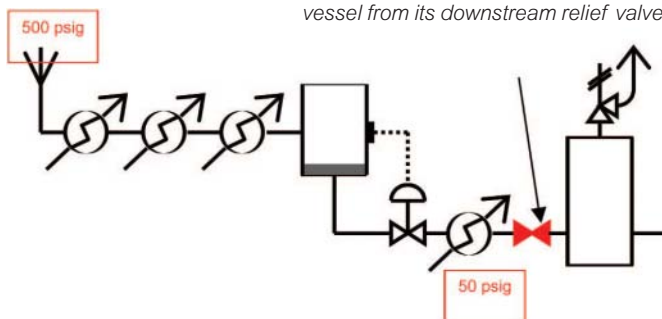
ACCIDENT Late modification on ethylene plant start-up!

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.

Valve was added during construction as a modification. This valve was closed during start-up, isolating the vessel from its downstream relief valve.



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 $-30^{\circ}\text{C}/-22^{\circ}\text{F}$) 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.

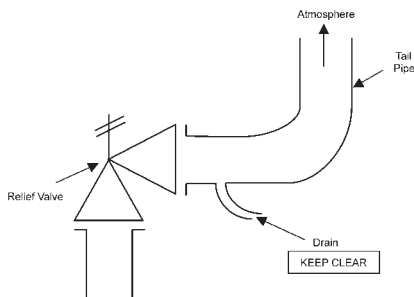
ACCIDENT Geysers!

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.

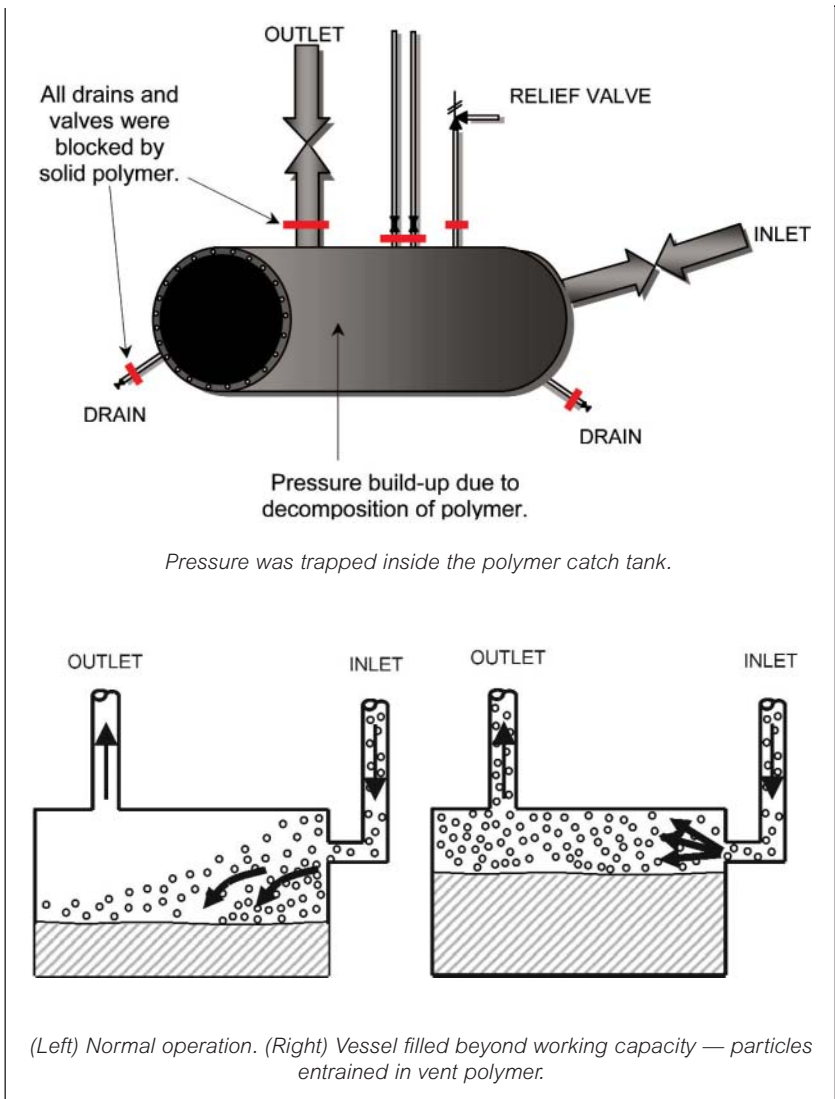


Polymer catch tank after the incident. Its cover was blown a few feet away.



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

Continued



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

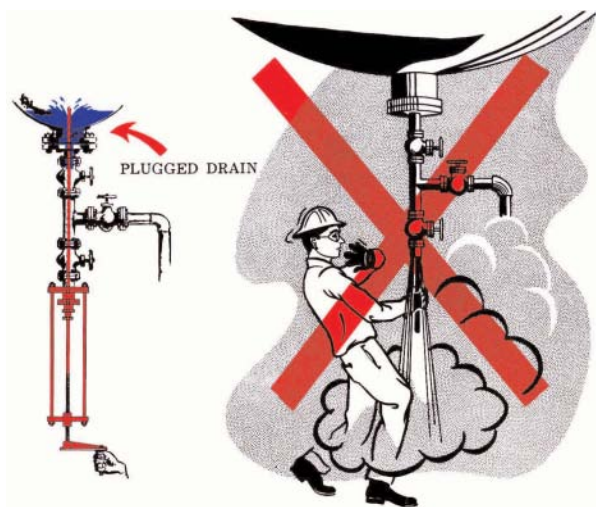
As many past incidents have shown, the clearing of blocked drains is a hazardous operation for which we really do not have a satisfactory and totally practicable answer. In the past, a number of techniques have been considered, but often the safest advice was to close the system down when it was not 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.

HAZARDS OF TRAPPED PRESSURE AND VACUUM

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.

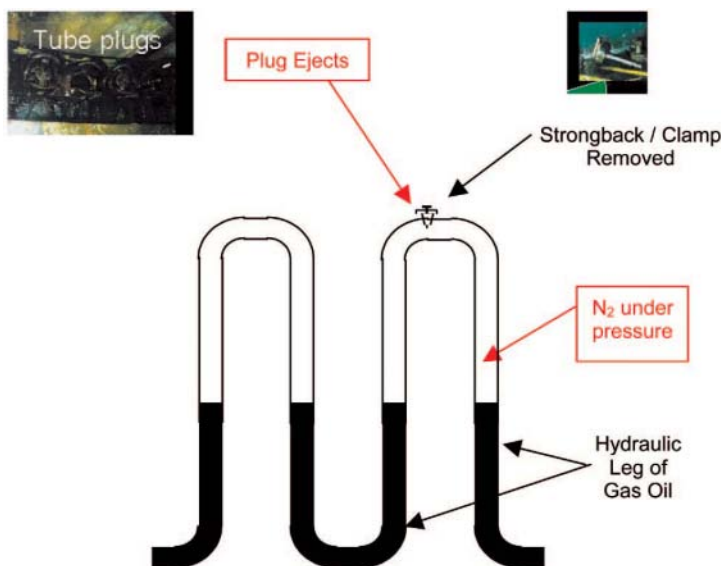


All plugged drains and bleeders must be opened safely.

2.4 Hydraulic legs

ACCIDENT Hydraulic legs can kick!

Contractors were trying to open furnace tubes to decoke them on a visbreaker unit. Nitrogen had been injected at 12 bar (174 psi) as part of the gas-freeing procedure and was trapped at the hydraulic pressure of gas oil in the tube legs. When the clamp was removed, the plug was ejected with great force striking one contractor's head. He was seriously injured.



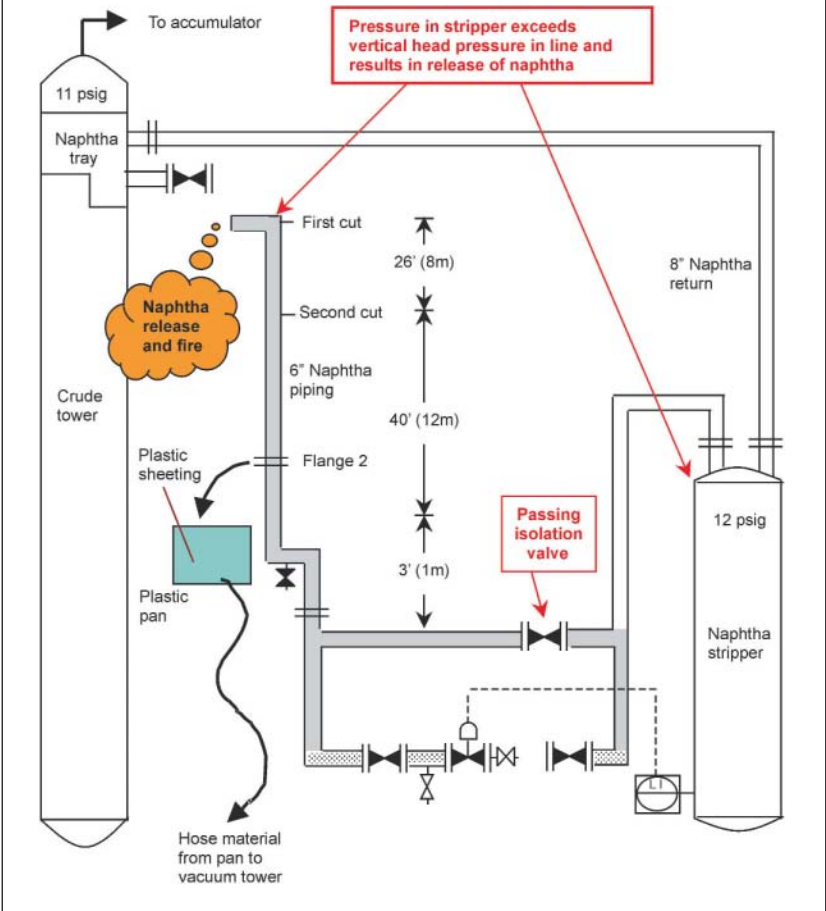
ACCIDENT High backpressure pushed liquid naphtha out of piping!

A leak was discovered at the top elbow of the naphtha piping, near where it was attached to the crude tower at 112 ft (34 m) above grade. Inspection showed that it was extensively thinned and corroded. To replace it, numerous unsuccessful attempts to isolate and drain the naphtha piping were made. Nonetheless, the line replacement was still scheduled while the unit was in operation.

On the day of the incident, the piping contained approximately 90 gallons of naphtha, which was being pressurized from the running process unit through a leaking isolation valve.

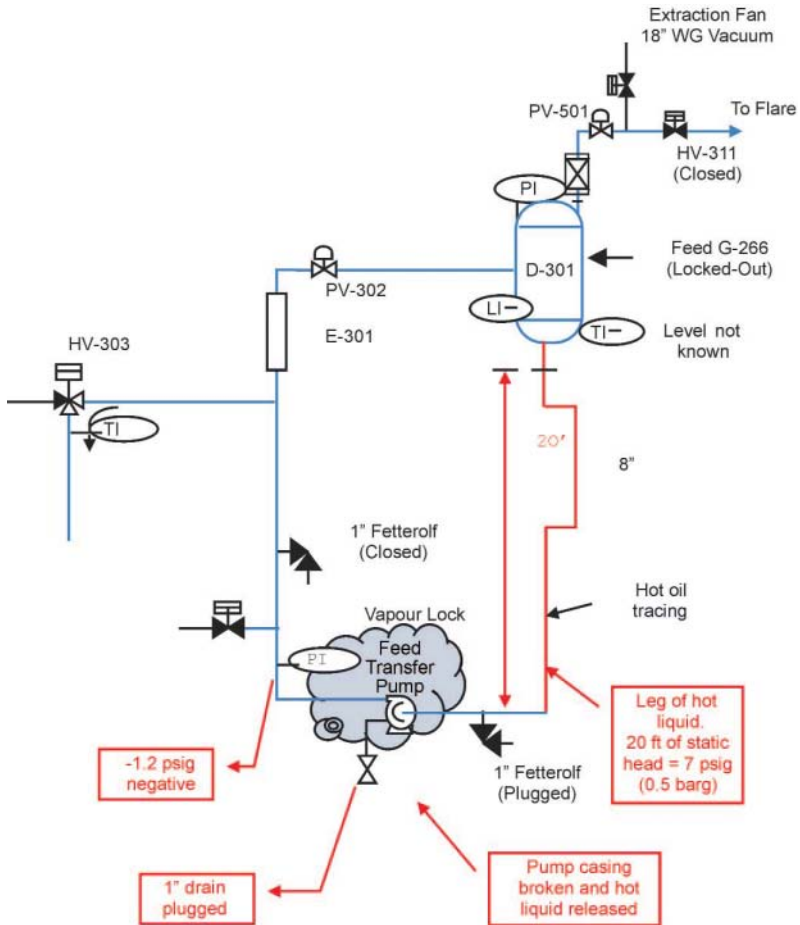
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After several unsuccessful attempts to drain the line, workers made two cuts into the piping using a pneumatic saw. After a second cut, naphtha began to leak. The supervisor directed the workers to open a flange to drain the line. As the line was being drained, naphtha was suddenly released from the open end of the piping that had been cut first. The naphtha ignited, most likely from contacting the nearby hot surfaces of the crude tower, and quickly engulfed the tower structure and personnel.



ACCIDENT Remaining hazards not identified!

Two maintenance technicians were badly burned with hot butanediol when they opened a pump casing. The plant had been shut down and flushed overnight, but changed procedures and line blockages allowed vapour locked hot liquid to be held in the piping until the pump casing was opened when it sprayed out over the two technicians.



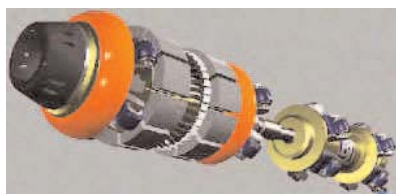
2.5 Trapped pressure in pigging operations

Pigging operations, commonly undertaken for pipeline inspection or cleaning, are potentially dangerous operations because they involve high pressures to drive the pig from one end of the pipe to the other. Due to the potential for release of high pressure, pig launching and receiving operations demand careful attention and safe execution of each task in the correct sequence. The four incidents described in the next pages show that pigging can be a risky operation.

What are pigs or spheres?

Pigs or spheres are devices used primarily to remove scale and debris from long runs of piping. There are a wide variety of shapes and styles of pigs available; the simplest being the round ball type used to push liquids out of gas lines, to the fully instrumented intelligent pigs used to measure pipeline thickness/conditions. The pig launcher is used to launch a pig. This serves as the entry point and mechanism for inserting the pig into a live pipeline. Pig receivers are used to collect pigs. Pig launchers and receivers are sometimes collectively known as ‘traps’.

‘PIG’ is sometimes interpreted as a ‘pipeline inspection gauge’. They are usually cylindrical or spherical. Some pigs are as simple as teflon spheres while others are equipped with sophisticated devices, for example, for pipeline thickness measurement.



Various types of pigs.

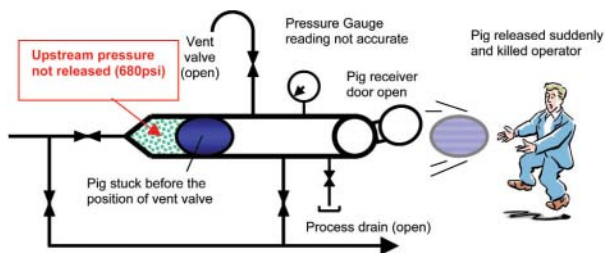
The following four pigging incidents span over 20 years; ideally lessons should have been communicated and learned over this period on how to avoid incidents with this equipment. Remember that a pig trap, when incorrectly used, is nothing but a big air canon, as the following incident shows.

ACCIDENT Fatal incident—struck by a pig!

A trainee operator died from serious injuries after being struck by a pig ejected from the pig receiver. A senior operator and the trainee operator, who was only three weeks into his 'on-the-job' training, isolated the pig receiver from the natural gas pipeline that operates at 680 psig (48 kg/cm²g). The pressure inside the receiver was released to atmosphere by opening the following three valves:

- a 1-inch (25 mm) vent valve located nearest the main isolation valve;
- a 2-inch (50 mm) drain valve near the receiver's door;
- a weep vent valve located on the actual receiver's door.

The senior operator stated that they heard the gas depressurize through these valves and the pressure gauge's reading dropped to zero. (Pressure gauge for high pressure ranges are inaccurate at low pressures and it was later found that zero was equivalent to 20 psig/1.45 kg/cm²g). The operators then opened the receiver's door, a task that could not have been undertaken if there was any pressure behind the door. The pig was not located within easy reach of the door. The senior operator asked the trainee to wait while he went to his truck to pick up a mirror so that he could reflect light down the barrel to see where the pig was lodged. He heard a loud pop as he proceeded to his toolbox on the truck. He then found the trainee fatally injured.



Investigations revealed the following findings:

- The pig did not arrive at the receiver barrel door as desired. It was lodged under pressure and out of sight in the receiver barrel. The pig was stuck in the barrel and would have blanked off the upstream vent line, thus preventing depressurizing.
- The company had a written safety program, but nothing specific to pigging operations. There was no written Standard Operating Procedure (SOP) or emergency procedures established by the company for the operators to follow during pigging operations.
- There was no proper equipment to perform the job, thus resulting in the senior operator resorting to use a mirror to reflect light into the receiver barrel.
- This was the first time that the trainee operator went to this site to receive 'on-the-job' training when he was killed. The company did not have a formal training program with regard to pigging operations. It relied on whatever experience and expertise current employees had for training new employees on the job.

ACCIDENT Another incident occurred where the receiver was not depressurized before opening. Look at the impact on the pipe done by the ejected pig (missile).

pig



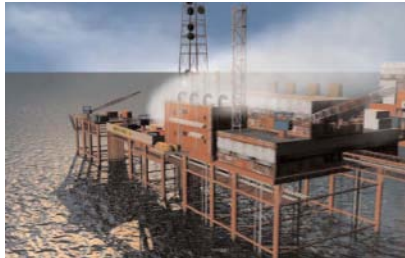
All pig launchers and receivers should be subject to a process hazard analysis to ensure that the design has adequate safety features and that procedures/interlocks are sufficient to prevent operators from following an incorrect sequence of tasks.

ACCIDENT O-ring of pig launcher failed and ethylene released!

A smart pig (internal inspection tool) was launched but the data collected was unsatisfactory so a second launch was planned. The pig launcher was left floating on the ethylene pipeline at 1,700 psig (120 barg) for 28 days between the first and second launches. This caused the launcher door and its new viton O-ring to be exposed to high pressure for an extended period. Viton absorbs high pressure ethylene, resulting in destructive decomposition that damages the physical structure of the O-ring seal. During the second launch, the O-ring failed and ethylene was released.

It was found that each technician had a different idea of the correct way of closing and tightening the trap and launcher doors. 'Aflas' is recommended by the vendor over 'viton' for high pressure ethylene service.

ACCIDENT



A major gas leak occurred on a platform when an O-ring seal failed on the door of a vertical pig trap—the gas cloud drifted over the platform without finding an ignition source. Previous minor leaks were solved by increasing the diameter of the O-ring seal without addressing the root cause—corrosion over decades of service had increased the gap between the flanges from less than 0.2mm, the diameter of a human hair, to around 4mm, half the diameter of the O-ring.

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

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

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.

ACCIDENT Powerful pig overturned front loader!

A near-miss pigging incident occurred when a contractor was dewatering a 10 mile (16 km) section of pipeline after a hydrostatic test. A foam pig was being pushed with air to displace the water. The pig got stuck and contractors began pressuring up the section to approximately 400 psig (28 barg). The water was being removed from a 12 inch (30 cm) bypass line. Having decided that a restriction had inhibited the pig from moving freely, they opened the end of the temporary trap. At this point, the pig was experiencing an upstream pressure of 400 psig (28 barg) against ambient pressure downstream. The differential force was almost half a million pounds!

In order to 'catch' the pig, a large front loader was placed in front of the open trap. The pig shot out of the trap, completely flipped the loader and continued to fly approximately 150 yards (137 m) in the air, destroying a wooden platform along the way. The foam pig broke into pieces after leaving a trail of destruction.

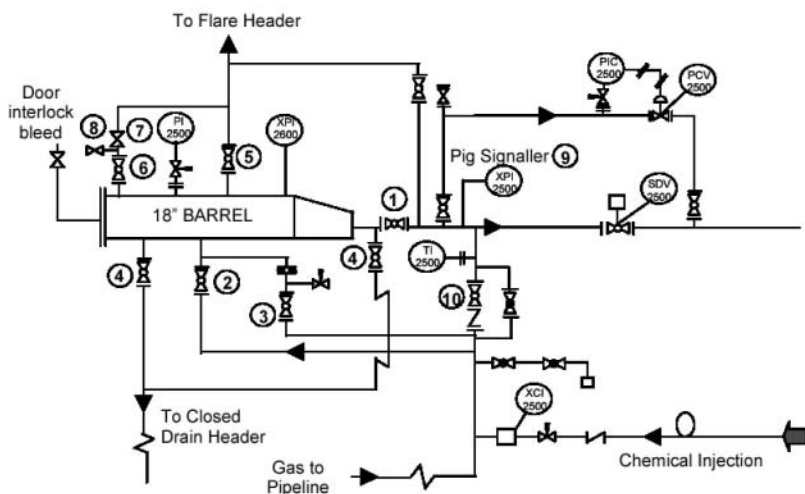


(Top left) This is the pig trap after the incident. (Right) The large front end loader was completely flipped over by the ejected foam pig.

Recommendations and good practice for pigging operations

- Develop written Standard Operating Procedures (SOPs) that include step-by-step tasks for accomplishing pigging operations. Provide the proper equipment to carry out the task, including torch light (not mirror), probing device, etc.
- Post warning signs at the job site (e.g. 'Do not stand in front of receiver barrel door', 'Follow Standard Operating Procedures').
- Post the task-by-task instruction adjacent to the receiver/launcher.
- Install a pig indicator at the very end of the pig receiver barrel. This will give a positive indication that the pig is in the position/location for safe removal.
- Establish comprehensive pigging procedures that include actions and precautions to be taken in case of trapping, blockage or other extraordinary situations.
- In case of trapping, calculate the force anticipated and plan accordingly. Never have anyone or critical equipment in the path of a pig. Crack open traps to release pressure in stages instead of opening abruptly.
- Consult pig launcher/receiver manufacturer's instructions and understand all possible limitations before launching or receiving a pig.
- After a hydraulic test, depressurize and dewater the line to atmosphere first before launching the pig.
- Before pigging, inspect all restrictions and bends of the pipeline to ensure that they are big enough to accommodate the pig that will be used.

An example of pig launcher/receiver design



The sample procedure that follows details the steps necessary to launch a pig. The valve numbers in the instruction correspond to those marked on the schematic diagram. You may assume that at least two trained operators are launching the pig for the gas line.

An example of step-by-step tasks for pig launching

1. Ensure that the pig trap outlet valve (1) and both barrel inlet valves (2) and (3), two drain valves (4) and vent valves (5), (6), (7) and (8) are fully closed prior to start of launch procedure.
2. Open vent valve (5) to vent pressure from launcher. Close valve (5). Do not open end closure door until launcher is completely vented to atmospheric pressure and check this by opening valve (6) and bleed valve (8) while valve (7) remains closed. Then, close valves (6) and (8) afterwards.
3. Check that Pressure Gauge PI-2500 reads zero.
4. Open end closure door fitted with an interlock bleed and insert the pig until the front cup reaches the reducer, past the Pig Signaller XPI-2600 on the barrel.
5. Close end closure door and interlock bleed. Ensure door is completely shut and sealed.
6. Ensure Pig Signaller XPI-2500 (9) is set to indicate passage of pig.

7. Open vent valve (5) and open small bore barrel inlet valve (3) slightly to purge air from the launcher.
8. Fully close vent valve (5) and slowly bring the launcher up to main-line pressure by opening full valve (3).
9. Check Pressure Gauge PI-2500 is at full main-line pressure.
10. Fully close valve (3), before the pig trap outlet valve (1) is fully opened, to avoid damage to the pig as it exits the launcher.
11. Fully open the pig trap outlet valve (1).
12. Fully open the main inlet valve (2). If pig does not immediately exit launcher as indicated by Pig Signaller XPI-2500 (9), slowly close the main launcher bypass valve (10).
13. Confirm that pig has been launched and passed through Pig Signaller XPI-2500 (9).
14. Fully open the main-line inlet valve (10).
15. Fully isolate the launcher by closing the pig trap isolation valves (1) and (2).
16. Depressure the launcher by opening slowly vent valve (5) followed by the two drain valves (4). After that, the launcher remains depressurized with vent valve (5) and (7) and two drain valves (4) closed.

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

Double isolation valves

Beware of passing valves and use double gas tight valves for isolating high pressure gas systems. Refer to Oil Industry Advisory Committee's (OIAC) publication *The Safe Isolation of Plant and Equipment* [ISBN 0 71760 871 9].

Pig position signaller

Many pig receivers incorporate pig signallers—one at the barrel and the other at the adjacent incoming pipe. This tells the operator that the pig has arrived



before commencing the opening sequence. These signallers need careful maintenance as they can easily get blocked by corrosion, particularly aluminium alloy parts in maritime atmosphere.

Interlock system for safe pig trap operation

The greatest hazard associated with accessing pressurized vessels such as pig traps is the risk of opening the trap while it is still pressurized or contains residual hazardous product. For this reason, the only reliable way to prevent the possibility of

unsafe opening is to interlock the pig trap opening mechanism with the trap's vent and/or drain valves.

The interlock system that is used on the trap door can range from any number of options, such as:

- A mechanical system that requires the use of a key to unlock the door. This key is only released if the vent valve and/or drain valve on the receiver has been opened.
- An electronic system whereby a locking bar is held in place to keep the door shut and can only be released once a permissive condition (for example, pressure inside the receiver drops to zero) has been met.

The valve and pressure interlock arrangements ensure that all the valves are operated in the correct sequence and that the closure door cannot be opened if there is any residual pressure inside. Pig trap suppliers are now offering a range of options for accomplishing door interlocking. Traps without door interlocks can also be retrofitted. Whichever system is used, it is important to ensure that it is failsafe and that it does not remove other critical manual checks required within the procedure.

The operation of isolation block valves on pig traps must be treated as critical safety tasks since they have to be operated whilst the pipeline is in service.

Note: Some pig traps are located in confined space area such as weather protection enclosures in underground pits. Access to these areas should be restricted and permitted only after atmosphere testing, particularly when nitrogen is used (refer to BP Process Safety Booklet *Hazards of Nitrogen and Catalyst Handling*).

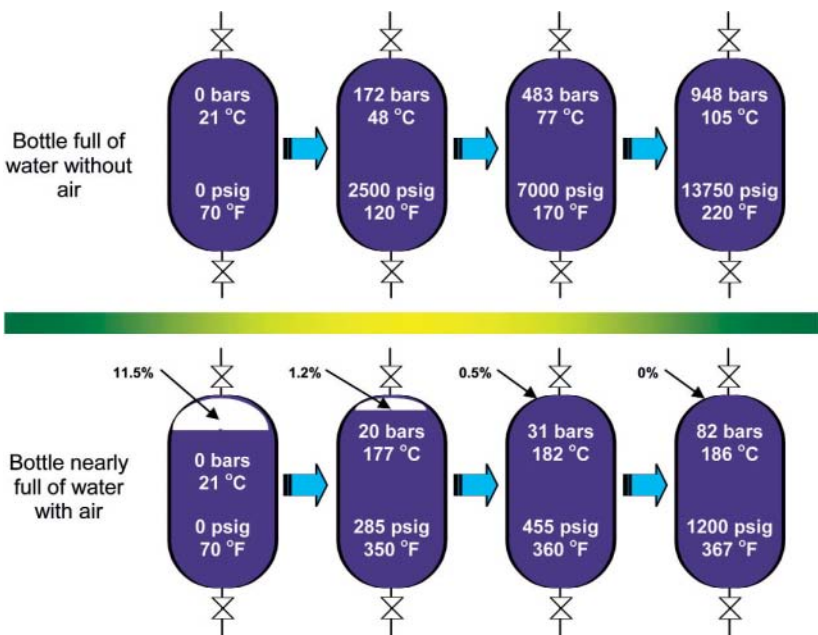
2.6 Thermal expansion

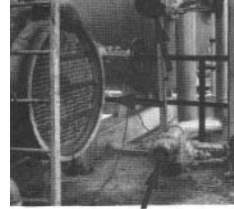
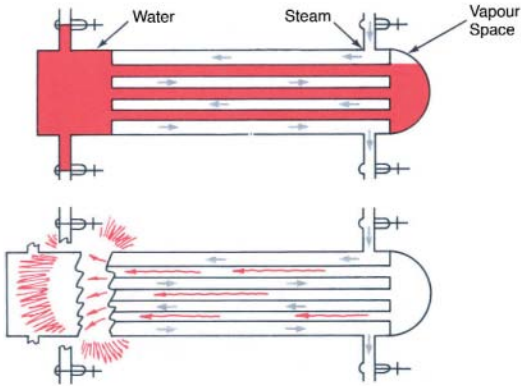
Most liquids cannot be compressed. This has an advantage—the pressure loss is nearly instantaneous should a leak occur. That is why all pressure proof tests are made with a liquid, mainly water or gasoil, never with a gas that accumulates energy when compressed (this is how an air rifle works...). However, there is a disadvantage—if there is no vapour space to absorb pressure when compressed, a liquid quickly builds up a high pressure when it is fully confined and heated.

Remember that a vessel full of:

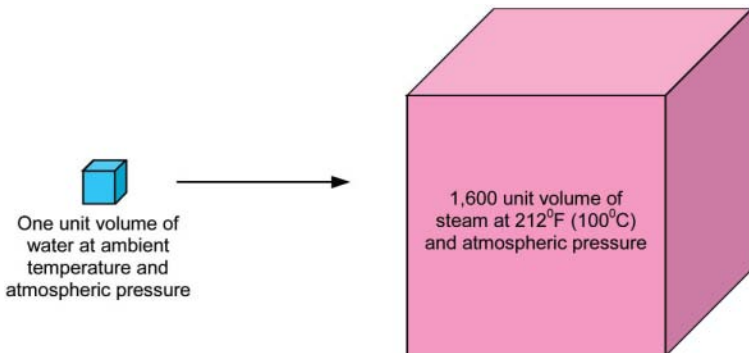
- water will see its pressure increase by 6 bar (87 psi) for each degree celsius rise in temperature;
- LPG will see its pressure increase by 10 bar (145 psi) for each degree celsius rise in temperature.

The resulted increase in pressure can lead to the rupture of pipes or vessels if there is no means of escape for the overpressure. This is why thermal pressure relief valves are necessary and must not be isolated.



ACCIDENT Thermal expansion is dangerous!

Thermal expansion in this condenser resulted in serious injuries to personnel and caused extensive property damage. The condenser was opened and cleaned. The cast-iron heads were replaced, followed by a hydrostatic test to the tube side. Without venting the water side, a steam hose was connected to the shell side for testing. Thermal expansion plus vapour pressure in the tubes ruptured the condenser with a jet-like thrust. See arrows marking rupture points.



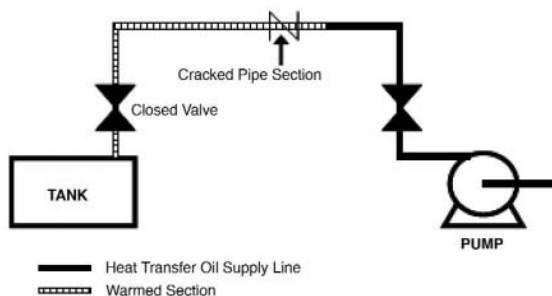
There is a 1600x increase in volume when water is heated to steam.

ACCIDENT Danger of water in hot heavy oil storage!

An explosion and fire at a refinery was believed to have been due to water entering a hot heavy oil tank (decanted oil). The rapid generation of steam caused the overpressure of the tank. There have been a number of 'water explosion' incidents over the years because of poor temperature indication and control in the tank, lack of rundown temperature control, sudden disturbance of tank bottom layers, etc. In the 1970s, a major disaster occurred at a site with multiple fatalities when a lube oil autoclave bottom water layer 'boiled up'. It had been forgotten to keep the mixer operating through the heating cycle. The atmospheric rated vessel was subjected to pressure, ejecting it through the building and 'off site'.

ACCIDENT Warming up of a closed and filled line!

A line at a polymer plant was carrying heat transfer oil whose freezing point was 12°C (54°F). Ambient temperatures were low. To prevent solidification of the oil due to low ambient temperatures under no flow conditions, a steam tracing system had been included in the design. During start-up, the line was only partially pre-warmed. The oil from the pre-warmed section expanded, building up pressure in the blocked pipe. The line was also blocked by a closed valve. Eventually, the pipe developed a 200 mm (8 inch) crack and spilled its contents on a road.



This is a typical tank farm incident and that is why isolation of long lines must include a check of the thermal PSV locations.

ACCIDENT Deadhead flange cracked in pieces!

A cast iron deadhead flange on a pipe that was not fitted with a thermal relief valve burst/cracked due to high ambient temperatures [low 30°Cs (80°F)] spraying liquid hydrocarbons onto the adjacent ground. The spillage was limited to the amount between two shut block valves, approximately 20 gallons (75 litres).



Sections of LPG lines that can be blocked in by valves should be protected from overpressure by thermal relief valves.

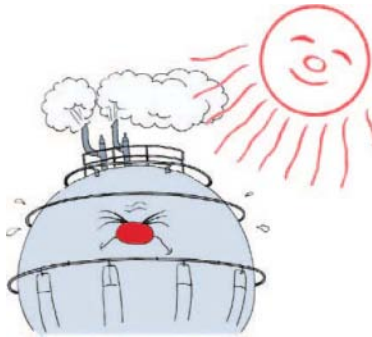


HAZOPs must check the need for thermal relief under the deviation 'higher temperature'. All possible causes for higher temperatures must be identified and studied.

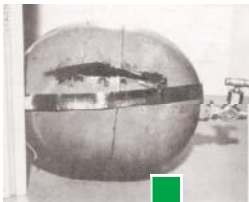
Lifting of relief valve of an overfilled vessel caused by thermal expansion.



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



ACCIDENT



A 2 litre bottle was filled with butane at 15 bar (220 psi) and -3°C (27°F). Test pressure was 34 bar (500 psi).

The laboratory ambient temperature was 24°C (75°F), giving rise to pressure of more than 67 bar (975 psi). This resulted in rupture of the bottle and ignition of its content, destroying the laboratory.



ACCIDENT Another effect of thermal expansion in an LPG sampling bottle.



Remember that some items of equipment such as LPG sampling bottles are not fitted with thermal relief valves so:

- use only sampling bottles for LPG with an internal pipe;
- follow the sampling procedure;
- always leave a vapour space of at least 20% in the sampling bottle.

ACCIDENT Pressure cooker!

This pressurized spray can baked in the sun in a car with the windows rolled up. Then it exploded, blowing out the back window. This is just one example of what can happen when a pressurized, over-the-counter spray can exceeds the 120°F (50°C) temperature limit listed on the can. Warnings and instructions are posted on cans, but most people do not read the label until it is too late.



Paint spray can.

The examples above explain how compressed gas cylinders are sensitive to temperature rises. It is therefore not surprising that under fire condition they may explode and present a serious hazard to workers and responders. See also Section 2.12 in this booklet.

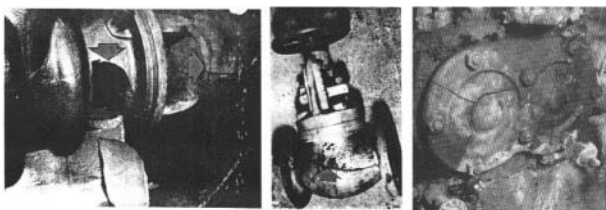
Refer to British Compressed Gases Association Guidance Note 15 *Managing Gas Cylinders Involved in a Fire*, 2004.



This gas bottle was involved in a spill fire and exploded.

Gas cylinders must be kept away from potential fire areas as far as reasonably possible: remove them from process areas or storage tank bunds when not in use.

2.7 Ice or hydrate formation



Freezing water can burst equipment and cause serious losses.

Ice is solid, crystalline water. When frozen, water molecules are arranged in wide lattice in an orderly fashion, occupying more volume for a given mass. Thus, ice is less dense than water and it floats. If a pipeline or vessel is filled full of water and blocked at both ends, the water may freeze during winter and burst the equipment. Therefore, winterization programmes must be developed and followed for plants in temperate climates.

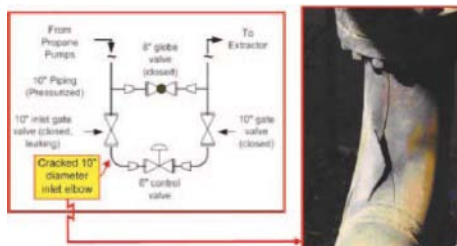


Process lines often have branch connections which are used intermittently. Water may collect in the lines and freeze in some climates, fracturing lines or valves.

A hydrate is a compound which has water chemically combined within it. Though incidents associated with hydrate are rare, hydrate is usually formed in wet natural gas pipeline and may cause the same problems as ice.

ACCIDENT Major propane release from frozen pipe 'dead-leg'

In a propane deasphalting unit, a redundant pipe elbow cracked after water in the 'dead-leg' froze (see drawing and photograph) and then thawed releasing liquid propane to atmosphere.



The propane cloud traveled downwind and was likely ignited by the boiler house. The flames flashed back to the source creating a jet fire. The

Continued

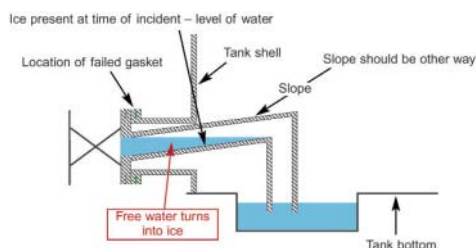
resultant fire caused extensive damage and the refinery had to be completely shut down for two months.



For more details on this incident, refer to US Chemical Safety Board Report No. 2007-05-I-TX dated July 2008.

ACCIDENT Ice in water draw-off line!

A flange gasket failed on a water draw-off line of a gasoline storage tank during a thaw following prolonged freezing temperatures, resulting in the loss of 13,750 gallons of gasoline.



Outlet branch with plug of ice.



Failed joint.

ACCIDENT Knock-out pot on air compressor bursts!

A small amount of water had collected in the non-return/check valve while in the closed position (compressor cut-out on pressure switch control). Severe frost had caused the water to freeze so that when the compressor cut in again, the discharge line was blocked in and the pressure rose rapidly beyond design.

ACCIDENT Isobutane leak from outlet flange on Hortonsphere!

The ambient temperature had been extremely low for some days so failure of the flange may have been caused by freezing water or, it has been suggested,

Continued

through the formation of hydrate. Hydrate formation is experienced during periods of low ambient temperature more commonly in gas lines; this was the first experience of it with liquid butane lines. Hortonspheres are drained on a weekly basis and only trace amounts of water are normally found. In this instance some additional water may have accumulated in the bottom of the sphere due to steaming out to remove air in preparation for commissioning following a recent inspection or from exceptionally wet butane (steam condensate is sometimes used to relieve fouling in the LPG splitter feed preheaters).

ACCIDENT Jet fuel tank spill!

A spill of about 8,200 barrels of Jet-A fuel from a broken sight glass on a storage tank's water drainage piping occurred when the sight glass was broken due to expansive forces exerted as water in the piping froze.

ACCIDENT Explosion and fire due to freeze-up in deadleg!

An explosion and fire occurred in the pipe alley of a Vacuum Distillation Unit. The incident was caused by the freeze-up and subsequent failure of a 2 inch (50 mm) carbon steel pipe which released a high pressure spray of light hydrotreated naphtha towards the vacuum furnace and transfer line, where it ignited. Total cost of the incident is estimated at \$14 million—\$10.5 million in production losses, the remainder in maintenance and associated costs. The failed line had been taken out of service approximately 20 years before, but had never been fully isolated or decommissioned. The piping acted as a large pocket or 'dead leg', allowing water to accumulate. As the result of an extreme cold front, the trapped water froze, expanded, and cracked the pipe. During a subsequent warm up of the weather the next day, the ice plug melted, releasing hydrocarbon.

ACCIDENT Water froze in deadleg!

A section of utility piping failed in a distillate desulfurization unit. The failure was the result of internal overpressure generated from water freezing in a dead leg section of piping. There was a release of hot product from the stripper section of the hydrotreater. The resulting vapour cloud ignited, and fire damage to nearby equipment released additional hydrocarbon. Although the unit was quickly isolated, there was extensive damage to pumps, several air coolers, analysers, instrumentation, electrical conduits, and process piping. Direct damage to the unit was \$5.9 million, and the unit was down for 52 days.

- Out of service pipelines and 'dead-legs' must be identified by operators and during the PHA revalidation and MOC processes. They should be removed if reasonably practicable to do so and, in the interim, the mechanical integrity should be assured through the inspection and freeze protection programme, or the lines positively isolated.
- 'Dead-legs' should be carefully monitored in the piping inspection programme since the stagnant end may also corrode at a much higher rate in addition to accumulating more water.
- It is good practice to check for leaks immediately when freezing stops (i.e. when temperatures allow possible ice plugs to thaw).

2.8 Leak and pressure testing

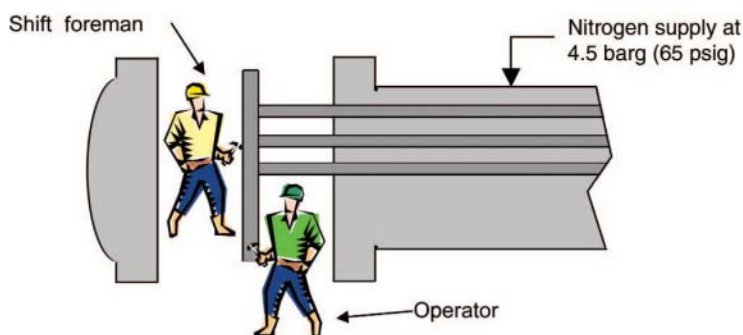
Compressed gas is dangerous and must be employed with caution. Numerous accidents have occurred and a few examples are given below. They demonstrate that leak tests using air or nitrogen at low pressure can kill...

ACCIDENT Ejected bundle!

A leak test on a heat exchanger was being conducted using low pressure gas (4.5 barg or 65 psig) when the tube bundle was ejected with great force striking two employees. One of them died from massive internal injuries as a result of the bundle striking him directly in the chest. The other was seriously injured. It was found that a test ring was not used to secure the tube bundle in case it propelled outwards, and spot welds that temporarily secured the bundle sheet to the shell failed.



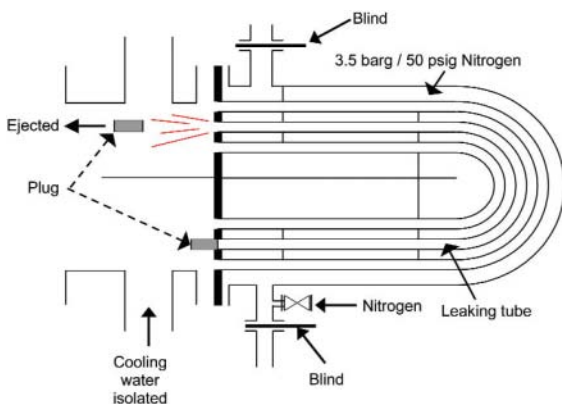
Shift foreman's position
at time of accident.



Location of personnel at the time of incident

ACCIDENT Ejected plug!

Remember that gases accumulate energy when compressed (this is how an air rifle works). Therefore, a system under gas pressure is exactly like a loaded rifle waiting to be discharged.



Exchanger plug blowout.

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

ACCIDENT Drum failed due to corrosion!

A drum was being pneumatically tested for leaks to meet a certain design pressure. The drum failed during the test, blowing off the end of the drum, a 4 ft by 4 ft (1.2 m by 1.2 m) piece of steel, with enough force to throw the plate across the road narrowly missing an employee, who if hit would have certainly been seriously injured or killed.

The tank had design pressure of 125 psi (9 bar) but failed at 80 psi (5.5 bar) because it was badly corroded.



- Never use air or gas for a pressure proof test. The energy stored in a pneumatic test is far greater than for a hydraulic test and therefore hydraulic testing is always safer.
- When carrying out a hydraulic test, always ensure that all places where air/gas could be trapped have been vented and the area around the test barricaded.
- When working on a piece of equipment that may contain residual air or gas pressure, never stand in front of it (for example, heater pipe plug, heat exchanger tube, pig receiver door).

ACCIDENT Fire extinguisher failed due to corrosion!

An operator was killed when he applied a hand-held fire extinguisher to put out a small smouldering fire. Part of the bottom of the extinguisher cracked open when the internal CO₂ cylinder opened (225 psi/17 bar) hitting the fire watch in the chest. The cause of the incident was corrosion outside the bottom of the cylinder under the rubber protective foot. Water entered the rubber lining causing serious corrosion on the outside of the extinguisher. Equipment must be checked regularly and before use.

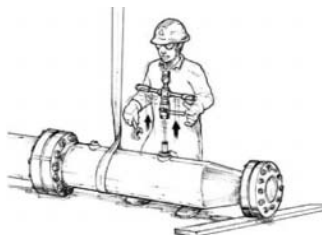
ACCIDENT Tank lift off and land on top of process unit !!!

This incident occurred during a pneumatic test of the tank associated piping. A blind was not installed to isolate the piping, only block valves were isolating the tank from the piping. When pressure was applied, the tank 'lifted off' and was found on top of the unit!



ACCIDENT Fatal testing!

In a welding shop, two workers pressurized two 16-inch 'pig traps' to 150 bars (2,150 psi) to check the welds. Then one of the workers, a young worker, started to disassemble the connection between the piping being tested and the pressure-recording device. However, he did not depressurize the piping pieces first. He used a pipe wrench to remove a test tee from a 1-inch ball valve that isolated the test tee from the piping pieces. The test tee did not unthread from the valve as expected. Instead, the valve itself unthreaded from the pipe nipple connecting the valve to the still-pressurized pig traps. As a result, the valve and the test tee shot upwards, striking the worker and causing serious injuries. He died in hospital after surgery.



For more details and recommendations on this incident, refer to www.WorkSafeBC.com.

ACCIDENT Pressure testing of choke manifold!

Pressure testing was being performed on a offshore well choke manifold up to 5,000 psig (345 barg) inside a pressure test bay at an onshore base. While a workshop foreman and a technician were inside the test bay inspecting the choke manifold for leaks, a thermowell (3/4" NPT) failed and hit the technician in the leg, seriously injuring his right knee.

The force acting upon the thermowell can be calculated as follows:

Force	= Pressure×Area
Test pressure	= 5,000 psi (345 bar)
Affected area	= 0.785 sq ins (5.065 cm ²)
Therefore, Force	= 3,925 pounds (1.8 tons)!



The injury was caused when the technician was struck by a thermowell ejected from a 3/4" NPT female tapping in a 5,000 psig (345 barg) choke manifold during a pressure test.

Continued



=



The 3/4" NPT Thermowell, which is about 9 inch (23 cm) long and weighs approximately 2.2 lb (1 kg), struck the technician on his knee from approximately 20 inch (50 cm). When the thread failed, the stored energy was released and propelled the thermowell at a velocity of 94 mph (151kmh)!



Severe corrosion had affected the mechanical integrity of the female thread. The forces generated by the 5,000 psig (345 barg) test pressure overcame the mechanical strength of the corroded thread and caused the thermowell to be ejected.

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

ACCIDENT Tree handling tool failure during hydrostatic test!

A Christmas tree was hydrostatically pressure tested up to 1.5 times the design pressure of 15,000 psi (1,034 bar). Weighing 460 lb (209 kg), the tree handling/test tool failed and was sent through the roof, travelled in the air, and re-entered the hi-bay approximately 20 ft (6 m) to the South East, glanced off a roof support beam, fell to the floor and came to rest 28 ft (8.5 m) from the impact point, narrowly missing a propane tank on a forklift.



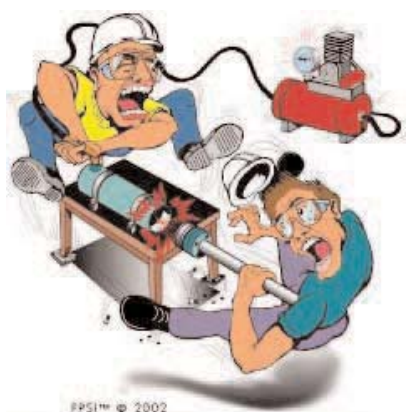
(Left) Test/tree handling tool. (Right) The impact point is 3 ft (1 m) from the propane tank on forklift truck.

Compressibility of water at high pressure leads to a significant potential energy event without having trapped air.

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

ACCIDENT Pressure trapped in pieces of equipment!

A hydraulic accumulator vessel containing oil/nitrogen at 400 barg (5800 psig) suffered a sudden and catastrophic failure. This resulted in the accumulator breaking loose from its mountings, striking the deck above and coming to the rest on another deck of the platform.



ACCIDENT Pressure transmitter calibration incident!

A contract instrument technician had a near miss whilst using a Druck instrument for on-site calibration of a pressure transmitter. Whilst the Druck unit was being 'pumped up' as part of the testing process to a pressure of 240 psig (16.5 barg) the fine pressure screw adjuster was ejected from the unit at high speed past the technician's left ear. The technician was wearing the required head and eye protection at the time. Investigation indicated that the only safeguard stopping the screw adjuster from detaching itself from the unit was the plastic threaded collar which was retained on the inside by a locking nut.

**Recommended actions for pressure testing**

Pressure tests may be a routine operation, but do not forget that pressurization is in fact energy storage. Its instantaneous release behaves like a bomb explosion and may cause severe damage to persons and equipment. As for most operations, *good preparation* is essential to avoid incidents. It is recommended to use the following checklist:

- A detailed checklist procedure must be prepared in line with the standards and specifications. It must cover the testing operation from filling up to emptying the vessel.
- Good co-ordination is essential to avoid performing the hydrotest at the same time as other operations. A work permit procedure/Job Safety Analysis should be used.
- The equipment should be in good condition and adequately maintained and certified.
- Testing equipment (even if brand new) must be checked.
- Testing equipment must be as far as practicable from the recording and pumping station.
- The test area must be barricaded and a warning sign erected.
- Exposure of personnel to testing should be minimized by using protective measures such as test cells, removable barriers, test pits, standoff distances and reduction of volume at which tests are performed.
- During the test, from filling up until the end of depressurization, all non-essential people must be out of the test area.
- The test crew must attend a toolbox talk.
- All people must wear their appropriate Personal Protective Equipment.
- Inspection for leaks shall be performed at least 15 minutes after the test pressure has been reached and only by designated personnel.
- Never tamper with, or tighten any fittings (including connections, bolts, hoses and the like) while under pressure or during pressure-up stages.

2.9 Hydrostatic testing

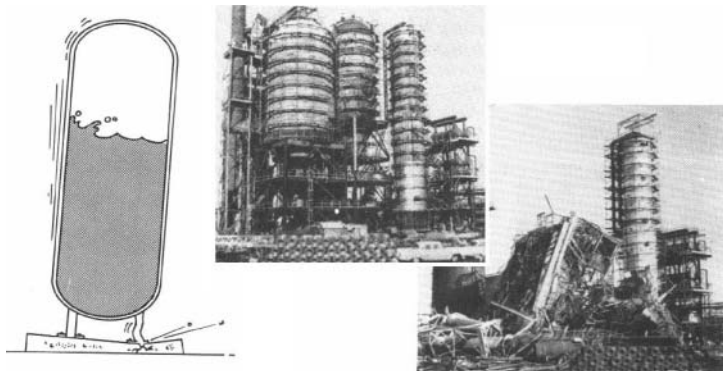
ACCIDENT



This 20-year old, 12,580 bbls (2,000 m³) sphere collapsed during preparation for a hydrostatic test because the support legs were severely corroded beneath the fireproofing concrete coating by salt water used in periodic water spray testing. An inspector was killed.

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

It is very important to make sure that structures are able to withstand other types of load during a hydraulic test (for example, there is often a wind limit at which high towers can be hydraulically tested; snow and ice may also provide additional loading). Check the original design criteria.



Failure of structure under water load.

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

Refer to BP Process Safety Booklet *Hazards of Water* for more details.

2.10 Work permits and isolation certificates

ACCIDENT

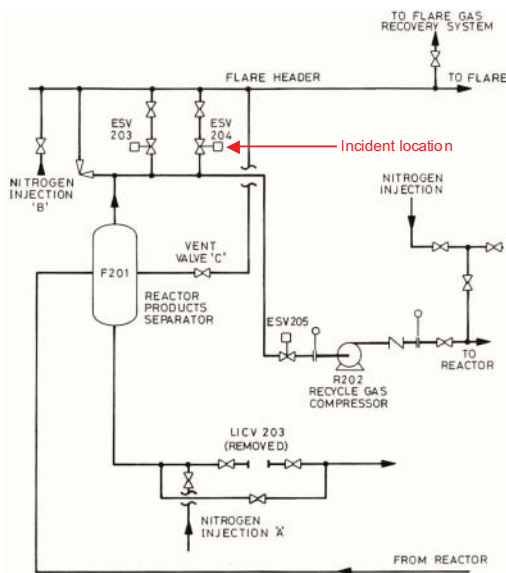
Have you checked the system before signing the work permit?

During a shutdown, the opportunity was taken to repair a small leak on the stuffing box of decompression valve ESV-204 between the compressor suction line and the flare header. The chief operator responsible for making the circuit ready for work filled in the 'readiness certificate' and signed on the 'order for execution' paragraph. When the instrument foreman reported to the control room the chief operator was not there and the certificate was handed to him by the panel operator.

Work started. When the bonnet was unbolted from the body a small leak of gas occurred. This was not unexpected since the operation was scheduled to be performed with a nitrogen purge of 50 to 100 mbar (0.73–1.45 psi) to avoid any possible return of gas from the flare system. At the moment when the top part was detached from the valve a vertical jet of gas and black dust suddenly escaped and ignited spontaneously with an explosion and subsequent fire, injuring three workers.

The main reason for this incident was that the chief operator had signed the certificate without having checked that the various operations laid down had actually been carried out as specified. Subsequent investigation revealed that neither the purging operation nor the closure of the block valve on the flare side of ESV-204 had been carried out. Consequently, dismantling of the bonnet had taken place in an unpurged system under high pressure.

An inadequacy was also discovered in the written instruction outlining the actions to be taken prior to the repair, which includes the nitrogen purge using injection points 'A' and 'B', with purge gas flowing to the flare header through valve 'C'. This procedure bypassed the ESV-204 valve omitting the purging of the area where the task was to be performed.



Hydrocracker reactor circuit.

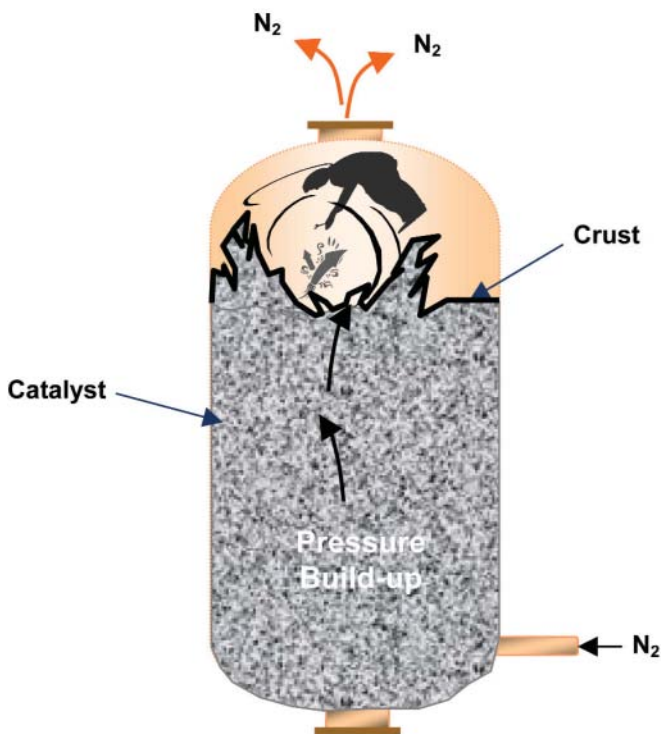
2.11 Trapped pressure underneath catalyst crust

ACCIDENT Contractor fatality during reactor catalyst removal!

A contract employee was fatally injured while removing catalyst from a hydrodesulfurization (HDS) reactor.

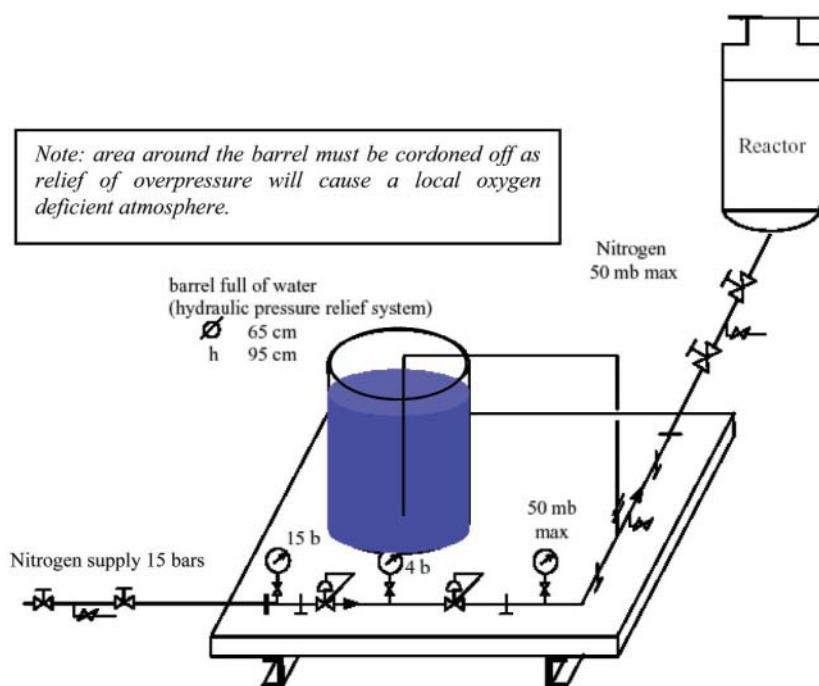
After shutdown and a nitrogen purge, the reactor inlets and outlets were blinded, and a nitrogen hook-up provided to supply a continuous purge for use by the catalyst unloading contractor. The atmosphere at the reactor top opening was checked for oxygen, flammable material and hydrogen sulphide and found to be satisfactory. Wearing respiratory equipment suitable for inert gas entry work, the worker went inside the top of the reactor to remove the internal structure.

There was a crusted layer on top of the catalyst bed below the distribution tray in the top of the reactor. What was unknown to everyone was the build-up of nitrogen pressure under the crusted layer. When the worker inside the reactor chipped the crust, the sudden release of pressure killed him. His equipment and part of the reactor contents were expelled upwards through a 22 inch (0.6 m) diameter manhole.



Precautions

Nitrogen injection pressure should be lowered to less than 0.7 psig/50 mbar, or strict formal checking procedures should be enforced. An example of a pressure regulating system with simple pressure relief device is given below:



Note: Remember that nitrogen (or any other gas) should never be used for strength testing of pressure vessels except in very special circumstances following a risk assessment and approval process.

For more details on nitrogen hazards, refer to BP Process Safety Booklet *Hazards of Nitrogen and Catalyst Handling*.

2.12 Trapped pressure in a fire

ACCIDENT

Aluminium cylinders exploded due to flame impingement!

A gas oil pump failed catastrophically causing a pump seal fire that impinged on two adjacent calibration gas cylinders. A few minutes later, two aluminium gas cylinders exploded due to flame impingement. The cylinders contained analyser calibration gases (N_2 , CO, and CO_2). The intense heat from the burning hydrocarbons caused localized metal weakening and ductile fracture of the aluminium. As the aluminium temperature rose above 400°F (204°C), the strength of the aluminium at the flame impingement area decreased until it could no longer contain the internal pressure. The pressure had not increased to the point where the rupture disks in the bottles would burst.



The two compressed gas aluminium cylinders that ruptured due to flame impingement.

The pressure relief devices will function in a fire but will not necessarily protect the vessel from fracture since the strength of the vessel material will be greatly reduced causing rupture well below the safety valve's set pressure.

All areas of vessel containing pressure must be kept cool with water spray in a fire or other passive protection.

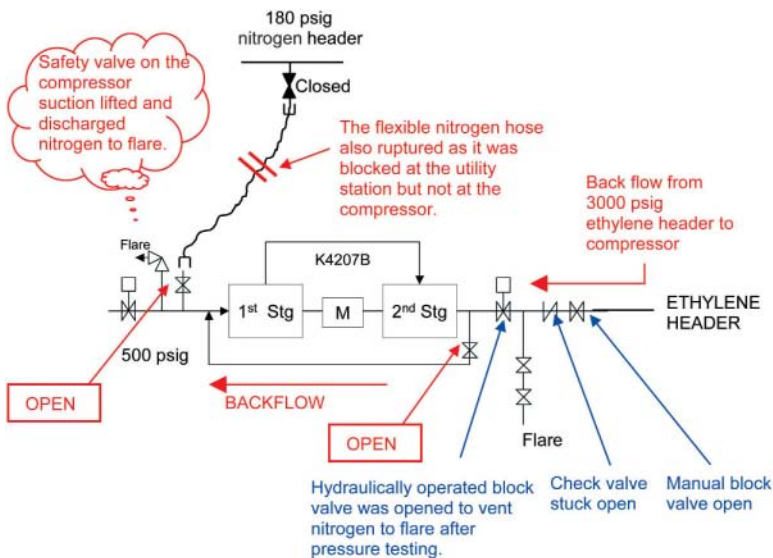
2.13 Utility/process connections and flexible hoses

ACCIDENT Temporary hose ruptured during HP compressor testing!

A flexible nitrogen hose from a utility station was connected to a compressor for pressure testing. As the pressure in the compressor slowly built up, a hydraulically operated valve on the compressor discharge was opened to vent the nitrogen to flare. It appears that the downstream check valve was stuck in the open position and gas backflowed into the machine from the 3,000 psig (207 barg) ethylene header. The safety valve on the compressor suction was lifted, discharging the gas to flare. The nitrogen hose ruptured (it was blocked at the utility station but not at the compressor suction and was rated for only 300 psig).



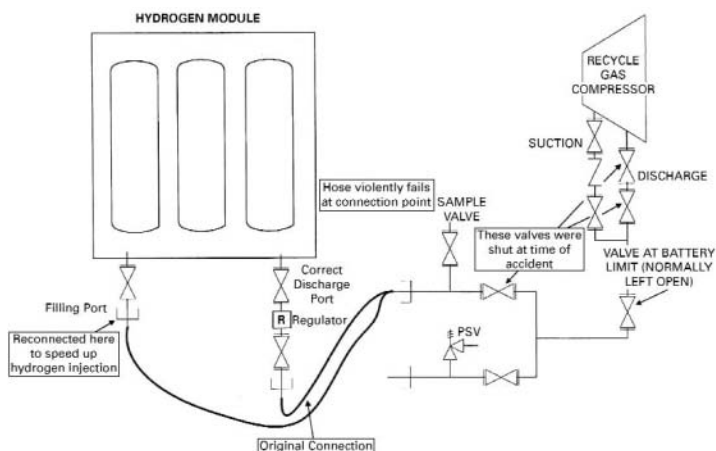
Ruptured nitrogen hose due to high backpressure.



Check valves/non-return valves are notorious for their vulnerability in preventing backflow.

ACCIDENT Fatal burns from hydrogen fire!

High pressure hydrogen from a module consisting of $12 \times 1\text{m}^3$ cylinders at 150 bar (2,205 psig) was used to regenerate catalyst in the Cat Reformer. Each cylinder was fitted with a needle valve and the twelve were connected together with steel tubing. The module had a filling connection (with no pressure regulator) and a discharge connection equipped with a pressure regulator and a pressure safety relief valve set at 14 bar (206 psig). See diagram.



One day, the process operators noticed that the pressure in the Cat Reformer was building up too slowly. From past experience, the shift supervisor considered that the regulator was faulty. (After the incident, investigation found that broken pieces of Teflon seats from the needle valves were blocking the pressure regulator's passage ways and the needle valves were damaged due to over-tightening with wrenches). He decided to switch the flexible hose from the end, after the regulator on the module, to the module's filling line which was not equipped with a regulator. The switchover was authorized under a cold work permit. Six cylinders were then emptied one by one by the area operator in 35 minutes and the unit was pressured up to 7 bar (103 psig). The area operator then closed the cylinder needle valve at the hydrogen module followed by the three block valves on the filling line to the recycle gas compressor.

As the Cat Reformer's pressure decreased and as the area operator had other tasks in hand, the shift supervisor decided to discharge the remaining cylinders alone. Failing to remember that the block valves downstream to the compressor were shut, he opened a cylinder discharge needle valve and the module's filling valve. The flexible steel hose was subjected to the full cylinder pressure of 150 bar (2,205 psig). The hose connection flew off and hit the shift supervisor causing him to faint from a broken shoulder bone. The hydrogen immediately ignited whereupon the shift supervisor became exposed to flames.

ACCIDENT Domestic water supply contaminated with LPG!

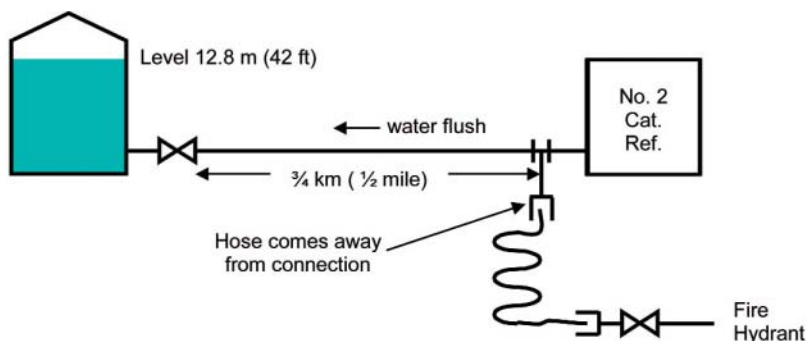
LPG contaminated with H_2S had been discharged to an LPG storage sphere following an upset in the amine unit. The LPG in the sphere was released to the fuel gas system instead of the flare. The sphere was then filled with domestic water to displace the remaining gas volume. It was not appreciated that the pressure in the fuel gas system would be higher than the pressure of the domestic water supply. A flexible hose was connected to the sphere from a hydrant and, in spite of a non-return valve in the water line, LPG flowed backwards into the domestic water supply. A considerable amount of LPG entered the refinery's domestic water lines and took a great deal of flushing to remove. To prevent a recurrence (a) domestic water will not be used for this duty unless the system is fitted with a 'break' tank; (b) the domestic water hydrant adjacent to the LPG spheres will be kept locked.

Comment

Temporary arrangements however urgent they appear to be, should be formally scrutinized through a modification procedure and authorized in writing.

ACCIDENT Failure of temporary connection causes spillage!

To prevent one solvent contaminating another, a common rundown line to storage from a catalytic reformer needed to be flushed with water at product change-overs. The rundown line (see sketch) was not equipped with permanent flushing facilities so a canvas fire hose was used with water from a nearby fire main, as a temporary measure. The receiving tank, sited approximately $\frac{3}{4}$ km ($\frac{1}{2}$ mile) away, was already filled to a level of 12.8 m (42 ft) with liquid when water was supplied to the hose. The end blew off the temporary connection and since there was no isolation valve at this point on the line, the solvent poured out. Approximately 1,000 gallons escaped from the pipe before someone could reach and shut off the isolation valve at the base of the tank.



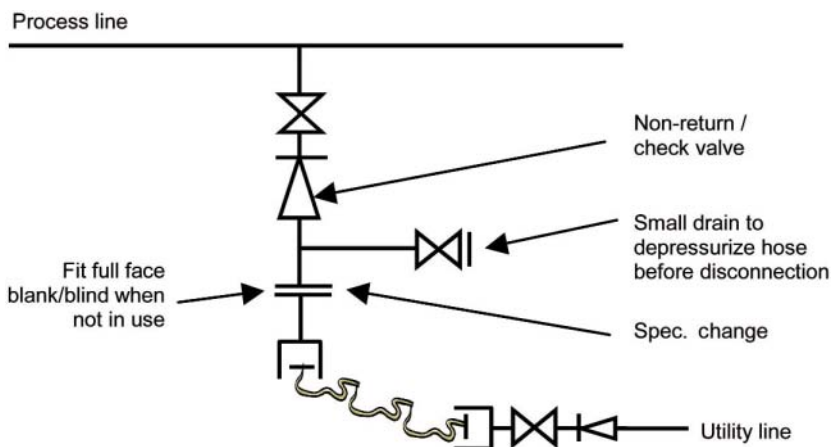
ACCIDENT Flexible hose not rated for high pressure service!

An operator was injured when a stainless steel flexible hose connected to a compressor ruptured during start-up. A wrong choice of flexible hose was made by the compressor skid manufacturer. The maximum working pressure of the hose was 27 barg (400 psig) while the required actual pressure was 69 barg (1000 psig). Luckily, the flammable gas released did not ignite.

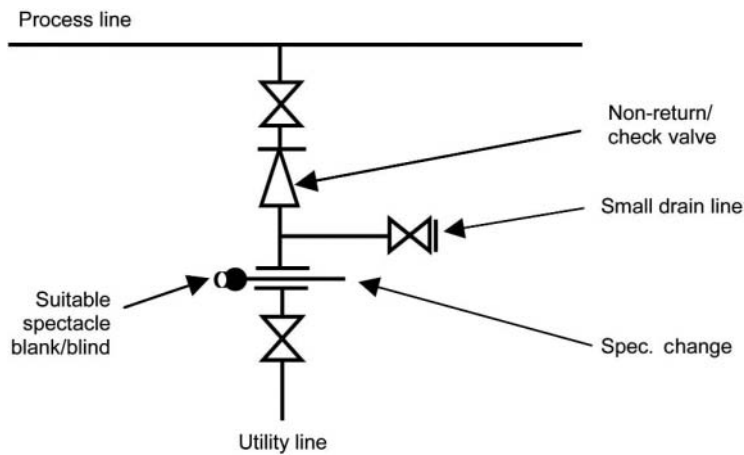


Appropriate assurance procedures must be in place so that any component being installed in a pressurized application is inspected, tested, certified and/or verified as suitable for its intended service prior to installation.

Temporary hose connections from utility stations should follow good industry practice. High pressure steam, nitrogen, compressed air, etc. utility stations are hazard areas where residual pressure could be trapped. All utility stations should be fitted with a small drain valve to relieve pressure prior to disconnection of flexible hoses (see the following sketches).



An example of a temporary utility hose connection.

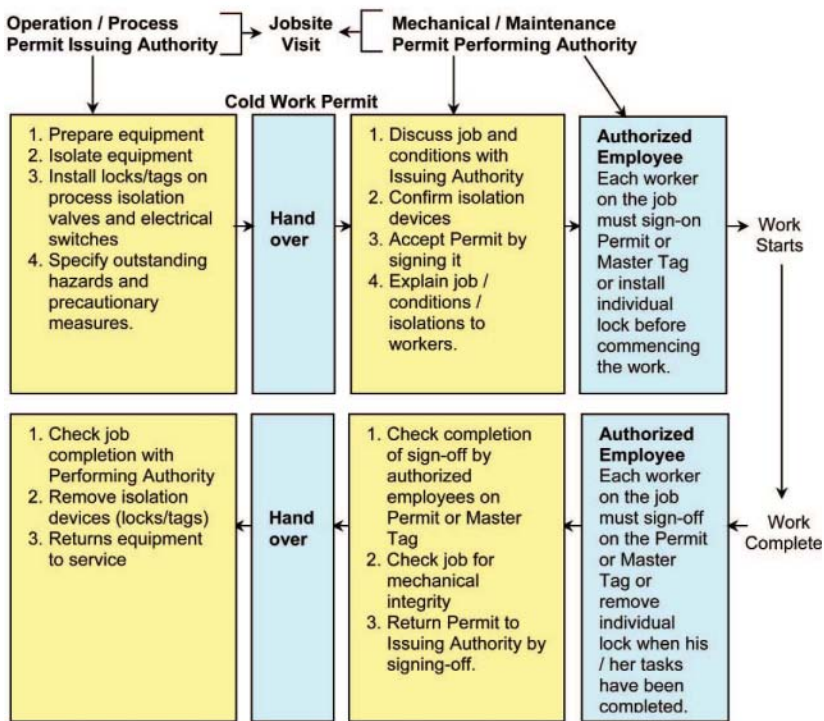


An example of a permanent connection for utility services.

Unacceptable behaviour

- Breaking flange/containment without first proving whether the system is under a pressure or vacuum.
- Breaking flange/containment under a pressure or vacuum.
- Not wearing the appropriate protective clothing as a second line of defence when breaking containment.
- Pressurizing equipment including hoses beyond their design pressure rating.
- Starting a job with a work permit without a joint site visit by the permit issuing and performing authorities.

Lockout/tagout sequence

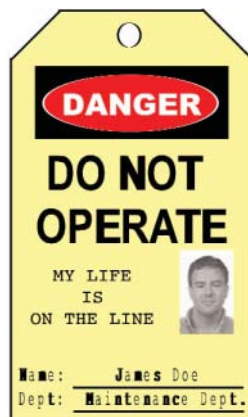


Ensure all potential remaining hazards that include the possibilities for trapped pressure are discussed during the job/site visit by the Permit Issuing Authority with those who are going to do the job.

WARNING! Workers who install or service equipment and systems may be injured or killed by the uncontrolled release of trapped pressure.

Take the following steps to protect yourself if you install or service equipment and systems:

- Follow Standard Operating Procedure/Process Instructions.
- Identify and label all sources of hazardous energy, including trapped pressure.
- Before beginning work, do the following:
 1. De-energize all sources of hazardous energy/trapped pressure:
 - Disconnect or shut down pumps, engines or motors;
 - De-energize electrical circuits;
 - Block fluid (gas or liquid) flow in hydraulic or pneumatic systems;
 - Block machine parts against motion.
 2. Block or dissipate trapped pressure (stored energy):
 - Discharge capacitors;
 - Release or block springs that are under compression or tension;
 - Vent fluids from pressure vessels, tanks, or accumulators—but never vent toxic, flammable, or explosive substances directly into the atmosphere.
 3. Lockout and tagout all forms of hazardous energy—including electrical breaker panels, control valves, etc.
 4. Make sure that only *one* key exists for each of your assigned locks and that only you hold that key.
 5. Verify by test and/or observation that all energy sources are de-energized.
 6. Inspect repair work before removing your lock and activating the equipment.
 7. Make sure that only you remove your assigned lock, tag or sign off on the permit.
 8. Make sure that you and your co-workers are clear of danger points before re-energizing/pressurizing the system.
- Participate in training programmes offered by your employers.



Only the worker who installs a lock and tag should remove them after work is complete and inspected.

It is important to highlight that however good a procedure or training is put in place, design should aim to be fool-proof and to engineer risks out. The example below clearly illustrates that even very well trained operators whose life is directly at risk if they make a mistake, will one day push the wrong button or operate the wrong valve.

ACCIDENT The incident occurred onboard a diving support vessel undergoing commissioning of its saturation diving system. The system was compressed to an equivalent internal depth of 300+ m. (1,000 +ft) and then returned to ambient surface pressure. A saturation diver entered the dive system transfer chamber, less than an hour after the system had been returned to surface pressure, and decided to flush the toilet system as there was a strong smell of sewage. On operating the bulkhead valve to evacuate the holding cylinder no movement of the contents was heard, so the diver assumed that there was no pressure in the system and opened the ball valve next to the WC. In doing so he inadvertently operated the valves out of sequence. The external ball valve had not been checked and was in the closed position. Trapped pressure inside the holding cylinder was then released into the chamber via the WC, back-flushing the contents of the holding cylinder (raw sewage) into the chamber with it, covering the diver. The force of the trapped pressure, which could have been as much as 30 bar (435 psi), was sufficient to lift the toilet seat and fracture it. The diver (following a shower and change of clothes) visited the medic, who confirmed no medical action was required.



3

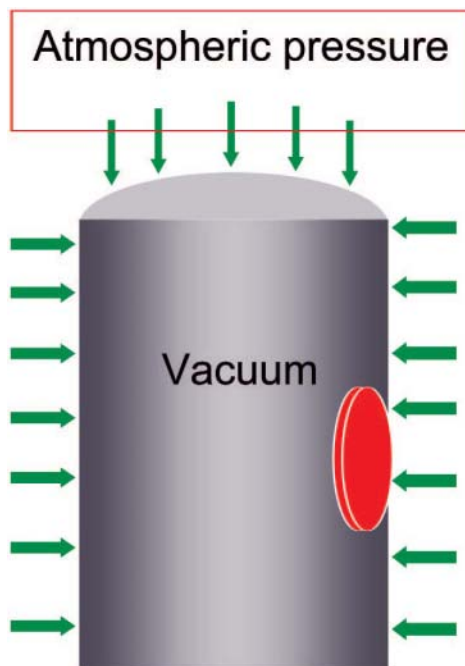
Hazards of vacuum

3.1 Ignorance of hazards of ambient pressure

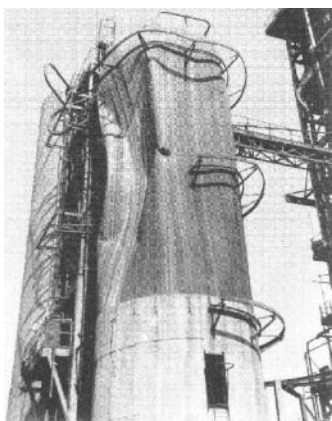
The same concepts for pressure apply to vacuum. However, in vacuum systems the pressure is pushing inward, not outward.

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

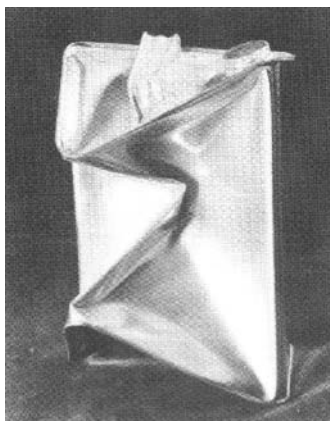
If a tank is not designed for vacuum, it will likely be damaged if placed under vacuum.



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

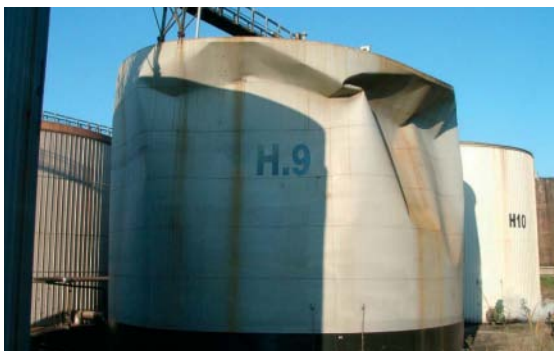
The following incidents relate to the failure of vessels from unexpected vacuum. It is believed that the equipments' designers and operators just did not expect such problems. There were multiple causes for each failure, including modification to vent piping, insufficient monitoring of pressure and human 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!



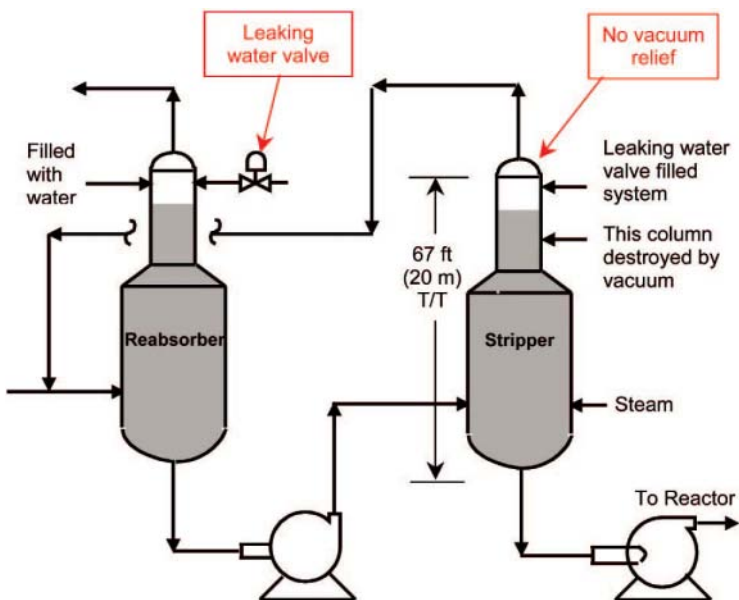
A truck arrived to unload chemicals at a chemical plant. After connecting the unloading arm, the operator started the pump before the driver opened the top man-holes. Air could not replace the displaced liquid in the tank. The road tanker was so badly damaged that some wheels didn't even touch the ground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

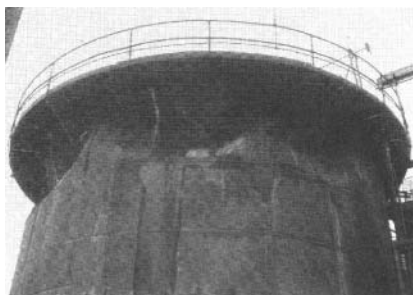
After this incident, vacuum breakers were installed on all of the vessels in this process that were not designed for full vacuum. In addition, the stripper vent line was rerouted.



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.

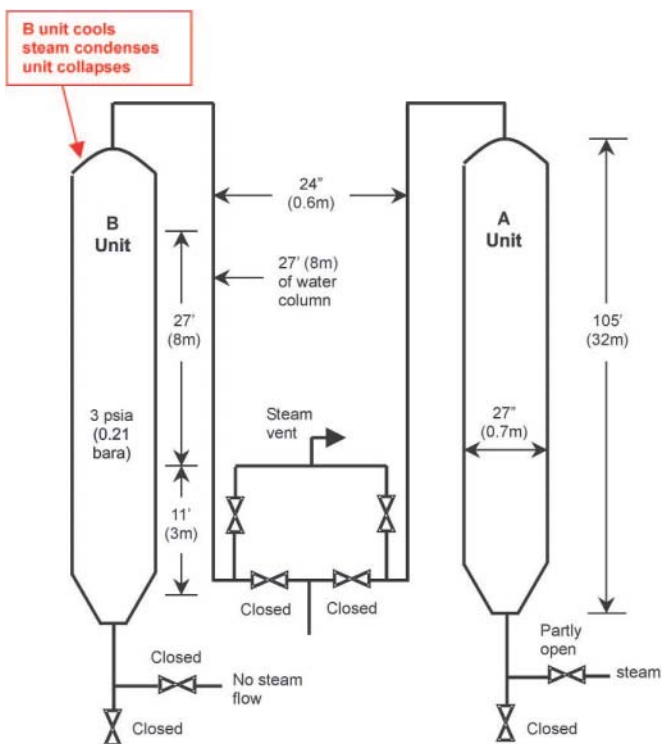
For more details on water or steam, refer to BP Process Safety Booklets *Hazards of Water* and *Hazards of Steam*.

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.

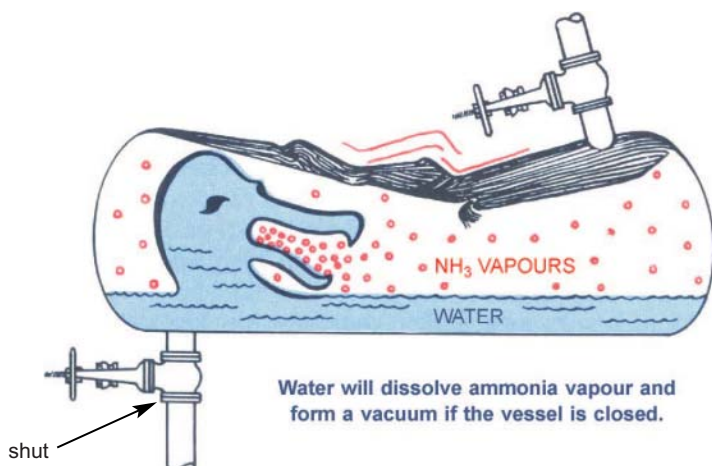
Separated from atmosphere by a column of water, vacuum was created in 'B Unit' as the steam cooled further. The range on the coker pressure instrument was 0 to 60 psig (4 barg), hence unable to indicate a negative pressure. The coker crushed inwards like an aluminium beer can, squeezed in the middle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

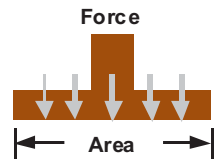
The Management of Change (MOC) procedure should examine all types of changes including changes in the composition of feedstocks or products.



4

Points to remember

1. Pressure = Force/Area.



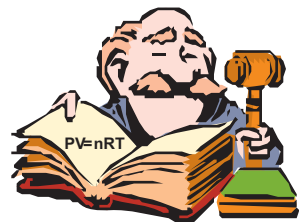
2. Liquid Pressure = Depth x Density.

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!

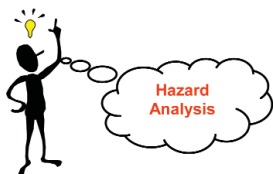
7. Compressed Air—Danger!
Compressed Liquid—Danger!



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.

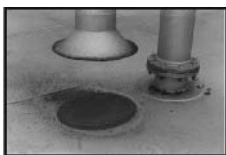
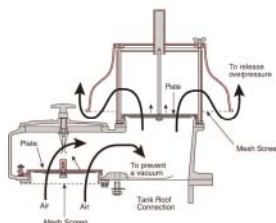
9. Vessels that have to be opened up as part of normal operating procedures (for example, pig launchers/receivers) should be fitted with an interlock arrangement to remove any possibility of the door being opened prior to the vessel being completely depressurized.



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.

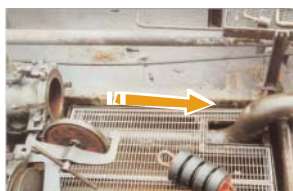
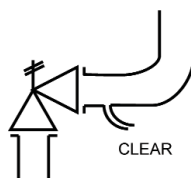
13. Equipment must not be used if any safety device is malfunctioning.





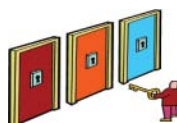
14. Any proposed departure from the Standard Operating Procedures must be subject to a 'Management of Change' procedure.

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.



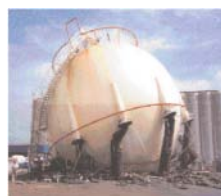
18. When not in use, traps and launchers should be isolated from pressurized pipelines to prevent unnecessary loading that may weaken their mechanical integrity.

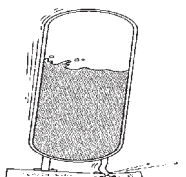
19. The specification of safety critical items should be reviewed at periodic intervals to ensure that the best available materials for the particular service have been identified and used.



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.





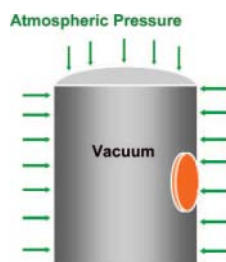
30. Appropriate assurance processes must be in place so that any component being installed in a pressurized application is inspected, tested, certified and/or verified as suitable for its intended service prior to installation.

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.

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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

Short bibliography for regulations and norms

European Pressure Equipment Directive 97/23/EC

Pressure Equipment Regulations 2003 (UK)

Pressure Systems Safety Regulations 2003 (UK)

American Society of Mechanical Engineers (ASME): Boiler and Pressure Vessel Code

American Petroleum Institute (API).

- 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.
- API 945, Avoiding Environmental Cracking in Amine Units.

OSHA Standards. Construction:

- 1926.29, Acceptable certifications (pressure vessels and boilers).
- 1926.152, Flammable and combustible liquids.
- 1926.153, Liquefied petroleum gas.
- 1926.306, Air receivers.

Other useful sources:

- American Society for Testing and Materials (ASTM).
- American National Standards Institute (ANSI).
- British Compressed Gases Association Guidance Note 15 'Managing Gas Cylinders Involved in a Fire'.
- Oil Industry Advisory Committee (OIAC): 'The Safe Isolation of Plant and Equipment' [ISBN 0717608719].

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