

ExxonMobil DESIGN PRACTICES	FIRED HEATERS BURNERS		ExxonMobil Proprietary
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Revision Memo

- 11/03** Highlights of this revision include:
1. Editorial Changes
 2. Revised burner vendor selection references.
 3. Deleted reference to high intensity forced draft burners
 4. Added definitions for Atomization, Nitrogen Oxides (NO_x)
 5. Included discussion on Ultra low NO_x burners and CFD modelling.
 6. International Practices replaced with Global Practices
 7. Added discussion on distribution of Vent/Waste Gases to burners
 8. Figure 4 has been replaced and Figure 5 has been revised.
Both new figures represent two recent Ultra Low NO_x burners
 9. Burner Selection Guide (Table 1) updated
 10. Figure numbering revised for editorial purpose
 11. Reference to High-Intensity forced draft burners removed

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SCOPE

This section covers the burners used in refinery process heaters. Guidelines are presented for burner selection and burner system design. Except as specifically noted, burner selection is consistent with meeting Global Practices requirements for equipment noise levels. Details of the most commonly used burners are included. For other burners and unusual applications, refer to the Heat Transfer Equipment Section of EETD.

REFERENCES

DESIGN PRACTICES (OTHER THAN SECTIONS OF SECTION VIII)

Section XV	Safety in Plant Design
Section XVIII	Air Pollution Control, Industrial Hygiene, and Noise Control
Section XXV	Fuel Systems

GLOBAL PRACTICES

GP 2-1-1,	Equipment Noise Level Data Requirements
GP 2-1-2,	Plant Noise Design Criteria
GP 3-4-1,	Piping for Fired Equipment
GP 7-1-1,	Fired Heaters
GP 7-4-1,	Burners for Fired Heaters
GP 15-1-1,	Instrumentation for Fired Heaters

OTHER REFERENCES

John Zink Company, Burner Catalog	} Divisions of Hamworthy Combustion Engineering Ltd.
Airoil-Flaregas Burner Catalog	
Hamworthy Burner Company Catalog	
Peabody Burner Company Catalog	

Callidus Technologies, Burner Catalog
Zeeco, Burner Catalog

BACKGROUND

Burners fall into two main categories: natural draft and forced draft. Prior to about 1960, nearly all ExxonMobil fired heaters were equipped with natural draft burners. In the mid-1960s, large refining capacity expansions resulted in higher capacity heater designs. High capacity burners, typically forced draft, were specified to reduce the manpower needs for operation and maintenance.

In the mid-1970s, as a result of energy conservation pressures, many fired heaters were designed or retrofitted with combustion air preheaters which often resulted in a forced-draft burner selection to overcome increased pressure drop.

In more recent years, low NO_x burners are being specified on most new heater designs, and retro-fitted on many existing heaters. These are available in both forced and natural draft, depending upon the required NO_x reduction, and the burner vendor's design. In addition, the installation of FLEXICOKING Units has resulted in heaters being equipped with burners capable of burning the low calorific off-gas generated. These, too, may be either natural or forced-draft burners. More recent Low NO_x burner designs are referred to "Ultra Low NO_x" burners since achievable NO_x emissions are significantly lower than in earlier low NO_x burner designs.

A few years ago, advances in basic burner design, utilizing features common in boiler burners, resulted in the axial flow burner as an option in the larger heat release category. These forced-draft burners are typically considered where the heat release requirements per burner exceed about 12 MBtu/hr (3.5 MW) and combination gas/oil firing is required.

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DEFINITIONS

Atomization

- Atomization is a process by which fuel oil is converted into small droplets. This increases surface area to mass ratio which helps liquid fuel to vaporize and combust rapidly. Atomization can be either by mechanical means or by means of a medium (steam or air).

Burner Turndown

Burner turndown is the ratio of the maximum design capacity to the minimum rate at which the burner can operate satisfactorily:

$$\text{Turndown} = \frac{\text{Maximum Burner Design Capacity}}{\text{Minimum Burner Capacity}} \text{ (e.g., 3 : 1 turndown)}$$

Turndown can be referred to the air side and fuel side of the burner.

Lower Heating Value (LHV)

The theoretical heat of combustion of a fuel, when no credit is taken for the heat of condensation of water in the flue gas. This is also called the net heating value (or low calorific value) and is usually expressed in Btu/lb (kCal/kg). By convention, lower heating value is used for specifying burner firing rates as well as heater efficiency.

Maximum Burner Capacity

The maximum firing rate an individual burner can continuously sustain with acceptably stable combustion characteristics.

Maximum Burner Design Capacity

- The maximum specified heat release of a burner. This is typically higher than the Normal Burner Design Capacity. **GP 7-1-1** specifies the additional heat release margin that should be applied to normal design firing rate of burners.

(Note on margin: In certain circumstances this margin can be exceeded, for example, to provide sufficient capacity to pick up additional heat load when one burner in a heater is removed from operation for maintenance, cleaning, etc. With a small number of burners, this additional margin can be excessive. The difficulties in operating burners at normal firing rates with high margins must be recognized. It may not be cost effective to live with operational difficulties for 95% of the heater run length just to provide allowances for the 5% when the burner may be removed from service. In any case, the Maximum Design Capacity must not exceed the Maximum Burner Capacity.)

Minimum Burner Capacity

The minimum firing rate an individual burner can continuously sustain with acceptably stable combustion characteristics.

Normal Burner Design Capacity

The heat release of individual burners when the heater is operating at design firing rate with all burners in service.

- Nitrogen oxides (NO_x)** - The sum of nitric oxide (NO) and nitrogen dioxide (NO₂), collectively expressed as NO_x. Majority of nitrogen oxides formed by burners is in the form of nitric oxide (NO). After discharge into atmosphere, NO is eventually transformed into nitrogen dioxide (NO₂). Nitrous oxide (N₂O) formation is usually very small and generally not included in NO_x. NO_x emission is considered to be a prime factor in acid rain and ground level ozone or smog formation.

BURNER TYPES AND APPLICATIONS

A large variety of burner equipment is available for use in refinery and chemical plant heaters. Each type of burner has unique capabilities and limitations which will determine its applicability for a given service. Following are descriptions of the burner types most commonly used.

NATURAL-DRAFT BURNERS

- Most natural-draft burners rely on the draft developed in the heater and stack (or induced draft fan) to provide the air required for combustion. Some use the fuel gas energy to inspire up to 100% of the stoichiometric air required. All of these burners are classified according to the type of fuel which they burn, that is, gas, liquid or combination (gas and liquid). Burners are also

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classified based on how air is mixed with fuel (raw or premix), NO_x emission levels (conventional, low NO_x, Ultra low NO_x, etc) or burner configuration (floor up-fired, wall fired, flat flame, etc).

Some natural draft burners are used in forced draft heaters equipped with combustion air preheaters. In these cases, a combustion air fan is used to provide the head necessary to overcome the resistance of the air preheater, ducting and burner. Rather than providing a spare fan, it is common to fire the burner on ambient air in the event of a fan outage, using the natural draft of the stack, and bypassing the air preheater. New heater designs, however, should be specified to have either natural or forced draft burners. Use of a natural draft burner in a forced draft service is not desirable due to the compromises that must be made to the burner design to accommodate each firing mode.

The maximum capacity of a natural draft burner is normally limited to about 10 MBtu/hr (3 MW). At higher rates, mixing energy may become insufficient to provide stable combustion and consequently the efficiency of the combustion process suffers. This results in higher excess air to enable full combustion of the fuel and longer flame lengths.

Basic Components - While many designs exist, all natural draft burners are made up of four basic components:

1. **Fuel Injector** - Gas fuels typically employ several risers (also called guns or pokers) terminating in orifice(s) for injection of the fuel into the combustion zone. Liquid fuels are introduced by means of a burner gun which atomizes the fuel before introduction into the combustion zone.
2. **Air Control Device** - In the past, combustion air to the burner was regulated by air registers around the perimeter of the burners. Air dampers are preferred today. [Figure-1](#) shows a natural draft burner with air registers. [Figure-2](#) and [Figure-3](#) show burners with dampers for air control.
3. **Burner Stabilization Device** - Two main methods for stabilizing the flame exist. The first is the utilization of a burner tile and the second is to use a mechanical device, either a swirler or a stabilizer cone. Each device provides stabilization through recirculation of the hot gases to cooler regions of the combustion zone. In addition, the tile provides a source for re-radiation of heat back to the combustion zone.
4. **Burner Tile** - Assists in the shaping of the flame as well as provides some re-radiation back to the main combustion zone.

Gas Burners - These are either "raw gas" or "premix", depending upon the method used to combine the fuel and air.

1. **Raw Gas Burners** - A raw gas burner (also called nozzle mix burner) is one in which the fuel gas is injected, without prior mixing with air, into the combustion zone for ignition. Mechanically, this is achieved via one of two acceptable general burner configurations:
 - a. **Center Fired** - A single gas gun is mounted co-axially within the burner and is usually supplied with a flame stabilizing cone ([Figure 1A](#)).
 - b. **Multiple Pokers or Risers** - A number of gas tips, typically four to eight, are located around the circumference of the burner tile ([Figure 1C](#)).

Because of their low cost, center fired gas burners are usually used in applications where raw gas burners are selected and only gaseous fuels are fired. Multiple gas gun burners, however, have the capability of being modified to also fire liquid fuels or a second fuel gas by simply adding a center oil gun. Center fired oil guns are available for center fired gas burners, but this is considered to be an unacceptable design.

2. **Premix Gas Burners** - Premix burners use the kinetic energy of the fuel gas to inspirate and mix part or all of the combustion air (primary air) with the fuel gas in a venturi mixing tube. This air/fuel mixture is then introduced into the ignition zone through a distribution head mounted on the outlet end of the mixing tube. Any additional (secondary) air which may be required to complete combustion enters through, and is controlled by, an air register or control damper.

The size and shape of the flames produced by these burners vary considerably, depending on the configuration of the distribution head. Flames are typically non-luminous. These burners are normally classified as short flame, long flame (pencil) or radiant burners.

- a. **Short Flame Burner** - The fuel/air mixture is dispersed into the ignition zone through a spider-shaped head with each 'arm' containing fuel gas ports. The head extends across the full radius of the burner throat. Characteristically, the flames produced are relatively short, about 1 ft per MBtu/hr (1 m/MW) heat released ([Figure 1B](#)). Some spider burners are equipped with center-fired oil guns. However, this is considered to be an unacceptable design.
- b. **Pencil Flame Burner** - In these burners the burner head is centrally located and releases the fuel/air mixture in a vertical column co-axially with secondary air entering through the register. The resulting flame is long and narrow. These burners physically resemble short flame burners, except for the burner head. Pencil flame burners are normally used only for special applications and in pyrolysis heaters.

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- c. **Radiant Wall Burner** - These burners inspire nearly 100 percent of their combustion air. The air/fuel mixture is directed across, and essentially burns to completion on the surface of the burner tile which is oriented at right angles to the burner axis. Significant heat is transferred to the heater tubes by radiation from the burner tiles and hot wall. These burners are usually limited in capacity to about 0.75 MBtu/hr (0.2 MW). They are used only in specialized applications such as pyrolysis heaters, where very even heat distribution and control are required.

The noise produced by the expanding gas jet in premix burners is usually higher than that of raw gas burners. However, the noise can usually be adequately controlled by mufflers on the primary air inlet and/or by special inspirator spud designs. Premix burners have a drawback in that they have restricted turndown, as limited by flashback into the mixing tube. Flashback occurs when the velocity of the air/fuel mixture through the mixing tube and/or distribution head drops below the flame-front propagation velocity for the mixture. Hydrogen has a significantly higher flame velocity than do hydrocarbon gases. Thus, with high hydrogen concentrations in the fuel gas (30 to 50 Vol%), the degree of turndown can be limited. Usually, flashback will not occur in the approved premix burners, provided the burner is kept clean and the fuel gas pressure is maintained above 2 psig (14 kPa). Preignition of the air-fuel mixture can also occur if the mixing tube and/or distribution head heats up above the ignition temperature of the fuel.

Low Btu Gas Burners - The FLEXICOKING Process, and some other processes, produce a dilute, low-pressure off-gas with a heating value much lower than typical refinery fuel gases, often less than 150 Btu/ft³ (1350 kCal/m³). Safe disposal of this gas requires special burner design parameters aimed at providing good air/fuel mixing with the limited available gas-side pressure drop and acceptable turndown. These fuels normally require a minimum support from supplemental high heating value fuels. Forced-draft burners were designed for disposing of large amounts of this off-gas, as high as 40 MBtu/hr (12 MW) heat release rates and natural draft burners with heat release capabilities in the range of 6 - 10 MBtu/hr (2 - 3 MW) are available from John Zink and Callidus.

Originally, it was considered a difficult gas to burn, and significant support from a high calorific supplemental fuel was deemed necessary. ExxonMobil's Design Practice was to require a support gas at a rate of no less than 15% of the total burner heat release. Experience has shown, however, that the gas burns more readily than expected, and in theory can be fired with no support gas. For design considerations, however, it should still be assumed that support gas will normally be fired along with the low Btu gas at a rate of about 15%. This ensures that the necessary control logic will be provided to allow simultaneous firing of high and low Btu fuels.

- ▶ **Low NO_x Burners** - The burning of most fuels produces oxides of nitrogen, termed NO_x, which is of concern due to its adverse effect on the environment. Control of NO_x emitted to the atmosphere has now become an important criteria for burner design and selection. To some degree, it can also impact on the design of the fired heater. Low NO_x Burners typically provide NO_x reduction (compared to conventional raw gas burner) in the range of 50 to 75% and some recently developed burners are achieving about 90% reduction.

Oxides of nitrogen (NO_x) are produced in three main ways - from the organic nitrogen compounds in the fuel (called fuel NO_x), from high temperature reaction of nitrogen and oxygen (called thermal NO_x) and from instantaneous reaction between nitrogen, oxygen and hydrocarbon radicals (called prompt NO_x). Fuel NO_x is primarily associated with liquid fuel firing (fuel gas typically does not have organic-nitrogen), more typically residual fuel oils where the fuel nitrogen is concentrated. Thermal NO_x is derived from nitrogen in the air combining with oxygen at high temperature. Prompt NO_x is a rapid, low temperature reaction occurring primarily in the fuel rich portion of the flame. Prompt NO_x becomes an important consideration when emission levels are 20 to 30 ppm or below. This is more true in the latest developed low NO_x burners showing NO_x emission in 10-20ppm range.

Typical heavy fuel oils contain as much as 0.3 to 0.5 wt% nitrogen which contributes as much as 50% to the total NO_x produced within a conventional burner. As the fuel quality deteriorates, the fuel nitrogen content increases, which in turn results in higher NO_x emission.

For gaseous fuels, the NO_x emitted is primarily from thermal NO_x and prompt NO_x. Thermal NO_x process depends on the concentration of nitrogen and oxygen, peak flame temperature and residence time at the peak flame temperature. Of all these variables, the peak flame temperature has the most significant impact on NO_x emissions. Generally speaking, a lower flame temperature will result in a lower NO_x emission. For this reason energy-saving systems which preheat the combustion air will enhance the formation of NO_x due to the higher resultant flame temperature. Prompt NO_x formation is not well understood, but known to depend on conditions of the flame and tends to occur in the rich zones in the flame front. Oxygen availability is an important factor; high levels of excess air can reduce prompt NO_x formation. More details concerning NO_x formation, NO_x reduction performance of various NO_x control applications and cost-effectiveness can be found in DP XVIII, Air Pollution Control, Industrial Hygiene, and Noise Control.

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Burner designers have found that lower flame temperatures can best be accomplished by slowing the rate of burning by staging the introduction of fuel and/or air into the burner. The result is a cooler flame at its root due to the quenching effect of the air in the case of the staged-fuel design, or the lower flame temperature in the substoichiometric combustion zone in the case of the staged-air design. In addition to lowering the flame's root temperature, the process of staging the combustion allows more time for radiation to the surrounding heat sink, thus resulting in a lower average flame temperature. Conversely, a high mixing-energy, high-intensity type burner will tend to have a relatively short, high temperature flame, and will generally be a higher NO_x producer.

A reduction in flame temperature has no effect on fuel NO_x production which is dictated by the amount of nitrogen in the fuel. To combat this problem, some manufacturers have adopted air staging to reduce fuel NO_x. A limited amount of air is added to the primary combustion zone where a fuel rich mixture is formed. Due to the lack of oxygen in this region, molecular nitrogen is produced in preference to the oxides. The temperature is also slightly reduced as full combustion does not take place. The secondary air is then added to complete combustion of the fuel at lower temperatures.

Another design concept utilizes cooler flue gas (FGR-Flue Gas Recirculation), recirculated to the burner - the entrained flue gas dilutes the oxygen concentration and reduces the local flame temperature, thereby reducing rate of NO_x formation. Recirculation of external flue gas (from stack) can be accomplished with the use of a separate fan (usual application in boilers). More commonly, manufacturers utilize the inspiration of the expanding fuel leaving the burner throat to pull flue gases from within the firebox into the flame - a process called internal flue gas recirculation. Since reduced oxygen concentrations in the flame have a strong impact on fuel NO_x, internal flue gas recirculation burners are an effective NO_x control technique for burners firing nitrogen-containing fuel oil. This is especially the case with staged-air combustion.

- ♦ **Current Generation of Low NO_x Burners** - Most recent low NO_x burner designs make use of a combination of either air or fuel staging and internal flue gas recirculation. These are capable of achieving lower NO_x emissions than conventional low NO_x burners. New as well as retrofit applications have demonstrated 10-30 ppm NO_x emissions from these burners on gas firing. This can lead to NO_x reductions of about 90% compared to emission from conventional uncontrolled raw gas burners.

Figures 2 through 5 shows examples of burners using one or more of the above techniques for NO_x reduction.

Use of any of the NO_x control techniques may also impact flame stability. To reduce NO_x effectively, it is necessary to develop a burner that produces low emissions while maintaining adequate flame stability. As a result, the margin for error in the constructional tolerances of a low NO_x burner and the plant setup is reduced compared to a conventional burner. For this reason, it is important that a thorough inspection of the burner and components is carried out before commissioning and that components are maintained in good condition while in operation and storage. Burner component location and orientation are more critical to achieve the desired NO_x reduction and burner stability.

Liquid Burners - As with gas burners, there are many natural-draft types of liquid burners available. However, the only ExxonMobil acceptable configuration has a centrally located fuel gun, surrounded by primary and secondary refractory tiles (Figure 1C). The shape, length and quality of liquid fuel flames are a function of the atomizing gun design and the refractory tile design. Steam atomizing fuel guns are usually used and will be supplied unless another type of atomizer is specified. Mechanical and combination mechanical/steam assisted atomizers are available for special cases and are discussed below under Fuel System Design Considerations. On a rare occasion, compressed air is used as an atomizing media where atomizing steam is unavailable for initial start-up.

Combination Gas / Liquid Burners - Combination burners are essentially the combination of a liquid burner and a multiple-gun raw gas burner (Figure 1C). All previous comments on these two types of burners apply to the combination burners. These burners are capable of firing all gas, all liquid or both fuels simultaneously. Simultaneous firing of gas and liquid fuels in this type of burner results in slightly longer flames as compared to single fuel firing. When firing simultaneously, the total combined firing rate should not exceed the burner's maximum design capacity.

If firing both fuel oil and gas in a heater, it is recommended it be done simultaneously in all burners. That is, each burner should have oil and gas firing in combination, rather than some burners firing gas, while the others are firing oil. This will allow a more uniform heat distribution from burner-to-burner as well as allow the heater to fire with a minimum of overall excess air.

If the oil and gas firing is split among burners, the unit heat release will not be equal, and overall heater excess air must therefore be higher to accommodate those burners firing hardest. Care should be exercised when selecting dual-fuel burners, since they can be more easily over-fired. This is due to the normal requirement that combination burners have the capability of 100% design heat release while firing either fuel, singly. In many cases, under-sized oil guns are specified, recognizing that 100% oil firing may not be a normal operating case. In fact, this may mean only smaller gun tips and atomizers, both of which can be easily retrofitted with larger size at a later time.

Today, many ExxonMobil refineries are limited to gas firing exclusively due to sulfur dioxide emission regulatory limits. For this reason, most new burner installations are gas-only.

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FORCED-DRAFT BURNERS

- Forced-draft burners rely on fans to supply their combustion air under a positive pressure (normally in excess of 2 inches of water). In burners of this type, the kinetic energy of the air stream is utilized to achieve more efficient fuel/air mixing than is possible in natural-draft burners. As a result of this improved mixing, smaller specific flame volumes are obtained, and consequently higher burner capacities are permissible. Thus, fewer forced-draft burners are required for the same total heat release than would be the case with natural-draft burners. This is a benefit when firing heavy fuel oil where burner gun maintenance is manpower intensive. When firing clean fuel oils, or gases, high heat release burners may not be cost effective.

Figure 6 and Figure 7. schematically show a typical axial flow, swirl stabilized burner use for combination firing of oil and gas fuels.

BURNER SYSTEM DESIGN CONSIDERATIONS

EXCESS AIR REQUIREMENTS

The burner must be sized to ensure that the air required for good combustion will be available at the burner's maximum design capacity.

Natural-Draft Burners - The maximum air flow through the burners is governed by the available furnace draft at the burner level and by the flow characteristics of the burner's air register. Approved natural-draft burners should be capable of 10 - 15% excess air, firing either gas or oil.

Forced-Draft Burners - Heater designs with forced-draft burners should be based on 10% excess air.

BURNER TURNDOWN

- Turndown is a function of several factors, the most important being burner design and type of fuel. Other factors, including fuel pressure, atomizing steam pressure and the ability to control combustion air flow also affect turndown. Burner turndown does not normally affect burner selection or heater design, since burners often can be turned off or excess air increased when the heater is operated at greatly reduced firing rates. It may be noted that though a burner may be able to operate at a high turndown (i.e. lower firing duty), but the process control system may not allow operation at such low fuel pressure.

In situations where the fuel gas varies considerably in molecular weight, the burner gas orifices generally should be sized for the gas composition with the lowest expected molecular weight. As density of the fuel gas increases, pressure drop through the burner will decrease and will thus limit the turndown on the heavier fuel. For this reason, it is important for the designer to avoid over-specifying the expected molecular weight range in an effort to build in conservatism.

Raw Gas Burners

- For both natural-draft and forced-draft installations, burners typically have a turndown in firing rate of 5 to 1 or greater, assuming a constant molecular weight and heating value of the fuel gas. The fuel pressure at maximum design capacity should be at least 30 psig (210 kPa-g). Minimum fuel pressure is about 1 psig (7 kPa-g), and this sets the minimum burner capacity. Lower design fuel pressures will limit the turndown. Since fuel gas at 1psig (7 kPa-g) does not have enough controllability in process operation, turndown of 3 to1 is also acceptable, though burners can be tested for stability at 5 to 1 turndown.

Premix Gas Burners - These burners can be further limited in turndown by low molecular weight fuel gases, particularly if hydrogen content is high, because of the potential of the fuel to flashback (burning in the mixing tube). A minimum fuel pressure of about 2 psig (14 kPa-g) at turndown should be used to avoid flashback.

Oil Burners - These are usually limited to a turndown in firing rate of about 3 or 4 to 1 for both natural and forced draft burners. This limit is set by the range over which most fuel guns can atomize the fuel adequately for good combustion. As with gas, maximizing fuel pressure will maximize turndown.

Combination Gas / Oil Burners - When firing gas and liquid fuels simultaneously in both natural and forced draft burners, greater turndown with either fuel is obtainable. The reason for this added flexibility is the main fuel acts as a large ignition source for the secondary fuel. For dual fuel burners firing both fuels simultaneously, additional controls are necessary so that loss of main fuel will automatically shut off the secondary fuel if the secondary fuel is firing below its recommended single fuel turndown limit as given for raw gas and oil burners.

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BURNER SYSTEM DESIGN CONSIDERATIONS (CONT)

Air-Side Considerations - The air side conditions need not normally affect burner or heater turn-down since excess air can be increased during operation at reduced firing rates to maintain mixing energy. Air rate can be reduced in both natural-draft and forced-draft burners until there is insufficient energy for proper mixing of air and fuel. Natural-draft burners are usually capable of an air-side turndown of 2 or 3 to 1. Air-side turndown of most forced-draft burners is limited by a minimum air pressure of 1 to 2 in. of water (0.25 to 0.5 kPa-g).

NOISE TREATMENT

Most burner systems require some degree of noise treatment to meet ExxonMobil Global Practice noise limitations. These requirements are covered under *Noise Control* in [DP Section XVIII-C2](#). The following is a summary of acoustical treatment requirements for various burners.

Natural-Draft Burners

1. Premix Gas Burners - Due to the high exit velocity of the fuel gas from the inspirator, these burners usually require primary air mufflers. (The small radiant wall burners do not normally require these mufflers.) These burners may also require secondary air plenum chambers to attenuate the noise, largely depending upon the fuels burned.
2. Other Natural Draft Burners - When acoustic treatment is necessary, plenums are normally used for raw gas, liquid and combination fired natural draft burners.

Oil-fired burners mounted in common plenums have severe disadvantages, due to operating and maintenance problems that can be caused by residual fuel spills. To eliminate some of the problems associated with plenum mounted burners, the burners can be specified with individual windboxes. Highly volatile fuels such as liquid naphtha should not be burned in plenum mounted burners due to the high explosive potential that would result in the event of a fuel spill. Acoustical shrouds which are open at the bottom have been developed for use in this service. (For further details refer to R&D Report No. EE.32E.74.)

Forced-Draft Burners

Due to their closed designs, most forced draft burners normally do not require acoustical treatment. Fans, drivers and forced draft system ductwork may require some treatment, as discussed in [Section VIII-G](#).

COMPUTATIONAL FLUID DYNAMICS (CFD) MODELING:

Computational Fluid Dynamics (CFD) modeling is a numerical tool for combustion, heat transfer and fluid flow analysis. CFD is often used in developmental design of equipment and diagnosis of problems. CFD modeling is particularly gaining importance in low NO_x burner installations where several factors can affect performance in field.

Low NO_x burners in actual operation have been known to have resulted in flame leaning, bending and impingement on tubes resulting in operation at reduced throughput, unplanned shut down. Typically all low NO_x burner development and testing have been limited to single, small and simple test furnace settings where performance of multi-burner, large and complex furnaces is often difficult to predict. This necessitates understanding of interaction between burner flames, prediction of temperature and heat flux profile, etc. in actual applications.

CFD Modeling provides results that can diagnose such problems and when detected changes to burner (or heater, at times) design and arrangement can be implemented to resolve these problems. CFD modeling provides information on:

- Effect of furnace gas re-circulation on the burner flame envelope
- Flame interaction between burners
- Temperature and heat flux profile with new burners
- Tube metal temperature profile

There are a few companies who have competent experience in carrying out CFD's in this field. However, this is still an emerging field. For the latest on acceptable service providers, please contact Heat Transfer Equipment section of EETD.

Sample figures 15 and 16 show two different cases of CFD results. [Figure 15](#) shows unacceptable flame leaning towards furnace walls. [Figure-16](#) is a sample predicted heat flux profile as a function of radiant box elevation, where a high heat flux problem was identified.

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FUEL SYSTEM DESIGN CONSIDERATIONS

Refinery fuels are often low quality streams which may contain contaminants that can cause safety and/or operational problems if they are not properly treated and handled prior to being injected into the burners.

GAS FUELS

Fuel gases vary from clean, dry, relatively constant molecular weight streams to dirty, wet mixtures of process waste gases that can fluctuate significantly in composition and molecular weight. In the first case, the fuel should cause very few problems; but for the latter, safety and maintenance problems can occur unless the gas is thoroughly cleaned and dried. Both solids and liquids can plug fuel ports in the burner gun, thus restricting burner capacity and causing poor combustion and possible flame impingement. Low NO_x burners are particularly susceptible to fuelorifice blockages due to the small sizes necessary to provide fuel staging.

To protect against wet or dirty gas, knockout drums are a minimum requirement for all fuel gas systems. However, in some instances where the fuel is very dirty or wet, knockout drums cannot do an adequate job of cleaning the fuel. In locations where past experience has demonstrated this situation to exist, more efficient gas cleaning equipment such as coalescing filters should be specified downstream of the knockout drum if liquid and solid particulate removal is required. As a minimum, in all cases, strainers or filters for removal of particulate matter should be specified for all fuel gases, including pilot gas (**GP 3-4-1**).

Knockout drums should be located as close to the heater as allowed, but no closer than 50 ft (15 m) (**Section XV**). The intent of the knockout drum is to provide an opportunity for vapor to condense, and therefore it should not be heat traced. In cold climates, the drains and blowdown valves, only, are to be winterized. Piping downstream of the knockout facilities should be steam traced, insulated and drained if condensation of the gas is possible (**GP 3-4-1**). Stainsteel fuel gas piping downstream of main fuel gas filters should be considered for low NO_x burners where clean fuel gas orifices are absolutely required to meet NO_x emission limits.

Pressure - The fuel pressure when firing gas will determine the burner turndown. Gas burners typically have a turndown capability of about 5 to 1 or greater provided the fuel pressure available at maximum rate is 30 psig (210 kPa-g) or higher [i.e., fuel gas pressure at minimum burner capacity is about 1 to 2 psig (7 to 14 kPa-g)]. Lower design fuel pressures will limit the turndown.

In situations where the fuel gas varies considerably in molecular weight, burner turndown will be limited as the gas deviates from the molecular weight for which the burner was designed: increasing density will restrict the lower capacity limit, and decreasing density will lower the burner's upper capacity limit unless sufficient gas pressure is available to overcome the increased pressure drop. Therefore, since turndown of the total heat fired can be controlled by turning off burners on most heaters, fuel gas guns usually should be designed for the gas with the lowest molecular weight. In addition to specifying the expected molecular weight range, the designer should provide the burner vendor with the expected fuel composition range. The burners can be operated satisfactorily with gas pressures up to about 40 psig (280 kPa-g). Higher burner fuel gas pressures could produce noise problems.

For very low pressure gases [maximum available pressure of about 3 psig (21 kPa-g) at the burner], a special premix burner with steam eductor can be used. This burner is often used to combust waste gas streams, such as vacuum pipestill noncondensibles. Typical steam consumption of 0.3 pounds per pound (kg/kg) of fuel should be considered for supply to the burner at a pressure of 30 psig (210 kPa). A typical specification for this burner would be: "John Zink PM 16-5 Burner with 25 Cr-12 Ni alloy gas tips, waste gas eductor, primary air muffler, and pilot."

Distribution of Vent/Waste Gases - Vent or waste gases are sometimes routed to furnace for firing/disposal. These gases may have high mass flow (with low heating value), or low mass flow (with high heating value). If the quantity (mass or energy) of such gas is high (greater than about 10% of total combustion air mass or total heat fired), the gas should be distributed uniformly to all burners.

Heater Control - When dual firing is called for, one of the two fuels is normally base-loaded, while the other is varied for coil outlet temperature control. Normally fuel oil would be the base-loaded fuel with fuel gas in control. Sometimes, however, maximum gas firing is desired, for fuel gas header pressure control, in which case fuel oil is used as the coil outlet temperature control fuel. The designer should consider the realistic possibilities of firing either fuel, alone, since this will cause guns, valving, etc., to be sized for 100%, yet normal firing of each fuel will be at reduced rates. In many cases, oil guns of lower firing duty are specified, recognizing that 100% oil firing may not be a realistic operating case. This will allow maximum fuel gas firing as the base-loaded fuel for fuel gas header pressure control, while still allowing the fuel oil firing safely above its minimum stable turndown.

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FUEL SYSTEM DESIGN CONSIDERATIONS (CONT)

LIQUID FUELS

Liquid fuels range from highly volatile streams, such as naphtha, to very viscous and/or dirty fuels such as vacuum residuals and cracked tars. Regardless of quality, liquid fuels must arrive at the burner gun under the following conditions:

1. At a viscosity that will insure good atomization and combustion.
2. In liquid phase only.
3. Free of solids that can plug the small atomizer holes.

Fuel Viscosity - For good atomization, the fuel should be supplied to the burner at a viscosity of 25 cSt or less (preferably at 15 cSt). This may require heating the fuel oil. Lower viscosity ensures that the fuel can be atomized into small, fine droplets, allowing them to combust easily. At higher viscosities, the droplet sizes of the atomized fuel may become so large that combustion is incomplete. As a result, burner flames can become unacceptably large, and smoky. .

The temperature of residual and tar type fuels must be maintained high enough to meet this viscosity requirement. Experience has shown that 350°F (175°C) is the minimum temperature which gives good atomization characteristics of heavy fuels, even if a lower temperature would meet the viscosity requirements. More generally, the temperature of blends of residual or tar type fuels must be high enough to insure the viscosity of the heaviest component is 25 cSt or less.

Volatile Fuels - With volatile fuels such as naphtha, flashing (partial vaporization) of the fuel must not take place upstream of the fuel gun. This condition would result in severe burner instabilities (pulsation) and a potential cause for burner flame out. This potential can be minimized by specifying the proper burner gun type and tip (see *Atomizers* below).

Naphtha type fuels also present unique safety problems due to their high volatility which require special attention. These are:

1. High fire risk in the event of fuel spills (or explosion in the case of natural draft burners with acoustical plenums). Therefore, these fuels should not be burned with acoustical plenums present. Safety interlocks should be specified to prevent removal of a burner gun without complete shutoff of the fuel.
2. Leakage of naphtha into heated fuel oil systems, particularly of the circulating type, would result in flashing of these fuel lines and/or surge drums and hold up tanks. Therefore, the naphtha system must be segregated from the fuel oil system by physical separation. Severe plugging can also be experienced if naphtha and heavy fuels are alternatively used in the same piping system. The naphtha will act as a solvent and tend to wash the sediments left behind from the heavier fuel into the burners, causing sudden blocking of the small burner parts.

Atomizers - These are probably the most critical pieces of hardware in the liquid fuel system. If they are not correctly designed and sized, or if they become dirty or excessively worn during use, they will not atomize the fuel into sufficiently small droplets for rapid and complete combustion. Consequently, smoky combustion and/or flame impingement on process tubes and other surfaces in the heaters could result. Also, large fuel droplets can drip back into the burner resulting in serious maintenance and operating problems as well as a safety hazard.

1. **Types of Atomizers** - Three basic types of atomizers are used:

- a. **Steam Atomizer** - This is the most basic type, and the most common in refinery service. This atomizer utilizes the kinetic energy of steam to break the oil down into small droplets. The steam then acts as a carrier to convey the atomized fuel "fog" into the burner's ignition zone. For the steam's energy to be used effectively, its pressure must be higher than the pressure of the oil. Most manufacturers of steam atomizers recommend a steam-to-oil pressure differential of 20 to 30 psig (140 to 210 kPa). For good burner performance and turndown, the fuel oil pressure should be as high as possible, while still providing this differential. Hence, oil pressures of about 60 to 100 psig (420 to 700 kPa-g) are preferred.

Each burner manufacturer has a steam atomizer that he would provide as his standard. Some are greater steam consumers than others, and some are more prone to plugging than others depending on the burner heat release which determines the gun tip hole size.

The basic steam atomizer will typically consume up to 0.3 to 0.5 pounds of steam per pound of fuel oil fired (kg per kg). The designer should use 0.5 pounds per pound (kg per kg) for line sizing. In larger burners, the Y-Jet, or Skew-Jet, atomizers are used, which are lower steam consumers, typically about 0.1 to 0.3 pounds per pound (kg per kg).

- b. **Mechanical Atomizer (Pressure Jet Atomizer)** - This type has very limited application in refinery service and is only used where steam availability is limited. It uses the energy in the fluid itself for atomization, and thus high fuel pressures, 350 psig (2500 kPa), are required. These atomizers are highly susceptible to plugging because of the smaller orifice sizes, and, therefore, the fuel must be well filtered.