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Get the Most From Your Fired Heater

Though the functioning of these widely used heaters it appears simple, there is more to efficient operation than meets the eye. A common stumbling block is the control of draft.

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Furnace Improvements

Fired heaters are major consumers of energy in the chemical process industries (CPI) especially at petroleum refineries and petrochemical plants. Accounting for as much as 70% of total plant energy consumption in some instances. While most plant engineers and operators are aware of the importance of controlling excess oxygen in fired heaters, they often overlook a key determinant of efficient heater operation; the control of their draft, namely, the negative pressure inside the vessel with respect to the atmosphere.

A recent survey indicates two extremes in draft management. In most fired heaters, the draft is maintained at almost four times the value recommended. At the other end of the spectrum, some heaters run with no draft – in fact, with positive pressure at the radiant arch (the transition zone between the radiant and convection sections). Neither situation is desirable; they can cause considerable loss of energy, and can even be hazardous. Plants can save substantial amounts of energy by training operators in proper draft control and making minor hardware modifications. For a 100,000-bbl/d (BPD) refinery in the U.S., even a 1% improvements in thermal efficiency translates into energy savings of almost $500,000/yr. Automatic draft control can improve the efficiency of fired heaters if it is designed and installed correctly. Before explaining how, we provide a brief refresher on the concepts involved.

Fired Heaters

In a fired heater, the thermal energy liberated by the combustion of fuel is transferred to fluids contained in tubular coils within an internally insulated enclosure.

A typical fired heater consists of three major components; the radiant section, the convection section and the stack. Figure 1 shows a typical cross-sectional view of a vertical cylindrical fired heater. The fired heater is fired by oil or gaseous fuel. The process fluid, passing through tubes in the heater, absorbs the heat mostly by radiant heat transfer, and by convective heat transfer from the flue gases.

The flue gases are vented to the atmosphere through the stack. Burners are located on the floor (as stylized in Figure 1) or on the sidewalls of the heaters. Combustion air is drawn from the atmosphere. Combustion is directly affected by the draft.

Combustion

Combustion, the exothermic reaction resulting from rapid combination of fuel with oxygen, produces heat and flue gases. Fuel and air must be mixed thoroughly for complete combustion. In theory, it is possible to burn fuel completely with just the stoichiometric amount of combustion air. However, under actual operating conditions, perfect mixing of fuel and air is not possible within the short time that is involved in combustion. If only the theoretical amount of combustion air were provided, then some fuel would not burn completely. So, excess air is needed, expressed as a percentage of the theoretical quantity of air required for perfect combustion. This excess air shows up as excess oxygen in the flue gas. Table 1 shows the effects of excess air and stack temperature on the thermal efficiency of the fired heater. As a rule of thumb, every 10% increase in excess air reduces the heater efficiency by almost 1%, whereas every 35°F reduction in stack flue gas temperature increases efficiency by 1%.

Burners

Burners start and maintain combustion, in the firebox. They introduce fuel and air in the correct proportions and mix them, provide a source of ignition, and stabilize the flame. How the air is supplied to the burners is largely related to the concept of draft, discussed in more detail now.

In most fired heaters, the burners are natural draft, as explained below. These burners are the most dependent on the draft, as all natural draft burners are sized for a specific draft loss across the burner. Providing a higher draft than that design value will induce more air, whereas providing lower draft will lead to insufficient air for combustion.

The other type of burners used in fired heaters is forced-draft burners which get their air supply from a fan. These are not dependent on the heater draft.

There are also self-inspirating pre-mix burners, used in special heaters such as those for steam methane reforming, or for ethane cracking. Most of these burners are partially dependent on the draft available in the heater.

Draft

Draft is the pressure differential between air or flue gas in the heater and ambient air. It materializes because hot flue gases inside the firebox and stack are lighter than (and thus at lower pressure than) the colder ambient air outside.

In a given situation, the theoretically available draft, in inches of water column (inWC) can be calculated as follows:

$$\text{Draft} = 0.53\ HP\ [(1/\ T_{ambient}) - (1/\ T_{flue\ gas})]$$

Where H is stack height in feet, P is atmospheric pressure in pounds per square inch absolute (psia). $T_{ambient}$ is the ambient temperature in degrees Rankine and $T_{flue\ gas}$ is the flue gas temperature, in the same units.

Combustion air is drawn into the burners from the atmosphere, and hot gas rises due to buoyancy and flows out of the stack to the atmosphere. While passing through the heater's convection section and the stack, flue gases encounter friction resistance, known collectively as draft losses. Sufficient stack height is given to provide the buoyancy effect needed to overcome these losses, and to ensure that pressure is always negative inside the firebox.

There are four types of draft systems in the fired heaters:

Natural Draft: As implied above, this is the most common system (Figure 2). Air is drawn into the burners by means of the draft created by the radiant section. The taller this section, the greater the available draft. Typical draft gains are of the order of 0.1 inW.C. per 10 feet of box height in the radiant section.

Draft at the heater floor is the order of 0.3 to 0.7 in. for tall, vertical cylindrical heaters. Natural draft is the most simple and reliable type of heater, as the air supply does not fail. System performance is directly linked to the draft available in the heater. In these heaters, draft control is the most important operating parameter.

Forced-Draft: In this type of heater, the air is supplied by means of a centrifugal fan, commonly known as a forced-draft (FD) fan. A FD fan provides air at relatively high pressure, in the range of 2 to 6 in.WC , leading to better air-fuel mixing and smaller burners.

In this option, too, the stack is required to create a negative draft inside the fired heater.Draft control is important in these heaters, to minimize air

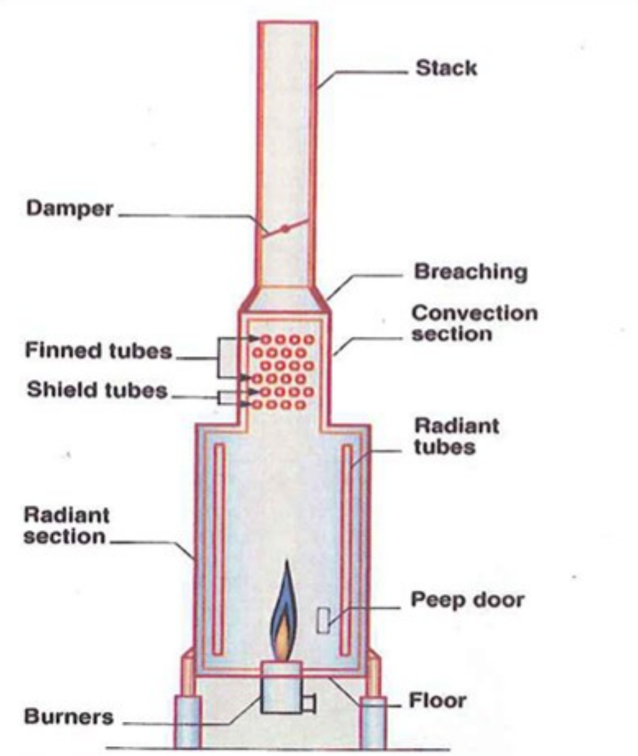
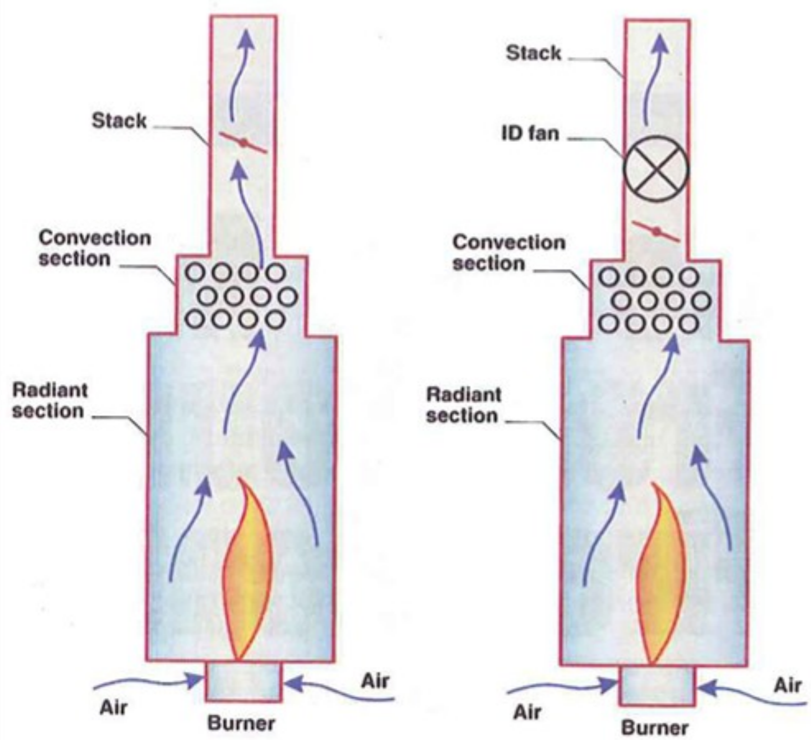


FIGURE 1. Three key components of fired heaters are the radiant section, the convection section and the stack



FIGURES 2 (left) AND 3. Two of the draft options that can be chosen for fired heaters are natural-draft (left) and induced-draft

TABLE 1. THERMAL EFFICIENCY VS. STACK FLUEGAS TEMPERATURE AND EXCESS AIR												
Excess Air, %	O_2 in Flue-gas, %	Temperature of Fluegas, °F										
		300	350	400	450	500	550	600	700	800	900	1,000
15	3.00	91.76	90.44	89.11	87.77	86.42	85.06	83.6	80.59	78.11	75.25	72.35
20	3.82	91.52	90.15	88.77	87.39	85.98	84.57	83.15	80.28	77.36	74.4	71.39
25	4.56	91.29	89.87	88.44	87.01	85.55	84.09	82.62	79.64	76.61	73.55	70.43
30	5.24	91.05	89.58	88.10	86.61	85.11	83.62	82.07	78.99	75.87	72.69	69.47
40	6.46	90.58	89.01	87.43	85.84	84.24	82.60	81.00	77.71	74.37	70.99	67.55
50	7.49	90.10	88.43	86.76	85.06	83.36	81.64	79.92	76.43	72.28	69.28	65.63

leakage and to ensure negative pressure throughout the whole heater.

Induced-Draft: When the height of the stack is inadequate to compensate for the draft-loss requirements, an induced-draft (ID) fan is provided on top of the fired heater (Figure 3). The resulting negative pressure inside the heater ensures adequate draft for the burners from the atmosphere. Most heaters in cracking and reforming units fall into this category. The size of the convection section in these fired heaters is very large, and the draft control is very important.

Balanced-Draft: When both forced-draft and induced-draft fans are used with a fired heater, the combination is known as a balanced-draft system. Most air preheating installations are, in fact, balanced draft.

In a typical air preheating system, the draft loss across the air preheater could be on the order of 2-6 inWC. The stack by itself cannot compensate for a loss of this magnitude. Instead, the FD fan supplies the combustion air, and the ID fan takes care of flue gas disposal. In these systems, draft control is required for efficient combustion. Figure 4 shows a typical balanced-draft heater with an air preheating system.

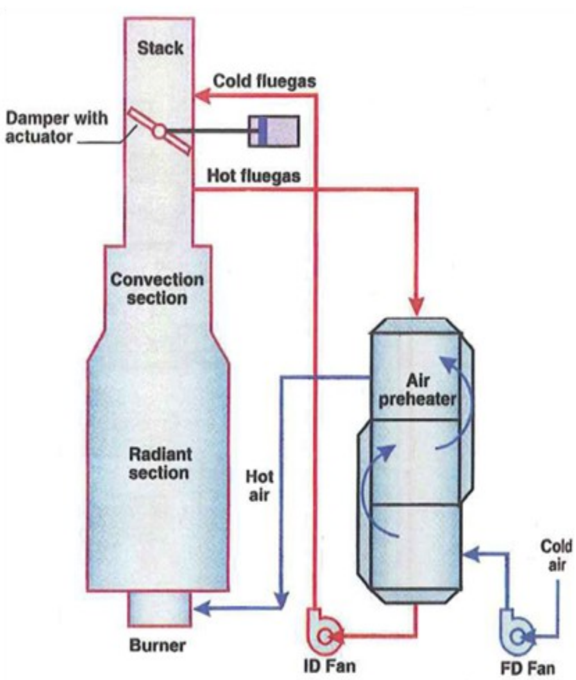


FIGURE 4. The balanced-draft option often goes hand in hand with the inclusion of an air preheater in the system

Draft Profile

Maintaining a negative pressure at all times throughout the fired heater makes the device inherently safe, and ensures that hot flue gases will at no time escape. By contrast, a positive pressure inside the heater can be hazardous for operating personnel, would cause flue gas leakage, as well as damage to the fired-heater casing and overall structure.

The typical draft profile for a balanced-draft heater appears in Figure 5. Other types of heaters have similar profiles, except for some minor variations associated with the (lone) ID or FD fan installation.

As can be seen from the draft profile, the radiant arch of the heater sees the highest absolute pressure throughout the whole heater, except for the stack tip. If draft at the arch can be controlled to be negative, the engineer can be sure that the entire heater will be at negative pressure.

The floor of the heater or the hearth, where the burners are typically located, experience draft due to the stack effect in the radiant section. In the convection section, flue gases admittedly encounter resistance due to tubes, but gain some draft due to the height of this section. If the convection section becomes fouled, the pressure drop across that section goes up and the draft at the arch can, in fact, becomes positive.

Similarly in the stack, the stack controls the draft. If the damper is closed too far, the arch draft will become positive; if it is instead opened too far, it will lead a very high draft in the arch. The right stack height provides the draft need to maintain negative pressure at the arch and to take care of friction losses in the convections section and stack.

Draft Control

In natural or forced-draft systems, the draft in the fired heater is controlled by the means of a stack damper, as just discussed. In induced-draft and balanced-draft heaters, the draft is controlled by ID fan. Because the arch of the heater has the highest pressure, it is commonly used as a point of control.

A value of 0.1 in W.C. is typically maintained at the arch in all fired heaters, except for some special, down-fired reformer heaters. This value ensures safe operation and minimal air leakage. Excess air must be minimized for efficiency improvement. On the other hand, enough air must be provided to obtain the correct and desirable flame shape and complete combustion. Closing air registers reduces air flow but increases heater draft. Closing the stack damper reduces the fired-heater draft. In order to regulate excess air effectively, the damper and registers must be adjusted jointly.

Air Leakage
A fired heater is not a pressure-tight structure. Air can leak into the heater through all openings available to it. This air does not take part in combustion, instead showing up in the stack. It can lead to inefficient combustion, to a waste of energy due to excess draft, and to the generation of NOx emissions*. Even with fuel prices at only $3 million Btu, one square inch of leakage area can lead to $32,000 in energy cost per 0.1 in W.C. of excess draft.

These precautions can minimize air leakage a fired heater:

- Keep all peepholes closed.
- Make sure that the doors are tight on the header box, which houses fluid-tubing U bends in the convection section.
- Keep the explosion door closed.
- Ensure there is only minimal air leakage via the penetrations of the tube guides (which hold the fluid tubes in place) into the floor of the heater.

One reliable indication of air leakage is the production of CO even at high oxygen levels. Carbon monoxide will be generated at the burners if the air to them is insufficient, but the leaked air (which does not help the burners) raises the oxygen content of flue gases and thus masks that insufficiency.

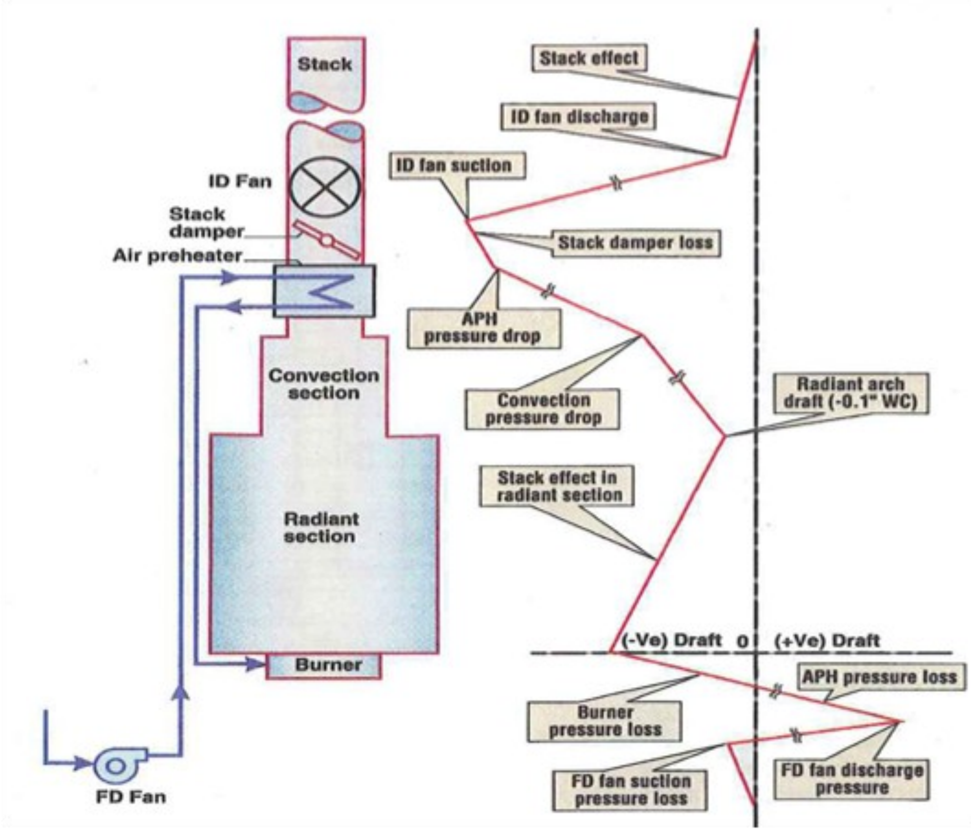


FIGURE 5. The gas-pressure profile varies markedly along the height of the fired heater, but is negative (below atmospheric pressure; to the left of the vertical axis in this figure) throughout almost all of it. Although not obvious from this figure, the pressure at the top of the stack is slightly positive

Typical heater configurations
Several heater and damper configurations can be found in chemical process plants:

Fired heater with no stack damper: Heaters of this type were built in the 1950s and 1960s. The burners installed in these heaters were typically of the premix version; in these burners; the amount of air inspirited is automatically proportional to the fuel gas pressure. Overtime, however, the burners in such heaters became replaced by either low-NOx burners or raw –gas burners (in which the fuel gas and air become mixed, externally, at the burner tip); both versions, unlike the premix burners, are draft-dependent. Therefore, these heaters need to provide the required draft. Old fired heaters that have not been thus modified are the most-significant sources of fired-heater energy loss today.

Heater with stack damper: Most fired heaters installed in the last 30 years fall in this category, having been designed with a manually operated stack damper.

The damper is typically operated from grade, by means of a cable and a winch. The damper is provided with an external position indicator; also, the winch is calibrated.

***Conversely, if the draft in the heater is (unfortunately) positive, hot gases from the**

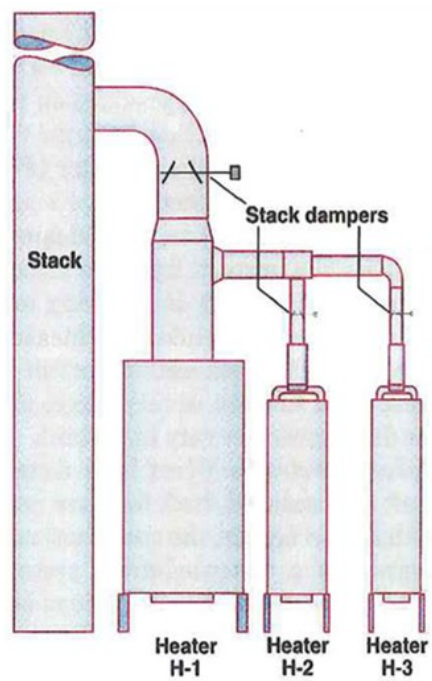
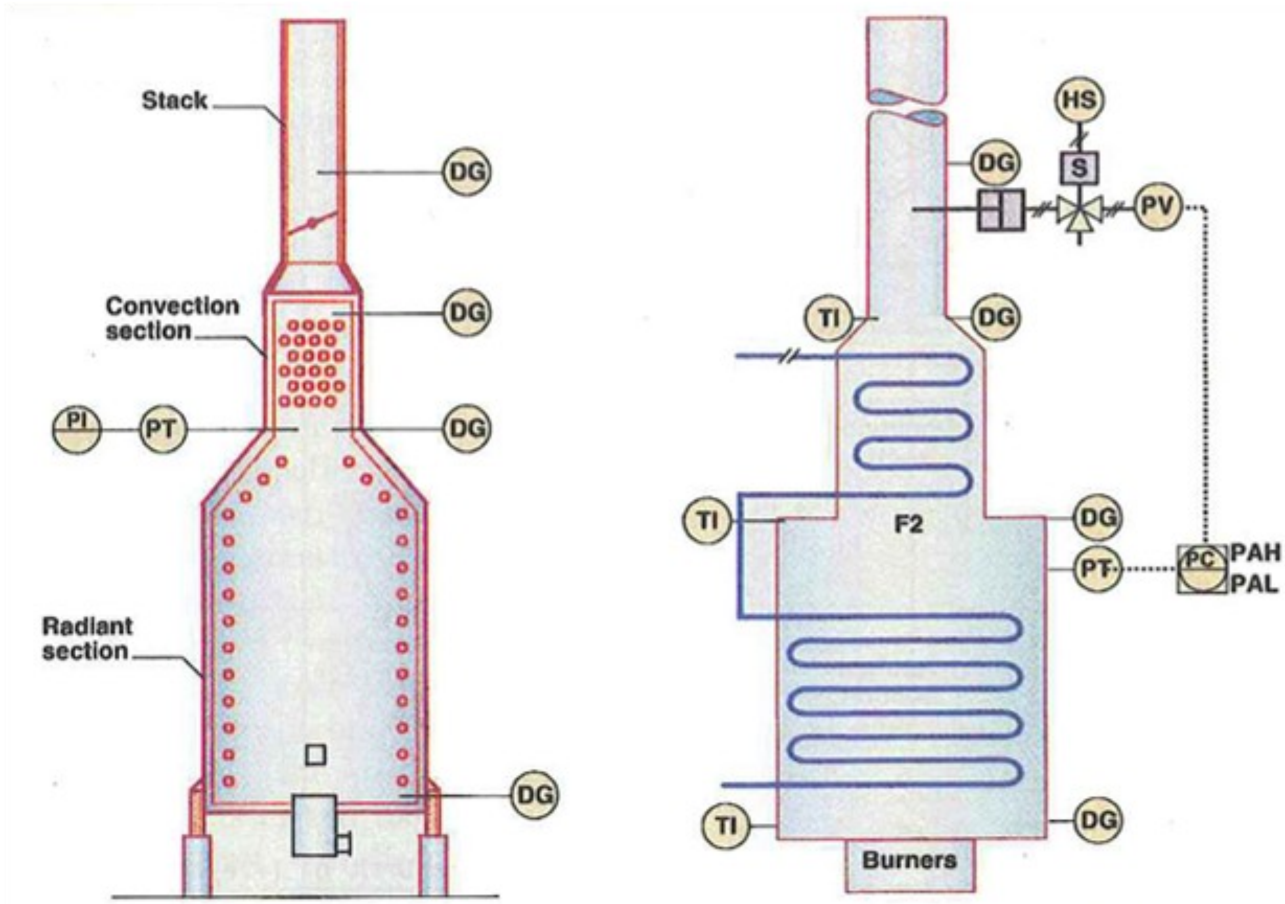


FIGURE 6. If several heaters are vented through the same stack, as shown here, control of the draft becomes especially complicated



FIGURES 7 (left) AND 8. Draft gages are mounted at several points on a fired heater (left). An automatic control system, focusing upon the pressure at the furnace arch, appears in Figure 8

firebox can leak out through the openings, which poses a safety hazard.

However, dampers of this type are of poor quality; they often get stuck, and sometime remain fully open. Operators tend to be reluctant to touch them so as to make adjustment to drafts. These dampers should be replaced with more-reliable versions, whether manually or pneumatic operated, from grade or at a control panel.

Heaters with off-take dampers: A number of cabin-type fired heaters with long convection sections are equipped with single or multiple off-take ducts, which connect the convection sections to the stack. In some such heaters, the dampers are installed in the off-takes instead of stack. Multiple off-take dampers should be operated uniformly, as to avoid any imbalance that could change the flue gas flow pattern in the furnace.

Multiple heaters with common stack: Similarly, in several installations, a number of heaters are connected to a common stack (Figure 6). This configuration is particularly common in Europe, where the local pollution laws may dictate using a stack as high as 200 to 300 ft. Such stacks are based upon grade, and the fired heaters are connected through the ductwork.

In these installations, the draft control becomes tricky. Any change in the firing conditions of one heater can affect the draft in all the other heaters and require their readjustment. In such circumstances, it is common to have an automatic draft control system for each heater. An alternative consists of having a manual loading station, along with pressure indicators, in the control room.

Heaters with ID fan: The two types of heaters that use ID fans to maintain the draft in the heater are: induced-draft fired heaters, as discussed earlier; and balanced-draft fired heaters with air-preheating systems.

In both types, the draft is controlled by the fan. Generally, the fans are provided with an inlet-box damper to control the draft; in some cases, the fan is instead provided with a variable-sped drive (VFD) for that purpose. Furthermore, some installations have a VFD on the ID fan, as well as a damper in the ID suction to control the draft. As a damper in the ID suction to control the draft.

Heaters with ID fans are generally large, so it is especially important that the correct draft be maintained. Due to the large number of burners and peepholes in large heaters, high draft can readily affect the operation adversely.

Draft Control

Controlling draft requires the following instruments and hardware:

Draft gauges: These gauges are simple instruments designed to measure draft or differential pressure. Typical draft-gauge locations in a fired heater are as shown in Figure 7.

Heater floor: A minimum of two gauges are recommended for the heater floor.

Heater arch: Having at least two gauges at the heater arch or at the convection section inlet is likewise recommended.

Convection section exit: Gauges here serve to check the total draft loss across the convection section. The minimum recommendation is one draft gauge, right above the stack damper. As an alternative, an arrangement with two gauges (above and below the damper) is useful monitoring the stack damper is adjusted, the draft upstream and downstream will change.

Installation options: These are several prevalent practices for installing draft gauges. For instance, each gauge connection can be made locally; a drawback is that most of the points are not easily accessible. Another common approach is to bring all the (pneumatic) gauge connections to ground level, and then install separate draft gauges there.

A third variation, rather commonly employed, is to manifold all the connections and install a single draft gauge. This option is economical, but it requires the operator to open and close valves every time the draft must be checked.

An advanced approach is to install pressure transmitters at the arch and send the signal to the control room; in this case, the other draft gauges are usually field-installed.

Regardless of the installation option chosen, it is important that the gauges have a correct range. Failure to meet this simple requirement is among the most common problems found with fired heaters in the field.

Stack Damper Reliability

The American Petroleum Institute's API 560 code specifies several requirements for a good stack damper. For example, it requires one blade for every 13 ft^2 of internal cross-section area. The blades should be of equal area, with their movements opposed.

The code also calls for the damper controls to be provided with external position indicators, and they should be designed so that the dampers move to the position specified by the purchaser in the event of control signal failure or motive force failure.

It is also important to check the stack damper at every shutdown, make sure it is working properly, and make repairs or modifications as needed. Damper operation is especially critical if the heater has an air preheating system; in this case, a tight-shutoff, quick-acting damper should be employed.

Many plants using air preheaters tend to keep the stack damper slightly open, for the fear of it getting stuck.

But as a result, either cold flue gas starts recirculating back into the system or the hot flue gas leaks into the atmosphere. Both of these scenarios cause a loss of efficiency. Instead, the damper should be kept fully closed, and its motion should be tested every two weeks.

Automatic Draft Control

As noted above, draft in fired heaters can be controlled automatically. One control scheme is shown in Figure 8. Although automatic draft control often suffered from damper-quality, pressure-measurement and other problems in the past, improvements in equipment quality have removed risks.

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