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BP Process Safety Series

Safe Furnace and Boiler Firing

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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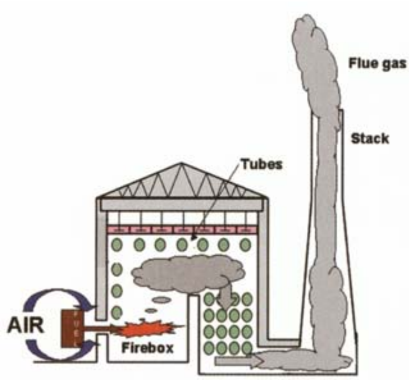
How fired heaters work

Fuel oil and gas have played a major role in the development of economical and automatic heating systems, both for home and industry. Basic fired heater design has changed little, and many years of operating experience have been acquired; however, we still have firebox explosions. In petrochemical furnaces and boilers, most of the explosions occur when the burners are being lighted. To understand this and other hazards, let us review how furnaces work.

2.1 Description

A fired heater is a piece of equipment in which heat released from the controlled combustion of fuel at the burners is transferred to material passing through the tubes along the wall, roof, or floor (hearth) of the heater. Figure 2a and 2b show simple petrochemical furnaces.



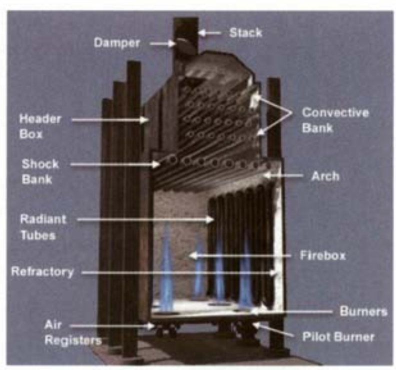


Figure 2a *Simple petrochemical furnace.*

Some preliminary definitions:

- *Fire box/combustion chamber:* The open area inside the heater where the combustion of the fuel takes place.
- *Flue gas ducting:* The large diameter piping between the convection section of the heater and the stack.
- *Convection:* The transfer of heat through the circulation of gases.

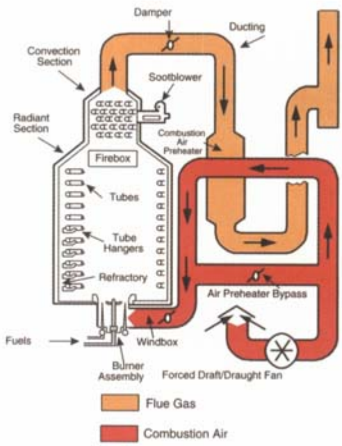


Figure 2b *A typical vertical furnace.*

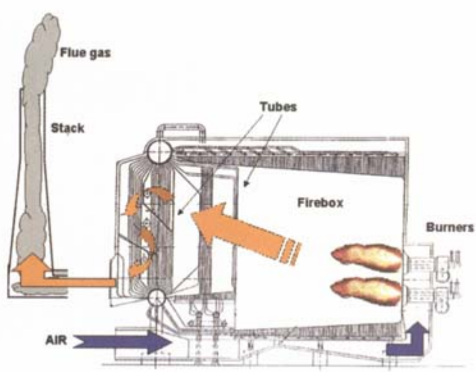


Figure 2c *A typical industrial boiler.*

This fired heater works just like the one at home, only it is bigger. Fuel and air are supplied through burners and air registers and burn under controlled conditions in the combustion chamber (firebox). The heat released by combustion is transferred through the furnace tubes to the oil, water, steam, air or whatever is circulating in the tubes. The furnace tubes can be located along the walls, roof and floor of the firebox.

The products of combustion (flue gas) flow from the firebox, through a stack, to the atmosphere. The hot flue gas flows up through the stack because it weighs less than the cool air outside. Sometimes fans are used to increase the flow of flue gas through the furnace.

Figures 3, 4 and 5 show views of typical petrochemical fired heaters. Furnaces may have burners in the walls, roof, floor or any combination of these locations. Neither burner location nor furnace type affects the fundamentals of safe furnace firing as given in this booklet.

Figure 3 *Two typical Vacuum Distillation Unit furnaces.*

Figure 4a *Vertical cylindrical furnaces.*

Figure 5a *Multiple box type furnaces.*

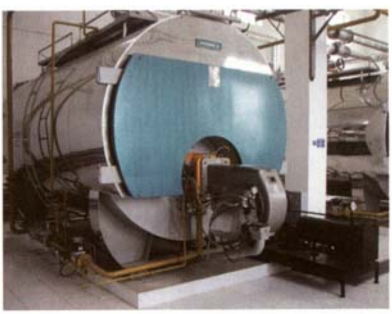


Figure 4b *Small boiler.*

Figure 5b *A hydrogen production furnace with burners on top.*

2.2 Combustion

Now that we have a general idea of how furnaces work, let us take a closer look at the basic furnace process combustion. *Combustion* as used in this booklet simply means the controlled burning of a fuel. Combustion (fire) in a furnace firebox occurs when fuel combines rapidly with oxygen present in the air. The three requirements for fire are fuel, oxygen from the air and a source of ignition, as represented in Figure 6.

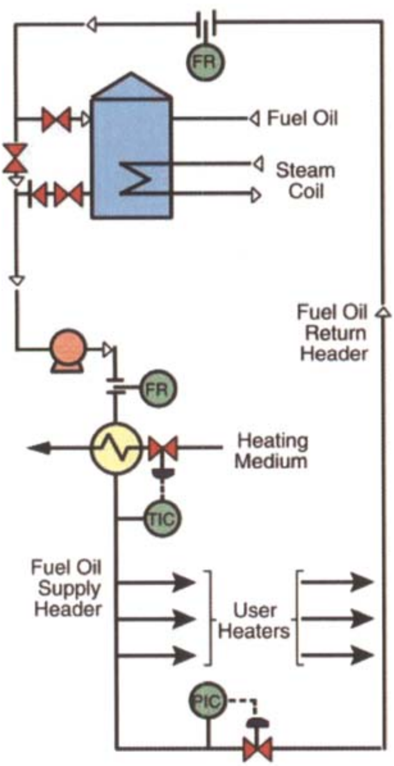
Figure 6 *The fire triangle.*

Fuel

Petrochemical furnaces burn oil, gas or both at the same time. Fuel gas for pilot burners is supplied from a separate system if possible to ensure a high integrity supply. Fuel gas has to be mixed with air before it can be ignited. Fuel oil has to be atomized, vaporized and mixed with air before it will burn properly.

Fuel gas and oil are combinations of hydrogen and carbon known as *hydrocarbons*. When hydrocarbons burn, the two elements unite with oxygen to form water vapour (H_2O) and carbon dioxide (CO_2).

Most fuel oil burned in petrochemical furnaces is a mixture of heavy residual bottoms. Fuel oil may be a single component or a blend of components from several sources, but the only property that really affects efficient burner operation is the viscosity of the oil at the burner. Thus, heavier fuels are heated, normally by steam, to reduce their viscosity at the burner. To be sure that the burners can atomize the oil properly, it is often necessary to heat it to temperatures ranging from 150°F (65°C) to 450°F (230°C). Sometimes heavy vacuum-tower bottoms at about 700° F (370°C) are pumped through a fuel-oil piping loop to the furnace burners, with the excess oil going back to the tower.



Like the fuel gas system, the entire fuel oil system is heat-traced and insulated; however, the fuel oil supply to user heaters is pressure controlled by spilling a return flow of oil to the fuel oil storage tank when there is an excess amount (see Figure 7).

At each heater, all fuel passes through a remote isolating valve, dual filters to remove any solid materials which might block burners, and a local isolating valve at each burner location.

Figure 7 *A fuel oil system.*

Refinery fuel gas contains mostly methane and ethane, which are too volatile to put in marketable products.

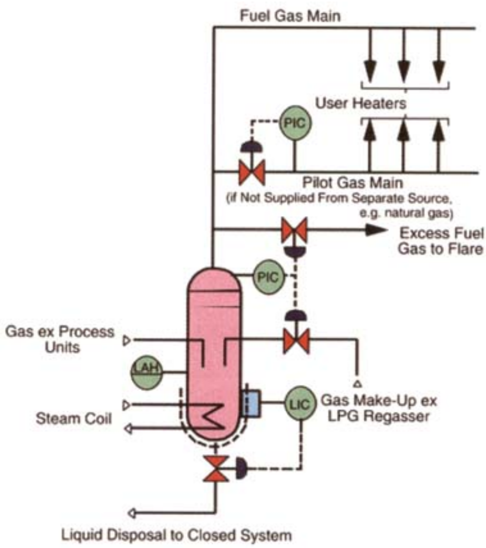


Figure 8 *A fuel gas system.*

Fuel gas is collected from various process sources in a central fuel gas mix drum (see Figure 8). Here, liquid is knocked out and discharged to a closed system. The fuel gas mix drum and associated piping to the heaters are heat traced and insulated to prevent condensation during cold weather.

If condensation occurs and the liquid is carried forward with the gas, unignited fuel can accumulate in the firebox or flue ducting. This can cause an explosion when sufficient air for combustion is available.

The fuel gas may also contain hydrogen (sometimes as much as 85 percent) and small amounts of heavier gases. Inert gases (such as nitrogen, carbon dioxide and water vapour) may also be present. Usually there will be a very small amount of oxygen in the fuel gas.

Be *extremely* careful about purging the firebox before light-off if the fuel gas contains hydrogen. Purging is always vital to safety, but it is particularly critical if there is a chance that hydrogen, with its broad flammability range, has leaked into the firebox during shutdown.

When fuel burns, a large volume of hot flue gas is formed. For example, the burning of 10 cubic feet (0.28 m^3) of fuel gas with 200 cubic feet (5.7 m^3) of 70° F (21°C) air produces about 1,300 cubic feet (37 m^3) of hot flue gas.

The hot flue gas gives up heat to the furnace tubes and contracts as it cools.

The 1,300 cubic feet (37 m^3) of flue gas will shrink to about 400 cubic feet (11 m^3) by the time it reaches the stack, as shown in Figure 9. Furnaces are designed to handle this normal expansion and contraction of flue gas. Combustion, of course, is carefully controlled by regulating fuel, air and draught. About one quarter of the heat produced in a furnace is lost in the flue gas leaving the stack.

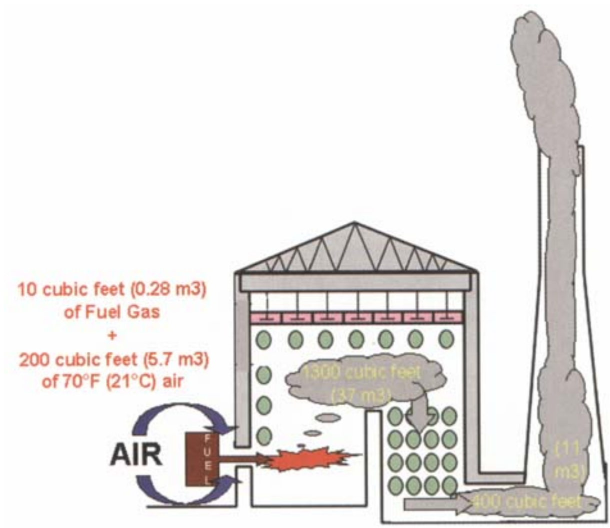
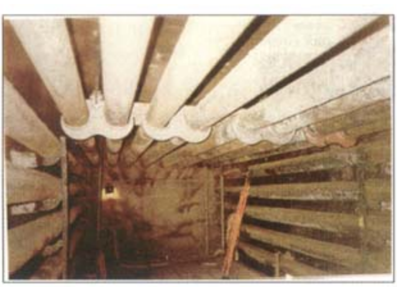


Figure 9 *The burning of fuel generates a large volume of flue gas which cools and shrinks as it passes over the furnace tubes.*

It is important to remember that the fuel used has a direct impact on the fired heater—it can change the heat rate, the corrosion rate, the accumulation of particles, etc. Changing the fuel specification is a modification that should be risk assessed formally.

ACCIDENT A crude distillation unit furnace had been designed to burn low sulphur fuel oil. It was decided to burn high sulphur fuel oil to increase the cost efficiency. But the furnace tube supports, which were cast alloys of composition 25Cr-20Ni or 25Cr-12Ni, suffered rapid deterioration in an environment of high sulphur with vanadium and sodium.

Within nine months of introducing high sulphur fuel oil, roof supports were failing in the furnace. All 80 roof hangers had to be replaced.



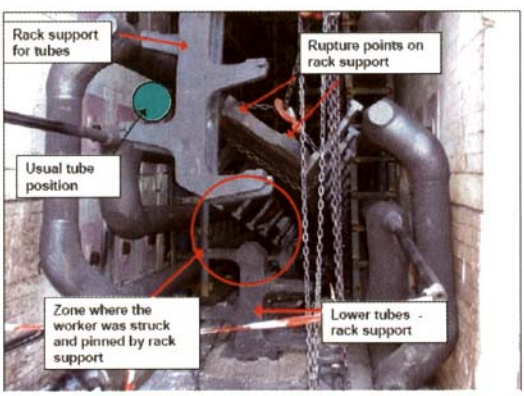
New roof hangers.

Corroded roof hanger.

Important note: The risk of equipment falling from height should always be thoroughly assessed before any work inside a furnace. After months or years of intense heat, some hangers, bricks or tubes may have been seriously damaged, and severe injuries can result if this hazard is overlooked as demonstrated by the incident above and the two below.

ACCIDENT A demolition contractor was fatally injured when several furnace tubes fell on him during an attempted rigging operation. The furnace tubes were unsecured and resting against the shell of the furnace when the accident occurred. Several attempts had been made by the crane operator to reposition the tubes safely on the floor of the furnace shell. It was during an attempt by the deceased to place a sling over the tubes that they suddenly shifted and slid off the end of the furnace shell, hitting him and crushing his skull.

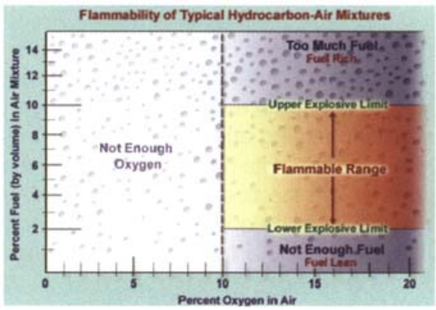
ACCIDENT A tube support hanger failed and fell onto a maintenance contractor as the tubes were being removed (see picture below). Support hangers are subject to a seven-year maintenance schedule which includes a visual inspection and dimension check to determine if they are fit for continual service. Cracking in the support hangers is a recognized occurrence in steam-cracker furnaces and are repaired during these shutdowns.



The contractor received a broken shoulder and injured arm, but there was a potential for a fatality. Pre-existing cracks around the hanger supports were not identified as a risk during maintenance.

Air

Burning fuel with exactly the right amount of air (called *theoretical air)* would provide the precise amount of oxygen needed. None would be left over, and all the fuel would be burned.



Such combustion, however, would require the almost impossible—perfect mixing of fuel and air. Therefore, refinery furnaces must admit more than theoretical air in order to burn all the fuel. Expressed as a percentage above theoretical, refinery furnaces are normally designed to admit up to 40 percent excess air.

It is impossible to determine accurately how much excess air is being used by looking into a furnace. Therefore, accurate flue-gas analysis is always necessary to determine the amount of excess air in order to adjust the furnace for proper combustion.

However, a smoky flame usually means that there is not enough air.

The Orsat apparatus, as shown in Figure 10, was one method used to analyse flue gas. A measured volume of flue gas from a point near the firebox outlet is drawn into the Orsat, which measures the volume percent of carbon dioxide (CO_2) and carbon dioxide plus oxygen ($CO_2 + O_2$).

The measurement to determine the amount of carbon monoxide (CO) is usually omitted because CO is generally not found in flue gas if oxygen is present.

Assuming no CO, a chart similar to that shown in Figure 11 can be used to determine the amount of excess air.

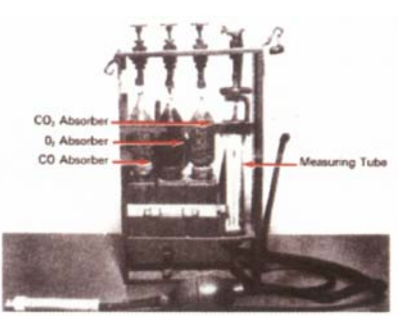


Figure 10 *An Orsat is one method used to analyse flue gas. The analysis can be used to determine the amount of excess air in a firebox.*

For example, we mark the CO_2 (10 percent in this case) on the left-hand line and the $CO_2 + O_2$ (15.8 percent in this case) on the right-hand scale. A straight line drawn between these two points indicates 35 percent excess air on the centre scale.

The same line indicates the hydrogen to carbon (H/C) ratio in the fuel. This ratio is used when calculating furnace efficiencies.

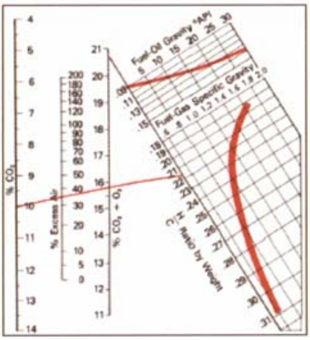


Figure 11 *This chart is used with data from an Orsat flue-gas analysis to determine percent excess air in a furnace.*

Nowadays, analysers as shown in Figure 12 are used to determine the amount of oxygen and combustibles present in the flue gas.

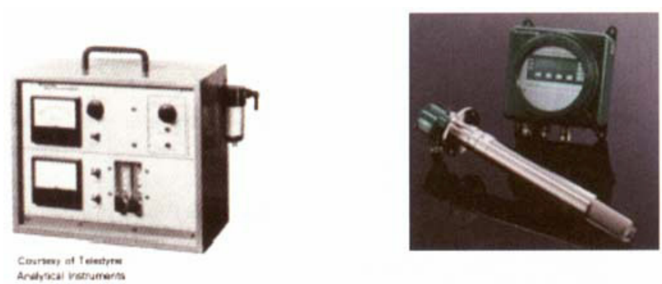


Figure 12 *These analysers measure the amount of oxygen and combustibles present in flue gas.*

Knowing the amount of oxygen, the average curve shown in Figure 13 can be used to determine the amount of excess air with little error because curves for all gas or oil fuels lie very close to the one shown. Combustibles, of course, should not be present in the flue gas. If they are, combustion air should be adjusted at once.

Accurate control of excess air is important for a number of reasons. Fuel is wasted if there is too much excess air to be heated to stack temperature. Insufficient excess air may cause the following problems:

- incomplete combustion;
- excessive firebox temperature;
- flame impingement.

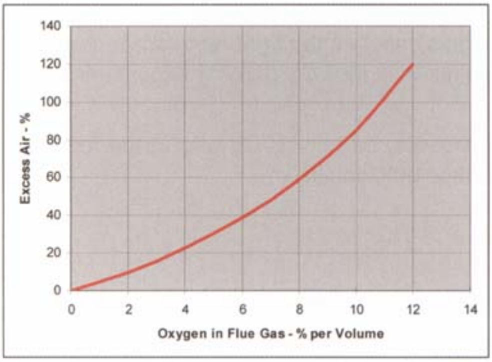


Figure 13 *This average curve for gas or oil fuels can be used to determine percent excess air from the amount of oxygen in the flue gas.*

Incomplete combustion wastes fuel because some of the fuel is not burned for lack of air. Money is going up the stack. Also, the unburned fuel may ignite explosively if there is a sudden increase in the amount of air admitted to the furnace.

Decreasing excess air by reducing the burner air register openings and partially closing the stack damper results in a higher firebox temperature. The furnace tubes may get hot enough to cause coking.

Reducing excess air also lengthens flames, and they may touch the tubes.

This condition is called *flame impingement* (Figure 14). Flame impingement occurs when the length and/or the width of the flames increase and touch the tubes, and from poor burning firing. Flames have a temperature of about 1,370°C (2,500°F) and will cause internal coking if allowed to impinge on the tubes. Coke is a good insulator of heat and therefore a higher outside metal temperature will result to achieve the same process temperature. If the outside temperature design was about 524°C (975°F) and the tube temperature is increased to 635°C (1,175°F), the tube will only be about one-fifth as strong. It will eventually oxidize (get thinner) and bulge/rupture much quicker.

Figure 14 *Flames should never strike furnace tubes, as they are shown doing in this figure.*

For all heaters, there is a minimum pass flow below which tube damage can occur due to overheating. The minimum pass flows for each heater must be specified in the operating manual. Low flow trips and alarms are usually provided to protect the heater.

Tube coking (Figure 15) and tube rupture can occur as the result of flame impingement. Uneven coke laydown will make one side of the tube expand more than the other, leading to bowing and bulging. Also, localized 'hot-spots' develop on tubes where partial loss of flow or flame impingement has occurred. Flow to the affected pass should be increased and adjacent firing reduced.

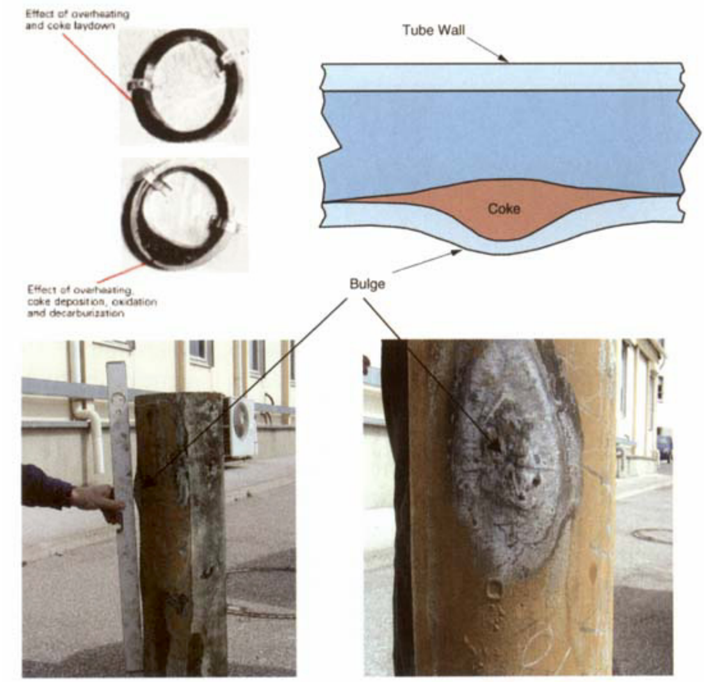


Figure 15a *Flame impingement overheats tubes and causes coking.*

Tube rupture is the ultimate outcome of coked tubes. When this occurs, a tremendous amount of fuel is added to the firebox and flames spread outside the heater through peepholes and openings between structural members (particularly dangerous if any operator is in the vicinity).

Let us see why tube ruptures occur. Flames have a temperature of about 2,500°F (1,370°C). Assume for our example that the oil in a clean carbon-steel furnace tube has a temperature of 900°F (480°C). Under these conditions, with flames not touching the tube, the tube might be about 975°F (525°C).

Now, when the 2,500°F (1,370°C) flame strikes the tube, the temperature of the tube rises rapidly. The layer of oil next to the inside of the tube gets very hot and may turn into coke. Coke is a good insulator. Let us suppose that, after a 1/8-inch (3 mm) thick layer of coke has been deposited in the tube, the condition causing flame impingement is corrected. Can we go merrily on our way?

No, we cannot. Because of the insulating effect of the 1/8-inch (3 mm) layer of coke inside the tube, the tube-skin temperature will now be about 1,175°F

(635°C). At this temperature, the tube is only about one-fifth as strong as it was at our initial temperature of 975°F. The weakened tube may yield and eventually rupture. Even if the tube does not rupture, the hot metal on the tube surface will continually oxidize and get thinner, as shown in Figure 15 a and b.

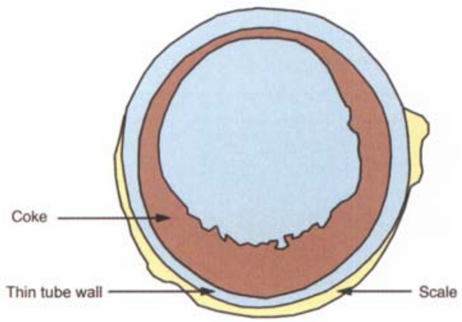


Figure 15b *Tube thinning.*

ACCIDENT The failed tube shown in Figure 15c, which was a 5 Cr tube, was coked locally in between two burners closest to the end of the furnace. A tight adherent layer of coke, about 1/4 inch (6 mm) in thickness, was inside the tube located on the fire side of the tube. This led to longer term overheating and eventual longitudinal bulging. A crack occurred causing the initial release of naphtha into the firebox. This was followed a few minutes later by the tube being ripped open circumferentially releasing 600 psig (41 bars) naphtha into the furnace. This type of failure is not typical, but is more likely to occur in high pressure services. The coke formed in the failed tube due to high heat flux/flame impingement.

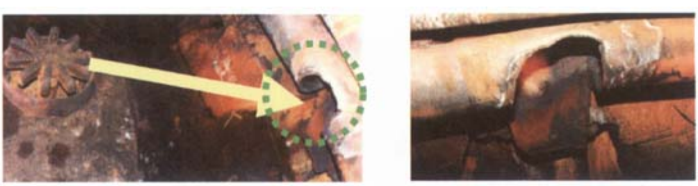


Figure 15c *Left picture shows distance from burner to tube rupture. Right picture shows rupture.*

Because of these hazards, operators should inspect fires and radiant-section tubes (those in the firebox) several times during each shift, or more often if necessary. All firebox tubes should be visible from the furnace peepholes.

The first indication of internal coking is usually a dark spot on the surface of the tube. Visual inspection of the furnace tube through view ports can give indications that coke may be present in the tubes. Things to look for include glowing red tubes, sagging or bowing of the tubes between supports, and silver streaks (a hot spot may look like a silver dollar).

Periodic turnaround inspection of selected tubes with ultrasonic thickness measurement may be necessary to measure the thickness of the tubes and radiography to measure the thickness of coke deposits. Furthermore, in coking services, decoking should be done as a routine maintenance item, particularly as coking decreases the heater efficiency, requiring more heat input and therefore increasing coking (see Figure 15d).

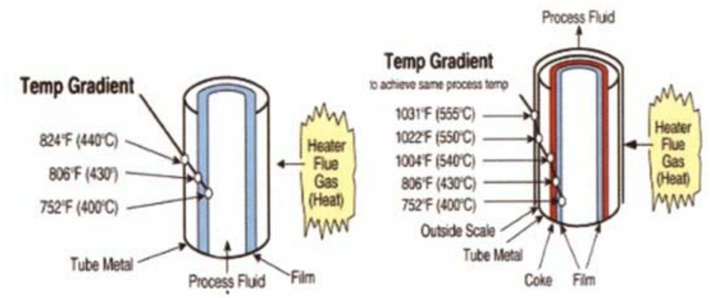


Figure 15d *Temperature gradient in clean tube compared to coked tube.*

Tube ruptures usually begin as small leaks, and prompt observation leaves ample time to shut the unit down in a routine manner. If naphtha or lighter material is in the tubes, the flame coming from the leak will be pale blue and hard to see. A leak of heavier oil will look similar to a candle flame.

Sometimes tubes rupture without warning as shown in Figure 16a, requiring a unit to go to a safe off-process condition.

In the particular case of Figure 16a, some oil entered the firebox when the tube ruptured, but most of it went up the stack as very black smoke.

Later, steam was admitted to the furnace tubes for the usual blowdown.

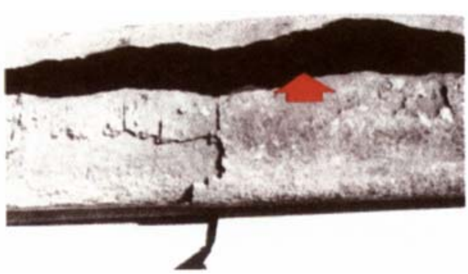


Figure 16a *Ruptured furnace tube.*

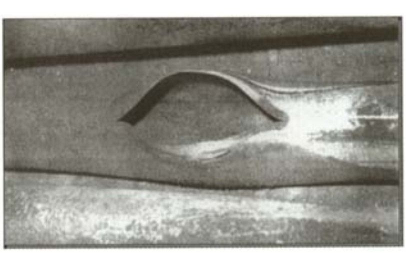


Figure 16b *Tubes rupture in ductile mode, with a typical 'fish mouth'.*

Instead of going to the blowdown drum, however, the oil and steam came out of the large hole in the tube and fell into the firebox. Hot brickwork ignited the oil, and the furnace explosion doors were blown open.

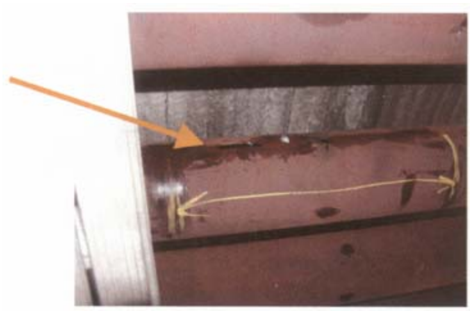
Another thing to watch in connection with air control and tube coking is heat distribution in the firebox. At best, heat distribution is not uniform. Too much heat in one place can cause coking. To keep heat distribution as even as possible, do the following:

- use the same amount of fuel for each burner;
- open all air registers the same amount;
- keep air registers closed on unused burners;
- allow no more than 100°F (40°C) difference between temperatures at various locations in the firebox.

Sometimes tube-skin thermocouples are installed to help the operator keep a uniform heat distribution. The thermocouples also provide a warning when tube temperatures get too high.

Inspection techniques must be thorough and conducted by trained and competent personnel. As the near-miss below shows, relying on a hydrotest without decoking and measuring the thickness is not good enough, as coke can maintain the tubes leak-proof—for some time.

ACCIDENT The Distillate Desulphurizing Unit (DDU) was shut down for its first planned cycle ending turnaround. The reboiler furnace tubes were internally cleaned using a mechanical device (pig) in preparation for inspection. After the tube cleaning was completed, a failed furnace tube was found. Upon further inspection additional thin furnace tubes were discovered.



Many incidents have also occurred when the wrong material was used to replace tubes or pipes as in the following two examples. Design, reception, maintenance and modification of alloyed piping must follow rigorous practices.

ACCIDENT A Crude Distillation Heater materials of construction were alloy 5 Cr 1/2 moly. In 1969 an inspection identified erosion/corrosion of the straight pipe section and subsequently replaced the straight section in carbon steel. This change of material was not properly recorded in the master records or inspection file and therefore the erosion/corrosion was not assessed. The pipe section failed in service in 1985—16 years later.

10' thinned pipe

ACCIDENT A combined Crude/Vacuum Distillation Unit was partially dismantled in 1982 to keep only the vacuum unit. At the time, it was thought that the vacuum unit would also be dismantled in less than three years. Therefore, all 4/6Cr materials that needed to be modified/replaced were changed to carbon steel. This choice of material was not recorded. In 1993, a T-shaped pipe failed (see first picture below). After replacement, the unit was restarted, to be stopped again six months later when a pin-hole leak developed on an elbow (second picture). A full review of all alloyed piping was conducted to solve the problem.

2.3 Draught (UK)/Draft (US)

The definition of a draught (UK)/draft (US) is the slight negative pressure (vacuum) that exists within the heater that draws air into the heater and pushes the combustion gases out of the stack.

The hot, rising flue gas in a stack weighs less than an equivalent column of cooler air outside the furnace, leaving less than atmospheric pressure inside the furnace. The cool, heavier outside air pushes into the furnace through the air registers and supplies air (oxygen) for combustion. Thus, the draught at any point in the furnace, breeching or stack (as shown in Figure 17) is simply the difference between the pressure of the flue gas at that point and the pressure of the air outside the furnace.

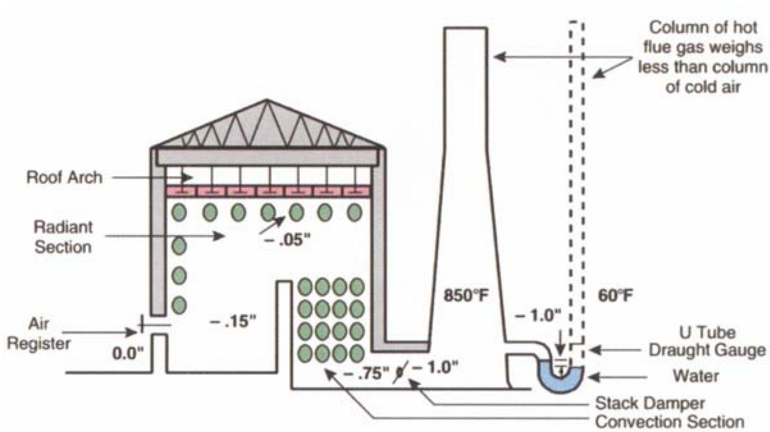


Figure 17 *This diagram illustrates the principle of draught measurement and shows typical draughts at various places in a furnace.*

Hot gases are less dense than the colder air outside a heater. Like an open fire at home, a draught or very slight negative pressure is created that draws in more combustion air into the burners/fire zone.

When this draught is obtained by the use of a stack only, it is termed natural draught (the taller the stack, the greater the draught available).

When the height of the stack gives insufficient draught, an induced draught fan is installed to pull flue gases out of the heater. When better air/fuel mixing is required, a forced draught fan is installed to push combustion air into the heater. This creates a positive pressure in the windbox (combustion air supply ducting). Where a combination of induced draught and forced draught is used, it is termed balanced draught heater.

Note that sometimes fan blades will become covered with ice if there is a source of moisture nearby, such as a cooling tower. Never try to de-ice a running fan. Turning a steam hose on such a fan may seem like an easy way to get rid of the ice, but the fan will probably be wrecked as a result of unbalance as the ice flies off the blades.

Perfect mixing of fuel and air to achieve the precise amount of oxygen needed for complete combustion is impossible. Therefore, heaters must use more than the theoretical proportion of air to achieve complete combustion.

A smoky flame usually means that there is insufficient air. Incomplete combustion is not only inefficient in fuel use, the unburnt fuel can ignite explosively in the flue gas ducting.

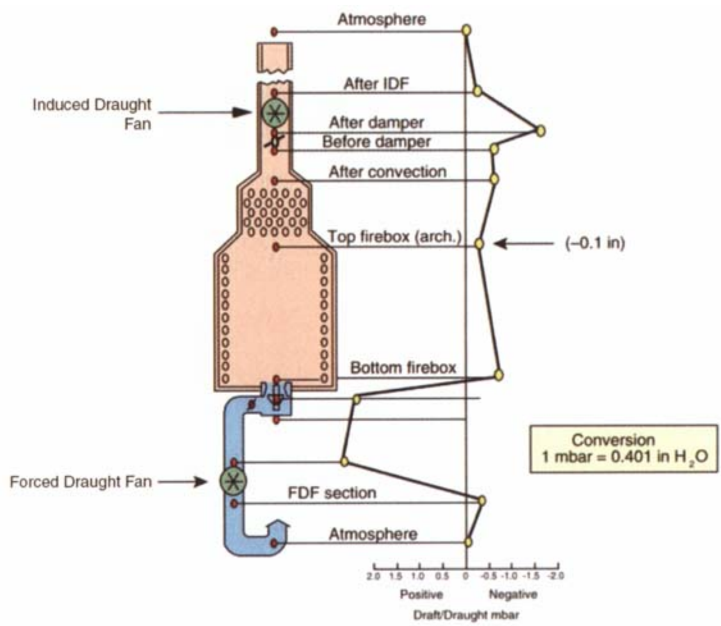


Figure 18 *Basic draught pattern in a fired heater.*

Air is drawn into a natural draught burner by the draught created by hot gases rising through the heater. This means that the air velocity is slow, and so is the air/fuel mixing, producing a longer flame than a forced draught burner. To compensate for this less efficient mixing of air and fuel complete combustion, it is necessary to operate with 20–25% excess air (=4–5% O_2 in flue gas).

For a forced draught burner, combustion air is provided by a fan and the air is evenly distributed through the burner. Thus air velocity is higher, giving more efficient air/fuel mixing. This produces a shorter flame that only needs about 10% excess air for complete combustion (=2% O_2 in flue gas).

The draught inside a heater can be controlled in a number of ways; for example, through the opening and closing of the stack damper, through adjustment of the burner air registers or in the case of a forced draught heater through varying the position of the vanes in the inlet to the force draught fan.

Ideally, the damper and the burner air registers should be adjusted such that the draught at the inlet to the convection section is about −2.5 mm (−0.1 in.) H_2O.

This pressure difference, or draught, is measured in inches of water on a draught gauge because the differential is too small to be easily measured on a pressure gauge. For example, a draught of one inch (2.5 cm) of water equals 0.036 pounds per square inch pressure (2.5 mbar) difference between the outside air and the flue gas.

Draught gauges are calibrated to show positive (more than atmospheric) and negative (less than atmospheric) pressures. Zero on the gauge represents atmospheric pressure. Negative pressures (those below zero) have a minus (−) sign and indicate the amount of draught. The larger the number following the minus sign, the more the draught. A reading above zero simply means that the pressure inside the furnace is greater than the atmospheric pressure outside. Figure 18 shows a typical draught in a balanced draught heater.

Draught is affected by wind. The impact of a strong wind raises air pressure on the upwind side of a furnace, thereby increasing the pressure difference (draught) between the outside and inside of the furnace. The effect on the downwind side is just the opposite, and draught is reduced.

Therefore, when a strong wind is blowing, light the upwind burners first to take advantage of the extra draught.

This in turn heats the stack and creates more draught for lighting downwind burners.

When a furnace is properly set, the air registers are open far enough to provide sufficient air for combustion. The air register and stack-damper settings must be in proper balance so that there is a slight draught (say about −0.5 inches of water) near the roof of the furnace (a stack damper is a type of butterfly plate valve that is one way of controlling draught). Flue duct dampers should be provided with clear position indication at ground level adjacent to draught instrumentation/indicators.

When the air register and stack-damper settings are correctly balanced, a small amount of air pushes in through the roof and keeps it cool.

To admit more air to the furnace, open both the registers and damper a little wider. To admit less air, pinch down on the register openings and close the damper a little. Failure to keep the register and damper settings in proper balance will put pressure on the furnace roof. This condition, which is usually indicated by a bluish haze of flue gas coming off the roof, will damage the roof arch and corrode the steel work.

When oil is used as fuel, ash accumulates on the convective-section tubes and causes loss of draught. The stack damper is usually opened wider to make up for this loss. Figure 19 shows a manual damper control marked to ensure that the crank is turned in the proper direction.

Figure 19 *This manual damper control is marked to show which way to turn the crank.*

When looking through peepholes at fire or tubes, use a firing shield (Figure 20). Sufficient peep holes on the heater are required to permit a clear view of each burner.

The shield will protect you from a blast of hot flue gas if there should be a positive pressure inside the furnace. This danger is greatest at peepholes near the roof.

Figure 20 *Use a firing shield for facial protection when looking through furnace peepholes.*

Water accumulation should be prevented in flue ducts because this reduces area for the flow of flue gas and cuts the draught. In addition, vaporization of this water cools the flue gas and further reduces draught.

Water in flue ducts can result from operating an air preheater (which gets its heat from the flue gas) too soon after light-off. You recall that water vapour is one of the products of combustion found in flue gas, and this vapour will condense if the flue gas is cooled to a low enough temperature. To prevent this, the air preheater should not be started until the flue-gas temperature is at least 350°F.

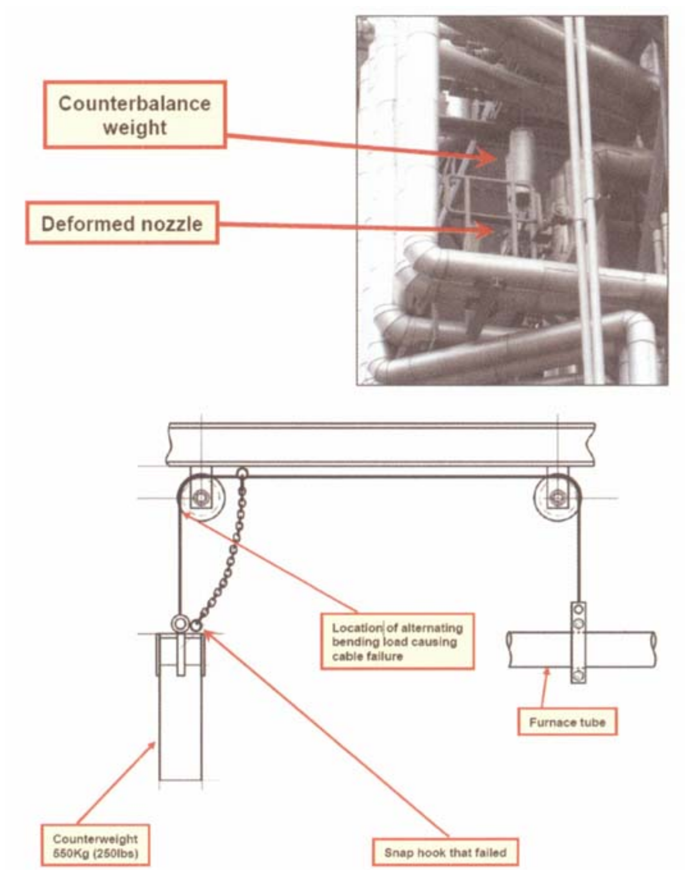
Note on the design of small fired heaters: It is often both cost-efficient and safer to replace small fired heaters with inherently safer electric heaters. Typical examples are regeneration furnaces for driers. Obviously, a small potential remains from overheating and rupture, but with nitrogen as the drying agent the consequences are much less and with no risk of explosion.

Note on maintenance

It may be sometimes forgotten that a fired heater is not just burners on a firebox. Many other components will require regular inspection and maintenance: for example stacks and their foundations will require regular structural survey, instruments will require regular calibration and testing, etc. The need for a rigorous and comprehensive maintenance programme is demonstrated by the following incident.

ACCIDENT The cable on a furnace tube support system failed resulting in a counterbalance weight [550 Kg (250 lbs)] falling approximately 20 m (66 ft) to the ground. A 1-inch (DN-25) nozzle containing naphtha/steam mixture at 600°C and 3 barg) was hit and deformed. The furnace was immediately shut down and a barrier was put up around the area.

This incident had the potential to injure someone or for a serious loss of containment from damaged equipment resulting in fire/explosion.



continued

The following causes were identified:

- Swinging movement of the counterbalance weight over years caused bending movement adjacent to pulley.
- The backup safety system failed (the snap hook on the safety chain broke).

Lessons learned:

- Ensure that this type of equipment and associated safety systems are not forgotten in the inspection programmes.
- The design of these systems should take into account static load, external conditions and system loading and must be analysed during hazard reviews and commissioning.
- Secure counterweights against swinging.
- Ensure safety backup chains are not too long in order to prevent a dynamic load in the event of a cable failure.
- Change cables every 4 to 6 years and review alternative hanging supports.

Determine inspection methodology for cables as damage mechanisms cannot always be detected by visual examination.

3

Explosions

Now that we have taken a look at how furnaces work, and what combustion is, let us discuss explosions. An *explosion* is the violent, uncontrolled burning of fuel. An explosive mixture can accumulate in the firebox from flameouts, unatomized liquid fuel, leaking fuel valves or other causes. Ignition of such an accumulation (by a torch or hot brickwork, for example) can result in an explosion.

You recall from our discussion of combustion how a large volume of flue gas forms when fuel is burned, and how this volume shrinks as the flue gas is cooled in passing over the furnace tubes. When an explosion occurs, this large volume of flue gas is formed almost instantly, and there is no time for it to cool and shrink. Because the furnace was not designed to handle this, something has to give, as shown in Figure 21a.

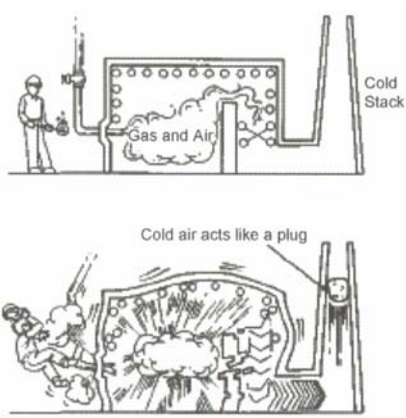


Figure 21a *A careless operator who tries to light a burner before testing the gas valves and purging may be injured or even killed. If the furnace is cold, damage will be greater because cold air in the stack acts as a plug.*

Some of the flue gas can go up the stack, but the chances are that the furnace will still be damaged.

The damage will be even greater if the stack is cold, because the cold air in the stack acts like a plug.

Later in this booklet, we will discuss some of the faulty operating practices that have caused explosions. Unfortunately, there are many examples, including the following incidents.

ACCIDENT A power house contained seven power boilers used to provide steam at the manufacturing complex. All boilers were housed in the same building. Boiler No. 6 was being shut down for annual maintenance. Workers were completing the shutdown process by blanking the natural gas supply (see step (1) in Figure 21b). The main natural gas control valve was opened (2), before the blanking was completed, to facilitate purging any remaining natural gas from the supply lines through the boiler by opening the pilot burner valves (3).

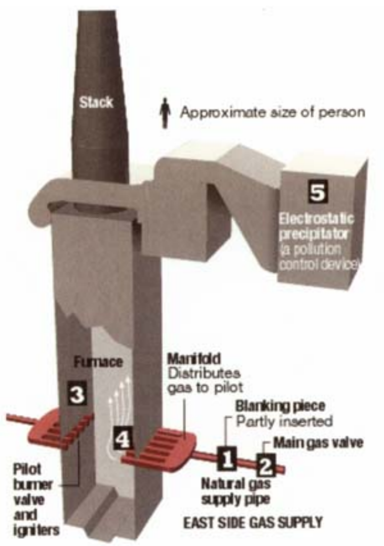


Figure 21b Shutdown process of a boiler.

Gas flowed into the furnace and built up (4). An explosion occurred a few minutes after, resulting in the death of six workers and seriously injuring 14 others. Investigators believe an electric spark in an electrostatic precipitator (5), may have ignited gas flowing through the furnace exhaust. The power house had to be destroyed and more than 35 temporary boilers installed to restore power to the complex.

ACCIDENT Following an emergency shutdown due to instrument air failure, an explosion occurred during attempts to relight the furnace of the Crude Fired Heater (see Figures 21c and d).

Damage to the furnace roof and duct work was extensive with total incident cost estimated to be $8.2 million.

The cause of the explosion was a failure of the operators involved to follow established safe isolation and start-up procedures on the fired heater. The haste to relight the furnace, to prevent shutdown of downstream units, resulted in the failure to satisfactorily isolate the fuel gas during the purging stage and to carry out a proper gas test of the heater's atmosphere before introducing the lighted torch.

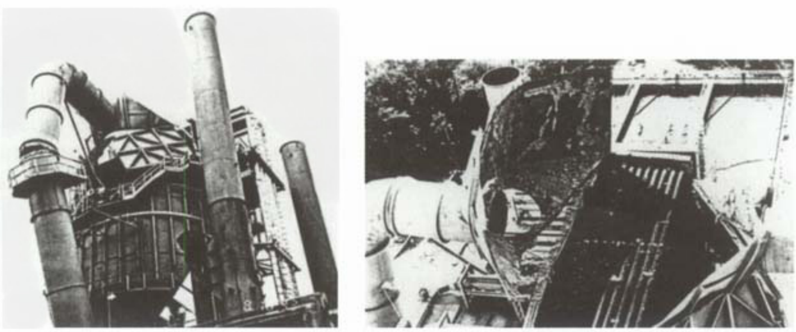


Figure 21c and d

ACCIDENT Another recent incident occurred in a plant when a furnace had to be shut down for a few hours to clean process equipment in a unit. The heater is fed with heating gas and/or natural gas from a control block installed on top of the furnace. The flame, which is directed downwards, heats the heating coils. The air needed for the combustion is sucked in at the top of the furnace with the aid of a ventilator and via the air pre-heater, where flue gas heats this air.

In order to block off the gas supply, the natural gas input pipe has to be closed off at battery limits. The pipe is then flushed with nitrogen to remove the gas. Most of the gas pipe can be flushed by opening a valve to a safe location (blow-off pipe). The final section before the burner can only be flushed by opening the input valves of the main burner and blowing into the body of the furnace. The valves' safety system has to be overridden to do this.

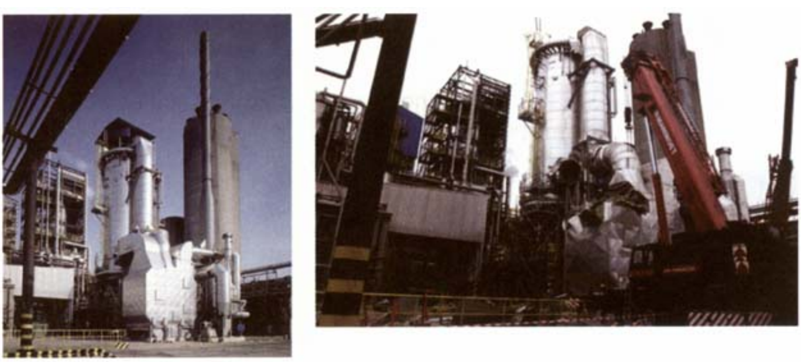
continued

There is a platform on top of the furnace (which is 25 metres high) to facilitate maintenance work and control activities.

Three workers were on the top of the furnace replacing the insulation after minor maintenance when the start-up procedure was begun.

Despite the procedure, the overridden safety system was not reactivated, leaving the valves open. When the gas supply was then opened, the nitrogen in the pipe was flushed out by natural gas, and gas flowed through the open input valves into the furnace. An explosion occurred, the most likely ignition point being the hot surface of the burner block.

Although experts rated the explosion as 'relatively weak', the pressure increase in the furnace was sufficient to raise its cover (diameter approximately 3.8 metres). The cover then fell back down at an angle of roughly 45 degrees, with the fatal result that the three employees who were located on top of the cover fell into the furnace, which at that moment had a temperature of about 345°C (653°F). It was found that the work in which the three victims were engaged was not in any way connected with the explosion and that their presence on the platform while the furnace was being started up was permitted.



Figures 22a and b *Furnace before and after the accident.*

ACCIDENT This heater was severely damaged during start-up as a result of a firebox explosion. The operator had some difficulty with the instrumentation and decided to complete the start-up by bypassing the interlocks.

This allowed the fuel line to be commissioned with the pilots out. The main gas valve was opened and gas filled the heater. Then the heater exploded destroying the casing and damaging several tubes. Fortunately, no one was injured.

These incidents are a good reminder that in performing any operation of a non-routine nature, personnel need to be cautioned to slow down and be careful.

- During cold light-offs, sufficient time needs to be allowed for operators to thoroughly prepare a heater and to light it off following the procedures. Having additional operators on hand to assist in these planned sequences would be beneficial.
- During hot re-lights, when operators often want to proceed expediently, they must also be told to proceed cautiously. Trying to save a few barrels of throughput to get a heater relit quickly is not nearly as important as doing it carefully and correctly. In any environment, it is preferable to lose a few barrels of throughput rather than the use of a heater, or unit, for an extended period.
- Start-ups and shutdowns of fired heaters are delicate operations and non-necessary personnel should not be allowed in the area. Established start-up procedures must be followed. If they are not correct, the supervisor should be informed and the procedures corrected.

On top of good design and training, it can be useful to place warnings on equipment such as:

- a warning placed at the torch location such as 'Be sure you have followed all steps before lighting the torch', 'Double check burner cock valve positions before lighting the torch';
- signs placed at the fuel gas control valve or burner cocks such as 'Ensure the pilot is lit before opening the burner cock'; and
- warnings placed at minimum flow bypass valves (until replaced with separate fuel source pilots) such as 'Do not close/adjust this valve after the main control valve is opened'.

4

Fuel systems

Fuel systems must be handled with care. Knowledge of both the fuel system and required safety practices is essential to safe furnace firing.

4.1 Fuel-gas lines

Shutdown

When a process unit is shut down for turnaround, the fuel-gas line must be blinded at the battery limits (Figure 23a).

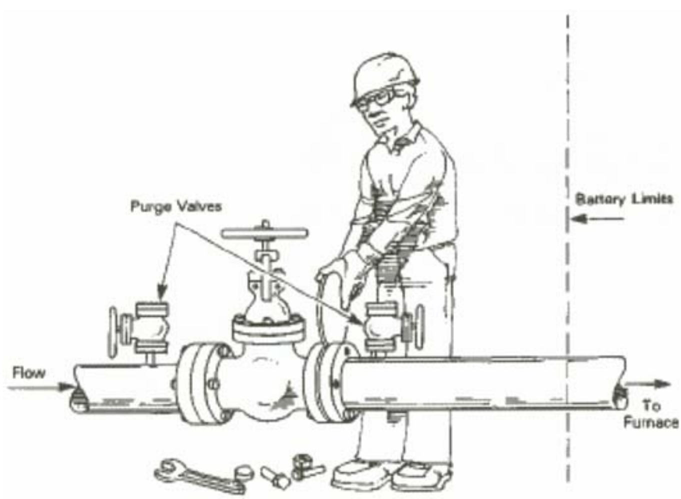


Figure 23a *Blind the fuel-gas line at the battery limits when a process unit is shut down for turnaround.*

Purge the line with steam or inert gas if required by specific operating instructions. Steam purging, however, may create problems due to (1) plugging resulting from loosened deposits (sometimes this plugging does not show up until the unit is back onstream), (2) freezing of un-drained condensate and (3) by creating an intense vacuum during condensation (see BP Process Safety Booklet *Hazards of Trapped Pressure and Vacuum*).

The fuel-gas line to the furnace should be blinded as soon as the furnace is shut down. As an added precaution, gas burners are sometimes disconnected.

Blinding is necessary to make it safe to work in furnaces, on burners or vessels with fuel-gas connections, or on the gas lines themselves. The fuel-gas burner valves should be checked for tightness during the unit shutdown. It is important for safety in the furnace operation to keep burner valves in good condition, including the greasing of lubricated plug cocks.

Start-up

Pressuring the fuel-gas system is one of the things to be done just before lighting a furnace. The detailed procedures for pressuring a gas system as given in the unit operating instructions must be strictly followed. If the system was purged during the shutdown, the general steps are as follows:

1. Remove the main furnace fuel-gas blind (Figure 23b).

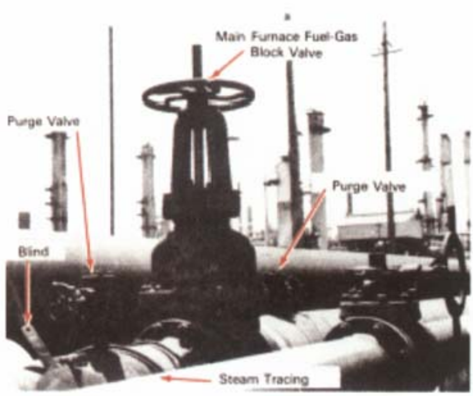


Figure 23b *Blind removal from furnace fuel-gas line.*

2. Purge *all* the air from the system with steam, inert gas or nitrogen into the firebox. An air-in-steam analyser (for steam purge) or an oxygen analyser (for inert gas or nitrogen purge) can be used to indicate when all the air is out of the system. Avoid unnecessary openings of vents and drains, because of:
   - risk of fire;
   - risk from vented nitrogen (refer to the BP Process Safety Booklet *Hazards of Nitrogen*).

Avoid using steam to get round problems of condensate in lines or firebox and be careful to keep the lines from freezing in cold weather if you purge with steam.

3. Close the burner valves and vents and shut off the purge material. Be sure the burner valves are shut tight.
4. Crack open the main fuel-gas valve so that fuel gas will force the purge material out the drains. *Do not purge into the firebox.* Leave the burner valves closed. Again, avoid the use of steam to purge the system as it will create a vacuum when condensing (see BP Process Safety Booklet *Hazards of Trapped Pressure and Vacuum*) and the condensate will have to be purged.

5. When draining is complete, do the following:
   - Close the bypass around the burner control valve. This will help prevent fuel gas from getting into the unlighted furnace in case the closed burner valves leak. The block valves on either side of the gas control valve should also be closed.
   - Close and plug the drains to minimize the amount of fuel gas blown to atmosphere and prevent the escape of fuel gas during unit operation. Again, avoid unnecessary openings of vents and drains (see step 2).
   - If steam was used to purge air from the system, it may be necessary to drain additional condensate after the burners are operating. Never leave an open drain unattended.
6. The fuel-gas system is now ready for start-up.

4.2 Condensate in fuel-gas lines

Liquid hydrocarbons must be kept out of burners and fireboxes. If unatomized liquid fuel enters a firebox, it will smoke as it burns, and the furnace may appear to have a split tube. At the same time, the furnace will get hotter, because burning liquid fuel gives off much more heat than an equal volume of fuel gas.

Sometimes, the liquid entering through the burners can be throttled until it is used up. However, if there is too much, some will fall to the furnace floor as it burns, and some will fall from the aspirators of premix burners to the deck outside the furnace (Figure 24).

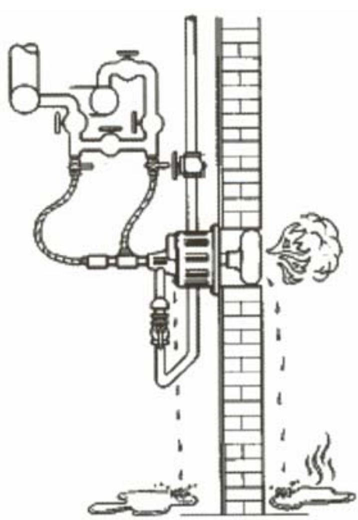


Figure 24 *Liquid in a fuel-gas system can run out of a burner both inside and outside the furnace, causing a serious fire hazard.*

The unburned liquid on the furnace deck is a serious fire hazard.

Gas dry drums like the one shown in Figure 25 are installed to keep liquid hydrocarbons and water out of fuel-gas systems. The drum should be equipped with a high-level alarm. A high-level shutdown of fuel gas to the heater is desirable.

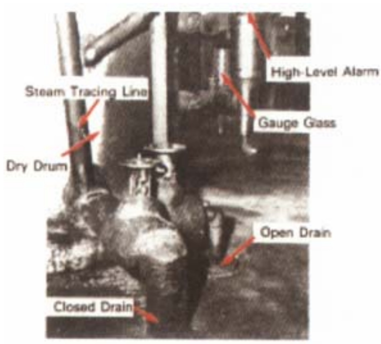


Figure 25 *Gas dry drum with high level alarm, gauge and drains.*

Condensation in piping, or carryover or overflow from towers can be responsible for the presence of liquid hydrocarbons in fuel-gas systems. High gas velocity through an absorbing tower can entrain liquid and cause carryover, or a faulty bottom level controller can permit tower overflow.

Liquid entering the dry drum faster than it can be drained will eventually reach the burners and spill into the furnace.

Such a condition may require that the process unit be shut down in order to drain the fuel-gas system. If the process unit has an air preheater, there is a good possibility that the equipment can be set on fire from poor combustion of the fuel-gas-line liquid.

Precautions must be taken to avoid such fires in air preheaters, due to the destruction which occurs.

Water vapour in fuel-gas systems will condense during cold weather. The water may freeze and plug the line at low spots or risers. If a fuel-gas system contains water and condensed hydrocarbons, a snow-like hydrate is formed. In one case, a 20-inch fuel-gas line was completely blocked with hydrates on a 0°F (−18°C) day. These hydrates may also slough off the inside of the line during thaws and collect in low spots in sufficient quantity to cause plugging.

Heat is the answer to most of these problems. Steam tracing and insulation as shown in Figure 26 are frequently used to keep fuel-gas lines warm.

Pilot-gas lines may also contain hydrocarbon condensates in cold weather, and they should also be heated if necessary.

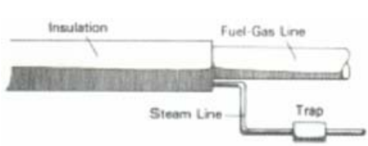


Figure 26 *Steam trace fuel-gas lines if condensate is a problem.*

4.3 Water in fuel oil

Water in fuel oil can cause unit upsets, or even furnace explosions.

It is difficult to draw water from a tank of fuel oil because the water and oil have about the same gravity.

Frequently, the water collects in layers throughout the oil.

Water gets into fuel oil in two principal ways—by rain entering through a leaking tank roof, open hatch or gauge cable opening and by leaking of steam coils used to heat the oil (Figure 27).

A few good rules for the care and operation of fuel-oil tanks are as follows:

- Keep tank roofs and steam heating coils in good repair. Prevention is the best solution to the water problem.
- Keep the oil at 200°F (93°C) or lower. If the oil gets above 200°F (93°C) and water is present, the tank may foam over. The BP Process Safety Booklet *Hazards of Water* discusses foamovers in detail. Take time to read it.
- Do not pull the tank oil level below the heater. Loss of suction and danger of fire from pyrophoric iron sulphide on the exposed heating coils are the chief hazards.

Temperature and pressure conditions at the fuel pump may be such that a slug of water from the oil tank will flash to vapour. This can cause the pump to lose suction, thereby cutting off the oil flow to the burners. The resulting flameout may upset the furnace and the unit.

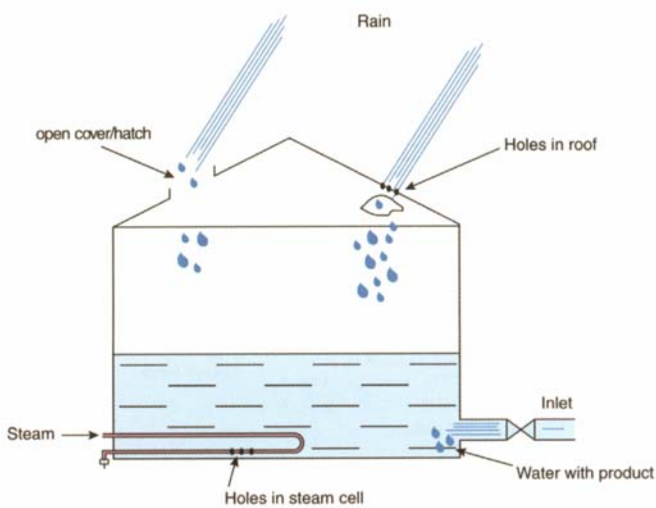


Figure 27 *Keep water out of fuel oil. Tank roofs and steam heaters should be kept in good repair.*

However, explosion is the greatest danger. After flameout, oil may again flow to the unlighted burner. You recall from our discussion of explosions the danger resulting from an accumulation of unburned fuel in a furnace firebox.

Combination burners, of course, do not have this problem when the gas portion is operating.

4.4 Disposal of waste gases or vapours by burning

Some refinery units produce waste gases or vapours which are both combustible and toxic. These gases or vapours must be disposed of safely; simple venting to furnace fireboxes through open-end ducts or pipes to existing burners is an explosion hazard and should not be permitted.

Hydrogen sulphide (H_2S) is an example of such a gas or vapour. It paralyzes the sense of smell (even in low concentrations) and is extremely dangerous to breathe. Burning H_2S produces sulphur dioxide (SO_2) which has a disagreeable biting odour, is a severe respiratory irritant, and may be fatal in high concentrations.

Waste gases such as H_2S can be burned safely in refinery furnaces when equipment similar to that shown in Figure 28 is provided:

- A liquid seal or similar flame-arresting equipment in the waste-gas line to the furnace.
- A knockout drum with a high-level alarm and a continuous steam purge in the waste-gas line to the furnace.
- A separate burner in the firebox used only for the waste gases and not for process-heat requirements.
- A separate pilot and pilot gas system for the waste-gas burner.

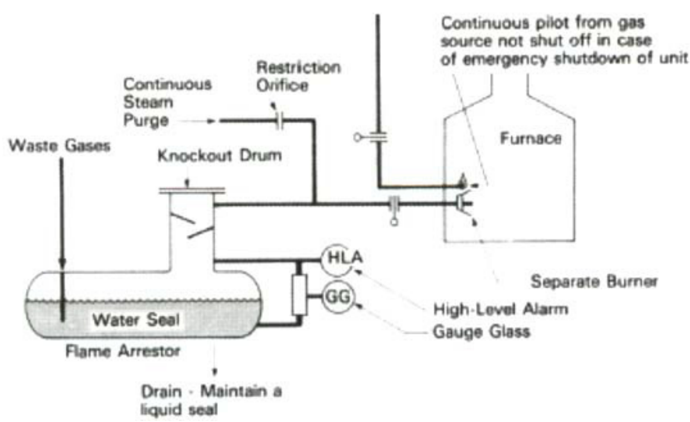


Figure 28 *Safe venting of waste gases or vapours to furnaces requires extra equipment.*

Where waste gases are being burnt it is important that the environmental impact is assessed and that appropriate abatement equipment is installed where necessary.

5

Burners

Many different burner designs are available for use with oil, gas or both.

Most refinery furnace burners can be classified as premix gas, non-premix gas, steam atomizing oil or combinations thereof.

Liquid or gaseous fuel (or a combination of both) is introduced into the heater at the burners, where it is mixed with combustion air and ignited. Steam is the atomizing medium used to atomize the liquid fuel. Burners can be installed at the firebox floor, along the sides, or even from the roof. Figure 29 shows various configurations.

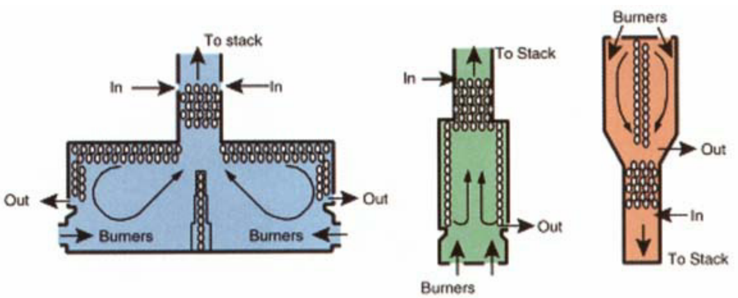


Figure 29a *Various configurations of fired heaters.*

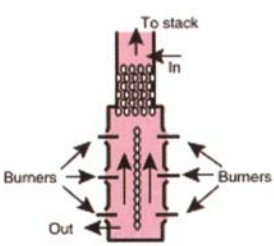


Figure 29b *Typical burner.*

All the fuel fed to a furnace burner should be burned completely with a relatively uniform flame pattern. A good burner in proper condition will thoroughly mix fuel with a sufficient quantity of air to give complete combustion and a uniform flame pattern. It is important that all burners are stable over the whole range of possible fuel compositions and draught conditions. New burners should always be tested to ensure this.

5.1 Premix gas burners

A long yellow flame generally indicates poor mixing of gas and air.

The yellow colour results from carbon particles which are produced when some of the gas cracks before it burns.

To obtain good mixing and to burn the gas with a short flame, a premix burner is used (Figure 30).

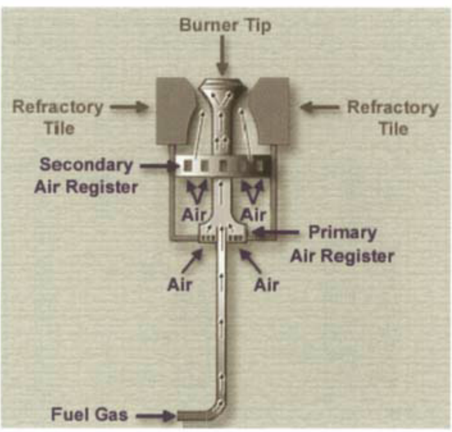


Figure 30 *A premix gas burner.*

In the premix burner, gas under pressure is passed through a small orifice or spud to form a jet. The jet pulls in primary air through the aspirator opening, and the gas and air are mixed in the mixing tube before being distributed through the holes in the burner tip or spider. As the gas-air mixture emerges from the spider, secondary air is added; and the entire mixture of gas, primary air and secondary air burns with a short blue flame.

Under certain conditions, the flame may travel backwards and burn in the mixing tube. This is called *flashback,* and the burner will be damaged unless the condition is corrected. If the flame continues to burn in the mixing tube, the burner should be shut off and allowed to cool before relighting.

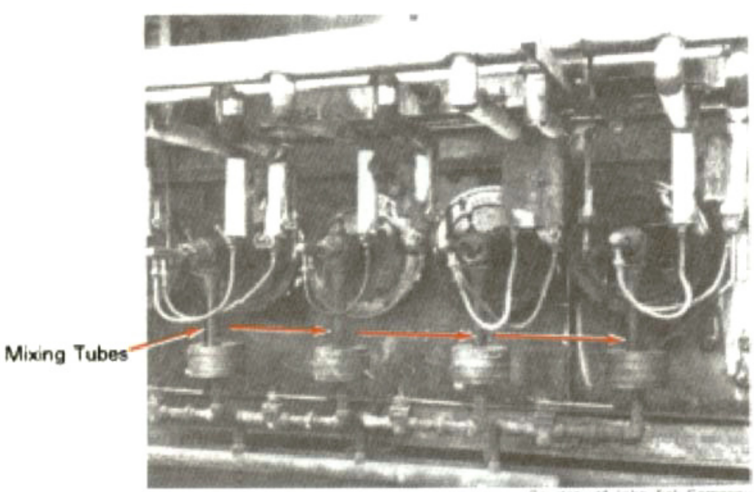
Flashbacks cannot occur if (1) the gas-air mixture in the mixing tube is too rich to burn or (2) if the velocity of the mixture through the spider holes exceeds the velocity at which the flame will travel backwards in the mixture. Thus, flashbacks can be prevented by reducing primary air to produce a rich mixture in the mixing tube or by increasing the firing rate so that the velocity through the spider holes exceeds the backward velocity of the flame.

Low gas pressure may cause flashback in all burners, but the flame should return to the fronts of the spiders when pressure is restored. When flashbacks do occur because of low pressure, be extremely careful to see that no burner goes out. *If a burner does go out, shut it off at once.* A low-pressure condition may be improved by shutting down some of the burners—this makes more pressure available for burners still operating.

When normal gas pressure is restored, the burners which were shut off can be relighted safely by the procedure discussed later in this booklet. Do not relight off an adjacent burner.

Flashbacks can also occur when a partially blocked burner spud decreases gas flow. In such a case, the burner should be cleaned at the first opportunity.

Uneven fires and flashbacks can occur if gas composition varies greatly. For example, hydrogen with its wide flammability range (4 to 75 percent by volume in air) contributes to flashbacks when mixed with fuel gas. This occurs because flame travels faster in hydrogen than it does in natural or normal refinery fuel gases. Premix burners with a special mixing-tube design, as shown in Figure 31, are required if the fuel gas contains a high percentage of hydrogen.



Courtesy of John Zink Company

Figure 31 *Premix gas burners with a special mixing-tube design are required to prevent flashbacks when the fuel gas contains a large amount of hydrogen.*

5.2 Non-premix gas burners

When, because of certain design conditions, a non-premix burner (Figure 32) is used, all the air mixes with the fuel beyond the burner tip.

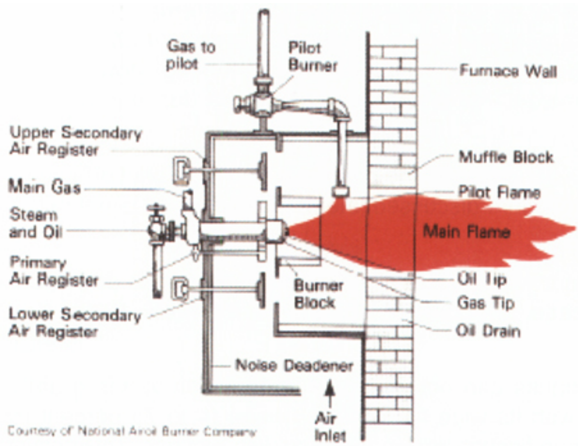


Figure 32 *A non-premix gas burner.*

Combustion begins at the tip with primary air and is aided by the burner block which gets hot and radiates heat back to the burning fuel. The muffle block also gets hot and aids combustion. Secondary air mixes with the fuel beyond the burner block.

The non-premix burner shown in Figure 32 has the air inlet enclosed at the furnace. This minimizes shifting of heat distribution inside the furnace because of outside wind. Notice also that the air duct is lined with material to muffle combustion noise. To some extent, the flame direction from this non-premix burner can be shifted up or down by manipulating the secondary registers.

Good gas firing

5.3 Steam-atomizing oil burners

Figure 33 shows an oil burner gun.

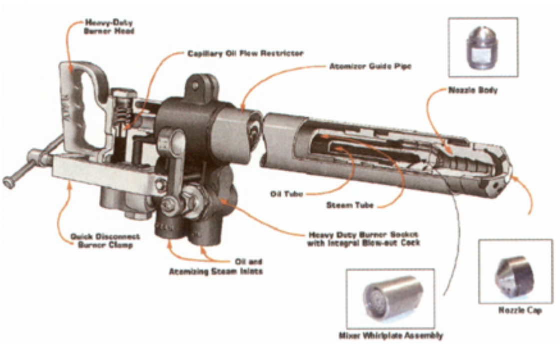


Figure 33 An oil burner gun.

Oil enters the burner throat where it is atomized by high-pressure steam before flowing out through the burner tip. The tip is designed to provide the desired fire pattern for each particular firebox.

As the oil leaves the burner, the small particles vaporize, mix with air and start to burn. The heat from the flame then vaporizes the remaining fuel oil, and it also burns. A smoky fire occurs if the oil particles do not vaporize or find oxygen before leaving the combustion zone. Smoke indicates that (1) too much oil is being fed; (2) the air registers are closed too far; or (3) there is insufficient draught.

Sparks in an oil flame are caused by poor oil atomization. This may be the result of insufficient or plugged steam holes in the burner throat. To keep burners working properly, clean the burner tube frequently with steam by closing the oil block valve, opening the steam bypass, and moving the oil cock handle back and forth. If the flame has an irregular pattern after steam cleaning, the burner should be removed for cleaning and overhaul. If the flame goes on and off, it may be because the steam bypass valve is not shut tight.

Wet atomizing steam may cause coke to form on the tip of the oil burner.

Such coke should be knocked off with a rod.

Good oil firing

5.4 Combination burners

Combination burners can burn oil and gas at the same time. The principal parts of such a burner are shown in Figures 34a and 34b.

The tip of the oil gun should be about one inch (2.5 cm) in front of the gas spider when the oil burner is operating. When not in use, the oil gun should be pulled back or removed to keep it from burning up.

Although combination burners can operate on either gas or oil, it is desirable to burn some gas with the oil.

Heavy fuel oil burns much better with the gas burner operating, and the gas also serves as a pilot if the oil flow is briefly interrupted.

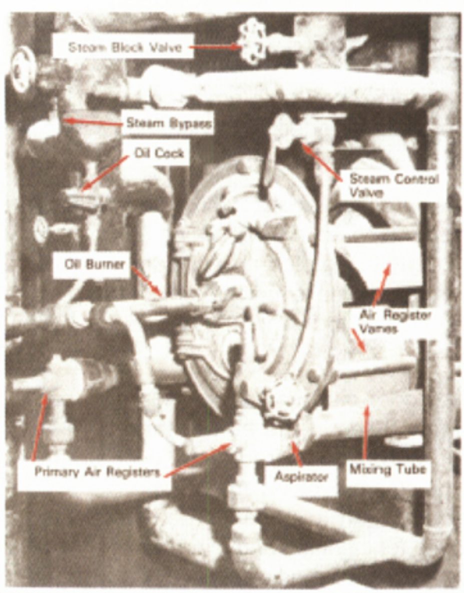


Figure 34a *Combination burner controls.*

Important points include:

- Oil gun safety interlock: prevents removal of oil gun with fuel flowing.
- Ignitor port: should be capped when not in use.
- Air registers and dampers: should be able to be moved freely.
- Quarl's and primary blocks: reflect heat back into the flame for increased stability and should not be broken or cracked, or fouled with coke.
- Viewing ports (not shown): should be kept clear of debris.
- Pilot flames: should be kept alight at all times.
- Pilot gas fuel supply isolation valve should be at the side of the heater next to a viewing port, not under the heater.

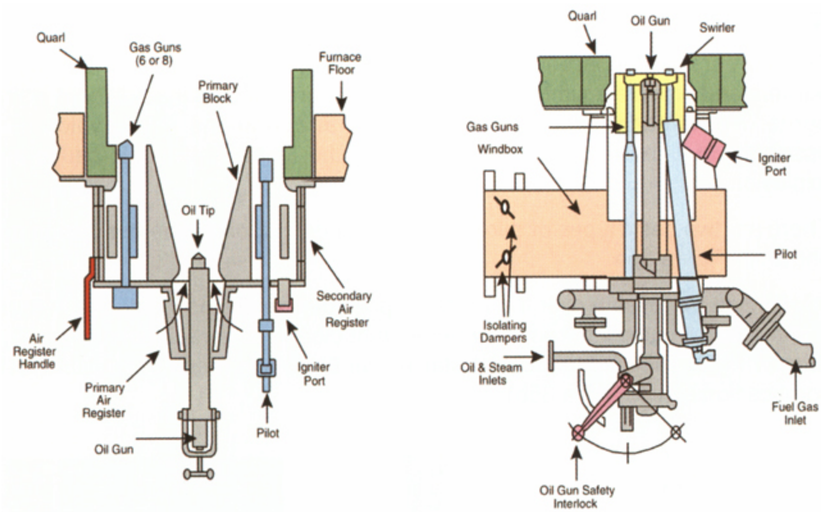


Figure 34b *Cross section of typical combination burners.*

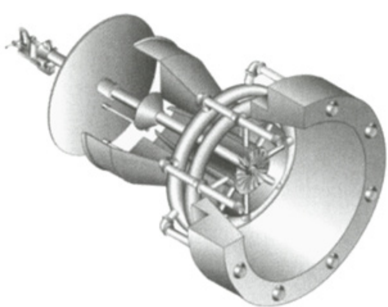


Figure 34c *Example of combination burner.*

5.5 Pilot burners

Pilot burners are important safety devices. They are used to light the main burners and provide an immediate re-ignition source should the adjacent main burner momentarily extinguish during normal operations. This avoids the possibility of unburned oil and gas entering the firebox that could cause an explosion.

There are two basic types of pilot burner dependent upon the heater design as shown in Figure 35a.

Pilots must be reliable over the range of possible conditions inside the heater and preferably supplied from an independent clean and sweet fuel gas supply (free of H_2S). Their flame must be stable over the whole range of possible fuel compositions (see Figure 35b).

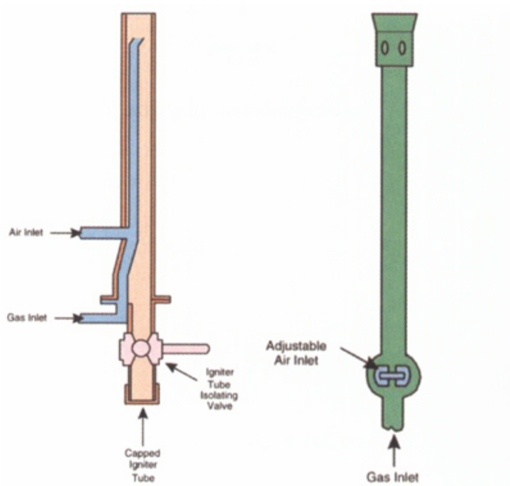


Figure 35a *Various pilot burners.*

Figure 35b *Good pilot flame.*

Fuel gas for the pilot burners should be supplied from a clean and non-corrosive separate source if practicable. Maintenance of these systems is also important. Poor pilot performance (flame distortion) is usually attributable to pilot burner blockage. Therefore, periodic inspection and cleaning is required.

The extent of maintenance required is based on the cleanliness of the fuel gas and whether or not a dual filter is provided in the fuel gas line to remove any solid materials. Consequently, natural gas is preferred as pilot fuel.

5.6 Automatic controls for burner regulation

Most petrochemical furnace outlet transfer line temperatures are controlled automatically by regulating burner fuel supply. A typical system as shown in Figure 36 works as follows:

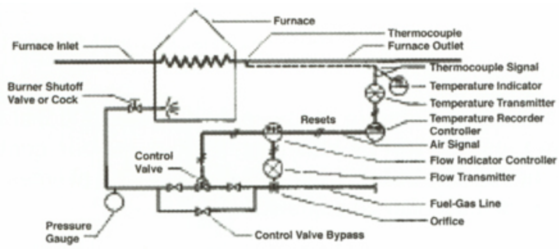


Figure 36 *A typical petrochemical furnace control system.*

- A transfer-line thermocouple sends a temperature signal to a temperature recorder controller (TRC).
- The TRC signals a flow indicator controller (FIC) that either more or less heat is needed.
- The FIC sends a signal which adjusts the position of the fuel control valve.

Unit operating instructions should fully explain the operation of the automatic temperature control system.

When furnaces are being started, the fuel is controlled manually with the FIC bypass and then with the FIC. The transfer-line temperature is increased slowly. When the temperature reaches the proper range, the TRC is put into operation, and automatic flow control is established on the FIC. The TRC is then used to increase the outlet temperature to the desired level at the rate designated by the operating instructions.

Raising the furnace outlet temperature at the proper rate is necessary to prevent tube plug and tube roll leakage.

Frequently, these leaks are caused by sudden temperature changes, which result from raising the furnace outlet temperature at an uneven rate or just opening header-box doors when the furnace is operating. Leakage in header boxes is evident from the following signs:

- Fire in the header-box or furnace firebox. A header-box fire will be self evident and can be snuffed with steam from hoses or connections provided for that purpose. Sometimes vapours from the leaks are sucked into the firebox, and the resulting flame may be visible.
- A smoky stack or an unusual rise in transfer line or stack temperature. Such signs frequently indicate leaks from convective-section tubes.

- The presence of hydrocarbons in the flue gas. These may indicate that vapours from a leak are being sucked into the furnace. Leaks in header-boxes may require a unit shutdown. A leak of heavier oils is usually self-sealed by the coke formed. Lighter oils do not coke, and the leak will persist until the furnace is shut down. *Never* open the doors of a leaking header-box while the furnace is operating—a flash fire can occur if you do.

When fuel oil is on manual control, refinery furnaces must always burn enough gas to keep the TRC in control.

The amount of gas available in many refineries varies considerably. The fuelgas system pressure can be stabilized through various control systems which result in the refinery boilers burning the excess, but at times the gas flow to refinery furnaces must also be adjusted.

This means that the fuel oil flow to each burner will have to be changed as necessary. Fuel oil adjustments should be made in steps to keep the TRC in control, and be made at all burners to keep firebox heat distribution uniform.

Many fuel systems are equipped with low pressure and/or low flow alarms or control valves which close automatically to avoid the hazards of flashbacks and flameouts in furnaces burning a single fuel. To avoid sending fuel into a hot firebox after the control valve closes, a manual relatch device should be provided. This device must be manually relatched before the fuel control valve can reopen. In such an event, be sure to follow unit instructions on how to relight the burners and put the controls back in operation.

Burner management systems (BMS)

These systems are now a normal part of new fired heaters and contribute significantly to safe furnace operation, with two key benefits:

1. Monitoring safe start up using logic and interlocks,
2. Providing a self checking ESD system during normal operation.

Therefore, any upgrade of a fired heater / control system should consider including such a management system as a retrofit (also refer to next section).

Where burner management systems are in place it is important that:

- Routine proof testing is carried out at the defined intervals;
- Appropriate controls, together with records, are in place to ensure that any bypass or overriding of the system is properly authorised.

However, these systems should be carefully designed (for more information, refer to the standards listed in the Short Bibliography section) and operators should understand their limitations, as demonstrated by the following incidents (below and in next section).

ACCIDENT On this particular night, the furnace of a desulphurisation unit was automatically tripped off five times due to a false low level alarm on another part of the unit. The furnace was successfully re-started four times. During the fifth attempt to start it, a deflagration occurred. The operator was injured because the start-up panel was located close to the furnace. The base of the furnace in particular suffered damage (see picture below) which required more than two weeks of repair work.

The following contributing factors were identified:

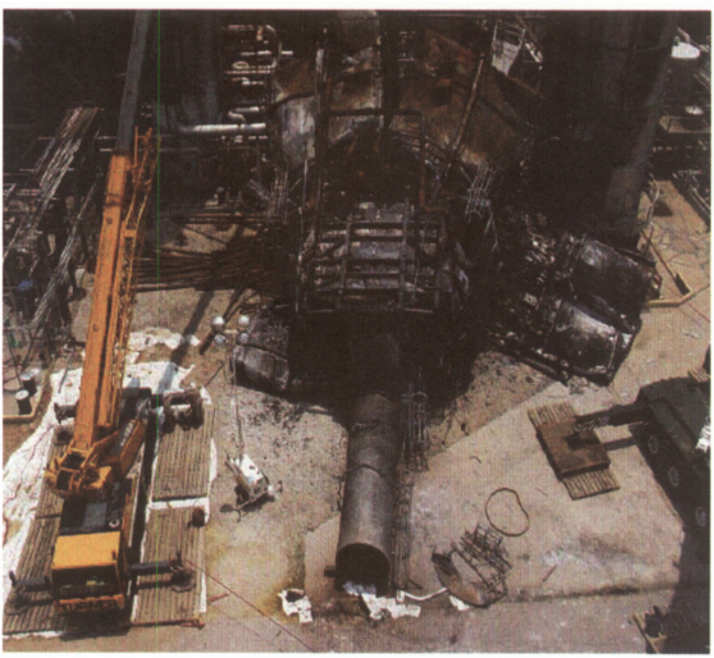
- The operating panel featured no positive display of flame monitoring; neither of the pilot burners nor the main burners. The labelling on the keys and lamps of the control panel did not reflect the true functions or conditions of the BMS with respect to flame condition.
- The BMS logic allowed all the main gas trip valves to be repeatedly opened without ignition of any of the main burners resulting in a near continuous flow of unburned gas into the furnace.
- A signal bypass (carried out without documenting a hazard assessment) meant that the flame detection of the pilot burner always showed it to be in a "GOOD" state; correspondingly the three trip valves in the pilot gas line to the burners were always "OPEN" and this "OPEN" signal was also displayed on the control panel in form of a lamp stating "ignition gas burning". Because of this "GOOD" state the trip valves to the main burner could be opened even if in fact there is no pilot flame burning.
- There was a normal start-up procedure for the furnace but this was not covering the hot-restart scenario.

5.7 Modification of burner systems

Burners are critical components of a fired heater. Any proposed modification should be managed under a rigorous management of change procedure as demonstrated by the following incident.

ACCIDENT A natural gas fired reboiler furnace for the ethylbenzene tower was retrofitted with low NOx burners as part of the site strategy to comply with the regional NOx emission regulations. The new burners kept plugging with coke and iron oxide creating unstable flames. Efforts to correct flame instability through damper and air register adjustments appeared unsuccessful and allowed too little air in the radiant section to sustain the flames at the burners and a large fuel gas cloud accumulated.

The flammable fuel/air mixture ignited resulting in a loud puff followed by a major explosion. The explosion caused the radiant section enclosure of the fired heater to burst/breaking seam bolts, dislodging supports for the convection section overhead and knocking down a number of vertical tubes from their hangers. Fire erupted in the radiant section and continued to be fed with fuel from the ethylbenzene tower due to failed tubes.



continued

More than 150 fire-fighters were involved in fighting the fire. Water cooling streams were strategically applied onto the support structure to guide the collapsing convection chamber, flue and stack into an open area on the plant site. (See Photograph)

The ethylbenzene from the tower continued to feed the fire for 3.5 hours until it was fully consumed. The fired heater was completely destroyed. No injuries occurred as a result of the incident and subsequent emergency response activities.

Before new technology is introduced:

1. Ensure that a thorough hazard review is conducted.
2. Ensure adequate performance testing is conducted.
3. Ensure that all fuel lines to burners are clear of construction dirt and debris.
4. Ensure that a thorough detailed pre-startup safety review is conducted.

6

Furnace lighting and shutdown

The most hazardous periods in the operation of a fired heater are during start-up and shutdown. Explosions will occur if a source of ignition is introduced into the firebox containing a flammable mixture of fuel and air.

It is vital that a source of ignition is not introduced until the firebox has been purged and checked to be gas free.

Most furnace explosions are attributable to failure to observe safe operating procedures during start-up. Lighting a furnace or boiler is inherently a hazardous operation in that two of the three sides of the fire triangle (ignition source and oxygen) are present at the time of light-off. If the third side (fuel) is also present in the right amount, an explosion will result.

Accumulated fuel can lead to a severe explosion, whether in your gas furnace or water heater at home, or in the firebox of a boiler or furnace in the plant (Figure 37).

ACCIDENT

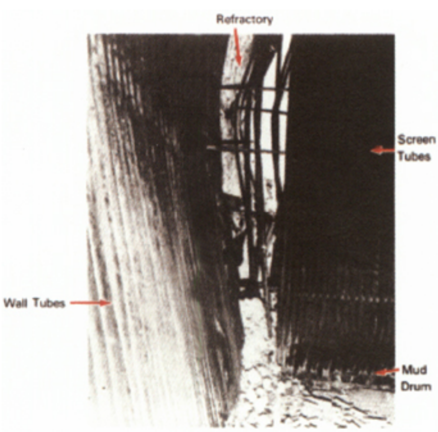


Figure 37a *Flammable vapours from any of several sources can accumulate in a firebox during a shutdown. It should be assumed that any explosion when lighting off will be severe as was the one in this boiler firebox.*

Safe furnace firing, therefore, must start with the assumption that *fuel can be present* and *procedures must be set up to remove this fuel from the firebox before a burner is lighted.* Figure 37b shows the damage that can be done by an explosion in the firebox of a crude oil heater on start-up.

ACCIDENT

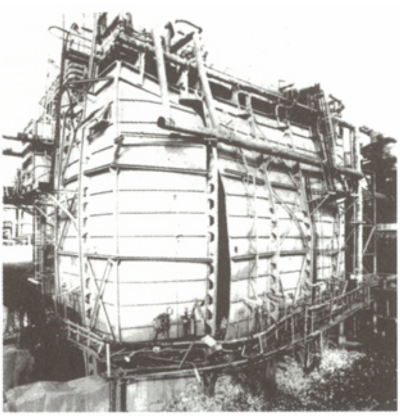


Figure 37b *Explosion during start-up in this fired heater caused £1 million damage (1983) and delayed the start-up of the Crude Distillation Unit by ten weeks.*

The following rules have been developed on this basis and are the result of years of both fortunate and unfortunate experience.

Refer also to Chapter 3 for more examples of incidents.

6.1 Preparation and pilots

The following should be done before lighting any type of furnace burner:

1. Look into the firebox to be sure there are no flammable materials such as wood, paper or rags. Flammable materials left in fireboxes have caused accidents. *Be very sure there is no accumulated oil in the firebox.* Remember that oil or gas can seep into the firebox through the floor of a furnace setting on the ground.

2. Brick up access openings if required, and close all observation doors and access openings (Figure 38). Header boxes and plates should be closed tightly. Air should enter the furnace through burner registers only.

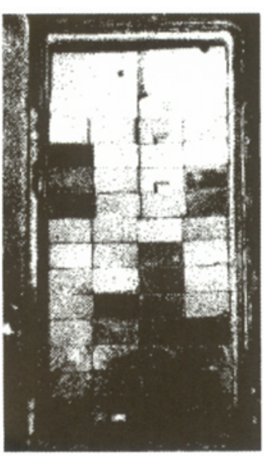


Figure 38 *Brick up access openings, if required, and close all observation doors and access openings when preparing to light a furnace.*

3. Recheck fuel-system valves for proper setting. All defective valves in the fuel gas and fuel-oil lines should have been repaired and tested during the shutdown. It is good practice to grease lubricated plug cocks, if any, at this time.

   Where a burner management system is installed, confirm that this is operational.

4. *Be sure that fuel valves and cocks at the burners are tightly closed* (see Figure 39). An open or leaking valve can result in an explosive firebox mixture.

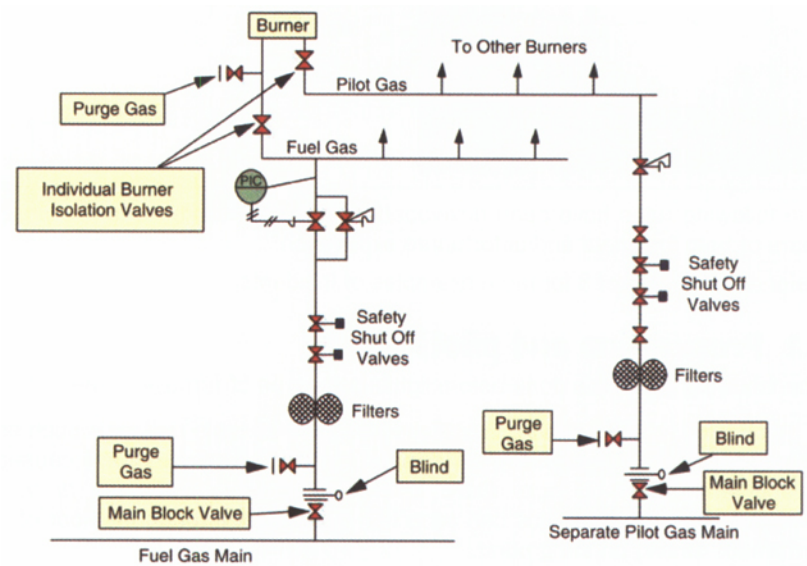


Figure 39 *Sketch of pilot gas and fuel gas lines.*

> **ACCIDENT** In one accident, two boiler burners were lit and later one was shut off without adjusting the draught. This caused the other burner to go out. The gas was immediately shut off at the main line, *but not at the burner.* The firebox was then purged, and the main gas valve was reopened. Gas flow through the open burner valve accumulated in the firebox. Insertion of the lighting torch set off a terrific explosion.

5. Adjust the draft gauges to proper zero setting and open them to the furnace. Be certain that all air and flue-gas ducts are free of oil and water.

6. Be sure all burner air registers and the stack damper are wide open, and that they can move freely. Air will be needed first for purging and then for combustion. Boilers or furnaces designed to operate with forced or induced-draught fans should never be lighted off or operated under natural draught conditions. One attempt to do this resulted in a very severe boiler firebox

explosion. The hazard is even greater if normal draught is not available for purging.

7. Start the fans that provide air to the firebox as soon as possible after the firebox is closed up. *Operate the fans at the specified air rate for the specified time to obtain a thorough purge of the firebox.*

8. At the start of this stage *all* blinds in pilot and fuel gas, fuel oil and waste gas systems must be *closed.*

   After the heater is examined, the fuel lines to each individual burner are purged through with nitrogen. The nitrogen supply is connected downstream of the main block valve and isolating blank/blind in each fuel line to the heater (fuel oil, fuel gas and pilot gas) as shown in Figure 39.

   Pressurize each fuel system in turn up to the last burner valve with nitrogen. Conduct this test at 40 psig (2.5 bar) and check for leaks. Also pressure test the fuel oil burner's interlock purge valve, and safety shut off valves.

   Then depressurize the system and remove the blind from the pilot gas *only*. Then, repressurize the pilot gas system with nitrogen to check that any disturbed flanges are not leaking. Finally, depressurize this system to slight positive pressure of about 2 to 3 psig. (0.2 bar). Do not remove blinds/blanks from main fuel lines or any waste gas connections at this stage.

   Remember—never purge into the firebox.

9. Test the nearest dry drum on the supply gas main for liquid by carefully opening the telltale valve to the open drain (Figure 40).

   Any liquid found to be present should be drained through the closed drain. *Stay right there as long as the closed drain valve is open.*

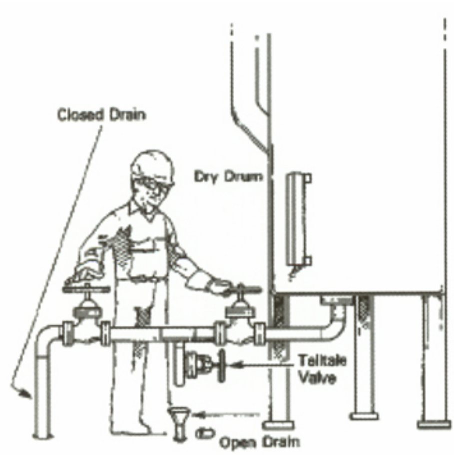


Figure 40 *Drain all the liquid from the fuel gas line dry drum when preparing a furnace for lighting. Check for liquid by opening the telltale valve periodically.*

(Note: Fully closed systems are safer—avoid flammable releases to deck.)

Do not take the chance of leaving the valve open for too long and pressuring the closed drain system with gas. Check the progress of the liquid drainage by occasionally opening the telltale. The draining of dry drums is important, because liquid in the fuel-gas system may enter the burner, put out the fire and create a severe explosion hazard in the furnace (Figure 41).

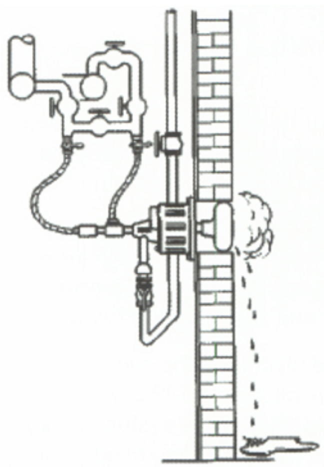


Figure 41 *Slugs of liquid from the gas line may put out fires.*

10. **Establishing flow and purging the heater:** The first step in commissioning a heater is to establish a safe minimum flow through the heater tubes. It is important that process flow measuring instruments are giving correct readings; for example, tappings and lead lines are not partially filled with water from any previous steaming out or pressure tests.

ACCIDENT Figures 42a–c show boilers which exploded when a lighted torch was inserted in a gas-filled firebox.

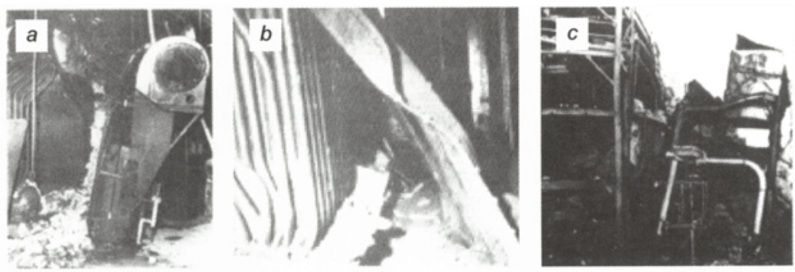


__Figure 42a__ A lighted torch inserted into a gas-filled firebox caused this boiler explosion. __Figure 42b__ Rear view of explosion damage to the boiler. __Figure 42c__ This boiler exploded because the operator tried to light a burner without purging the firebox.

Always assume that undesirable fuel is present in the firebox and so it will always be necessary to thoroughly purge the heater of this fuel.

Open the stack/flue damper fully and set burner air registers to their previously set positions (for common flue ducts, check that purging operations will not effect any on-line heaters).

The purging procedure to be followed will be dependent upon the type of heater (for example, natural or forced draught).

Natural draught heaters are normally purged with steam for at least 15 minutes or until white plumes are seen from the stack, as shown in Figure 43, to heat the air in the firebox and produce a draught, as follows:

- If the furnace has combination burners, shove the oil gun forward into firing position and open the steam valve wide. *Do not open the oil valve.*
- If the furnace has only gas burners, use steam lances inserted through burner openings.

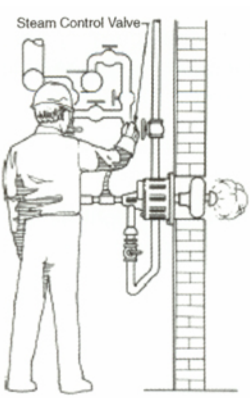


__Figure 43__ Use steam to create a draught and purge natural-draught fireboxes.

Steam long enough (according to specific unit instructions) to get an adequate draught and free the firebox of possible flammable mixtures.

On forced, balanced or induced draught heaters, fans are used to purge the firebox with air. The air rate and purge time period will be specified in the operating manual but should provide at least five complete air changes within the heater (at not less than 25% of the fan design air flow). Make absolutely certain that stock and air dampers are open and not blocked or inoperable. Many explosions have occurred within fired heaters because operators were not aware that there was not a free flow of purge air through the heater and assumed that everything was OK after running the fan for a specified period.

11. When you are ready to light the first burner, ensure that the number of people *anywhere* near the furnace is at an absolute minimum, and then adjust both the air flow through the burner to be lighted and the total air flow in accordance with unit operating instructions so that a stable flame can be obtained. *Remember, however, that at this time as much purging air as possible, consistent with flame stability, must always be moving into the firebox through the open registers of all unlighted burners.* This minimizes the explosion hazard if unburned fuel should enter the firebox by mistake.

12. **Gas test:** Shut off purges and gas test at various points including:

    - inspection ports;
    - convection section;
    - flue gas ducting;
    - air space immediately above the burner;

    as confirmation that *no* flammables are present before commencing the lighting-up process.

    This can take some time and should be planned in advance. Particular attention should be paid to convection and flue gas systems as experience shows that flammable gases can accumulate there in badly purged heaters. Gas testing must be carried out in the space above the burners to detect any leakage from the pilot gas system (main fuel systems including waste gas should remain blinded off at this time).

    This is a very important step which confirms that purging has been successfully completed and that it is safe to introduce a source of ignition into the heater. This step must never be bypassed.

    If you do not ignite burners in the next five minutes, the gas tests should be redone.

Pilots: On those furnaces equipped with pilots, be sure to light *all* the pilots before lighting any main burner (see Section 6.2 Lighting gas burners). After all the pilots are alight, check that they cannot be blown out by increasing the air flow. Open the air registers according to instructions.

Operators should not stand directly next to or under burners which are being lit and they should wear full face shields when looking through viewing ports.

After the pilots are burning properly, deblinding of the main fuels systems (including waste gas) can now commence. Light each main burner by opening the gas valve slowly (see Figure 44a).

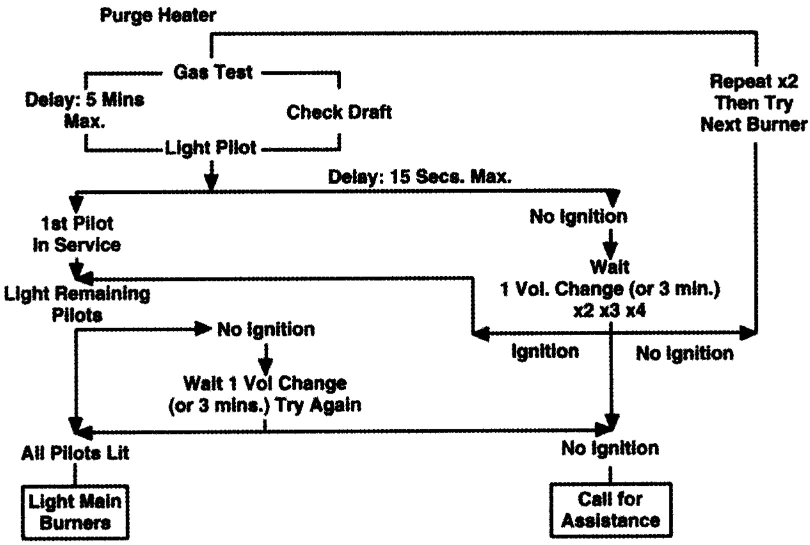


Figure 44a *Lighting pilot burners.*

Sometimes more than one attempt is required for successful combustion to occur (particularly after nitrogen purging of the pilot gas system during preparation).

If the pilot burner fails to ignite within 15 seconds, shut off the gas supply, wait for 3 minutes (natural draught burner) and then make another attempt. Follow your operating procedure for the permitted number of ignition attempts before repeating gas testing/purging or for calling for assistance.

Pilot gas may come from the upstream side of the gas control valve or from a separate source. The gas may be dirty enough to cause plugging. Therefore, pilot burners should be checked at least once each shift and cleaned and relighted promptly if they go out.

Some furnaces are equipped with a small gas bypass line (sometimes with a restriction orifice to keep gas flow to a safe minimum) around the gas control valve instead of a pilot burner (Figure 44b).

This valve should be car-sealed (chain-locked) in the wide-open position when the furnace is operating. If the gas control valve in the fuel-gas line closes, there should be enough gas flowing through the small bypass to maintain a flame at each burner. When the gas control valve reopens, each burner should remain lighted, but the fires should be inspected immediately. The small gas bypass line should always be inspected for cleanliness during each unit shutdown.

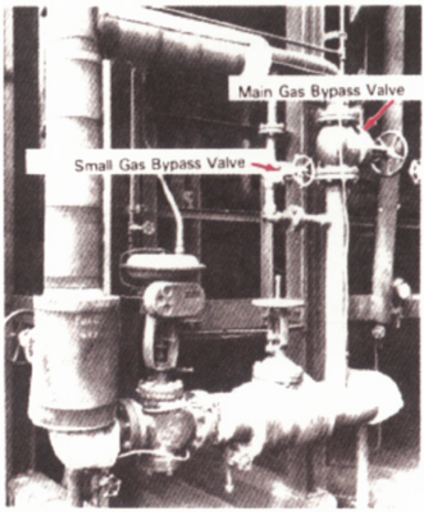


Figure 44b *Gas bypass valves. The small gas valve is car-sealed (chain-locked) open during furnace operation to prevent flame-out.*

One big advantage of pilot burners is that it avoids the need to have this small minimum gas flow bypass around the main fuel gas burner's control valve to maintain minimum firing. Tube failures have occurred when minimum firing was maintained, resulting in heat release high enough to overheat the tubes. By comparison, the heat release through the pilots is very small and controlled (see Figure 60 on page 66 for details).

Most burners are equipped with an igniter for the pilot. *This is the preferred method to give positive ignition*. Usually, the system incorporates automatic features so that if ignition is not achieved within a short time (in the order of 10 seconds), fuel gas is cut off to the pilot, and the spark-producing function is de-energized. Igniters must be retracted if the sparking mechanism can be damaged by heat. Figure 44c shows a typical igniter. Ignitors should be locked in position and switched on remotely.

Pilot gas valves should be at the side of the heater next to a viewing port and not under the heater.

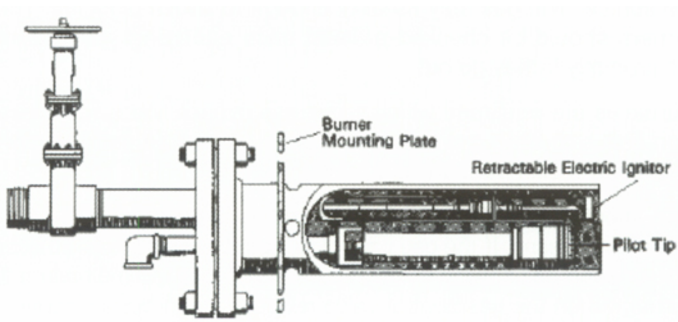


Figure 44c *An igniter with retractable design.*

6.2 Lighting gas burners

Let us take a look at rules for safely lighting a gas burner. These same rules apply to gas pilots and the gas portion of combination burners. Combination burners, of course, should always be started on gas if possible. The rules are as follows:

1. Prepare the furnace as outlined in Section 6.1.
2. Shut off steam to the combination burner to be lighted, and pull the movable oil gun back, as shown in Figure 45. On single-burner furnaces, be sure the firebox is warm enough to create a draught before you shut off steam.
3. If the oil gun is stationary, keep steam passing through it to cool the tip.

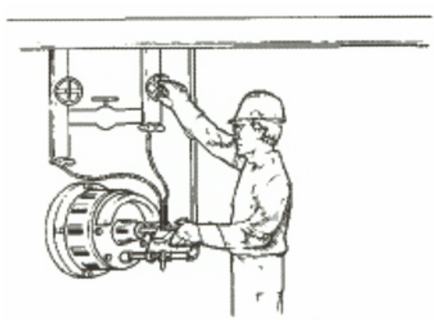


Figure 45 *Before lighting the gas, shut off steam to the oil portion of a combination burner, and pull the movable oil gun out.*

4. Deblind the main fuel gas supply to the heater and open the main block valve in the gas line *only* when the pilots are all lit (Figure 46) (see section 6.1 on Pilots). This will put full line pressure against the control valve blocks and bypass, if any. Pressurize the main gas system to 2.5 bar and test the blind flange joint. Depressurize to 0.3 bar.

   Recheck the dry drum and drain all liquid.

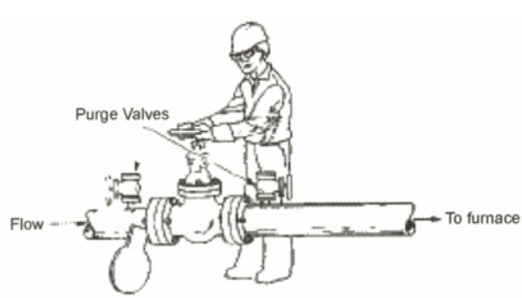


Figure 46 *Open the main gas valve to put gas to the gas control valve blocks just before lighting the main burners.*

5. Check again for stack draught (Figure 47).

Figure 47 *Check for stack draught before lighting the burners.*

6. Shut off primary air registers on premix gas burners to prevent flashback when lighting (Figure 48).

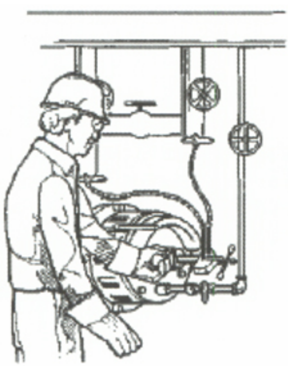
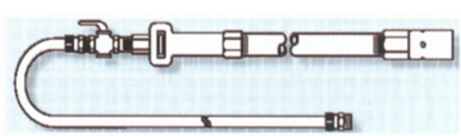


Figure 48 *Shut the primary air register on a premix gas burner before lighting to prevent a flashback.*

7. For those burners not equipped with an igniter, use a gas torch supplied by a small cylinder as it is more reliable and safer than a regulation torch (Figure 49). For ignition of burners in positive-pressure fireboxes, refer to Section 6.5.

Figure 49 *A regulation lighting torch. (Note: It is preferable to use a gas torch. Avoid open containers of flammables around a furnace or the operator.)*

A hand-held gas torch (John Zink design).



8. Remember that a strong wind increases draught at upwind burners, so it is best to light them first. After lighting the torch, *stand to one side* and check the draught by holding the torch in front of the air registers of the burner to be lighted (Figure 50). A draught will pull smoke from the torch into the firebox.

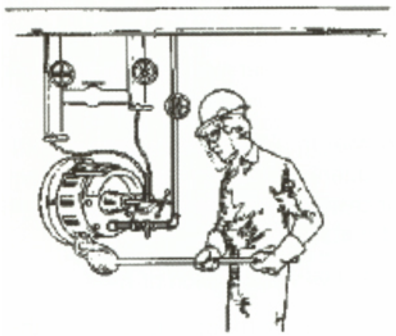


Figure 50 *Just before light-off, check the draught with the torch and think: Furnace purged? All fuel valves closed? Draught fans running? Dry drum drained?*

9. Reduce the steam flow to the other burners if necessary so that the fire you are about to light can easily be seen. Then, crack open the gas control valve (on manual control) just before lighting the first burner. Watch the fuel-gas line pressure downstream from the control valve.

10. Standing to one side, insert the torch through the openings of the burner to be lighted and open the burner gas valve slowly. If nitrogen or inert gas was used to purge the fuel-gas system, a few seconds may elapse before the fuel reaches the burners. If the burner does not light in the short period of time specified in the operating instructions, shut off the burner gas valve and remove the torch. *The firebox must be re-purged before attempting the next light-off.* Check to be sure that failure to light the burner the first time was not caused by too much air entering the burner or by holding the lighted torch in the wrong place.

11. When the fuel ignites, open the primary air registers until the yellow flame turns blue. Do not blow out the flame by opening the registers too much. Keep the lighted torch in place until the flame burns steadily (Figure 51).

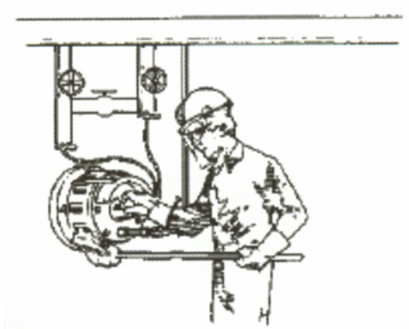


Figure 51 *Adjust the primary air on pre-mix gas burners, and be sure the gas is burning steadily before removing the torch.*

12. Light each furnace burner the way you lit the first one. *Never* light one burner from the other—to do so invites an explosion. Continue to open the control valve as needed to maintain pressure and keep fires stable as additional burners are lit. Sometimes the control valve bypass rather than the control valve is used during light-off.

As mentioned before, all these rules apply to gas pilots which have come into increasing use in the petrochemical industry.

After lighting, the following precautions should be observed to properly adjust the fires and obtain smooth burner operation:

1. Inspect the fire frequently. A lighted burner in a cold firebox may go out. Adjust dampers, burner air registers/shutters and fuel pressure for proper firing conditions as the firing rate is increased. Ensure adequate burner fuel supply pressures are maintained for stable flames.
2. Spread the start-up of burners to provide even distribution of heat.
3. If the first burner goes out before the others are lighted, or if all the burners go out, shut the fuel valves at once and repeat the *entire* purging and lighting procedure.
4. If one burner goes out while the others remain lighted, shut off fuel to that burner for five minutes, and establish the cause before attempting to relight.
5. Never permit a burner to ignite from an adjacent burner or hot brickwork, because unburned fuel may accumulate and explode.
6. Do not let flames touch the tubes. If they do, a hot spot may develop. Shorten the flames by increasing the flow of air to the furnace.
7. Wait for normal operating conditions before commissioning any fuel/waste gas burners.

6.3 Lighting oil burners

Oil burners without gas pilots should be lighted from a regulation torch. When there is a gas pilot, light it first and then light the oil from the pilot. With combination burners, it is desirable when firing heavy fuel oils to operate the gas portion for at least an hour and have the firebox temperature above 500°F (260°C) before admitting oil.

The steps in a safe procedure for lighting oil burners follow. Figures 34a and 34b (see page 38) show burner parts.

1. Be sure the fuel-oil pump is running and circulating oil at the required temperature and pressure if fuel oil is to be used.
2. Deblind the fuel supply to the heater and open the main block valve in the line *only* when the pilots are all lit (see section 6.1 on Pilots).
3. Push the oil gun forward, and then turn on steam by fully opening the steam block valve and the steam control valve. The gas fire from a combination burner may blow out if the steam is turned on before the oil burner gun is pushed forward.
4. Make sure the oil block valve is closed, and then open the oil regulating cock all the way by turning the handle parallel to the oil line. Open the steam bypass valve to clean and warm the burner.
5. When condensate has been removed and the steam is dry (dry steam is invisible), close the bypass.
6. Open the oil block valve, and then gradually open the oil cock. Adjust the cock by tapping the handle until oil flows through and starts burning. The oil will ignite from the gas flame or oil torch. Take care to see that unburned oil is not put into the firebox. Accumulated unburned oil will become hazardous as the firebox heats up.
7. Adjust the steam valve and oil cock to obtain the correct flame pattern. *Never let the flame touch the tubes.*
8. It is sometimes desirable to keep some gas flowing to a combination burner while oil is being fired. Heavy fuel oil in particular burns much better with some gas flame behind it. The gas also serves as a pilot in case of fuel-oil interruption. In some cases, firing controls are provided only in the gas line.

Where the system is protected by a burner management system follow the procedures outlined in Section 6.1. The procedures outlined by the burner manufacturer must be followed.

After lighting, the same precautions should be observed as for gas burners (see previous page).

6.4 Switching fuels

The steps in switching from oil to gas on combination burners are as follows:

1. Increase gas burning to make sure gas burner will stay lighted.
2. Close the oil block valve on the header.
3. Open the steam bypass and flush the oil out of the burner to prevent coking and plugging. Flush the oil cock by moving the handle back and forth.
4. Shut off the steam entirely, unless a little is required to prevent freezing during winter or to keep the tip cool.
5. Pull the oil burner gun back inside the gas burner. If the burner does not pull back, keep the tip cool with steam.
6. Adjust the gas to meet heat requirements.
7. If the oil burners and gas burners are separate, the appropriate steps are numbers 2, 3, 4 and 6.

Switching from gas to oil involves all steps listed in Section 6.3. The gas burning is reduced as necessary to meet heat requirements.

6.5 Ignition of burners under pressure

Air heater burners on fluid catalytic cracking units operate in a vessel which is under about 30 pounds (2 bars) of air pressure or more (Figure 52).

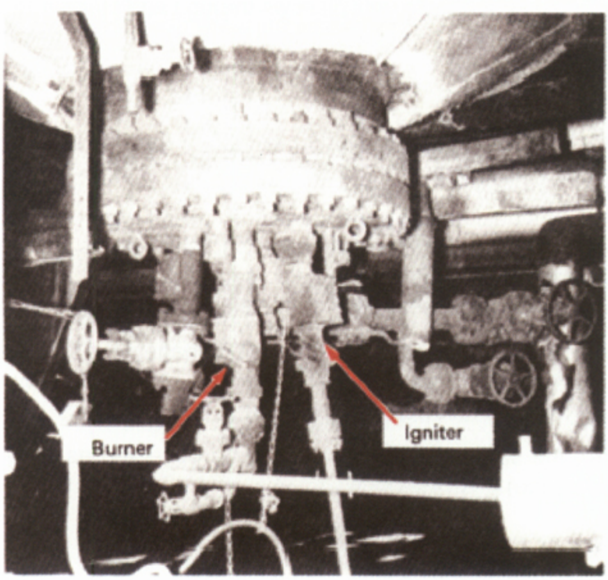


Figure 52 *This burner on a catalytic cracker air preheater operates under pressure.*

Next Page

The hot air and products of combustion from the heater discharge into the regenerator during start-up, and this provides heat to the system until the catalyst is hot enough to start torch-oil addition. A spark plug is used to ignite the gas burner. Good practice requires that someone continually observe the flame and be prepared to shut off the fuel immediately if the flame goes out.

On catalytic cracking units, waste-heat recovery units which burn CO gas (Figure 53) also operate with a firebox pressure above atmospheric.

Figure 53 *This waste-heat recovery operates under pressure to burn the carbon monoxide (CO) found in the flue gas of a catalytic cracker regenerator.*

There are also many boilers which operate under positive firebox pressure.

Burners on these units also use electric spark ignition.

This booklet does not give details for igniting burners under pressure. The specific firing instructions provided for each installation should always be followed. However, the same careful purging, blinding, and other preparations as described earlier in section 6.1 should be observed.

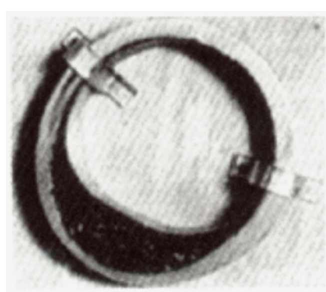
7

Some points to remember

1. Explosive mixtures can accumulate in a furnace firebox from unnoticed flameouts, unatomized liquid fuel, leaking fuel valves or other causes.

2. Be careful when lighting and relighting burners. That is when most explosions occur.

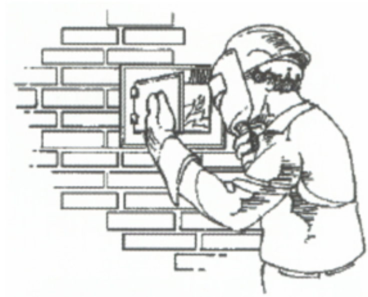
3. When reducing excess air, be sure that flames do not lengthen and strike the furnace tubes. Keep uniform heat distribution in the firebox to avoid tube coking.



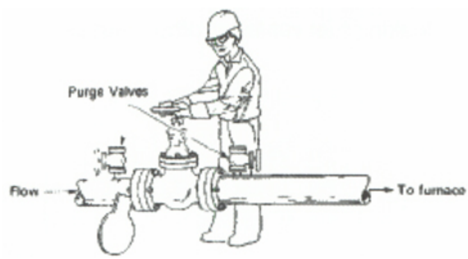
4. Inspect fires and radiant-section tubes several times during each eight-hour shift.

5. Keep a slight draught on a furnace roof to prevent burning the roof arch and corroding the steel work.

6. Use a firing shield when looking through furnace peepholes.

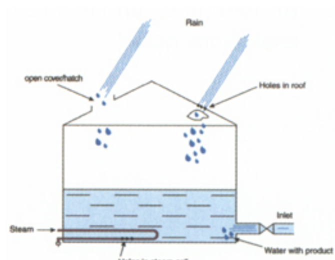


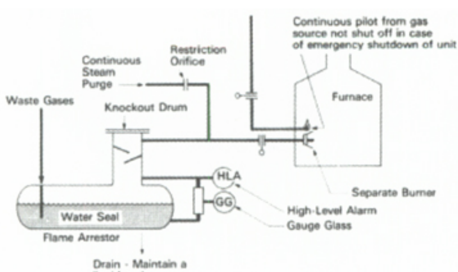
7. Never try to de-ice a running draught fan. Always stop the fan first and then de-ice.



8. Properly prepare the fuel-gas system for start-up by removing blinds, testing valves and purging all lines, as listed in Section 4.1.

9. Keep water out of fuel oil. Keep fuel oil temperatures at 200°F (93°C) or lower. Remember that water in fuel oil can start a chain of events ending in a furnace explosion.

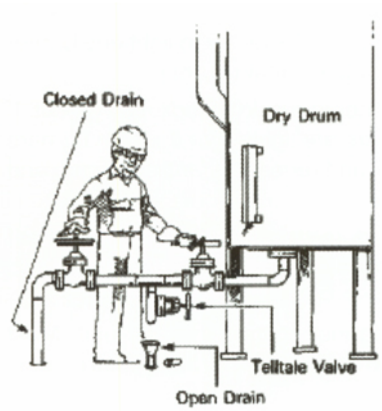




10. Use proper equipment to burn waste gases or vapours in a refinery furnace.

11. Avoid flashbacks from premix gas burners. Close the primary air doors on start-up, and remember that partially blocked spuds, low gas pressure, or changes in gas composition can all cause flashbacks.

12. Prevent header-box fires by avoiding abrupt changes in furnace temperatures.

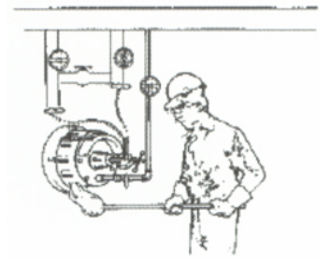


13. Follow all the rules for getting ready to light a burner. Be particularly sure that:
    - There is no flammable material in the firebox.
    - All burner valves are closed.
    - There is a good draught. If a strong wind is blowing, upwind burners will have a good draught, and downwind burners will have little or no draught. It is best, therefore, to light upwind burners first.
    - The firebox is properly purged.

      Remember to always keep some purging air moving through the registers of unlighted burners.
    - The number of people in the vicinity of the furnace is at an absolute minimum.
14. Drain gas dry drums before lighting a furnace.
15. Never light off or operate boilers or furnaces on natural draught if they are designed to operate with forced or induced-draught fans.

16. Light a pilot or burner from its igniter. If not equipped with an igniter, use a regulation torch. Stand to one side when lighting a pilot or burner. *Never* stand in front of the burner opening. Always check:

    Furnace purged? All fuel valves closed? Draught fans running? Dry drum drained?



17. Light each burner the way you lit the first one. Never try to light one burner from another. Light all pilots before lighting any main burner.
18. Inspect the fire frequently. A lighted burner in a cold firebox may go out. If the first burner goes out before the others are lighted, or if all the burners go out, shut off the fuel valves at once, and repeat the *entire* purging and lighting procedure.
19. If one burner goes out while the others remain lit, shut off fuel to that burner for five minutes, and establish the cause before attempting to relight it.
20. Review frequently and follow the firing instructions for your unit. Most furnace explosions result from failure to follow operating instructions carefully.
21. On shutdowns, be careful not to blow out gas fires with steam when purging oil burners.
22. When shutting down a furnace, shut off enough gas burners to keep adequate pressure for the rest.
23. Know fuel systems and shutdown procedures like the back of your hand. Safe off-process actions require prompt action.

Acronyms and abbreviations

BMS	Burner Management Systems
CDU	Crude Distillation Unit
CO	Carbon Monoxide
CO_2	Carbon Dioxide
ESD	Emergency Shut Down
FCCU	Fluid Catalytic Cracking Unit
FDF	Forced Draught Fan
FIC	Flow Indicator Controller
HDS	Hydro Desulphurization Unit
HDT	Hydro Treatment Unit
H_2O	Water
H_2S	Hydrogen Sulphide
IDF	Induced Draught Fan
O_2	Oxygen
PDA	Propane Deasphalting Unit
TRC	Temperature Recorder Controller
VDU	Vacuum Distillation Unit

Test yourself!

1. 'Heat-off' is the correct action to take in case of tube failure.

   True ☐ **False** ☐

2. What action would you take immediately following a 'heat-off' shutdown?
   a. Shut off the fuel to the pilots.
   b. Close the individual isolation valves on the fuel oil and fuel gas lines to the heater.
   c. Reset the trip system.

   a ☐ **b** ☐ **c** ☐

3. If your heater is shutdown on the ESD system and is ready to start up shortly afterwards, what action would you undertake first?
   a. Light up the pilots immediately.
   b. Purge the gas fuel lines.
   c. Purge and gas test the firebox for flammables/combustion.

   a ☐ **b** ☐ **c** ☐

4. 'Heat-off' includes shutting off fuel gas to the pilots.

   True ☐ **False** ☐

5. The shutdown of the burners should be staggered under normal shutdown procedure.

   True ☐ **False** ☐

6. When possible, the heater should be changed over to total gas firing before shutting down the heater.

   True ☐ **False** ☐

7. Low fuel pressure or poor atomization can cause the burner flames to be extinguished.

   True ☐ **False** ☐

8. 'Heat-off' includes isolation of vessels with large inventories and stops all pumping of hydrocarbons or hazardous materials.

   True ☐ **False** ☐

9. Keep waste gas burners in service as long as possible during the normal shutdown procedure.

   True ☐ **False** ☐

10 It is not necessary to install blinds after the main burners have been purged/shut off following a shutdown.

True ☐ False ☐

11 The pressure inside the heater is less than atmospheric pressure.

True ☐ False ☐

12 A minimum flow bypass is needed on the main burner fuel supply control system with the installation of pilots.

True ☐ False ☐

13 A forced draught fan pushes combustion air into the heater for better air/fuel mixing.

True ☐ False ☐

14 A forced draught burner requires more excess air than a natural draught burner and has a longer flame.

True ☐ False ☐

15 Natural gas is the preferred fuel to pilots.

True ☐ False ☐

16 Liquid carryover into the fuel gas to the burners and pilots is not much of a concern.

True ☐ False ☐

17 Draught control is achieved by the positioning of the stack damper and the burner registers.

True ☐ False ☐

18 Fuel oil is under pressure control and relieves excess fuel to the flare.

True ☐ False ☐

19 Heavier fuel oils are heated to reduce their viscosity at the burner.

True ☐ False ☐

20 Most heater explosions are attributable to failure to observe safe operating practices.

True ☐ False ☐

21 Low fuel gas pressure can cause combustion problems and flame failure.

True ☐ False ☐

22 A gas test should be taken near the burners, as well as at the convection section and flue gas ducting after an adequate heater purge period.

True ☐ False ☐

23 The stack damper should be fully closed while attempting to purge and light-off the heater.

True ☐ False ☐

24 Before lighting the first pilot, all blinds should be removed from all main fuel lines to the heater's burners.

True ☐ False ☐

25 It is permissible to light a burner from an adjacent burner.

True ☐ False ☐

26 Many heaters have foul gas burners. When would you commission them ?

a. After commissioning of pilot burners.

b. When heater is at normal operating conditions.

c. Any time.

a ☐ b ☐ c ☐

27 When is it permissible to light the first main fuel burner?

a. After the first pilot is lit.

b. When 50% of the pilots are lit.

c. When all the pilots are lit.

a ☐ b ☐ c ☐

28 The fuel gas lines to each individual burner are purged through with steam.

True ☐ False ☐

29 Steam purging of a natural draught heater is done before safe minimum flow through the heater process tubes is established.

True ☐ False ☐

30 Coke builds up inside heater tubes as result of:

- Flame impingement.

True ☐ False ☐

- Low process flow.

True ☐ False ☐

31 Tube skin thermocouples will register higher temperatures:

- On high process flow.

True ☐ False ☐

- When the tube is overheated.

True ☐ False ☐

32 No flow through a tube pass will be indicated by high furnace outlet temperature.

True ☐ False ☐

33 Depressurization/backflow of the unit can occur through a heater tube rupture.

True ☐ False ☐

34 Achieving an equal flow through each tube pass is very important.

True ☐ False ☐

35 Maximum skin temperatures depend on the type of steel the tube is made from.

True ☐ False ☐

36 Flow through a tube with a hot spot should be reduced.

True ☐ False ☐

37 Blow through steam connected to each tube pass is required to snuff out the burners and to minimize after-burning in the stack and/or explosions.

True ☐ False ☐

38 Steam is admitted to the heater passes to displace the hydrocarbon and to keep the tubes cool while shutting down in the event of a tube rupture.

True ☐ False ☐

39 No-one has ever been killed by fire caused by a tube rupture since the flames are maintained within the firebox.

True ☐ False ☐

40 Tube leaks in high pressure furnaces are likely to have sudden failure.

True ☐ False ☐

1F/2B/3C/4F/5T/6T/7T/8F/9F/10F/11T/12F/13T/14F/15T/16F/
17T/18F/19T/20T/21T/22T/23F/24F/25F/26B/27C/28F/29F/
30TT/31FT/32F/33T/34T/35T/36F/37F/38T/39F/40T

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Your notes