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BP Process Safety Series

Safe Ups and Downs for Process Units

A collection of booklets describing hazards and how to manage them

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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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Queries and suggestions regarding the technical content of this booklet should be addressed to Frédéric Gil, BP, Chertsey Road, Sunbury on Thames, TW16 7LN, UK. E-mail: gilf@bp.com

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Contents

1

Introduction

Petroleum refining is a highly specialized industry. Unit operations require many skills and a wide range of knowledge. Skill and knowledge are generally acquired through experience and training. Experience is sometimes a slow and painful teacher, so training is of paramount importance in operating safety.

This and the other booklets in the BP Process Safety series are tools for the training of supervisors, process operators and maintenance men to supplement experience, thereby shortening the learning period.

Failure to recognize and eliminate the hazards associated with shutdowns and start-ups of refinery units has resulted in serious injury, death and costly property damage (Figure 1a).

Figure 1a *Refinery damage after a fire.*

As demonstrated in Figure 1b, analysis shows that more than 20% of incidents occur during shutdown or start-ups, and it must also be recognized that some failures occurring during routine operations are sometimes the result of fatigue and stress accumulated in the equipment by ups and downs (for example, the pipe weld rupture that caused the fire shown in Figure 1a was probably linked to multiple start-ups and shutdowns that caused thermal shocks and vibrations).

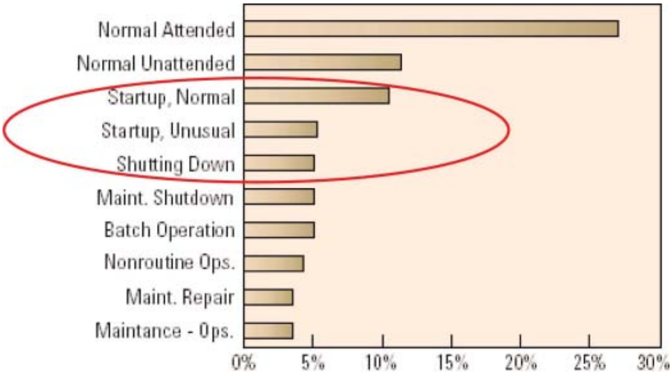


Figure 1b *Analysis of phase of operation during which the incident occurred (in 'Use of a comprehensive database to better manage process safety' by B. Kelly and M. Clancy, CEP 2001).*

The petroleum industry has devoted much time and money in designing units to avoid these booby traps. When a hazard cannot economically be eliminated in the design, however, it must be recognized and procedures set up to avoid the hazard. These procedures must be diligently followed.

The hazards encountered most frequently in shutdowns and start-ups of units are accidental mixing of air and hydrocarbons, contacting of water with hot oil, and freezing of residual water in piping and equipment. Other hazards commonly experienced during turnarounds are corrosive and poisonous liquids and gases and pyrophoric iron sulphide. Further hazards (associated primarily with start-ups) involve pressure, vacuum, and thermal and mechanical shock.

These can result in fires, explosions, destructive pressure surges and other damage to the unit, as well as injury to personnel.

Fires occur when oxygen and fuel vapour or mists are mixed in flammable proportions and come into contact with a source of ignition. They may burn out of control or touch off a devastating explosion.

Pressure surges resulting from unplanned mixing of water and hot oil may cause only minor damage or they may wreck equipment resulting in extensive costly downtime on process units.

Fire usually follows if the explosion bursts lines or vessels.

Failure to drain water from equipment or failure to maintain a sufficient flow of water or steam through a system may permit freezing which can cause extensive damage. Proper drainage or flow will prevent freeze damage (Figure 2).

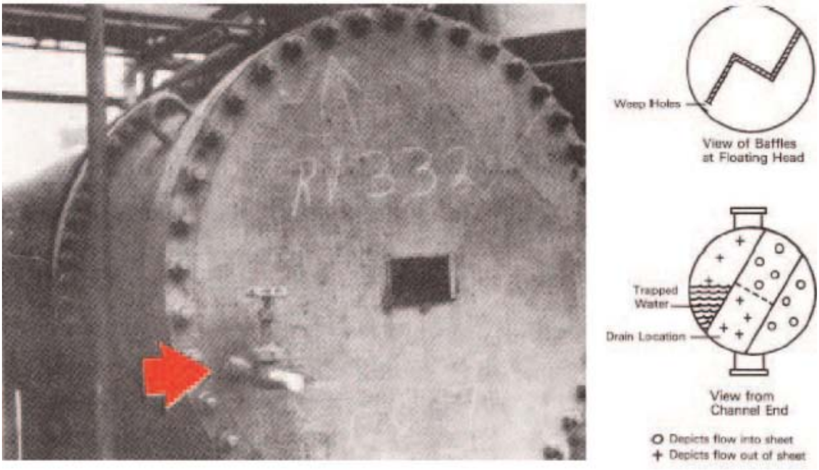


Figure 2 *A drain through the channel cover or weep holes in the baffles will prevent the trapping of water in exchangers with diagonal tube-side baffles.*

Because history shows that most of the serious refinery fires and explosions have occurred on units during start-ups and shutdowns, procedures must be developed which recognize and avoid hazards.

This booklet presents many of the tried and proven operating practices typical of the industry today, some of which are summarized in Chapter 5.

This booklet begins with shutdown, through which the narrative progresses to start-up. It actually covers the steps required for a complete turnaround, but the applicable steps would also apply to a turnaround of part of a unit.

2

Shutdown procedure

The complete plan for a shutdown, turnaround and start-up should include advance preparation at the unit and preparation by other departments whose operations will be affected (other units, tank farms, pump houses, utilities and the mechanical department).

The shutdown procedure should be in writing, and it should be followed strictly. Checklists, with blanks for time and initials, should be used to show the sequence of events to assure safety and efficiency of operations and continuity of work between shifts. The *critical path* (arrow diagram) *method* (Figure 3) has been used effectively in recent years for planning. In actual practice, separate diagrams are usually made for shutdown, repair work and start-up. In addition to serving as a checklist, the critical path (the chain of interconnected work requiring the longest overall time for completion) can be determined so that the work can be planned most efficiently.

The original diagram should be made in one colour. As each job is completed, the corresponding arrow should be marked over with another colour. The diagram so marked will indicate at a glance the work which has been completed up to that time and the work which remains to be done. It thus promotes good communications and job continuity. These in turn will contribute significantly to safe and efficient shutdown of equipment.

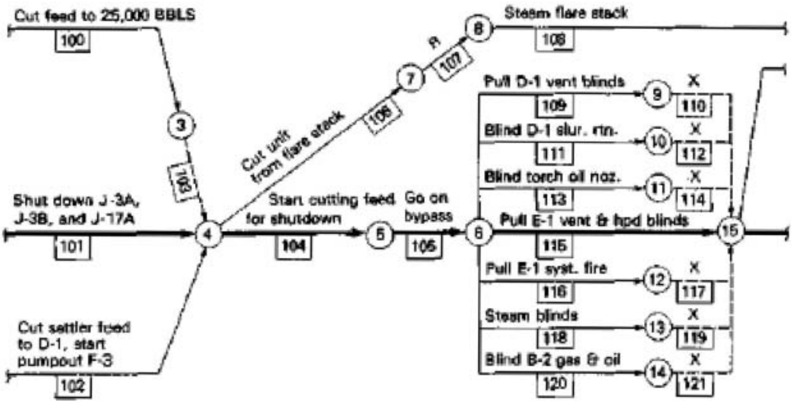


Figure 3 *Portion of a shutdown arrow diagram.*

The shutdown procedure should include the following consecutive phases:

- cooling and depressuring;
- pumping out;
- removal of residual hydrocarbons;
- removal of corrosive or poisonous materials;
- disposal of water;
- blinding and opening;
- removal of pyrophoric iron sulphide;
- inspection for entering.

Whenever practical, emergency equipment should be tested regularly while the unit is in operation. In addition, all emergency equipment (including emergency generator, driver trips, spare pumps and emergency instrument-air system) should be tested while the unit is being shut down so that any malfunction can be corrected during the downtime.

2.1 Cooling and depressuring

On fired units, first reduce the heat to the furnace by reducing fuel. Where possible, utilize the normal temperature controls. Simultaneously, reduce the charge gradually by about 20 percent of normal per hour, until it is about 30 percent of normal. During this reduction, the products from distillation towers should be held on test by reducing the side-stream drawoff and reflux rates in accordance with the reduction in feed rate and using tower temperatures as a guide. Stripping steam rates should also be reduced accordingly.

It is a good idea to throttle the cooling water to overhead condensers as charge is reduced, but not enough to cause slug flow and possible pipe damage due to incomplete condensation.

When the feed rate has been reduced to about 30 percent of normal, all fuel to the main and pilot burners should be shut off. Oil burners should be blown out with steam. A small amount of steam should be left blowing through the tips to keep them cool, or the tips should be withdrawn from the firebox.

The secondary-air dampers and the flue-gas dampers to the stack should be opened wide to permit the maximum flow of outside air through the furnace firebox for cooling.

Next, the outside (or ‘fresh’) charge oil to the unit should be shut off and internal circulation of the oil in the system started. Oil should continue to flow from the charge pump through the main components of the unit—exchangers, furnace tubes, towers, etc.—to the bottoms pumps and back to the suction of the charge pump.

Coolers in the circuit should be kept operating. Circulation should continue until the oil reaches a temperature in the range of 400°F to 450°F (200 to 230°C). This will probably require several hours.

When this point is reached, a small flow of dry steam should be started through the furnace coils. The steam should flow with the recycled charge oil through the coils and into the tower. It will pass upward in the tower and through the water-cooled overhead condenser where it will be condensed to water. The water should be drawn off from the reflux drum.

The charge pump to the unit should then be shut down and its discharge valve closed to prevent steam from backing through the pump. The steam to the furnace coils and into the tower may then be increased.

The fuel-gas line(s) to the furnace should be blinded as soon as the furnace is shut down to avoid accidental introduction of gas into the furnace.

When the main fuel-gas line is no longer needed for other purposes during the shutdown, a blind should be installed at the battery limits. On some units, the blind may be installed downstream of the dry-drum block valves. This is satisfactory if the drum is at or outside the battery limits. Any other connections within the battery limits to the main fuel-gas line, such as wet gas or lines to towers, should also be blinded. As an added precaution, gas burners of some units should be disconnected.

The fuel lines should be freed of hydrocarbons with steam or other inert gas if required by specific operating instructions. Steam condensate should be removed. All of these things are done to make it safe to work inside furnaces, or on burners or gas lines. At the same time, the fuel-oil line(s) should be removed from the furnace and the fuel-oil lines drained to prevent accidental introduction of oil into the furnace. The fuel-gas burner valves should be checked for tightness, and lubricated plug cocks, if any, should be greased during the shutdown.

For units normally operating above atmospheric pressure, the pressure should approach zero gauge as the temperature drops. Excess pressure should be relieved by releasing hydrocarbon gases to a gas collecting system. If the cooling tends to produce a vacuum in the unit, steam or other inert gas should be introduced to maintain the pressure slightly above atmospheric pressure so that the vessels will not be damaged and so that air cannot enter the unit.

If water is present, the release of pressure may cause freezing of the water due to vaporization of light hydrocarbons such as propane or butane, which have boiling points at atmospheric pressure of -44°F (-42°C) and + 31°F (-0.5°C), respectively. Where this is a possibility, water must be drawn frequently, and the depressuring and cooling must be done slowly enough to prevent the water from freezing and possibly closing off important drain points or causing other serious blockage or obstruction. Later these obstructing ice plugs may melt, releasing hydrocarbons which can flow, sometimes unnoticed, to a source of ignition (Figure 4).

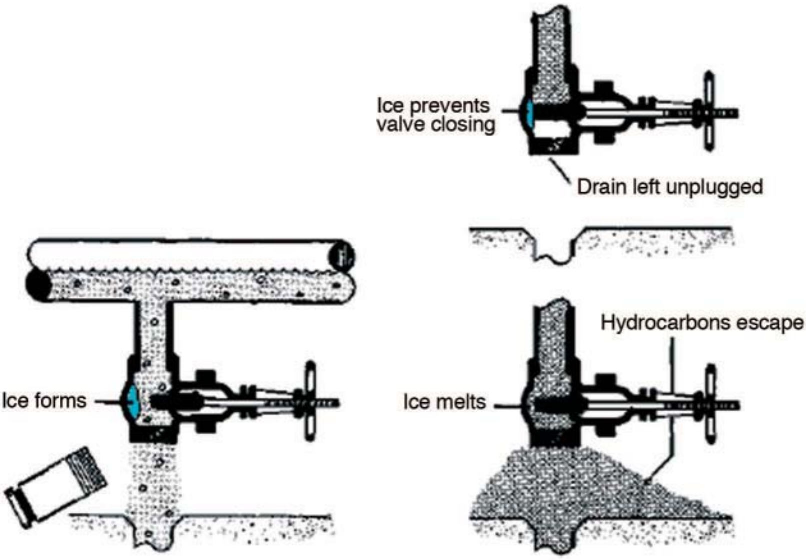


Figure 4 *Ice can block flow in a drain valve and prevent complete closing of the valve. It will thaw later and release light ends.*

Examples of serious accidents which resulted from failure to recognize this point are presented in the BP Process Safety Booklet *Safe Handling of Light Ends*.

When shutting down towers, care should be exercised to adjust cooling so that water is not condensed in the upper part of the tower and then dropped into hot oil in the bottom of the tower. The tower-top temperature should be kept safely above the water condensing temperature at the pressure involved.

Where a catalyst is involved, special cooling procedures may be required to avoid catalyst deactivation or physical damage to the catalyst. The procedure will depend on the specific process and the catalyst.

2.2 Pumping out

When the oil has been cooled to the required temperature, the oil and any other liquid materials which may have been separated from it in the unit (such as acids, caustic, and sludges) should be pumped or pressured from the unit.

Each material, depending upon its composition, should be routed to a prescribed place. Centrifugal pumps should be watched carefully to see that they do not lose suction. Running a centrifugal pump dry for even a short time may seriously damage it and create a hazardous situation due to packing or mechanical-seal damage. Reciprocating pumps are best for pumpout service because they have superior suction characteristics and are less susceptible to damage.

As the oil is pumped from the unit, it should be cooled further in heat-exchange equipment to a safe storage temperature.

Some equipment drains used during the shutdown operation may not have permanent connections to a pumpout or closed-drain system. If the material released from these drains can burn and then injure persons and damage equipment, temporary facilities should be installed to drain the material to a closed system or another safe place.

Inert gas or steam should be admitted to the unit during the pumpout operation for two reasons—firstly, to prevent entrance of air into the unit; and secondly, to prevent collapse of any equipment not designed to withstand a vacuum.

On shutdown of vacuum towers, special techniques are needed to avoid O_2 entry to the tower, to control liquid levels, to avoid formation of liquid water as the tower temperatures decrease, and to avoid excess pressure drop across the trays (which could upset them). These techniques are spelled out in the shutdown procedure and must be followed carefully.

The electric and steam-driven pumps and compressors which are to be worked on during the turnaround should have the main disconnect switches padlocked in the OFF (open) position, and the main steam valves to the drivers padlocked in the closed position.

Exhaust steam lines attached to steam-turbine cases should not be shut off unless the turbine itself is to be worked upon. This is a safety measure to prevent rupture of the turbine case which could occur if high-pressure steam was admitted to the turbine with the exhaust valve closed. A ‘Repair Hold Card’ tag should be attached to each padlock to prevent its removal before proper authorization to do so is given. Some refineries may use different methods such as the multiple padlock procedure, wherein each person working on the equipment in question puts his own padlock on the main disconnecting device. In any event, local safety regulations covering such situations should always be strictly followed.

Any gland oil or seal-gas system employed on the unit should be shut down along with the equipment it serves.

2.3 Removal of residual hydrocarbons

Removal of residual hydrocarbons can be done by displacement with an inert gas, water flooding to overflowing, or a combination of these two. The type of unit determines the appropriate purging material.

Refer also to the IChemE training package *Safer Maintenance*.

Displacement with inert gas

Steam is the preferred inert gas for oil processing units, unless it would damage equipment or material in the unit, such as a catalyst. Distillation and coking units are typical units in which steam should be used. In certain catalytic process units in which steam would damage the catalyst, nitrogen, carbon dioxide or gas from an inert-gas generator should be used instead. The choice would depend upon the catalyst involved and the cost of the respective purge gases.

When a gas is used for purging, it is commonly admitted at or near the inlet to the unit and flows from one vessel to another in succession, including finally the blowdown or flare system. This reduces the chance of bypassing any area and gives an orderly procedure. If parallel paths of flow exist in a unit, care must be taken to ensure that each path is purged. If 'dead-end' spaces exist in the system (such as behind metal shrouds in reactors), it may be desirable to pressure-depressure the system with inert gas to dilute the hydrocarbon to the acceptable concentration.

The purge gas should continue to flow into and through every part of the unit until tests show that the gas flowing from each drain and vent on the unit has a hydrocarbon content of less than 1 percent. The limit specified by operating instructions should be followed when combustibles other than hydrocarbons are present. Except where steam is being used, each vent and drain on the unit should be closed as soon as the test shows that the hydrocarbon content of the gas at that point is less than 1 percent. This will conserve purge gas and reduce purging time.

If steam is used, all drains and the vents at the highest points of the unit should be left open until tests show that only steam or water, or both, is issuing from each drain and vent on the unit, and again, that the hydrocarbon content at each drain and vent is less than 1 percent. This step ensures continuous drainage of all condensate as it forms and prevents any air from flowing into the unit during purging. When the purge is complete, the purge gas should be replaced by air.

Various devices available for measuring the hydrocarbon content of purge gases are shown in Figures 5–7.

Figure 5 *Combustible gas indicators operate on either the combustion principle, the thermal conductivity principle, or on infrared principle. To read percent hydrocarbon directly, they must be calibrated for the gases involved, and the proper scale must be used.*

Care must be taken to select an instrument which has been calibrated for the combination of purge gas and hydrocarbon being tested.

The hydrocarbon content of issuing purge gas cannot be measured *directly* with the normal combustible gas tester, as this type of instrument requires air to burn the combustibles in the instrument. However, at least one type of these testers can be equipped with a dilution tube which permits a known ratio of air to mix with the purge-gas sample. Thus, this specially equipped instrument can be used when nitrogen is the purge gas, but not steam. Be sure to return this type of tester to its normal testing mode after using it in an inert purge sample so that the dilution mechanism does not interfere with the normal sample. Infrared detectors are now able to detect flammables in inert gases.

Another instrument available for measuring the hydrocarbon content of nitrogen or other non-condensible purge gases uses the thermal-conductivity principle to measure the amount of hydrocarbon present (Figure 5). This instrument must be calibrated for the particular purge gas and hydrocarbon combination to be tested. (Other manufacturers provide suitable equipment, and the foregoing discussion is not intended to exclude that equipment.)

When steam is used for purging, neither of the instruments previously discussed can be used for testing the purge stream. Steam purge streams

Figure 6a *The air-in-steam analyser determines the amount of air, or other non-condensibles present in steam. A representative portion of the steam flows through the sample chamber, heating the sample chamber to steam temperature. Placing the sample chamber in the insulated container speeds up this step. A sample of the steam is then trapped in the chamber by closing in quick succession the inlet valve and outlet valve. The chamber is then lifted from the insulated container and cooled to 100°F (38°C). Condensation of the steam produces a vacuum in the chamber. The amount of pressure reduction is a function of the relative proportions of steam and non-condensibles (air) in the original mixture, and the air content can be calculated. This instrument cannot be used to determine concentration of air in inert gas. After purging with inert gas, absence of oxygen must be confirmed using one of several types of portable oxygen analysers suitable for this purpose.*

containing hydrocarbons no heavier than C6 can be tested with the air-in-steam analyser (Figure 6a). This instrument was available commercially from Mine Safety Appliances Company (MSA) for a number of years, although it is not presently in production. A number of these analysers are currently in use in the Amoco heritage refineries and the drawings are available from these sites.

Steam purge streams containing C7 and heavier hydrocarbons can be tested using the American Gas Association (AGA) technique shown in Figure 6b on page 12.

This device is quite simple, being a direct measurement of the hydrocarbon present in the condensed sample. The method is shown as a laboratory setup, but a portable testing device could be developed.

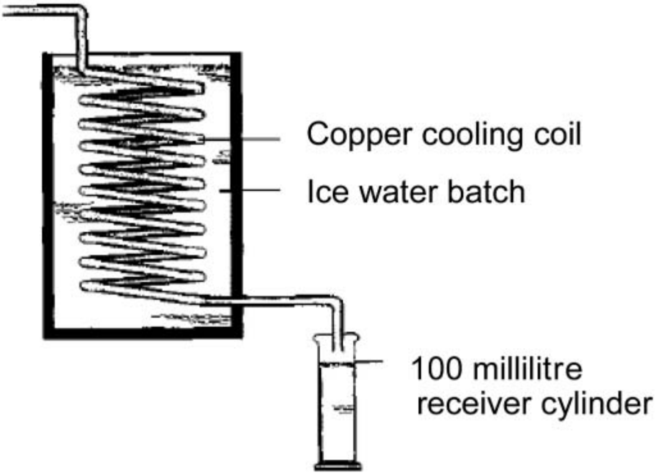


Figure 6b *Condensing coil for determining hydrocarbons in steam.*

When the AGA technique and equipment are used, sufficient cooling water should be available at the temperature of the condensate from the cooling coil to approximately 70°F (21°C). Samples of condensate are taken with 100 millilitre graduated cylinders at appropriate intervals during the subsequent purging, and the relative volumes of oil and water are read off directly. When the fraction of oil in these samples is less than 5 percent, the rate of steam-purging is reduced by about 50 percent, and a second series of condensed oil-water samples is collected. When the fraction of oil in these samples also falls below 5 percent, the steam-purging rate is again reduced by about 50 percent and a further series of condensates obtained.

This procedure is continued until the rate of steam purging has been reduced to the point where only a small positive pressure is maintained within the equipment. If, at this steam purging rate, the fraction of oil in the condensate is less than 5 percent, the vapour existing within the refinery vessel being purged will contain less than 1 percent by volume of hydrocarbon. A safe end condition has then been reached, and air may be admitted to the vessel.

A vessel purged with steam should be opened and gas tested as soon after purging as possible. If necessary, ventilating devices should be used to ensure a non-combustible condition.

Additional steaming should not be done at this time to correct a combustible condition, because an explosion could be set off by the generation of static electricity.

Steam is not recommended for purging equipment containing flammable mixtures (such as might exist in an oil storage tank that is down for cleaning or repairs), because steam entering the vessel might generate static electricity and cause a spark and an explosion. In this situation, the vessel should first be purged with an inert gas. This, then, may be followed by steam purging if it is required. If the vessel is to be refilled with air, the end condition previously specified for steam purging should be obtained for safety. More details on steam inerting can be found in BP Process Safety Booklet *Hazards of Steam*.

In some vacuum units (or in a propane dewaxing unit where even small amounts of water will cause serious trouble) residual, relatively light, hydrocarbons should be removed by a series of evacuations; each evacuation should be followed by filling the unit with nitrogen or gas from an inert-gas generator. These evacuations should be repeated until the hydrocarbon content of the gas in the unit is not more than 1 percent. The inert gas should then be replaced by air.

The effects of the above procedure can be achieved at pressures above atmospheric by repeated pressuring and depressuring of the system using an inert gas such as nitrogen.

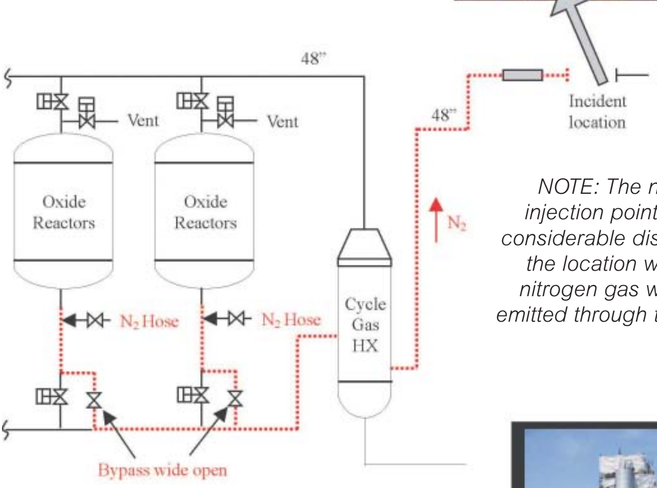
Nitrogen or other inert gases are effective in preventing flammable atmospheres. *However their use has also lead to many fatal accidents through the creation of atmospheres which are deficient in oxygen*. It is important not to enter any vessel which has been purged with an inert gas until it has been isolated and shown to be safe (even placing the head inside a manway may lead to suffocation). Care must also be taken not to create spaces in which the concentration of inert gas may build up as illustrated by the incident below.

Refer to the BP Process Safety Booklet *Hazards of Nitrogen and Catalyst Handling* for more details.

ACCIDENT A process column had been taken out of service for maintenance for several weeks. The column had been cleaned, several manholes were open, and a nitrogen purge was on the column. Two experienced workers were examining the flange surface of a remote manhole for stress cracks. They sprayed dye on the flanges and used a black light to identify the suspect areas.

A tarpaulin was draped over the flange but it is unclear whether this was to block the wind while they were using dye penetrant or to facilitate using the black light, or both. The confined space created by the tarpaulin was soon filled with nitrogen which asphyxiated both men. One man died as a result of the exposure and the other survived because he collapsed face down on the expanded metal grating, which allowed sufficient oxygen to sustain his life.

The immediate cause of the accident was the inadvertent creation of a confined space environment around an open manhole that was being purged with nitrogen. The basic causes were the failure to recognise a confined space and the risk of asphyxiation from nitrogen coming out of the manhole, and inadequate control of work on a column that was being nitrogen purged.



NOTE: The nitrogen injection points were a considerable distance from the location where the nitrogen gas was being emitted through the opening

Examples of temporary confined spaces

The evacuation and inert-gas purging process will require a minimum of several hours and in some cases 24 hours or more.

In certain catalyst or catalyst-handling sections of units, the catalyst must first be regenerated to eliminate hydrocarbons and then purged before air can be admitted.

What has been said about the hazard of air and hydrocarbons mixing in an operating unit cannot be emphasized too strongly when applied to a flare system. Here, if a combustible mixture exists, ignition is guaranteed by the continuous flame at the end of the line. When a flare system is to be shut down with the unit it serves, it should be gas freed; and the ignition source at the flare should be shut off before admitting air.

Lines should be purged with steam or inert gas before admitting air. Steam, however, must be used with caution in freezing weather because of the danger that condensing water may freeze and plug the system with ice.

The majority of accidents involving flare systems have one thing in common, namely, the entry of materials that the system was not intended to accommodate. Some of these are air, steam, heavy oil (which may congeal and plug the system), corrosive materials, low-boiling liquid hydrocarbons (which due to rapid evaporation may cause freezing of water or congealing of heavy oil) or an excessive amount of liquid which may blow out at the top of the flare (Figure 7).

Care must be taken to follow procedures which will prevent the introduction of any material to the flare system except under conditions that will not cause trouble.

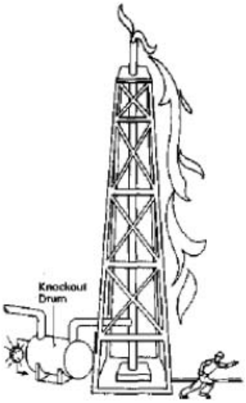


Figure 7 *Burning liquid can spill from flares if the knockout drums are overfilled (see also accident description in section 3.2).*

Water flooding

Water filling of equipment to overflowing is an effective way to purge. It displaces both gas and liquids, which otherwise might be trapped, and it cools the unit. If economically practical, it is desirable to use water at a minimum temperature of 100° F (38°C). The use of warm water aids the removal of hydrocarbons and other chemicals if they are present. Water flooding can be used only if the equipment and its foundation have been designed to support the weight and pressure of the water (Figure 8) and only if water will do no damage to the process.

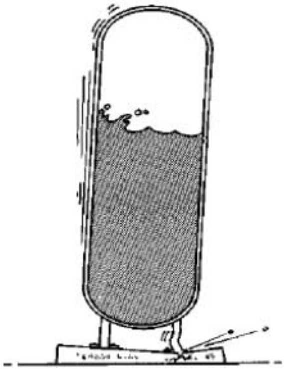


Figure 8 *Purging by water filling can only be used if equipment and foundations can support the weight and pressure.*

Before the water is introduced, all rundown lines from the unit, the feedline and other lines to the unit should be blinded at the battery limits to prevent water from entering these lines.

For work on some units and equipment, water flooding alone may be sufficient. However, unless a vessel is very clean and has no pockets, water flooding will not gas-free it for hot work or for inspection. If such work is to be done, especially where there are scale deposits, the vessel should be steamed before water flooding. After the water is dropped, the vessel should be tested to determine whether the hydrocarbon level is safe. It may be necessary to use ventilating devices to ensure a noncombustible condition. Steaming should not be done at this time since an explosion could be set off by the generation of static electricity.

The water filling may be done either by flowing the water from one vessel to another until the entire system is overflowing or by filling several parts simultaneously until the system is full.

As the water enters the unit, the materials displaced should be vented from a high point of each part of the unit to prevent trapping any oil, gas or other material. Towers should be flooded over into the reflux drums which are vented at the top while water is entering the tower. Oil flushed into the reflux drums may be pumped out or dropped to the closed drain as desired. After flooding, the water should be drained to the sewer. As the water level falls to the level of the vents on the respective towers, vessels, etc., the vents should be opened so that air from outside will flow into the vessel. It is extremely important that sufficient air enters the unit to prevent pulling enough vacuum on any part of the unit to cause it to collapse.

Enough air should enter the unit to permit subsequent entry by maintenance personnel.

To make certain that water is completely removed, water must flow from each drain. Plugged drains must be opened. A log of the drains should be made, showing the drain location, the time and date drained and the initials of the operator who witnessed the draining.

2.4 Removal of corrosive or poisonous materials

Any residual amounts of corrosive or poisonous materials (such as acids, caustics, salts and sludges present in parts of units) must be removed. Such gases as hydrogen sulphide, arsine and hydrogen fluoride are especially toxic and must be purged from any vessels to be entered. The material and procedure for purging depend upon the type of residual material to be removed.

Residual gases can be removed from a unit with a purge of steam or nitrogen, followed by water filling to overflowing, and then by displacement of the water with air. The reader should refer to the operating manual for the correct purge materials for that particular unit.

It is possible that toxic gases may dissolve in the water used to fill the vessel. Care must be taken when disposing of this water to ensure that the gas is not subsequently released to the atmosphere.

Sludges which are the product of acid or caustic treatment of a hydrocarbon may be flushed from the system when the acid or caustic is removed. Some of this sludge can remain and be removed by the water wash.

Disposal of this water must be done carefully to avoid release of the sludge in an unwanted location or the release of a toxic gas if the sludge is inadvertently neutralized. The shutdown procedure will spell out the disposal methods.

2.5 Disposal of water and freeze prevention

The use of steam and water for purging and for washing during a shutdown can introduce serious hazards in freezing weather. Much costly damage can occur to piping, exchangers, vessels, pumps, compressor jackets and other equipment from the freezing of water. Freezing must be prevented or the water removed.

In some localities, freezing weather must be anticipated. Equipment to be steamed or water washed, or equipment handling steam or water in normal operations, must be designed to minimize all pockets where water can collect. Drains must be located at all low points on each piece of equipment.

Fractionating tower trays and exchanger baffles must be provided with weep holes so that this equipment can be drained completely when shut down.

The possibility of water being trapped on trays or in exchangers as a result of plugged weep holes must be recognized. Hot-air blowers may be installed in towers and vessels to prevent freezing.

Water often can be trapped in large control valves, orifice runs and pumps, particularly multi-stage centrifugal pumps. As far as possible, these types of equipment should have bottom drains which must be used to prevent damage from freezing (Figure 9).

ACCIDENT

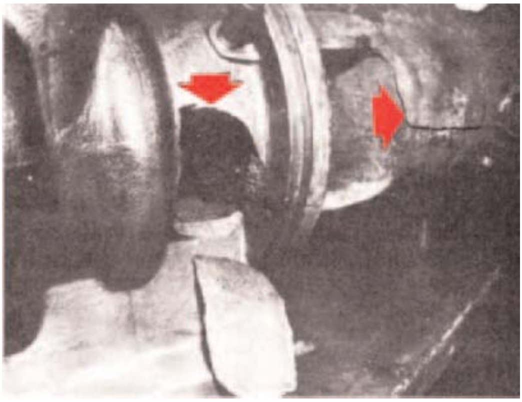


Figure 9 *This pump froze and burst.*

Exchanger tubes and furnace tubes are frequently bowed due to their service. In this condition, the tubes can trap water and are vulnerable to freezing and breakage. The shutdown procedure will point out the protective steps necessary such as blowing individual tubes with air or keeping the tubes warmed above 32°F (0°C).

Almost every centrifugal pump will trap some liquid within its internals when drained through the drain connections normally supplied. Such traps can range in size from small to very large. In many cases, complete drainage can be achieved by installing additional drains at low points on the pump casing and/or weep holes at the low points of inner volutes.

The design of many multistage pumps including barrel-type pumps is such that there is no practical way to drain them completely. For these, a flushing procedure should be developed to clear the pumps of hydrocarbons and to avoid or remove water accumulations safely.

The draining and flushing procedures must include all spare equipment as well as the equipment regularly used.

Provisions should be made to prevent water lines from freezing (Figure 10). This can be done in several ways. A sufficient flow of water can be maintained to prevent freezing. A section can be heat traced and insulated, or steam may be bled into the water to warm it. Main lines and their shutoff valves may be located underground below the frost line.

ACCIDENT

Figure 10 *Ice is stronger than steel.*

The firewater system is often used during downtime to provide water for flushing and testing of equipment. The system itself should be flushed and tested during this time. Freezing precautions should be observed on this system as required.

Compressor cooling-water jackets and sewer traps, in which the flow of water must be cut off, should be filled with an antifreeze mix such as alcohol or glycol and water. Steam traps and steam lines which are shut off in freezing weather are particularly susceptible to freeze damage. Proper drains should be provided. If steam tracer lines are shut off in freezing weather, they should be blown out thoroughly with air.

The purpose of freeze prevention is to prevent equipment damage and loss. This point must never be overlooked. Refer to the BP Process Safety Booklet *Hazards of Water* for more details.

2.6 Blinding and opening

Shutdown blinds should be installed in the various utility and oil lines which leave and enter the unit to prevent unwanted material from entering the unit while it is down (Figure 11). All connections to any tower or vessel which technicians are to enter during the shutdown should be blinded to prevent accidental entry of foreign material which might injure the workers. Maintenance workers opening various parts of the unit should wear appropriate protective equipment in addition to the normal safety equipment.

Goggles, face shields, respiratory equipment, and rubber gloves and coats may be needed depending upon the type of material that possibly may be encountered.

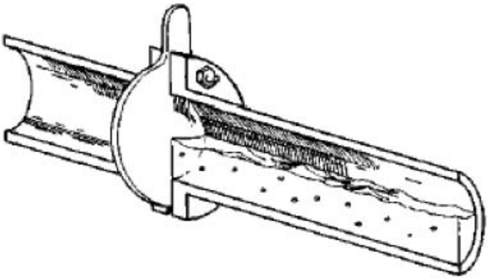


Figure 11 *Blinds are required to keep unwanted material from entering.*

Opening lines to install blinds should be done only after the operator in charge has given his approval and then *only* with extreme care. Flanges should be cracked open slowly so that any material incompletely purged from the unit can be handled safely. Small amounts of material may be vented or drained. If large amounts of materials are present, the flanges should be closed quickly for further purging of the equipment. Valves should not be removed until it is absolutely certain that the equipment to which the valves are attached is empty.

A list should be made of all blinds to be installed during the shutdown. Each blind location should be assigned a number. The date and time at which each blind is installed and the initials of the operator who witnessed its installation should be noted on the list.

Certain lines, vents, drains, etc., should be blinded at all times that the units are running. These running blinds should be removed at prescribed times during the shutdown to permit purging and draining of material from the unit. A list of these blinds should be made, and the date and time of removal of each blind and the initials of the operator who witnessed its removal should be noted on the list.

When all the blinds on the blind list are installed or removed, the unit should be opened for cleaning and repairs.

2.7 Hazards of pyrophoric iron sulphide

Pyrophoric iron suphide may accumulate at various places in equipment handling sulphur-bearing oil. It may resist oil, steam and water purges and washes; and when exposed to air, it will ignite spontaneously even at low temperatures. When wet, it will not ignite (Figure 12) but will do so as soon as it dries. The drying time may range from a few minutes to several days depending upon conditions. The simple burning of this material alone may do considerable damage. If hydrocarbon vapours and air are also present, an explosion and fire may follow the ignition of the iron sulphide.

Figure 12 *Pyrophoric iron sulphide must be kept wet.*

Within one oil company, there is typically one pyrophoric scale fire in distillation units every two to three years. There are many more reported incidents within the process industry. When this occurs inside equipment like columns, vessels, and tanks and exchangers containing residual hydrocarbons and air, the results can be devastating.

Figure 13 *This column was completely destroyed by a pyrophoric fire. The fire happened during the replacement of the carbon steel structured packing, which involved cutting out the old column internals and removing each bed of packing. Despite persistent attempts to extinguish the fire, the incident progressed to the point where the splitter fell over early the next morning.*

Why do pyrophoric fires occur?

Pyrophoric scale (FeS) is generated during crude oil processing, when rust (iron oxide) is reduced by H_2S in the absence of oxygen:

$$Fe_2O_3 + 3H_2S \rightarrow 2FeS + 3H_2O + S$$

In the presence of oxygen (during a turnaround), the pyrophoric material will oxidize as follows:

$$4FeS + 7O_2 \rightarrow 2Fe_2O_3 + 4SO_2 + \text{heat}$$

This is a highly exothermic reaction, and the pyrophoric scale will become incandescent and will glow or spark (the word 'pyrophoric' is derived from the

Greek for ‘fire-bearing’). This becomes a source of ignition for any nearby combustibles. The reaction is accelerated by high temperature and if the FeS is dry.

Where do pyrophoric fires occur?

Pyrophoric scale can occur within process vessels, exchangers and distillation columns. In general, the higher the sulphur in the crude processed, the higher the tendency for FeS production. In refineries, the equipment most prone to pyrophoric combustion induced fires are distillation columns in crude and vacuum distillation units, as deposits of iron sulphide are formed from corrosion products that most readily accumulate at the trays, pump around zones, and structured packing. Also, pyrophoric fires are a common occurrence in heavy fuel oil and asphalt (bitumen) tanks.

Within vessels and heat exchangers, there is a large thermal mass and the pyrophoric scale will often burn out locally without causing any significant damage. However, with packed distillation columns, there are additional problems:

- Structured packings have high surface areas with extremely thin sheet metal —usually only 0.15 mm thickness. They have a low thermal mass, and so will heat up very quickly in the event of a pyrophoric fire. The packing structure often traps the FeS and enhances the contact between the FeS and the oxygen. Severe damage of the packing and vessel wall may occur due to pyrophoric scale combustion. There does not necessarily need to be any hydrocarbon source to cause a serious fire.
- The high surface area of structured packings and the interface between each of the layers may well result in a greater retention of coke and hydrocarbons than other types of random packing and certainly trays. This clearly provides the fuel for a potentially destructive fire.
- Some types of packing metallurgy are very reactive (e.g. titanium) and can ignite into a metal fire. Stainless steel packings generally used in refining are not as reactive and should not result in a metal fire, but as stated in the U.S. Department of Energy Handbook *Primer on Spontaneous Heating and Pyrophoricity* [DOE-HDBK-1081-94] ‘some metals, such as aluminium, iron, and steel, that are not normally thought of as combustible, may ignite and burn when in finely divided form’.

ACCIDENT The plant was in the early stages of start-up after a planned six-day maintenance shutdown. A fire started in the evaporator drum, and subsequently ruptured the bottom of the vessel (see picture). The drum was randomly packed with thin titanium rings to ensure the vaporization of droplets before they reached downstream vessels where they may cause corrosion. It is believed that the warm air introduced during start-up and the presence of iron oxides and hydrocarbons helped start the fire on the highly reactive metallurgy of the rings.

(*continued*)

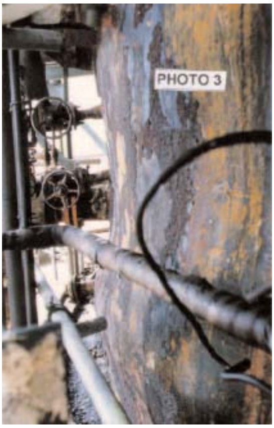
When do pyrophoric fires occur?

When the process equipment internals are exposed to air (such as during turnaround) pyrophoric fires can occur at any time. The risk of pyrophoric autoignition continues throughout the turnaround, and there have been a number of incidents where a fire has occurred many days after opening a vessel.

ACCIDENT A fire occurred at the main distillation column of a Vacuum Distillation Unit, which had been undergoing shutdown in preparation for a major overhaul. The fire was a structured packed bed fire internal of the main distillation column, located at the bottom of the wash oil packed zone near to the bottom of the column. The ingress of air into the main column activated pyrophoric scale/coke within the beds, providing the ignition source for a large presence of coke in the beds. Some packed sections retrieved were heavily coked.

Estimated cost of loss was $1.2 million.

Figures 14 *Internal damage*



Bulge on shell

ACCIDENT A naphtha tank (floating roof) was emptied for maintenance and left unattended for several weeks. One day, flames and smoke were observed coming from the tank. Upon investigation, it was found that pyrophoric scale had ignited leading to combustion of residual naphtha in the tank.

ACCIDENT An open top floating roof deck on a slop oil tank sunk after heavy rain and a blocked internal drain. After the oil was pumped out and tank cleaning commenced, a fire occurred in the rim seal area, probably as a result of pyrophoric iron sulphide being present. It proved quite difficult to extinguish.

How can pyrophoric fires be prevented?

The most important aspect of preventing a pyrophoric fire is to ensure that the column internals are thoroughly water wetted prior to allowing air into the vessel. This is essential for packed beds. The internals should be repeatedly water wetted throughout the shutdown to ensure that a fire does not occur at a later stage.

Water washing is usually carried out by circulating wash water through the existing distributors. It is possible that these could be blocked or inadequate for the desired wash rates, so it is difficult to ensure that the column packed beds are adequately water washed. Some refineries have used chemical cleaning methods to help neutralize pyrophoric scale.

The following best practice guidelines should be incorporated in the column shutdown procedures, especially for structured packed columns which present a greater pyrophoric risk than random packed beds.

Before opening vessel manways:

- Normal procedures should be followed for hydrocarbon freeing and steaming of the vessel.
- Each packed bed should then be individually water washed for at least two hours. The water wash rate should preferably be 10–15 m^3/m^2 hr (3.4 to 5.1 $USGPM/ft^2$). This wash rate is quite high and it may be necessary to use the existing process pumps for circulation of water. Check whether the existing distributors can handle these rates. It may be necessary to modify the wash rates to suit the distributors.
- Vacuum distillation unit wash beds will be difficult to water wash at this high rate (due to hydraulic limits of the distributor). In this case, there is also a serious risk of coke retention within the bed. Consideration should be given to back-filling the VDU with water to above the level of the wash bed. Note that it may be necessary to check that the foundations can take the additional weight.
- The use of chemical cleaning solutions containing neutralizing agents.

It is recommended to use chemical neutralizing agents on all packed beds which may be prone to coking (VDUs, FCC main fractionators, coker bubble towers). In view of the potentially destructive nature of a column fire fuelled by coke or residual hydrocarbons, everything practically possible should be done to eliminate pyrophoric sources of ignition. With other columns, if adequate water washing of the beds is not certain then a chemical wash as a secondary level of protection should be done. This could include packed debutanizers, CDUs, gas plants.

- Procedures for chemical cleaning should be agreed in conjunction with the chemical vendor—but it should be noted that ‘vapour phase’ chemical cleaning is not a substitute for thorough water washing of the beds.
- The column should be cooled to 40°C (104°F) before air is allowed into the vessel. This can be achieved by using cold wash water. During the period when air is introduced into the column, the TI's should be carefully monitored for signs of pyrophoric combustion within the column. If there is an indication of a localized fire, the column should be immediately steam purged to remove air. The column should then be flooded with water.

When opening the manways:

- Ensure that water hoses are available at each manway.
- Progressively open the manways from the top downwards, and not all at once.
- Monitor the air at the top of the column for increasing levels of SO_2, CO and CO_2.

During the shutdown:

- Each packed section should be periodically water washed to prevent dry out. The water wash frequency will depend on the ambient conditions, but would be typically once a day (possibly on nightshift). This can be carried out using hand held water hoses.
- Do not perform hot work above or below packed beds. All attempts should be made to remove the packing prior to performing hot work. If hot work is required, a thorough safety and fire protection review should be performed, including the prevention of and response to ‘metal fires’, and facility management’s approval should be obtained.
- Do not cut, grind, or weld the packing.

In some cases, it will not be possible to prewet the sulphide prior to opening the unit. Whether the material has been prewet or not, water hoses should be available to wet down the sulphide immediately upon opening the equipment. The wet iron sulphide can then be mechanically removed and taken to an area where its subsequent ignition and burning will cause no damage (Figure 15). In certain places where water might be undesirable or freezing would be a problem, an oil such as mineral seal can be used to prevent ignition of the sulphide. Mineral seal oil should never be used in towers or vessels because it is flammable.

2.8 Inspection for entering

When the unit is fully opened, it must be gas tested and approved before anyone is permitted to enter any vessel, tower or reactor to inspect, clean or repair it.

To allow anyone to enter a vessel, the preferred isolation is physical disconnection (removal of spool or valve) and blanked open ends. Failing this,

Figure 15 *Burn pyrophoric iron sulphide at a safe distance from units.*

ACCIDENT A slop oil tank in a Catalytic Cracker Unit (FCCU) exploded and fire followed. The roof of the tank was blown off against the stairs of an adjacent tank. The fire was extinguished after 40 minutes. At the time of the accident the tank was not in service. It was isolated for planned repair work on a local level indicator but it still contained some hydrocarbons. The critical factor, that allowed this accident to happen, was the nitrogen blanketing not being in service.

Oxygen entered the tank via the pressure and vacuum safety valve as a result of the breathing process triggered by temperature fluctuations in the days prior to the incident. Laboratory analysis indicated that FeS was present in the tank. Because of the absence of any other credible ignition source, the investigation team concluded that the pyrophoric FeS auto-ignited once it became dry enough.

spades fully rated for the line pressure must provide positive isolation. Valve isolation only, locked or not, is unacceptable for confined space working.

A permit must be issued with authorization by a responsible person, testing of atmosphere must be conducted (oxygen content is normal, safe level of suspect toxic or combustible gases etc.), verified and repeated as often as defined by the risk assessment and a stand-by person is stationed at all time outside the vessel. Refer to the BP Process Safety Booklet *Confined Space Entry* for more details.

The shutdown procedure must provide specific instructions for entry.

Towers and vessels must have the top manway or vent nozzle open. Enough manways at other locations should be opened to provide adequate ventilation before personnel are allowed to enter. If a foul atmosphere persists in the vessels, an air or steam siphon or an air blower should be used to provide adequate ventilation.

2.9 Layaway of unit

If a unit is to be kept out of service for a longer time than the normal turnaround, additional precautions should be taken to ensure safety and to protect the equipment against deterioration so that it can be returned to service later with a minimum of delay and expenditure.

Detailed procedures for laying up a unit are beyond the scope of this booklet but are available in operating manuals, company documents and in the API publication *Guide for Inspection of Refinery Equipment.*

3

Start-up procedure

Detailed plans and procedures for re-start should be prepared in advance of the unit shutdown. Preparation for the start-up of a unit should begin with a complete review of the start-up procedure by the supervisors and operators. A detailed procedure should be set up similar to the shutdown procedure. As mentioned in Chapter 2, the arrow diagram method is ideally suited for both shutdown and start-up planning. On start-ups it will be necessary to use checklists in combination with the arrow diagram. It is recommended that the operators record and initial the completion of each step.

There should be a requirement to follow a Management of Change process for start-ups after an emergency shutdown, if the normal start-up procedure does not cover this situation.

The importance of communications between shifts and between individuals must be emphasized. Each shift must clearly understand what has been done on prior shifts and what is expected of it.

Some overlap of supervision between shifts can improve communications and continuity of work. In some cases management and engineering staff may be involved in assisting the normal shift team in the start-up. In these cases the ‘chain of command’ and responsibilities of both the normal shift team and those giving assistance must be clearly defined.

The activities of those on the unit should be coordinated with the activities of the pump houses, tank fields, other units, the power station and the water pumping station.

The procedure should include the following consecutive phases:

- preliminary preparations;
- preparation of auxiliary equipment and services;
- elimination of air;
- tightness testing;
- backing in fuel gas;
- elimination of water;
- bringing the unit onstream.

3.1 Preliminary preparations

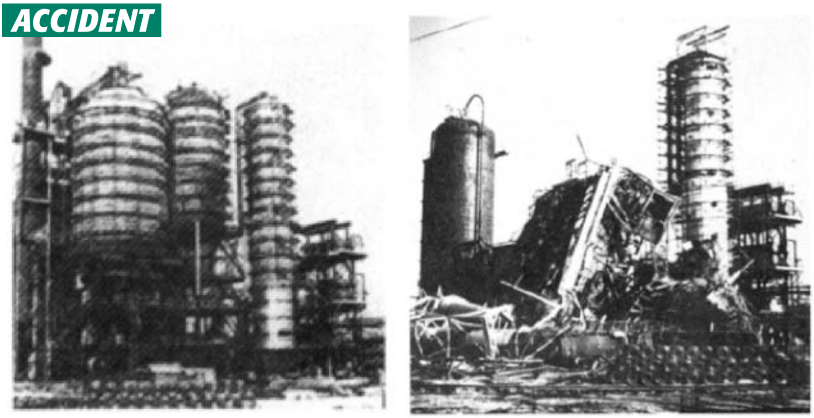
Upon completion of a turnaround, there should be a preliminary and then a final inspection to determine whether all scheduled shutdown work has been completed.

All vessels, towers and other equipment which were opened should be inspected to ensure that all foreign materials were removed and that trays, floats, float arms and piping are clean and in working order.

At the final inspection, manways and pipe flanges should be closed and bolted up immediately to ensure that no foreign material will enter to foul or damage the equipment. The final inspection should include a tightness check of these closings.

If the towers and other vessels and supporting structures were designed for it, they may be hydrostatically tested, but collapse of equipment under test can cause serious damage (Figure 16).

ACCIDENT



Before

After

Figure 16 *Failure of structure under water load.*

Tests should be made in accordance with a procedure prepared prior to the start-up. Pumps and piping should be inspected during and following these tests.

Scaffolding materials, tools and surplus materials should be removed from the operating area.

Furnace fireboxes should be inspected and all debris removed from them.

Failure to remove shutdown blinds and failure to install running blinds can cause serious upsets and damage. The start-up procedure, giving the prescribed time for removal of shutdown blinds and the installation of running blinds, must be followed. A blind list should be included as a part of the start-up procedure, and each removal or insertion of a blind should be noted and initialled by the operator in charge (Figure 17). If a blind is overlooked, much time and work may be wasted and hazardous conditions may be created, especially if the correction has to be made at a critical time in the start-up. If blinds are reinstalled after having been removed and signed out, this must be noted on the blind list. No blind may be installed or removed without permission from the operators.

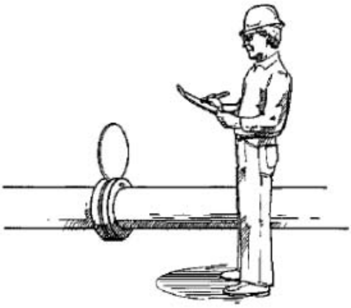


Figure 17 *Records are important to make sure blinds are installed and removed.*

The safety practices specified for removing and installing blinds in section 2.6 should also be followed during start-up.

Operators frequently assume a valve is closed or open because of its appearance or ‘feel’. Critical valves should be broken loose to verify the valve position and operability. It is extremely important that critical instruments and alarms and automatic shutdown devices are checked out prior to start-up to be certain that they are reliable.

3.2 Preparation of auxiliary equipment and services

Electrical and instrument systems electrical circuits required for lighting and instruments should be energized.

Shutdown systems, burner management systems and other protective systems should be tested and prepared for operation.

Instruments and controls should be checked, tested for operability and activated as soon as possible.

These checks should confirm that any isolation valves that were closed during maintenance have been returned to the operational state.

The electrical system supplying power should then be placed in service. When asked to reenergize any circuit on which a padlock and ‘Repair Hold Card’ tag have been placed, the electrician should inspect the repaired equipment and verify from the signatures on the ‘Repair Hold Card’ tag that the equipment is ready to return to operation. The ‘Repair Hold Card’ tag and padlock should then be removed, and the circuit be reenergized.

ACCIDENT During the course of starting up an ethylene plant after a major overhaul, cold liquid hydrocarbon flooded the liquid drain header, filled the knock out drum and flowed into the flare stack itself. The flare stack failed due to low temperature embrittlement.

The knock out drum was fitted with two independent level instruments. Both actuated alarms set at 8% and 22% of drum capacity. After the incident both instruments were found to be isolated at their top tappings. Had these instruments been available, both alarms would have sounded four and a half hours before the drum flooded and the plant could have been safely brought under control.

The knock out drum had been inspected internally during the shutdown. It had been fully isolated in order to permit entry. Two days before the incident, a supervisor went out to the drum to line up the isolation valves prior to start-up. In carrying out this task, which was made more difficult by the presence of the scaffolding, he missed the top isolations of both level transmitters. The plant was therefore started up with two vital alarms inoperative.

Steam systems

When steam is turned into a unit, possible hazards include thermal and mechanical shock, overpressuring of steam-turbine casings, introducing water into places where it is not wanted, and freezing of water in the system. To avoid these hazards, all steam block valves at vessels, towers, steam turbines (exhaust-steam side is left open) and the control headers of the snuffing system should be closed. All drains and vents on the lines inside the unit and the bypasses on all steam traps should be opened. Then the steam block valves to the unit should be opened slowly. This will allow the system to warm up slowly.

Slow opening of the valves will prevent temperature shock and water hammer which could cause serious damage to lines and equipment (Figure 18).

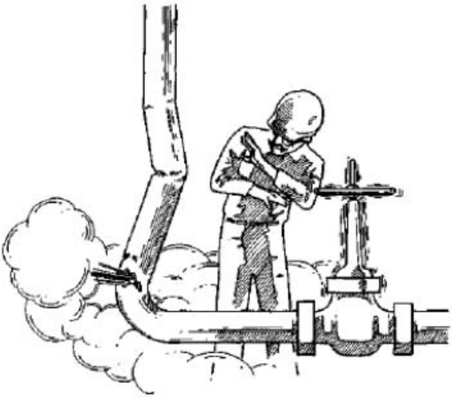


Figure 18 *Steam systems must be warmed up slowly.*

The water that condenses must be withdrawn from the system through the drains. Complete draining will prevent water hammer and reduce the hazard of water in the process system during later stages of the start-up. Steaming of lines must be continued until water is out and dry steam issues from each vent and drain. Then the steam block valves to the unit should be slowly opened wide; the drains, vents and steam-trap bypasses closed; and the steam traps put in service.

During freezing weather, extreme care must be taken to prevent condensate from collecting and freezing in the system.

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

Air systems

Before putting the plant air system in service, the connection to instrument air should be blocked off. All utility station air-hose connections should be opened and, as the battery-limit air valve is slowly opened, the lines should be blown out to remove dirt and scale from the system. Stay clear of open connections at this time. The connections may then be closed and the system pressured up to plant air pressure.

The instrument air system can then be commissioned according to the procedure which has been established for the system.

Water systems

The hazard to avoid when filling the water system is unintentionally allowing water to get into places where it can freeze (Figure 19). To prevent the accidental entry of water, any connections that are only used for purging or washing during the shutdown should be blinded. When there is no danger of freezing, activation of the water system will involve no more than opening the closed water valves to establish the desired flow and venting air at high points of the system.

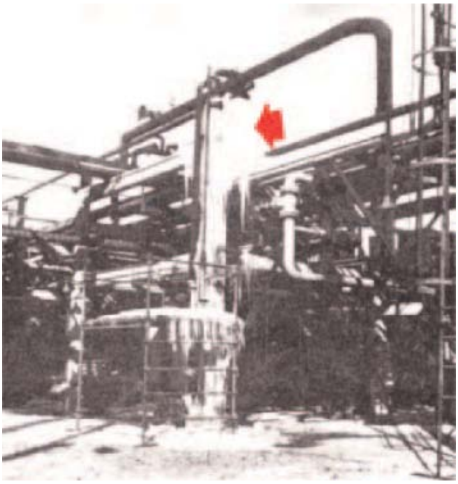


Figure 19 *Freezing water can burst equipment and cause serious losses.*

If the temperature has been below freezing, water should have been kept flowing through the unit during the turnaround; underground valves below the frost line should have been closed and the entire water system thoroughly drained; or portions of the system should have been steam heated. The purpose of these methods is to prevent freezing and damage to equipment. If the first method was used, the water system is ready for the start-up. If the system has been drained, it should be filled by lining up the usual flow through the unit and opening the main block valve to allow sufficient flow at all points to prevent freezing. High points should be vented.

If parts of the system have been steam heated, the heating will be discontinued either immediately prior to or following the establishment of normal water flow through the unit.

The firewater system, if it was used during downtime to provide water for flushing and testing of equipment, should be returned to its normal state of readiness for fire-fighting.

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

Fuel-gas system

The first demand for fuel gas will probably be for backing into equipment after purging (see Section 3.5). For this reason, it will probably be necessary to activate the main fuel-gas line substantially in advance of the furnace start-up. The main fuel-gas line will have been blinded at the battery-limits shutoff valve; branch line(s) to the furnace and back-in lines to equipment will also have been blinded; and the gas burners may have been disconnected.

As with other hydrocarbons, the hazard of mixing with air during activation should be avoided. Activation of the main fuel-gas line should begin with the removal of the battery-limit blind. Air must be purged from the header with steam or some other inert gas before admitting fuel gas. If steam is used in freezing weather, precautions must be taken to prevent freezing of condensate in the lines. When purging, all vents and drains should be open until the air has been displaced, at which time the purge material should be shut off. The main fuel-gas line should then be cracked open and fuel gas admitted to replace the purge material. If steam was used, enough gas must enter the system to prevent a vacuum. The flow should continue until all purge material, including any condensate, is drained from the lines and gas starts to issue from each drain and vent (Figure 20).

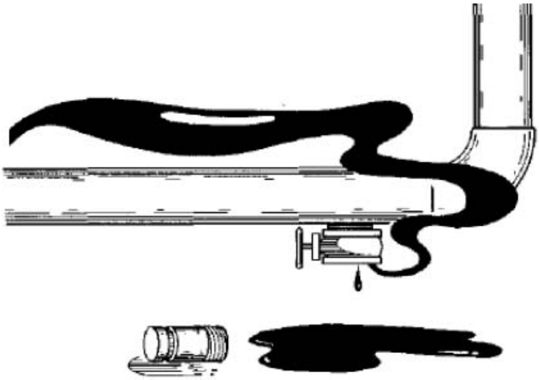


Figure 20 *Use fuel gas to force purge material out of the system drains. When gas emerges, shut valve and replace plug.*

Care must be taken to minimize the amount of fuel gas blown to the atmosphere. Fully closed systems are safer—avoid flammable releases to deck.

When the replacement of purge material is complete, the drains and vents should be closed and plugged to prevent escape of gas during operation of the unit. At this point, the main fuel-gas header is activated, and blinds may be removed for backing in fuel gas to equipment.

The burner valves should not be reconnected until just before the furnace is to be fired. The fuel line(s) to the furnace should then be purged and activated, following the same procedure described above for the main fuel-gas line. The burner valves should be open during the purging operation, but they should be closed before the fuel gas enters the line(s). No gas should be admitted to a burner until it is ready to be lighted and a torch is in front of it.

For more information on lighting a furnace, refer to the BP Process Safety Booklet *Safe Furnace and Boiler Firing*.

Fuel-oil system

The fuel-oil system will have been drained from the battery limits to the furnace, and the fuel-oil burners will have been removed from the furnaces during the shutdown. The system should be filled in the same manner as the fuel-gas system in order to prevent mixing of hydrocarbon vapour and air. It is desirable, when firing heavy fuel oils, to operate the gas portion of the combination burner for at least an hour and have the firebox temperature above 500° F (260°C) before inserting the oil burner gun and admitting oil.

Miscellaneous auxiliary equipment

At this time, the remaining auxiliary equipment on the unit can be made ready for operation. If a gland-oil system is used, it should be activated in accordance with specific unit instructions.

It must be shut off at the glands until each pump is put in operation.

The pump-out, closed drain, sewer, inert gas, seal gas and nitrogen purge systems should be checked to make sure that they are in operable condition.

3.3 Elimination of air

The next step in the start-up procedure is to eliminate air from the unit. The importance of removing air from the system is described in the BP Process Safety Booklet *Hazards of Air and Oxygen*. Eliminating air (oxygen) from any unit before hydrocarbons are introduced is most important to ensure safe start-ups. An example of what can happen if this is not done is shown in Figure 21.

ACCIDENT

Figure 21 *Three vertical drums (4'4"ID x 44' long with 51/2" wall thickness) fragmented by a detonation of oxygen and propane.*

Air should be purged from the unit with an inert gas or liquid. The choice of purge material depends upon the materials of which the unit is constructed, the process, and the cost of the purge material.

Steam is commonly used to purge air from units, but it is not unusual to use nitrogen or gas from an inert-gas generator. The gas used should not have an oxygen content of more than 0.5 percent.

When the air has been displaced by purge gas, the purge gas in turn is displaced by either fuel gas or the hydrocarbons to be processed in the unit. It is necessary to replace air to avoid the serious fire and explosion hazard likely to exist whenever air and hydrocarbons are brought together in a closed system. If air and fuel are permitted to mix in flammable proportions, it can be assumed that nature will provide a source of ignition to start a fire.

If the equipment and its foundations are designed for hydrostatic testing with water, air may be displaced by filling the equipment to overflowing with water.

The line through which water overflows should be connected to the topmost point of a vessel (Figure 22), or else air will remain in the vessel trapped in the vapour space above the point of overflow. After water overflows the vessel, the water can be displaced by fuel gas or by hydrocarbons to be processed in the unit.

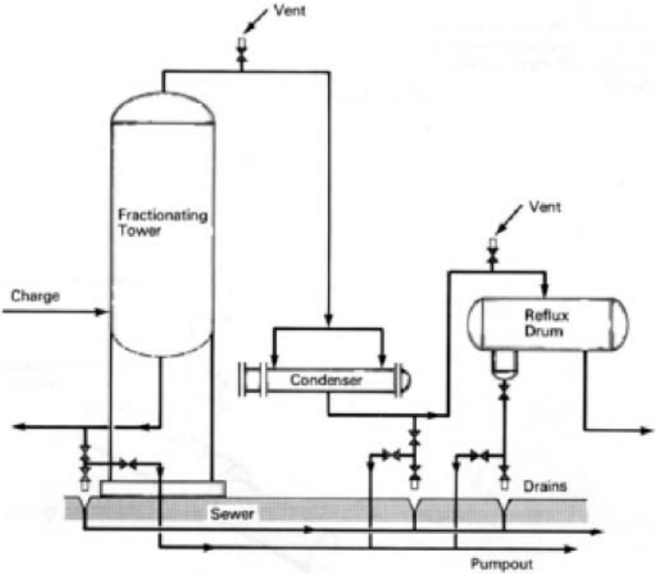


Figure 22 *Vents or overflows should be at the high points of equipment and drains at the low points.*

In some units, the section containing catalyst should be purged with nitrogen or inert gas from a generator, while other sections may be purged with steam or water.

To steam purge a fired unit, steam should be introduced just downstream of the discharge valve of the feed pump and pass through preheat exchangers, furnace tubes and reflux drums.

Additional steam may be injected at the base of each tower and stripper and perhaps at other points, depending on the unit.

In many cases, use of system sketches (usually provided for other reasons) can expedite this steaming need. These sketches (drawings of line systems) can be used to show where steam is to be introduced and where drains are to be opened for water removal and vents opened for venting gas.

Drains and vents designated in the written start-up procedure must be opened before the steaming is started.

Drains must be kept open until only dry steam is vented and can then be closed but must be opened intermittently to remove additional condensate. All vents except those on the tower tops may be closed after there has been a free flow of steam for 20 to 30 minutes. A sufficient number of vents must be left open to avoid overpressuring any part of the unit.

Specific details require attention before and during the purging of some units.

For example, taps to most instruments, except some pressure gauges, must be closed to prevent entrance of steam into the instrument lines (Figure 23).

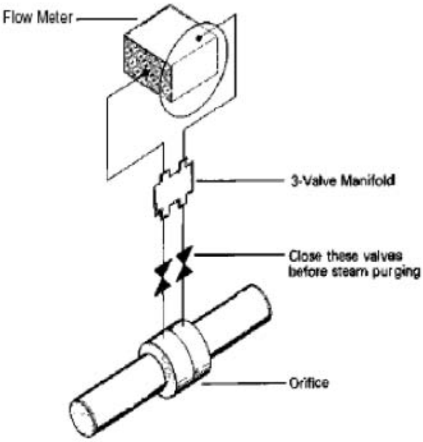


Figure 23 *Instruments which would be damaged by steam must be shut off during steam purge.*

It is important that a note is made of all tappings that have been isolated in order that they are re-opened again at later stages of start-up.

If neoprene or buna-N is used in certain pump seals, the steam must be bypassed around the pumps to prevent damage to the seal material. Bypasses around any check valves that might prevent flow of steam must be opened. Water sides of coolers and condensers must be drained and vented. When steaming through heat exchangers, take care that means are provided to prevent pressure building up on the side not being steamed.

If relief valves discharge into a blowdown or flare system, the entire system from downstream of each valve through the blowdown or flare system must then be purged. If steam is used, it should be displaced with fuel gas to make certain that no air enters to mix with hot oil or gas should a relief valve discharge into the system.

The steam purge of a unit accomplishes three things:

- it removes the air from the unit;
- it heats the equipment to remove ice and to evaporate water from the system (taking care to drain condensate as it forms);
- it discloses plugged drains and vents.

All plugged drains and vents must be opened before proceeding with the start-up.

A device for determining the air content of the steam purge is illustrated in Figure 6a (see page 11). If tests show that oxygen is still present in a concentration greater than 1 percent by volume (equivalent to 5 percent air), purging must be continued, unless specific instructions to the contrary are given in the start-up procedure.

If nitrogen or gas from an inert-gas generator is used to purge the system instead of steam or water, the same general procedure should be followed.

The main difference will be that drains and vents will only be kept open long enough to ensure the complete drainage of any liquids present and until analysis shows oxygen content of the vented gas to be no more than 1 percent. (Specific instruction on oxygen content will be shown in the start-up procedure.)

The pressure should be held as low as possible to reduce the gas quantity required to complete the purge. The oxygen content of the purge gas entering the system must be kept as low as possible. A gas having 0 percent oxygen will purge the equipment most quickly. The combustible content of the purge gas used must be maintained at less than 1 percent to ensure that there is no danger of combustion regardless of the oxygen concentration that might exist in any part of the unit.

Units can be effectively freed of air by two or three evacuations or depressurings, each followed by a repressuring of the system with purge gas. The process should be repeated until tests show that the oxygen content has been reduced to a safe level.

Note that the use of inert gas may present gassing hazards to workers by decreasing the oxygen content (refer to the BP Process Safety Booklet *Hazards of Nitrogen and Catalyst Handling* for more details).

A log should be kept of all analytical tests performed during the steam or inert-gas purge recording the point tested, time of test, oxygen content observed and initials of the person making the test. The critical sample points, such as specific vents and drains, should be given in the written start-up procedure.

If the unit has a flare system which was shut down with the unit, it should be prepared for start-up by applying the same precautions used in the process unit proper. As in the shutdown of the system, precautions should be taken to prevent entry of materials that the system is not designed to handle.

Before igniting the pilot flame, the flare system should be purged of air using a noncondensible inert gas or, if there is no danger of freezing, steam. Purging is especially important if it is possible that hydrogen can enter the flare system from the unit, since hydrogen has a broad flammable range.

Some ignition systems for flare stacks have air and fuel-gas connected to a common header. On such systems, the air and fuel-gas connections should be disconnected or blinded after the flame is ignited. This prevents air from leaking into the fuel gas.

The flare knockout drum should be drained regularly so that slugs of liquid are not vented out of the stack. Any combustible liquid vented will be ignited by the flare and fall to the ground where it may cause a serious fire or injury.

3.4 Tightness testing

Before a unit can be started or operated safely, it must be free of leaks so that hydrocarbons cannot escape and air cannot leak in. Tightness testing with either pressure or vacuum must be continued until all leaks have been stopped.

Great care must be taken in testing to subject equipment only to pressure or vacuum for which it is designed.

Overpressuring can burst the equipment and too much vacuum can collapse it (Figure 24). This applies to equipment of all sizes, from pressure gauges to vessels. Refer to the BP Process Safety Booklet *Hazards of Pressure and Vacuum* for more details.

ACCIDENT

Figure 24 *To educt catalyst from the reactor and regenerator of a catalytic cracker, the fresh-catalyst storage bin was placed under vacuum by means of a steam evactor. The catalyst was moved from the unit to the evacuated vessel through a flexible hose. The system was used twice over a three-year period without incident. During the third use, the vessel collapsed due to pulling too much vacuum. The reason—during the first two uses, the portable evactor designed for this purpose was employed. On the third use, a larger evactor was employed without a suitable vacuum-limiting device. When all vacuum hoses to the system were shut off at lunchtime, the storage bin buckled. As the bin buckled, the movement broke the steam connection to the evactor and prevented complete collapse of the vessel.*

Pressure tightness test

After all vents have been closed, this test can be made by pressuring the purge gas in the unit or by applying water pressure if water has been the purge medium. Pressure should be raised to either 50 psig (3.5 barg) or within 10 psig (0.7 barg) of the lower relief-valve setting, whichever is lower. With the pressure held at this point, there must be an inspection for leaks at all joints, manway plates, flanges, header plugs, vents and drains. Where gas is the testing medium, soap solution may be applied to the joints to aid in this check (Figure 25). Leaks usually will be indicated by the sound of escaping gas, by the appearance of steam or fog, or by a flow of water.

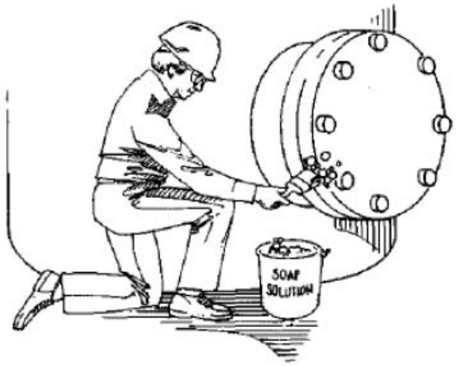


***Figure 25** All leaks must be stopped before the unit is started.*

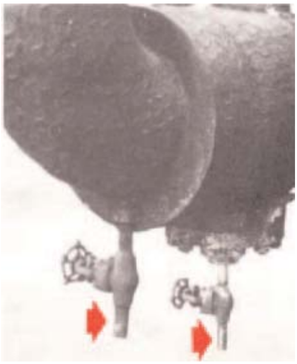
If leaks cannot be stopped by tightening bolts, the system must be depressured and leaking gaskets replaced or other faults corrected.

The outflow of purge gas through an open joint will generally prevent air entering the unit. However, when air cannot be prevented from entering the unit during repairs, the purging and pressure tightness testing must then be repeated. *The air must be eliminated*. When a unit is tight and air-free, the purge gas or water pressure can be reduced to 1 to 2 psig (70 to 140 mbar) by opening a high-point vent and allowing a small flow of purge gas or liquid to continue through the vent until ready for the next step in the start-up procedure. This step will be either vacuum tightness testing, backing in fuel gas or introducing the hydrocarbon to be processed into the system.

Vacuum tightness test

For a unit that is to operate under vacuum, a vacuum test should follow the pressure test. The vacuum test helps to reveal leaks, removes most of the water from the system and prepares it for the charging of cold oil.

While purge gas is flowing from the open vents following the pressure tightness test, the parts of the unit which are to operate under vacuum should be isolated from the rest of the system by closing specified valves. All low-point drains on pumps, exchangers, coolers, equipment and piping associated with the vacuum section should be opened again to drain off all possible condensate and then closed. The drain should then be plugged or blinded to prevent entrance of air at these points (Figure 26).



Arrows indicate solid plugs

Figure 26 *When drainage is complete on vacuum units, drains should be plugged or blinded to prevent entrance of air.*

Vents should then be closed and either plugged or blinded, and the vacuum-generating equipment should be started. As the vacuum increases, the purge gas to the system should be throttled slowly until it is cut off entirely.

A full normal operating vacuum should then be pulled on the unit to test all equipment normally under vacuum.

When this point has been reached, the vacuum-generating equipment should be shut off. If the vacuum gauge, accurate to 1/2 inch of mercury (13 mm), does not drop more than 1 inch of mercury (24.5 mm) per hour, the unit under test is considered tight and ready for start-up.

A vacuum loss greater than 1 inch of mercury (24.5 mm) per hour indicates large leaks of vaporization of water in the system. If it is necessary to break any flanged joints to repair leaks, the vacuum on the system must be dropped by slowly admitting purge gas to the system until it is under a slight positive pressure.

It may be advantageous to conduct the vacuum test for leaks by sections (Figure 27).

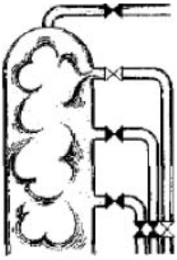


Figure 27 *It may be advantageous to conduct the vacuum test for leaks in stages.*

In a vacuum distillation unit, the first step may be testing the tower and strippers. When it is determined that these are tight, the lines connected to the tower and strippers can then be tested one at a time by successively opening the block valves at the tower or strippers. To test the pumps that take suction on the tower or strippers, close the discharge valves tightly and use gland oil to seal the packing against air in-leakage and then open the suction valves to the pumps.

When a pump has been tested and found to be tight, the suction valve and gland oil to the pump should be shut off to prevent drawing excessive amounts of gland oil into the system.

If vacuum equipment has been purged of air and pressure-tightness tested with water, the water must be displaced with an inert gas after which the vacuum test should be made as described above.

Following the vacuum test, and prior to introduction of hydrocarbons, any air that may have leaked into the system during testing must be purged from the system according to specific unit operating instructions.

3.5 Backing in fuel gas

The next step will be the replacement of purge material with refinery fuel gas, natural gas, or the hydrocarbon to be processed. Before opening the fuel-gas valve, care must be taken to vent equipment so that its pressure is below that of the fuel-gas line to prevent flow of purge material into the fuel-gas system.

The manner of replacement will depend upon what purge material was used. If water was used, the fuel gas will be admitted at the high point of the waterfilled system and the water drained to the sewer (Figure 28). Remember that H_2S might be a concern.

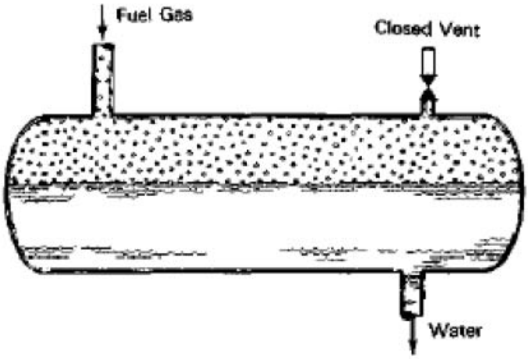


Figure 28 *Purging should be followed by filling unit with fuel gas.*

Just before draining water and admitting fuel gas, all vents left open for water overflow must be closed to prevent air from entering the unit.

Gas is admitted until water ceases to flow and gas is detected at each low-point drain in the system. Each drain must be closed when this occurs to prevent gas from escaping, thereby creating a fire hazard. After all drains have been closed, fuel gas should continue to flow until the pressure in the system is at least 1 to 2 psig (70 to 140 mbar). This will prevent air from leaking into the unit.

If the equipment is designed for pressures as high as fuel-gas line pressure (usually in the range of 15 to 30 psig (1 to 2 barg)), the equipment can be brought to that pressure and left ‘floating’ on the fuel-gas line.

If the purge material was nitrogen or another inert gas, the pressure of the purge material in the system following the tightness test should be reduced to 1 to 2 psig (70 to 140 mbar). All drains and vents must be closed to hold this pressure. Fuel gas is then backed into the unit. The gas is admitted until the system is brought to the maximum pressure that is safe for the equipment or to the normal fuel-gas pressure, whichever is lower. The unit may then be left ‘floating’ on the fuel-gas line if it has been designed for that great a pressure.

If the purge material was steam, one or more vents at high points will have been left open with enough steam admitted to provide a small, continuous flow from the vents and a pressure of at least 1.0 psig (70 mbar). Preferably, the pressure should be raised to about 5 psig (350 mbar) below the fuel-gas pressure to decrease the likelihood of the pressure falling below atmospheric. The fuel gas is then admitted by gradually opening the valve in the fuel-gas line until it is wide open. Steam entering the unit is then throttled gradually until it is shut off. As gas enters the equipment, the vent valves remaining open are closed to prevent the release of gas into the area.

The drain at each low point must be opened and left open until all condensate has drained. Each drain to be opened and checked should be listed in the start-up procedure. A log should be kept of the drain check, showing time of check, absence of condensate, and initials of the person who made the final check of the drain. Each drain must be closed when the flow of water stops and fuel gas begins to escape. Each vent must be closed as soon as gas issues from it.

When all drains and vents have been closed, the unit may be brought to a safe pressure or to the normal fuel-gas pressure, whichever is lower. The fuel gas is then shut off with the gas bottled up, or the unit may be left ‘floating’ on the fuel-gas line.

If even a slight vacuum is inadvertently pulled on the unit during the back-in of fuel gas, the equipment should be purged again before proceeding with the start-up. Such a condition might call for some special techniques in purging.

3.6 Elimination of water

Eliminating all water before hot oil is introduced is generally the second most important precaution to ensure safe start-ups. Other serious consequences of mixing hot oil and water are described in the BP Process Safety Booklet *Hazards of Water.*

Water still in the unit can be eliminated by circulating through the system, first, cold oil and then warm to hot oil.

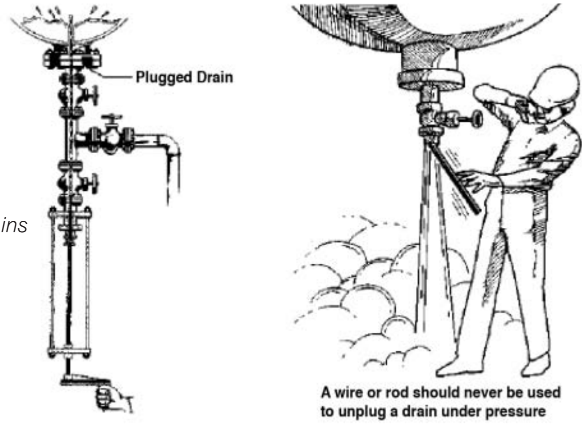
Generally, the oil normally charged to the unit is used. For units which process heavier oils, a low-pour-point gas oil should be used.

The oil temperature during cold circulation may start at 50–100°F (10–38°C), increasing during warm circulation to 100–180°F (38–82°C), and finally in the hot circulation to 180–350°F (82–177°C) and higher. Hot circulation is necessary only for units normally operating at temperatures higher than the boiling point of water.

For unfired units, cold oil is pumped through the unit in the normal oil-flow pattern, using the feed pump and as many other pumps as necessary. When the oil has completed the circuit through the unit, it is returned to the suction of the feed pump for recirculation.

The cold oil will carry liquid water in the system to the low points of the unit.

During the circulation, the drain at each low point in the unit must be opened until no more water is found. The circulation rates must be sufficiently high to sweep out the water, not merely flow over or by it. All plugged drains must be opened (Figure 29).



A wire or rod should never be used to unplug a drain under pressure

Figure 29 *All plugged drains must be opened safely.*

When draining water, care must be taken to prevent unnecessary loss of oil to the sewer. This must be strictly observed because of safety, economy and pollution abatement considerations.

When all water is drained, the circulating oil is heated to raise its temperature gradually to about 180°F (82°C).

If a wide-boiling-range stock has not been used during cold-oil circulation, it must be charged at this time to provide low-temperature vaporization throughout the tower and also to leave enough heavy bottoms to flush the bottoms system. Circulating warm oil will rapidly melt any residual ice that may be present in the unit and carry the water to low points where it must be drained.

For units that operate at temperatures below the boiling point of water, circulation of 180°F (82°C) oil until no more water appears at drains will complete the water removal operation.

Instruments, gauge glasses and alarms should be checked out and placed in service as needed. They should be checked out as completely as possible to be certain that they are reliable and will correctly indicate the condition of the unit as the start-up progresses.

For units that operate at temperatures above the boiling point of water, the oil flow will be changed from circulation to once-through operation as the temperature rises above 180°F (82°C). At this time, the oil charge rate should be about 25 percent of normal or about the maximum capacity of the tower bottoms pumps. Off-test oil from the unit must be pumped to predesignated storage or process units. Feed tanks and low points in delivery lines must be drained of water before deliveries are made.

The fired heater should be used to heat the oil in high-temperature units.

Heaters should be lighted and fired according to instructions given in the start-up procedure. Safe methods for lighting a heater are described in the BP Process Safety Booklet *Safe Furnace and Boiler Firing*.

For units that operate at positive pressure, the fired heater or furnace outlet temperature should be raised 50 to 100°F (28 to 55°C) per hour until a temperature of 270°F is reached (132°C). This temperature should be maintained for about one hour. With the outlet at this temperature, the cooling effects in the system will be such that water will remain liquid. Again, any accumulated water must be drained from all low points in the unit.

The furnace outlet temperature should then be raised at a rate of 50 to 100°F (28 to 55°C) per hour, during which time the entire unit will be heating up. Oil will vaporize at an increasing rate. Residual water in the unit will also vaporize and pass along with the vaporized oil to cooler parts of the unit. In the reflux drums, product rundown lines, condensers, and coolers, it will appear again as liquid water, together with the condensed oil.

The water must be drained from the low points of these cooler parts of the unit so that it does not get back into the hot equipment or pass on the subsequent processing units and cause trouble there. Water must also be drained from all bypasses around exchangers and control valves so that it will not freeze and so that opening of the bypasses, after the unit is onstream, will send slugs of water through the unit.

Reflux lines and manifolds should be flushed with oil condensed in the system before the temperature of the tower reflux tray reaches 200° F (93°C) at, or slightly above, atmospheric pressure. All the regular and spare pumps on the unit must be run during this stage to flush water out of the suction and discharge lines. Heat exchangers, condensers, and blow-down and emergency lines should be flushed.

An alternative procedure for flushing water from reflux, drawoff and pumparound lines is to flush with circulating oil. Suitable connections to the circulating system will be required, depending upon whether cold or warm oil circulation is desirable. If these procedures are used, they must be included in the start-up instructions.

While a tower is heating, avoid introducing liquid oil above 200°F (93°C) until internal temperatures at the point of injection exceed 200°F (93°C). This precaution is required to minimize the possibility of suddenly vaporizing large quantities of water with hot liquid oil. Procedures should be designed to dry the upper parts of the tower with hot vapours from the bottom of the tower (Figure 30).

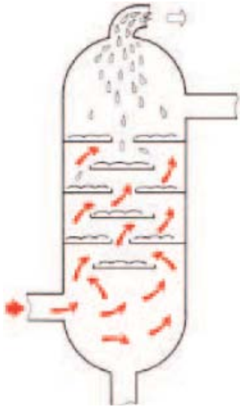


Figure 30 *Dry upper parts of the tower with hot vapours from the bottom of the tower.*

The water which collects in reflux drums must be drained continuously or at frequent intervals to prevent it from being pumped back to a tower with the reflux and violently upsetting the unit.

These drying operations will completely vaporize and remove the last traces of liquid water from the system and prevent damage which will result from contacting liquid water with hot oil. An indication of progress in water removal can be obtained from the rate that water collects in the reflux drums.

Again, as many instruments as possible should be thoroughly checked and placed in service during these steps so they can be used and relied upon as the start-up continues.

Until all the water is eliminated, considerable trouble will be experienced with hot-oil pumps losing suction. When suction is lost, it often will be difficult to reestablish.

These difficulties result from the vaporization of water from the oil-water mix entering the pump suction, causing the pump to become vapour bound. The operators must reestablish suction by repeated stops and starts of the pumps.

Appropriate manipulations of the pump discharge and vent-line valves (if the pumps are provided with vent lines) until the water (and consequent flashing and foaming) is eliminated will help regain steady suction conditions.

Dehydration can be considered complete when steady pump suction conditions have been established and when the tower-top temperature is 250°F (121°C) and the bottom temperature is no less than 375°F (190°C) and not more than 500°F (260°C) at 10 psig (0.7 barg) pressure. When this point has been reached, the charge rate to the unit can be increased about 5–10 percent of normal rate per hour, and the furnace outlet temperature increased 50 to 100°F (28 to 55°C) per hour until normal operating conditions are reached.

A vacuum tower may be considered as any other large vessel with three major differences:

- vacuum towers are generally larger than other towers, and for a given disruption will have exponentially multiplied forces;
- vacuum towers can be started up under vacuum (preferred) or under pressure—either method can be done safely; and
- the process of applying and maintaining a vacuum can create O_2 contamination problems, particularly in the tower overhead system between the overhead condenser and the vacuum jets.

Significant economic problems have been encountered due to damage from flawed vacuum tower start-up procedures. The principles for a safe, efficient start-up have been developed and are included in the start-up instruction for each vacuum unit.

3.7 Bringing the unit onstream

When the unit is water free, it can be brought onstream. This will involve adjusting temperatures, pressures, flow rates and levels, and rerouting gas and liquid streams until the unit reaches normal operating conditions.

After shutdowns, even the best instruments may give trouble. Operators must be trained to recognize possible difficulties even though the instruments may indicate that all is well.

If the oil used for dehydration has not been the normal feedstock to the unit, the switch from the dehydration oil to normal charge should be made slowly to prevent any upset in the temperature, pressure and flow conditions in the unit.

In a vacuum tower, the switch from dehydration oil to reduced crude should be made carefully. The start-up instructions will give the details of these moves.

Stripping steam, if used in the normal operation of the unit, may be started after dehydration is complete and the unit is being brought to normal operating conditions.

Bringing a unit onstream after dehydration is usually accomplished without difficulty. However, certain hazards must be recognized and avoided to bring the unit onstream safely.

Water shots

To avoid the hazards of water shots (sudden vaporization of pockets of water) (Figure 31), operators must be constantly alert for signs of water in incoming stock. This will be indicated by a steady or sudden pressure rise in the unit, depending upon the amount of water. If this occurs, the feed rate to the unit must be reduced until pressures return to normal.

ACCIDENT

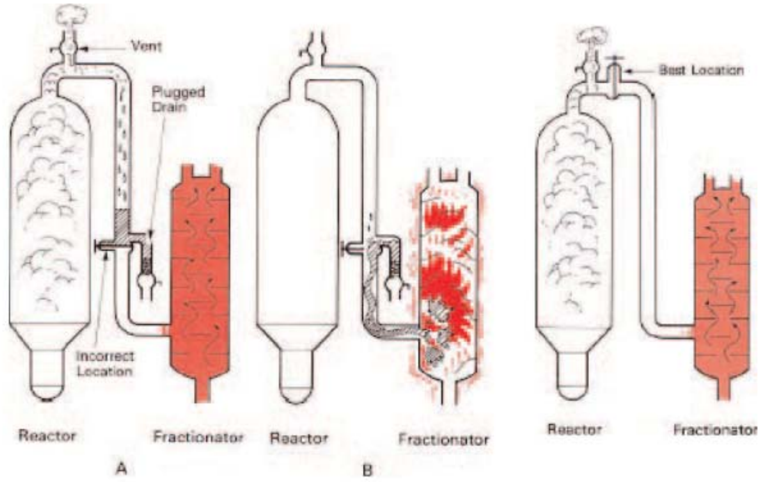


Figure 31 *Because of a plugged drain line, condensate accumulated above a valve in a vertical section of the reactor effluent line to the fractionator on a catalytic cracking unit (A). The fractionator contained a start-up gas oil with a tower bottom temperature of 470°F. This oil was entering the lower section of the feed line. When the valve was opened (B), the water fell into the hot oil and flashed, blowing out nearly half of all 16 trays in the fractionator tower (C). The surge also blew backwards into the reactor and regenerator and was violent enough to shut down the air blower. Had the unit been constructed with the valve located on the vapour line near the reactor, the accident would not have happened because no condensate could have collected in the line (D).*

Thermal and mechanical shock

Changes in temperature, pressure and flow should be made slowly and uniformly to avoid shocks which could lead to strain on the equipment. Care must be taken never to heat liquids trapped in equipment having no vapour space or pressure-relieving device. The liquid expansion that would result could damage and break equipment just as effectively as freezing or an explosion.

An illustration of the effects of such shocks can be found in Figure 1a on page 1 or in the following incident description.

ACCIDENT Before the incident, there had been severe thunderstorms passing over the refinery causing power interruptions and lightning strikes. The strikes caused a fire in the Crude Distillation Unit, and resulted in a shutdown of the FCCU and many other units.

Process unit heat balances became upset resulting in the loss of some facilities. At the process control room, numerous alarms were triggered and information on process parameters was affected, to the point that some of it became misleading.

While attempting to re-start the FCCU later that morning a debutanizer relieved and filled a flare drum with liquid. The wet gas compressor tripped resulting in the FCCU main fractionator overhead gas make being discharged to flare. This gas flow, in combination with liquid from the overfilled flare drum —i.e., two phase flow—created mechanical shocks and vibration in the flare header piping. The 30-inch (76 cm) diameter pipe at the flare drum outlet ruptured at its weakest point (the sudden hydraulic force of the hydrocarbon liquids entering the flare line caused it to break at the elbow bend).

Approximately 20 tons of flammable hydrocarbons escaped to atmosphere from the outlet pipe of the flare knock-out drum on the fluidized catalytic cracking unit (FCCU). The drifting cloud of vapour and droplets ignited about 360 feet (110 metres) from the flare drum outlet and the force of the explosion was equivalent to 4 tons of high explosive. This was followed by a fire.

The site suffered severe damage, and glass damage occurred in a nearby town 2 miles (3 km) away. Twenty-six people suffered injuries on-site, none serious. Rebuilding the damaged refinery was estimated at $76 million and the company was fined $320,000 with $230,000 legal costs.

Overpressuring

Overpressuring can be avoided by making sure that there is no blockage in outlet lines and that gas is released to the refinery gas-collecting system at the proper time and under the proper backpressure control.

Introduction of torch oil and catalyst heating

Torch oil is used in the start-up of fluid catalytic cracking units to help heat the catalyst. The oil is injected into the regenerator catalyst bed which is fluidized with preheated air. Safety in the use of torch oil depends upon ensuring immediate ignition and combustion of the oil as it enters the vessel. If it does not burn immediately but ignites after a quantity of oil has been dispersed through the vessel and mixed with air, an explosion or even a detonation could occur.

To avoid this hazard, the torch oil should not be injected until the catalyst bed in the regenerator is at least 4 feet (1.2 m) above the injection point and is at a temperature of not less than 700°F (371°C).

This will ensure immediate ignition of the torch oil (Figure 32). The flow of oil must be stopped if ignition is not indicated by a rise in bed temperature immediately after introducing the oil. When burning is assured, the oil flow rate can be increased.

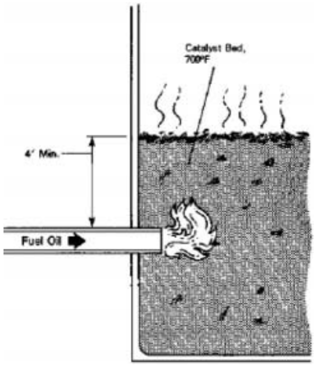


Figure 32 *Torch-oil injection. Catalyst bed must be hot enough to ensure ignition and continued burning.*

Separation of air and hydrocarbon

In some units, air is used in one part of the system but must be excluded from other parts to avoid fires and explosions. To ensure this separation, even though block valves are closed, proper pressure differentials must be maintained. The instruments, controls and seals (such as steam seals on certain block valves) required to indicate and maintain these pressure differentials must be kept in good working condition. Block valves on lines between ‘air-using’ and ‘air-free’ parts of units should be provided with connections to the bonnets to which steam or inert gas should be applied as a seal during start-ups. The pressure of the seal gas must be higher than the internal pressure of the system to insure an effective seal. The Fluid Catalytic Cracking Unit incident described in detail in the next section is a typical example of what can happen when air and hydrocarbons are not kept isolated.

Refer also to the BP Process Safety Booklet *Hazards of Air and Oxygen* in this series.

4

The importance of procedures and supervision

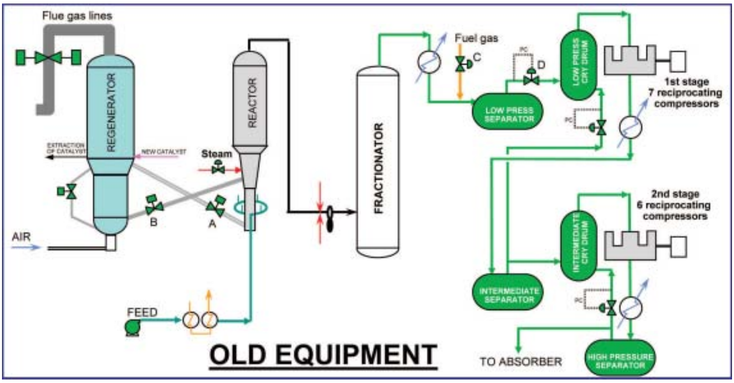
As outlined many times in chapters 2 and 3 most of the incidents during start-up or shutdown occurred when procedures were not followed or they were inadequate. Supervisors must make sure that procedures are understood, followed, and that they are up-to-date. The two serious incidents detailed below vividly illustrate this with both shutdown and start-up cases.

ACCIDENT **Massive explosion in regenerator vessel blew out 165 tons of metal pieces into the air!**

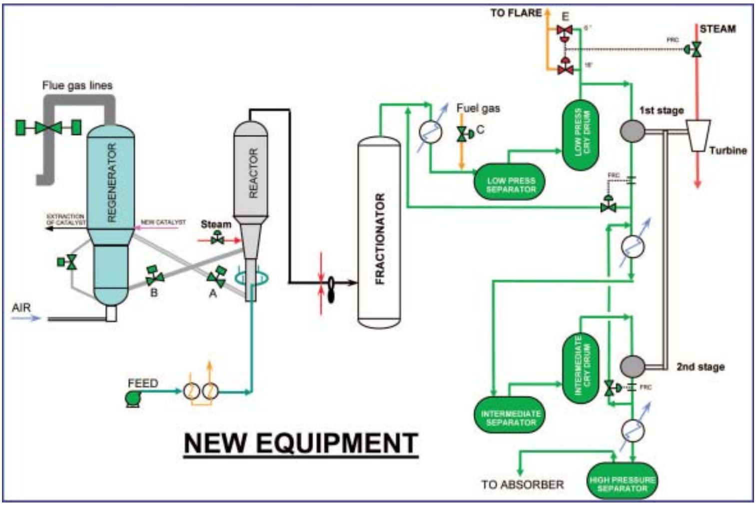
Fluid Catalytic Cracking Unit (FCCU) n°1 had been in service for 19 years without major incident. The 34 runs completed were all completed following the same shutdown procedure summarized below:

1. Slowly decrease feed to zero;
2. Shutdown preheat furnace;
3. Increase steam to reactor (stripping steam and through feed line);
4. Open fuel gas (*valve C on drawing below*) to LP separator to hold pressure in reactor to 200–280 g/cm^2 (3–4 psi) keeping some compressors running to hold pressure;
5. Continue catalyst circulation for 30 minutes to burn off carbon;
6. Close regenerator slide valves (*A on drawing below*);
7. Transfer catalyst from reactor to regenerator;
8. Close spent catalyst valves (*B on drawing below*);
9. Steam out reactor;
10. Dump catalyst from regenerator;
11. Stop all compressors;
12. Steam out all towers and drums and install blinds.

(*continued*)



It was decided to replace the 13 reciprocating gas compressors by a single new steam-driven two-stage turbine centrifugal compressor. The changes made to the unit were written up thoroughly in a supplementary operating instruction manual. The unit start-up and shutdown procedures were not changed accordingly because it was not thought that there would be an impact on these. The unit was successfully restarted for a six months run.



The first shutdown of the modified unit started on a Thursday and went through steps 1 to 10 smoothly (with the difference at step 4 being that the only compressor was stopped). However, the unit foreman decided to turn off the stripping steam to the reactor. The function of this steam is to isolate the air filled regenerator from the fuel gas filled equipment downstream of the fractionating column, which is located immediately downstream of the reactor (steam was not used downstream of the fractionator because of equipment limitations with respect to temperature).

(*continued*)

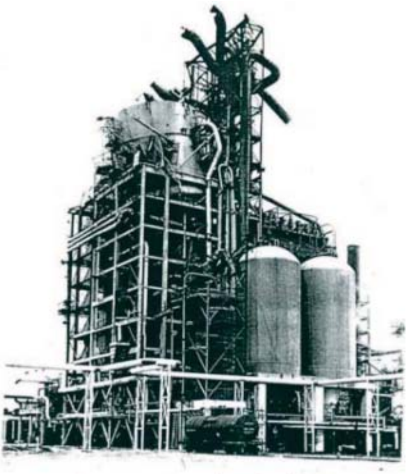
During previous shutdowns, operators had to inject steam from every available connection to maintain pressure in the reactor: fuel gas alone would not hold pressure up because some compressors were left running as per procedure and valve D (on low pressure separator gas outlet line) was allowed as much gas to leak through as could be added.

The new arrangement, used for the first time on this shutdown, was holding the fuel gas pressure very well since the compressor was stopped and the valves to the flare (E), used to control the pressure, were gas tight. Therefore, the operators did not see the need to inject steam to maintain the reactor pressure, when in fact steam was needed to isolate air from fuel gas.

No-one recognized that the unit pressure would behave differently on shutdowns, and therefore the procedure and the three days training on the new installation did not cover this aspect or the safety importance of steam injection in the reactor.

The catalyst unloading operation is a long one because of blockages. At about 5 pm on the Friday, the chief operator stopped the steam to the feed line to avoid making the catalyst muddy, thus eliminating the only remaining significant source of steam to the reactor. At 8:20 pm, most of the crew had gone into the control room to seek shelter from a severe rain storm. This was fortunate since this location was not damaged by the explosion. At about 8:30 pm an explosion took place in the regenerator, and its force blew off the 165 tons head of the regenerator. It travelled upwards 15 m (50 ft) and then fell 38 m (125 ft) horizontally away (see pictures). Recoil forces thrust the regenerator vessel and associated piping down several feet. There were no fires and no casualties.

Regenerator before incident

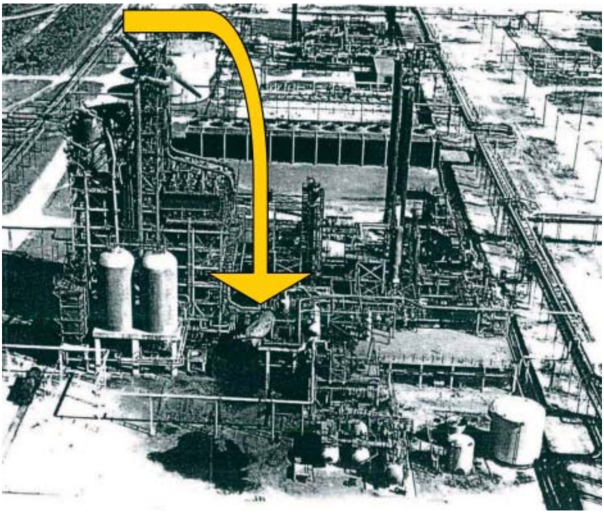


Regenerator after incident

(*continued*)

The investigation committee established that the explosive mixture was equivalent in energy to one ton of TNT. While the source of the flammable mixture has been confirmed as the fuel gas backing up into the air filled regenerator (slide valves A & B are not designed to be gas tight), the source of ignition has not but may possibly be due to:

- friction sparks (from small pieces of metal or refractory);
- static sparks (moving catalyst is a good static generator that can produce incendiary discharge sparks);
- autoignition on hot coke or hot catalyst.



Among many recommendations made by the committee, the following ones are highlighted here:

- **The operating department should be reorganized to provide more technical and practical supervision on shifts.**
- **Experienced supervisors with technical training should be assigned to each process unit during critical times of start-ups and shutdowns.**
- **All planned start-ups and shutdowns should be reviewed with operating crews before they are begun. Potentially dangerous steps should be thoroughly explained at these reviews.**
- **All operating manuals for process units should be kept up to date including start-up and shutdown procedures. Steps where deviations cannot be permitted should be highlighted with the reasons explained.**
- **Start-up and shutdown procedures should be followed in detail.**

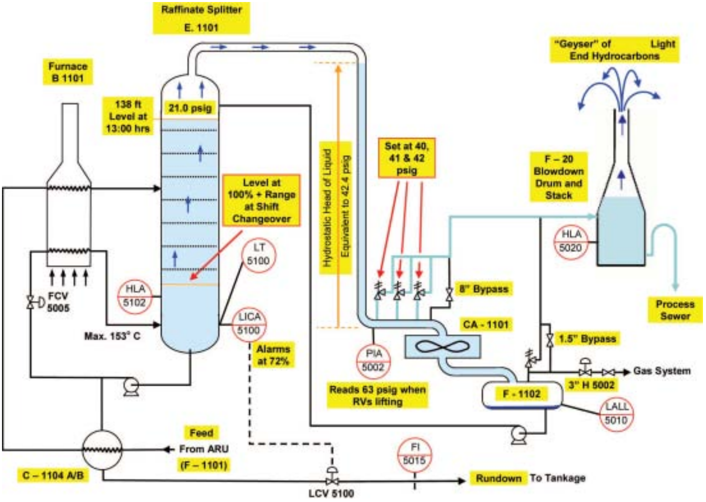
ACCIDENT 15 killed and over 170 injured in vapour cloud explosion during isomerization splitter section start-up

An explosion occurred after light-end hydrocarbons were discharged to atmosphere from a blowdown stack. The blowdown system received vapour/liquid hydrocarbons directly from vents and pressure relief valves on the unit. The discharge was the result of relief valves lifting to reduce the pressure in the overhead line of the Raffinate Splitter column after the column was overfilled and rapidly overheated during start-up.

Background

The Isomerization Unit (ISOM) converts low octane blending fuels into higher octane components for blending to unleaded regular gasoline.

The **Raffinate Splitter** E-1101 is one of four sections on the ISOM. It takes a non-aromatic stream from the Aromatics Recovery Units and fractionates it into light and heavy components. The heavy Raffinate is used for gasoline blending. It is a single fractionating column, 50 m (164 ft) tall with 70 distillation trays at 0.6 m (2 ft) spacing, a feed surge drum F-1101, a fired heater reboiler B-1101, a fin-fan overhead condenser CA-1101 and a reflux drum F-1102.



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The **blowdown system** F-20 is designed to receive, quench and dispose of hot hydrocarbon vapours and minor associated liquids from the ISOM pressure relief valves, vent and pump-out system during upsets or shutdowns. The blowdown system consists of relief pipework headers (two from other parts of the ISOM plus one from the Splitter), the blowdown drum and stack F-20 and a pump-out pump. Vapours disperse from the top of the stack and liquids flow out of the drum through a gooseneck into the site's sewer system. F-20 was commissioned in the 1950s and has been modified several times over the years. It is a vertical drum of 3.5 m (10 ft) diameter with a 34 m (113 ft) high stack, and has an approximate volume of 390 barrels (62 m^3).

Trailers are used as temporary offices at refineries, supporting contract workers involved in project work and turnarounds. In this case, they were required for a turnaround on the Ultracracker Unit across the road to the north of the ISOM. Local procedures called for them to be sited under a Management of Change control process. When a trailer is to be sited within 107 m (350 ft) of a process unit, there is a specific requirement for a Facility Siting Analysis. The closest trailer, a double-wide contractor trailer, was located within 46 m (150 ft) of the base of F-20 (the blowdown drum and stack) and this is where most of the fatalities occurred at the time of the explosion.

Damaged contractor's trailer

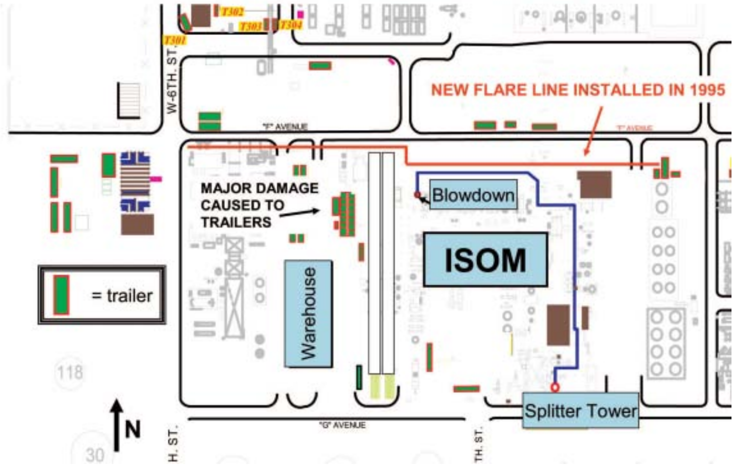
The ISOM start-up had commenced on the night of 22 March after a four week shutdown, with the Splitter and its associated equipment having been previously purged with nitrogen. Liquid levels had been established in the vessels of the Raffinate Splitter, and the fired reboiler circulation loop filled by the end of the night shift. During this process, the liquid level at the base of the Splitter column rose to above 10 ft, the 100% mark (top scale) on the column bottoms level indicator. Although the high level alarm fed by a signal from the displacement level detector had been activated at 72% of full scale, the independent high level alarm switch designed to alarm at 78% of full scale did not alarm. Despite the requirement to check the instrumentation on the column prior to start-up, this had not been done. The night shift operator did

(*continued*)

not report the failure of the independent high level alarm either verbally nor in writing in the shift log. The high level alarm linked to the column level indicator and associated level control valve in the rundown to tankage remained ‘on’ and acknowledged throughout the build up to the incident.

The Day Shift Supervisor arrived at the ISOM at 07.13, but did not conduct a job safety review, nor a walkthrough of procedures, as were required by the operating procedures. At 09.21 the outside operators briefly opened the 200 mm (8 inch) chain-operated vent valve bypassing the Splitter pressure relief valves in order to vent nitrogen to the Blowdown Drum. This dropped the pressure from around 0.28 bar g (4 psig) to nominally atmospheric pressure. This was in contravention of operating procedures that called for the use of the 3 inch (75 mm) vent gas system. Splitter reboiler circulation was commenced at 09.41 and feed introduced at 09.52 at a rate of 130 m^3/hr (20,000 bpd).

The board operator did print the wrong start-up procedure but never consulted it.



Plant layout with location of trailers

Coincidentally with introducing the feed, the Control Room Operator stroked the heavy Raffinate rundown control valve, which controls the level in the base of the Splitter, on manual to confirm that the route was open to tankage. He then closed the control valve on manual, although the operating procedures required that the Splitter level controller be placed on automatic with a 50% set point. **Despite filling the column at 130 m^3/hr (20,000 bpd), there was no product going out to tankage.** However, the heavy Raffinate flow was indicated to be in the region of 3,000–4,700 bpd, later believed to have been a zero error. There had been no change to the Splitter base level indication or alarm status from the night shift, i.e. it was still showing 100% with the 72% level alarm activated and acknowledged, and with the independent 78% alarm inoperative.

(*continued*)

At approximately 10.00 two burners were lit in the reboiler fired heater. The Day Shift Supervisor then left the refinery to attend to personal business and did not return prior to the incident occurring. Two additional burners were lit at 11.17, with the Splitter bottoms temperature increasing at about 24°C (75°F) per hour, despite operating procedures stipulating that the warm up rate should be no more than 10°C (50°F) per hour. At this time the Splitter Reflux Drum was found to be still empty of liquid, with the bottom level gauge connection passing vapour only. The column pressure had risen to 2.3 bar g (33 psig) [normal operating pressure 1.38 bar g (20 psig)] by 12.40, with the base temperature reaching 150°C (302°F) [normal operating temperature about 135°C (275°F)]. At this point outside operators opened the 200 mm (8 inch) chain-operated pressure relief bypass valve for a second time. An operator then reported that vapours, which looked like steam, were venting from the top of the blowdown drum vent. After 10 minutes this valve was closed by which time the column pressure had fallen to about 1.6 bar g (22.6 psig). The Splitter reflux drum continued to show 0% level until around 13.16, **the continued introduction of cold feed with no bottoms product outflow** had resulted in it taking far longer to produce light Raffinate than in a normal start-up.

At the same time as these activities a safety meeting was being held in the Control Room close to the ISOM panel, attended by Area Superintendents, Shift Supervisors and about 15 others.

At 12.41 the Board Operator opened the heavy Raffinate control valve for the first time since the Splitter feed had been introduced. No flow of heavy Raffinate rundown to tankage occurred until 13.00, most likely because a block valve had remained closed. **As soon as the heavy Raffinate started to flow, it created a major feed preheat raising the temperature of the feed very quickly from 52 to 127°C (126 to 260°F) in 10 minutes.** The feedrate to the Splitter had remained unchanged since it was first introduced at 09.52. A post incident analysis demonstrated that by the time of the incident the Splitter column level had risen to around 42 metres (137 feet) submerging 57 of the 70 trays within the column. The start-up procedure specified a 50% set point of the level indicator controller in automatic rundown mode to tankage (this is equivalent to approximately 1.5 m (5 ft) in the bottom of the column). The high level alarm associated with this instrument remained 'on' at 72% of the instrument's full range.

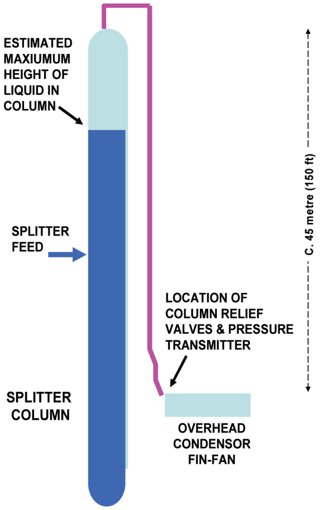
By 13.13 the pressure in the overhead line started to increase rapidly, peaking at 4.3 bar g (63 psig). Witnesses confirmed that the column pressure relief valves had opened to pass hydrocarbon directly into the Blowdown Drum through the 350 mm (14 inch) diameter header, and that a geyser of liquid was emerging from the blowdown vent, with liquid running down and forming a pool emitting vapours around the base of the drum. Burners in the reboiler heater were shutdown and blocked in, and the Splitter reflux pumps started up. Radio messages alerted operators of the leak before the hydrocarbon release ignited. Two or more explosions were reported about 1½ minutes after the release from the Blowdown Stack started (six minutes

(*continued*)

after the relief valves lifting), the first relatively minor followed by a blast timed at 13.20—this perception of separate explosions may be due to echoes, as modelling has shown that only one explosion occurred. A number of secondary fires resulted from blast damage to the ISOM, with fires eventually being extinguished after two hours.

The site Emergency Response Team was supported by mutual aid and helicopter ‘Life Flight’ was called in. Injured personnel had been evacuated by 16.44, and ambulance and Life Flight resources stood down. However one fatality was not found until 23.00 having been buried under debris.

The investigation team concluded that the Splitter was overfilled and rapidly overheated because ‘the Shift Board Operator did not adequately understand the process or the potential consequences of his actions or inactions on March 23’. Although the correct operating procedure was available, it was not used by the Board Operator and the outside operators used local practices to vent residual nitrogen instead of the installed system, without understanding the implications. Additionally, supervisory staff did not verify that the start-up procedure was being used and were absent from the unit for much of the start-up. Equally, if one of several possible interventions had been made the incident would not have happened.



The trailer park located to support another plant turnaround had been placed within 45 metres (150 ft) of the Blowdown Drum and was, quite naturally, the congregating point for contractors’ personnel conducting the turnaround. Local site Management of Change rules requires that where a trailer is to be placed within 100 metres (350 feet) of a process unit a Facility Siting Analysis must be carried out. However, this location had already been used many times for these trailers in the past.

The investigation team concluded in their report ‘that while many departures to the start-up procedure occurred, *the key step that was instrumental in leading to the incident was the failure to establish heavy raffinate rundown to tankage, while continuing to feed and heat the tower.’*

(*continued*)

By the time the heavy Raffinate flow was started (3 hours late) to tankage, the Splitter temperature had been raised so much and the level in the tower so high that the rapid exchange of heat between the rundown to tankage and feed triggered the lifting of liquid over the top of the tower into the overhead system. This was due to a combination of rapid vaporization at the feed inlet to the tower, coupled with vaporization of the liquid in the base of the Splitter.

Out of numerous causes and contributing factors (full investigation report is available on http://www.bpresponse.org), personnel competencies, the importance of procedures, incident reporting and supervision are highlighted next.

Procedures

While SOPs were certified as current, they did not include changes to relief valve settings made prior to the most recent recertification. This change significantly reduced the pressure that could be used for nitrogen pressure testing, for example, although there is no reason to suspect that this alone made a significant contribution to the incident. There were two start-up procedures available for the ISOM: ‘Start-up following a turnaround’, and, ‘Start-up following a temporary outage’. It appears that the Board Operator printed out the latter (but never used it), while the Supervisor gave an inexperienced outside operator a copy of the former which addressed the hazards of water and non-condensables. These were clearly not used as the investigation team found eleven major deviations from the SOPs, including commissioning of the Splitter base level controller and column pressure control systems. However, the investigation team also found, notwithstanding the above, that the operating procedures were generally of high quality, addressing all the safety warnings and key process control steps in detail. They concluded that, in general, operators were unaware of the risks of operating without use of procedures and considered the start-up to be a routine operation needing little evaluation or thought.

Personnel competency

There was clearly no attempt made to conduct even the most rudimentary material and energy balance over the unit by the Board Operator after feed was introduced to the Splitter. This was exacerbated by the lack of reconciliation between the position of the Splitter base level control valve to the indicated flow—it was closed on manual for the duration of the start-up but the indicated flow was around 4,500 bpd (zero error on meter).

The Board Operator did not appreciate the effect that decreasing liquid density with increasing temperature of the column bottoms would have on a liquid level measurement of the displacement type, which allowed the DCS indication to drift down from 100%.

(*continued*)

There would also have been clear indications to outside operators, not least the rising suction pressure on the Splitter bottoms pumps, and the absence of any level building in the reflux drum. None are reported. Knowledge of safety critical plant parameters apparent in the field are every bit as important as those shown on the control panel. The outside operators also had access to a satellite control room that had a repeat indication of what was shown on the control room DCS—in fact the night shift operator had used this to establish liquid levels and fill the reboiler circuit.

Deficiencies had been identified in the ISOM training programs in audits conducted in 2003 and 2004, including that the unit had no training plan and operating personnel individual training plans were not in place to address identified gaps. The unit Training Coordinator spent only 5% of his time on training activities, more often working as a relief supervisor and participating in HAZOPs MOC reviews, and turnaround planning.

Supervision

The fact that there was not one person supervising the start-up undoubtedly made a major contribution to this incident. Supervisors can support busy operators by taking a detached view and can sometimes spot things that those close to the action cannot (the accident at Three Mile Island is a case in point). Supervisors can also play an essential role in allocating resources to investigate and resolve discrepancies or attend to breakdowns.

Finally, there is little doubt that this start-up was taking a lot longer and becoming far more ‘difficult’ than would normally have been expected for what is a simple distillation column. When this type of situation becomes apparent, all operators and supervisors should have sufficient authority, knowledge and experience to stop the process, investigate what is actually happening, resolve the problems and start again.

Incident reporting and investigation

The investigation team found that there had been at least 19 incidents of hydrocarbon vapour having been released from the Blowdown Drum vent over the past 15 years, but none of these resulted in the release of liquid hydrocarbons flowing from the vent or accumulating at ground level. As incident records prior to 1999 were difficult to locate, the number could well have been higher. Recommendations for corrective actions focused on training and procedures rather than examining the adequacy of the operating philosophy.

Records and experience of previous start-ups showed that it was not unusual to start-up with a level above the 100% indication, with several start-ups occurring with the liquid level in the range 3 to 10 metres (9 to 35 ft) above the bottom tangent line of the column and well above the bottoms level indication. This was because these had been ‘warm’ start-ups, i.e. the

(*continued*)

column had not been drained after the preceding shutdown. There had been 18 start-ups in the previous five years, during which five (33%) had experienced a pressure spike to within 10% of the pressure relief valve set point, with two of these (13.3% of the total) resulting in the relief valves lifting and discharging vapour to the Blowdown Drum. The key difference between the previous start-ups and the one which resulted in this incident was that heavy Raffinate product flow was established on average 15 (but no later than 46) minutes after the Splitter feed had been introduced.

Remember that:

- **Start-ups/shutdowns are rare, so refresher training may be needed.**
- **Make sure all critical instrumentation/equipment are functional and that certifications are current.**
- **Make sure that all work permits have been closed and the equipment approved for use.**
- **Talk through the procedure as a team before each shift.**
- **Identify the hazards and safeguards listed in the procedures.**
- **Follow written procedures/checklists step by step.**
- **Make sure all valves/blinds/locks are in the proper position.**
- **Never go to the next step of the procedure before all conditions from previous steps are fully completed with satisfactory results.**
- **Check equipment setup thoroughly and monitor initial conditions in the field. Maintain excellent communication with the control room.**
- **Use Management of Change reviews before modifying any start-up procedures.**
- **Report any deviation/anomaly. Keep an open eye for ‘weak signals’.**
- **Do not be satisfied by short term fixes (‘symptom treatment’) but identify and treat the root causes of incidents.**
- **Ask questions and get help with operations which are not familiar to you.**
- **If unsure, or if multiple parameters seem to deviate from the usual ones indicated in the procedure, shutdown the process and alert potentially exposed personnel!**

5

Conclusion

Safe procedures for the ‘ups’ and ‘downs’ of any unit should be included in detail in the operating instructions.

The instructions should be clear and definite and give the exact steps to be followed. Vagueness must be avoided.

No deviation from procedure should be allowed, except on approval of the supervisor in charge of the unit. The Management of Change process should be used if the supervisor decides to deviate from the normal procedure.

The steps of the procedure should be given in the sequence in which they will be used. The checkoff system or critical-path system should be used to show the condition of the unit at all times. Checkoff lists should be used as necessary, and initialling by operators should be required. Emphasis should be placed on critical safety and process steps.

The proper activation of instruments must be emphasized so that reliable control and indications of operating conditions can be maintained at all times.

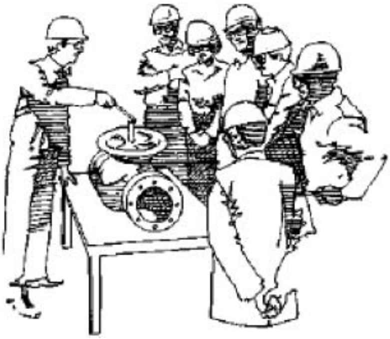
Operators must be well-trained. They should be aware of their dependence upon instruments and should recognize, investigate and seek causes for any discrepancies. Technicians well trained in maintenance and instrumentation should be available as required to correct equipment troubles and help put the instruments in service.

Adherence to procedures which clearly point out potential hazards, properly designed equipment, and alert, well-trained personnel should insure safe shutdowns and start-ups.

6

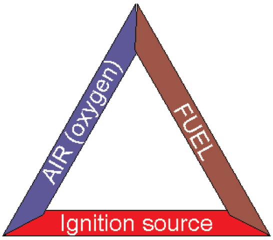
Some points to remember

1. Training and experience are important. Experience by itself may be a painful teacher.



2. Careful preparation is necessary. It saves time, equipment and money.

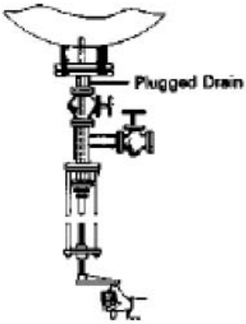
3. Procedures must be safe.



4. Hydrocarbon vapour-air mixtures must be rigorously controlled. Assume that there will be a source of ignition.

5. During shutdowns, remove residual hydrocarbons before admitting any air. During start-ups, remove residual air before admitting any hydrocarbons.

6. Dispose of water to prevent freezing and explosions from contact of water and hot oil. Guard against water in feed tanks and lines. Know what to do if water enters the unit unexpectedly.

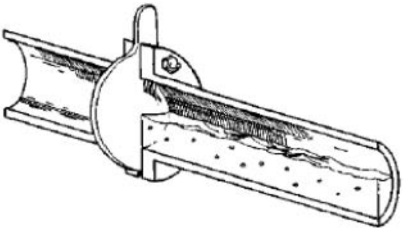


7. When venting or draining a unit, be sure that all vents and drains are unplugged.

8. Handle corrosive and toxic materials safely.

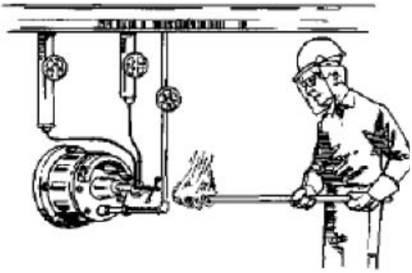
9. Keep pyrophoric iron sulphide wet until removed to a safe burning area.

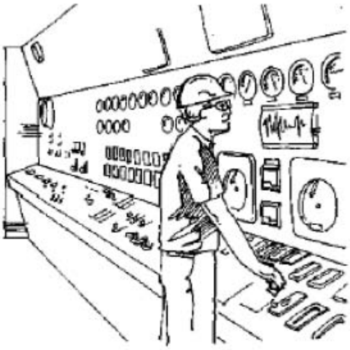
10. Use blinds where they are needed. Install and remove them at the right time. Use a checklist.



11. Be sure the unit is free of leaks.

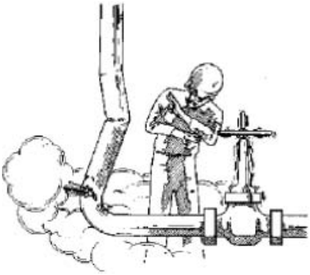
12. Light furnace fires safely.





13. Activate instruments properly so they can be relied upon during start-up.

14. Do not subject equipment to vacuum unless designed for it.



15. Change operating conditions gradually to avoid temperature and pressure shocks.

Acronyms and abbreviations

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

Test yourself!

1. Pyrophoric fires can occur only in packed columns.

True ☐ False ☐

2. Pyrophoric scales can self-ignite days after being exposed to air.

True ☐ False ☐

3. To prevent sudden air ingress in columns that may contain pyrophoric scale, the best practice is to open the top and bottom manholes first.

True ☐ False ☐

4. Water hammer effects are frequent when steam is admitted into a cold system too rapidly.

True ☐ False ☐

5. Water hammer can destroy equipment and cause injuries.

True ☐ False ☐

6. Ice uses less volume than the original water and therefore is not dangerous to equipment.

True ☐ False ☐

7. All vessels are designed to sustain the vacuum resulting from steam condensation.

True ☐ False ☐

8. All refinery equipments are designed to endure a long steaming time.

True ☐ False ☐

9. The only way to unplug a drain is using a rod or wire.

True ☐ False ☐

10. During start-ups, air must be removed before admitting any hydrocarbons.

True ☐ False ☐

1F/2T/3F/4T/5T/6F/7F/8F/9F/10T