
16 Natural-Draft Burners

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16.1 INTRODUCTION

Natural-draft burners are used in a wide range of residential and commercial applications, including gas-fired furnaces, water heaters, cooking ranges, and ovens. However, these burners are somewhat unique in industry. Most burners used in industrial combustion applications are forced or mechanical draft, where the combustion air is supplied to the burner with a fan or blower. In natural-draft burners, the combustion air is induced or drawn into the burner via the suction created by the

incoming fuel jets and via the buoyancy forces inside the furnace that create an updraft. These burners are predominantly used in the chemical process industry (CPI) and the hydrocarbon process industry (HPI). They are fired in a variety of configurations on a variety of fuel compositions that are mostly gaseous, but are sometimes liquid. There are many unique aspects of natural-draft burners, compared to forced-draft burners, discussed in this chapter.

There are some good resources available for the interested reader on the subject of natural-draft burners. A book by Robert Reed (1981), which is now out of print, had been the standard in the industry on the subject of combustion in the hydrocarbon and petrochemical processing industries, including the topic of natural-draft burners (particularly Chapter 5).¹ A recent book written by the John Zink Co., LLC (Tulsa, OK) is the most comprehensive publication of its type on the subject of combustion in HPI and CPI applications.² It includes extensive treatments of natural-draft burners, which are the workhorses for those industries. Much of this chapter was adapted from chapters in that book.^{3,4} The American Petroleum Institute has some good resources that include discussions of natural-draft burners, although less extensive than the previous publications.^{5,6}

16.2 HYDROCARBON AND PETROCHEMICAL INDUSTRIES

The hydrocarbon and petrochemical industries present unique challenges to the combustion engineer, compared to other industrial combustion processes. One of the more important challenges in those industries is the wide variety of fuels,⁷ which are usually off-gases from the petroleum refining processes that are used in a typical plant (see [Figure 16.1](#)). This differs significantly from most other industrial combustion systems, which normally fire a single purchased fuel such as natural gas or fuel oil. Another important challenge is that many of the burners commonly used in the hydrocarbon and petrochemical industries are natural draft which are not as easy to control as forced-draft burners, and are subject to things such as the wind, which can disturb the conditions in a process heater.

According to the U.S. Department of Energy (U.S. DOE), petroleum refining is the most energy-intensive manufacturing industry in the U.S., accounting for about 7% of total U.S. energy consumption in 1994.⁸ [Table 16.1](#) shows the major processes in petroleum refining, most of which require combustion in one form or another. [Figure 16.2](#) shows the process flow through a typical refinery.

The U.S. DOE Office of Industrial Technologies has prepared a Technology Roadmap for industrial combustion.⁹ For process heating systems, some key performance targets for the year 2020 have been identified for burners and for the overall system. For the burners, the targets include reducing criteria pollutant emissions by 90%, reducing CO₂ emissions to levels agreed upon by the international community, reducing specific fuel consumption by 20 to 50%, and maximizing the ability to use multiple fuels. The following were identified as top-priority R&D needs for burners in process heating: burners capable of adjusting operating parameters in real-time, advanced burner stabilization methods, robust design tools, and economical methods to premix fuel and air. The process heaters are considered briefly next.

16.3 FIRED HEATERS

Fired or tubestill heaters are used in the petrochemical and hydrocarbon industries to heat fluids in tubes for further processing. In this type of process, fluids flow through an array of tubes located inside a furnace or heater. The tubes are heated by direct-fired burners. Using tubes to contain the load is somewhat unique compared to the other types of industrial combustion applications. It was found that heating the fluids in tubes has many advantages over heating them in the shell of a furnace.¹⁰ Advantages include better suitability for continuous operation, better controllability, higher heating rates, more flexibility, less chance of fire, and more compact equipment.



FIGURE 16.1 Typical petroleum refinery. (Courtesy of John Zink Co., LLC.³)

TABLE 16.1
Major Petroleum Refining Processes

Category	Major Process
Topping (separation of crude oil)	Atmospheric distillation Vacuum distillation Solvent deasphalting
Thermal and catalytic cracking	Delayed coking Fluid coking/flexicoking Visbreaking Catalytic cracking Catalytic hydrocracking
Combination/rearrangement of hydrocarbons	Alkylation Catalytic reforming Polymerization Isomerization Ethers manufacture
Treating	Catalytic hydrotreating/hydroprocessing Sweetening/sulfur removal Gas treatment
Specialty product manufacture	Lube oil Grease Asphalt

Source: U.S. Dept. of Energy.⁸

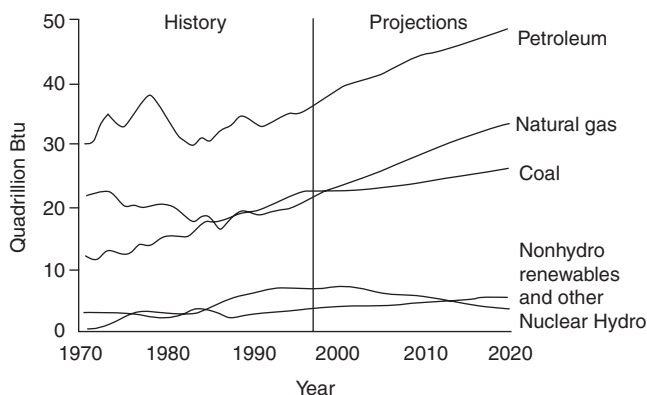


FIGURE 16.2 Typical refinery flow diagram. (Source: U.S. Dept. of Energy.⁸)

One of the problems encountered in refinery-fired heaters is an imbalance in the heat flux in the individual heater passes.¹¹ This imbalance can cause high coke formation rates and high tube metal temperatures, which reduce a unit's capacity and can cause premature failures. Coke formation on the inside of heater tubes reduces the heat transfer through the tubes, which leads to the reduced capacity. One cause of coking is flame impingement directly on a tube, which causes localized heating and increases coke formation there. This flame impingement may be caused by operating without all of the burners in service, insufficient primary or secondary air to the burner, operating the heater at excessive firing rates, fouled burner tips, eroded burner tip orifices, or insufficient

draft. The problem of flame impingement shows the importance of proper design¹² to assure even heat flux distribution inside the fired heater.

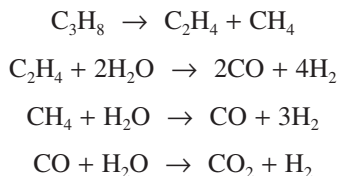
Recently, the major emphasis has been on increasing the capacity of existing heaters rather than installing new heaters. The limitations of over-firing a heater include:

- High tube metal temperatures
- Flame impingement, causing high coke formation rates
- Positive pressure at the arch of the heater
- Exceeding the capacity of induced-draft and forced-draft fans
- Exceeding the capacity of the process fluid feed pump

Garg (1988)¹³ noted the importance of good heater specifications to ensure suitable performance for a given process. Some of the basic process conditions needed for the specifications include heater type (cabin, vertical cylindrical, etc.), number of fluid passes, the tube coil size and material, fluid data (types, compositions, properties, and flow rates), heat duty required, fuel data (composition, pressure, and temperature), heat flux loading (heat flux split between the radiant and convection sections), burner data (number, type, arrangement, etc.), draft requirement, required instrumentation, as well as a number of other details, such as the number of peepholes, access doors, and platforms.

16.3.1 REFORMERS

As the name indicates, reformers are used to reformulate a material into another product. For example, a hydrogen reformer takes natural gas and reformulates it into hydrogen in a catalytic chemical process that involves a significant amount of heat. A sample set of reactions is given below for converting propane to hydrogen:¹⁴



The reformer is a direct-fired combustor containing numerous tubes, filled with catalyst, inside the combustor.¹⁵ The reformer is heated with burners, firing either vertically downward or upward, with the exhaust on the opposite end, depending on the specific design of the unit. The raw feed material flows through the catalyst in the tubes which, under the proper conditions, converts that material to the desired end product. The burners provide the heat needed for the highly endothermic chemical reactions. The fluid being reformulated typically flows through a reformer combustor containing many tubes (see [Figure 16.3](#)). The side-fired reformer has multiple burners on the side of the furnace, with a single row of tubes centrally located. The heat is transferred primarily by radiation from the hot refractory walls to the tubes. Top-fired reformers have multiple rows of tubes in the firebox. In that design, the heat is transferred primarily from radiation from the flame to the tubes. [Figure 16.4](#) shows a down-fired burner commonly used in top-fired reformers. In a design sometimes referred to as *terrace firing*, burners are located in the side wall but firing up the wall at a slight angle (see [Figure 16.5](#)). Foster Wheeler uses terrace wall reformers in the production of hydrogen by steam reformation of natural gas or light refinery gas.¹⁶

The reformer tubes are a critical element in the overall design of the reformer. Because they operate at pressures up to 350 psig (24 barg), they are typically made from a high-temperature and pressure nickel alloy, such as inconel, to ensure that they can withstand the operating conditions inside the reformer. Failure of the tubes can be very expensive because of the downtime of the unit, lost product, damaged catalyst, and possibly, damaged reformer. New reactor technologies are being developed to improve the process for converting natural gas to precursor synthesis gas (syngas).¹⁷

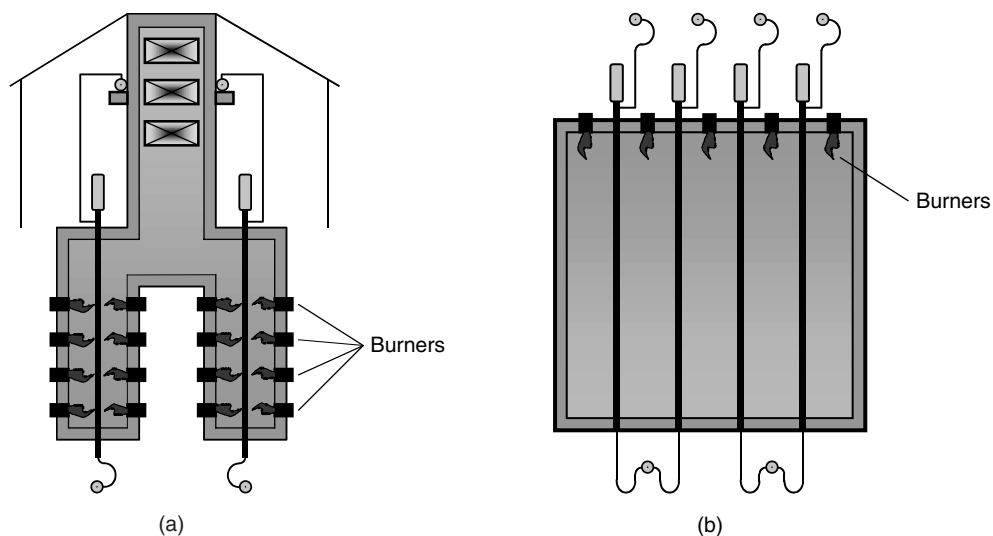


FIGURE 16.3 Side- and top-fired reformers. (Courtesy of Marcel Dekker.¹⁵)



FIGURE 16.4 Down-fired burner commonly used in top-fired reformers. (Courtesy of John Zink Co., LLC.³)

16.3.2 PROCESS HEATERS

Process heaters are sometimes referred to as process furnaces or direct-fired heaters. They are heat transfer units designed to heat petroleum products, chemicals, and other liquids and gases flowing through tubes. Typical petroleum fluids include gasoline, naphtha, kerosene, distillate oil, lube oil, gas oil, and light ends.¹⁸ The heating is done to raise the temperature of the fluid for further processing downstream or to promote chemical reactions in the tubes, often in the presence of a catalyst. Kern¹⁸ noted that refinery heaters can carry liquids at temperatures as high as 1500°F (810°C) and pressures up to 1600 psig (110 barg). The primary modes of heat transfer in process heaters are radiation and convection. The initial part of the fluid heating is done in the convection section of the furnace, while the latter heating is done in the radiant section (see Figure 16.6). Each section has a

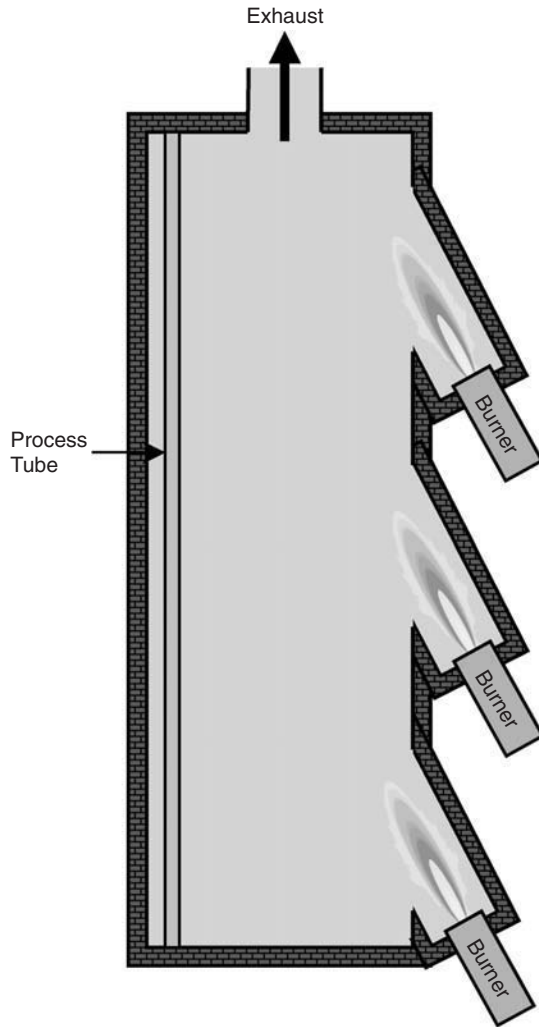


FIGURE 16.5 Terrace firing furnace.

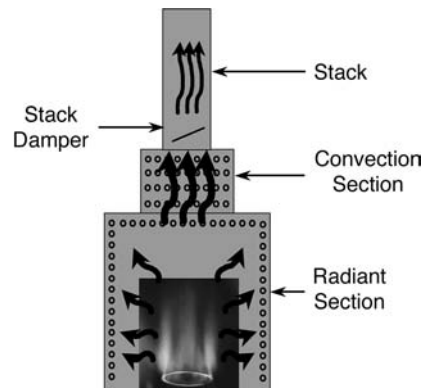


FIGURE 16.6 Schematic of the heating zones in a process heater. (Courtesy of John Zink Co., LLC.³)

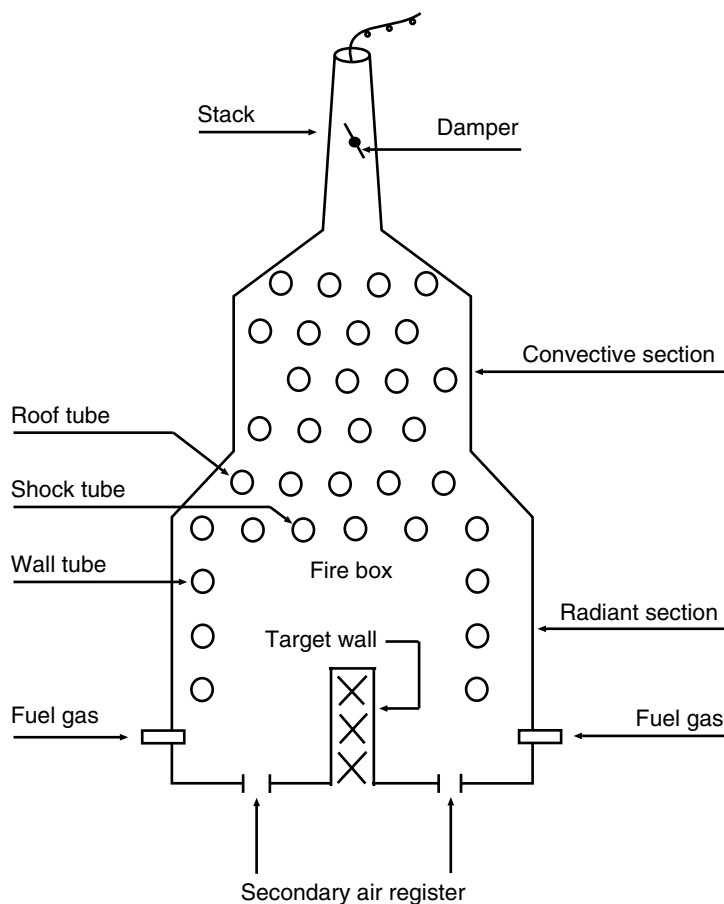


FIGURE 16.7 Typical process heater. (Courtesy of PennWell.¹⁹)

bank of tubes in it through which the fluids flow, as shown in [Figure 16.7](#).¹⁹ Early heater designs had only a single bank of tubes that failed prematurely because designers did not understand the importance of radiation on the process.¹⁰ The tubes closest to the burners would overheat. Overheating caused the hydrocarbons to form coke inside the tube. The coke further aggravated the problem by reducing the thermal conductivity through the coke layer inside the tube. The reduced thermal conductivity prevented the process fluids from absorbing adequate heat to cool the tubes, resulting in overheating and failure of the tubes. One of the key challenges for the heater designer is to get even heat distribution inside the combustor to prevent coking inside the tubes. Bell and Lowy (1967)²⁰ estimated that approximately 70% of the energy is transferred to the fluids in the radiant section of a typical heater and the balance in the convection section. The tubes in the convection section often have fins to improve convective heat transfer efficiency. These fins are designed to withstand temperatures up to about 1200°F (650°C). If delayed combustion occurs in the convection section, the fins can be exposed to temperatures up to 2000°F (1100°C), which can damage the fins.¹⁹

Kern noted that process heaters are typically designed around the burners.¹⁸ There may be anywhere from one to over a hundred burners in a typical process heater, depending on the design and process requirements. In the refinery industry, the average number of burners in a heater varies by the heater type, as shown in [Table 16.2](#).²¹ On average, mechanical draft burners have higher firing rates than natural draft. For forced-draft systems, burners with air preheat typically have higher heat releases than burners without air preheat. According to one survey, 89.6% of the burners in oil refineries are natural

TABLE 16.2
Average Burner Configuration by Heater Type

Heater Type	Avg. No. of Burners	Avg. Design Total Heat Release (10 ⁶ Btu/hr)	Avg. Firing Rate Per Burner (10 ⁶ Btu/hr)
Natural draft	24	69.4	2.89
Mechanical draft, no air preheat	20	103.6	5.18
Mechanical draft, with air preheat	14	135.4	9.67

Source: U.S. EPA.²¹

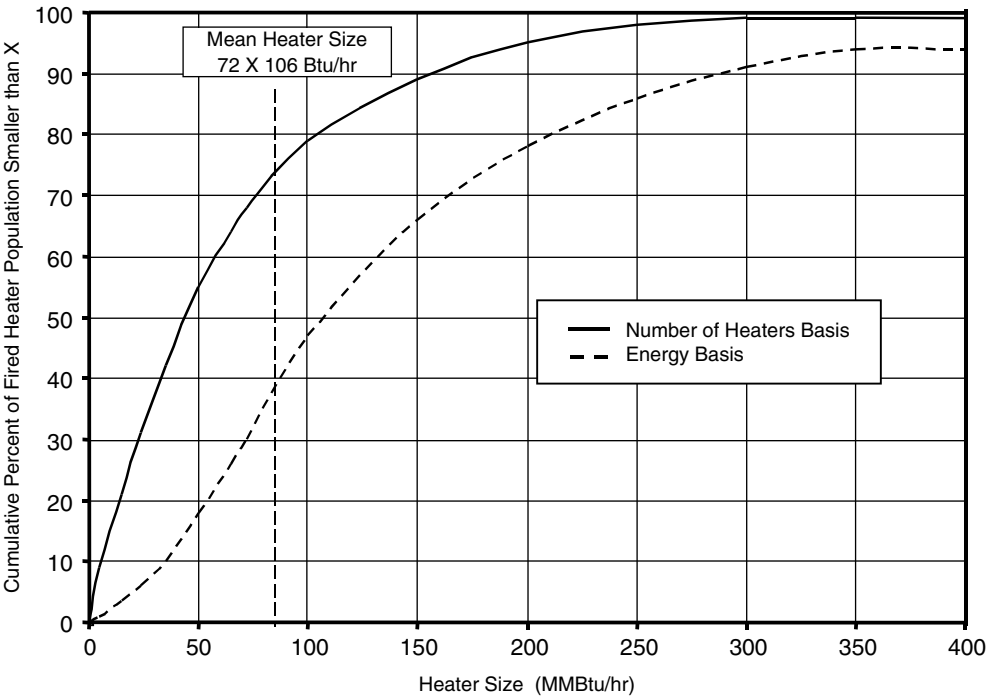


FIGURE 16.8 Fired heater size distribution. (Source: U.S. EPA.²¹)

draft, 8.0% are forced draft with no air preheat, and 2.4% are forced draft with air preheat.²² The mean size of all process heaters is 72 × 10⁶ Btu/hr (21 MW), which are mostly natural draft. The mean size of forced-draft heaters is 110 × 10⁶ Btu/hr (32 MW). Figure 16.8 shows the distribution for the overall firing rate for fired heaters. Table 16.3 shows the variety of processes in a refinery that uses fired heaters.

Table 16.4 shows the major applications for fired heaters in the chemical industry. These can be broadly classified into two categories: (1) low and medium firebox temperature applications such as feed preheaters, reboilers, and steam superheaters; and (2) high firebox temperature applications such as olefins pyrolysis furnaces and steam-hydrocarbon reformers. The low and medium firebox temperature heaters represent about 20% of the chemical industry requirements and are similar to those in the petroleum refining industry.²³ The high firebox temperature heaters represent the remaining 80% of the chemical industry heater requirements and are unique to the chemical industry.

Berman (1979)²⁴ discussed the different burner designs used in fired heaters, Burners may be located in the floor, firing vertically upward. In vertical cylindrical (VC) furnaces, those burners

TABLE 16.3
Major Refinery Processes Requiring a Fired Heater

Process	Process Description	Heaters Used	Process Heat Requirements		Feedstock Temperature Outlet of Heater, (°F)
			KJ/liter	(10 ³ Btu/bbl feed)	
Distillation					
Atmospheric	Separates light hydrocarbons from crude in a distillation column under atmospheric conditions.	Preheater, reboiler	590	89	700
Vacuum	Separates heavy gas oils from atmospheric distillation bottoms under vacuum.	Preheater, reboiler	418	63	750–830
Thermal Processes					
Thermal cracking	Thermal decomposition of large molecules into lighter, more valuable products.	Fired reactor	4650	700	850–1000
Coking	Cracking reactions allowed to go to completion. Lighter products and coke produced.	Preheater	1520	230	900–975
Visbreaking	Mild cracking of residuals to improve their viscosity and produce lighter gas oils.	Fired reactor	961	145	850–950
Catalytic Cracking					
Fluidized catalytic cracking	Cracking of heavy petroleum products. A catalyst is used to aid the reaction.	Preheater	663	100	600–885
Catalytic hydrocracking	Cracking heavy feedstocks to produce lighter products in the presence of hydrogen and a catalyst.	Preheater	1290	195	400–850
Hydroprocessing					
Hydrosulfurization	Remove contaminating metals, sulfur, and nitrogen from the feedstock. Hydrogen is added and reacted over a catalyst.	Preheater	431	65 ^a	390–850
Hydrotreating	Less severe than hydrosulfurization. Removes metals, nitrogen, and sulfur from lighter feedstocks. Hydrogen is added and reacted over a catalyst.	Preheater	497	75 ^b	600–800
Hydroconversion					
Alkylation	Combination of two hydrocarbons to produce a higher molecular weight hydrocarbon. Heater used on the fractionator.	Reboiler	2500	377 ^c	400
Catalytic reforming	Low-octane naphthas are converted to high-octane, aromatic naphthas. Feedstock is contacted with hydrogen over a catalyst.	Preheater	1790	270	850–1000

^aHeavy gas oils and middle distillates

^bLight distillate

^cBtu/bbl of total alkylate

Source: U.S. EPA.²¹

TABLE 16.4
Major Fired Heater Applications in the Chemical Industry

Chemical	Process	Heater Type	Firebox Temperature (°F)	1985 Fired Heater Energy Requirement (10 ¹² Btu/yr)	% of Known Chemical Industry Heater Requirements
Low and Medium Temperature Applications					
Benzene	Reformate extraction	Reboiler	700	64.8	9.9
Styrene	Ethylbenzine dehydrogenation	Steam superheater	1500–1600	32.1	4.9
Vinyl chloride monomer	Ethylene dichloride cracking	Cracking furnace	N/A	12.6	1.9
<i>P</i> -Xylene	Xylene isomerization	Reactor fired preheater	N/A	13.0	2.0
Dimethyl terephthalate	Reaction of <i>p</i> -xylene and methanol	Preheater, hot oil furnace	480–540	11.1	1.7
Butadiene	Butylene dehydrogenation	Preheater, reboiler	1100	2.6	0.4
Ethanol (synthetic)	Ethylene hydration	Preheater	750	1.3	0.2
Acetone	Various	Hot oil furnace	N/A	0.8	0.1
High-Temperature Applications					
Ethylene/propylene	Thermal cracking	Pyrolysis furnace	1900–2300	337.9	51.8
Ammonia	Natural gas reforming	Steam hydrocarbon reformer	1500–1600	150.5	23.1
Methanol	Hydrocarbon reforming	Steam hydrocarbon	1000–2000	25.7	4.0
Total Known Fired Heater Energy Requirement				652.4	100.0

Source: U.S. EPA.²¹

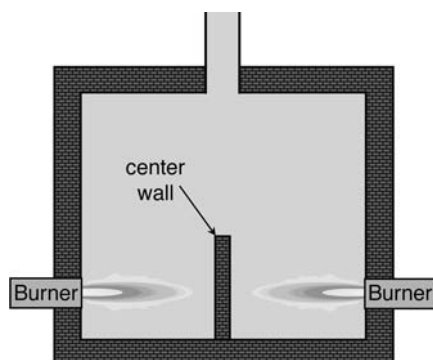


FIGURE 16.9 Sketch of center or target wall firing configuration. (Courtesy of John Zink Co., LLC.³)

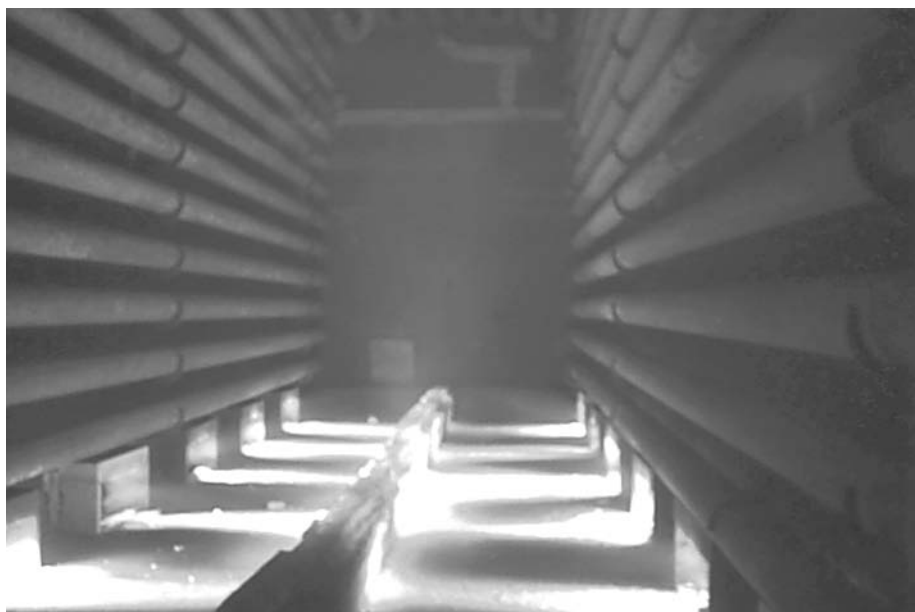


FIGURE 16.10 Horizontal floor-fired burners firing toward a center wall. (Courtesy of John Zink Co., LLC.³)

are located in a circle in the floor of the furnace. The VC furnace itself serves as part of the exhaust stack to help create draft to increase the chimney effect.²⁵ In cabin heaters, which are rectangular, there are one or more rows of burners located in the floor. Burners may be at a low-level, firing parallel to the floor. In that configuration, they may be firing from two opposite sides toward a partial wall in the middle of the furnace that acts as a radiator to distribute the heat (see [Figure 16.9](#) and [Figure 16.10](#)). Burners may be located on the wall, firing radially along the wall (see [Figure 16.11](#)), which are referred to as radiant wall burners (see Chapter 15). There are also combinations of the above in certain heater designs. For example, in ethylene production heaters, both floor-mounted, vertically fired burners (see [Figure 16.12](#)) and radiant wall burners are used in the same heater.

Typical examples of process heaters are shown in [Figure 16.13](#) and [Figure 16.14](#).²⁶ A cabin heater is shown in [Figure 16.15](#). Burners firing in a crude unit are shown in [Figure 16.16](#). Typical burner arrangements are shown in [Figure 16.17](#). Berman (1979)²⁷ noted the following categories of process heaters: column reboilers; fractionating-column feed preheaters; reactor-feed preheaters, including reformers; heat supplied to heat transfer media (e.g., a circulating fluid or molten salt); heat supplied to viscous fluids; and fired reactors, including steam reformers and pyrolysis heaters. Six types of vertical cylindrical fired heaters were given: all radiant, helical coil, crossflow with convection section, integral

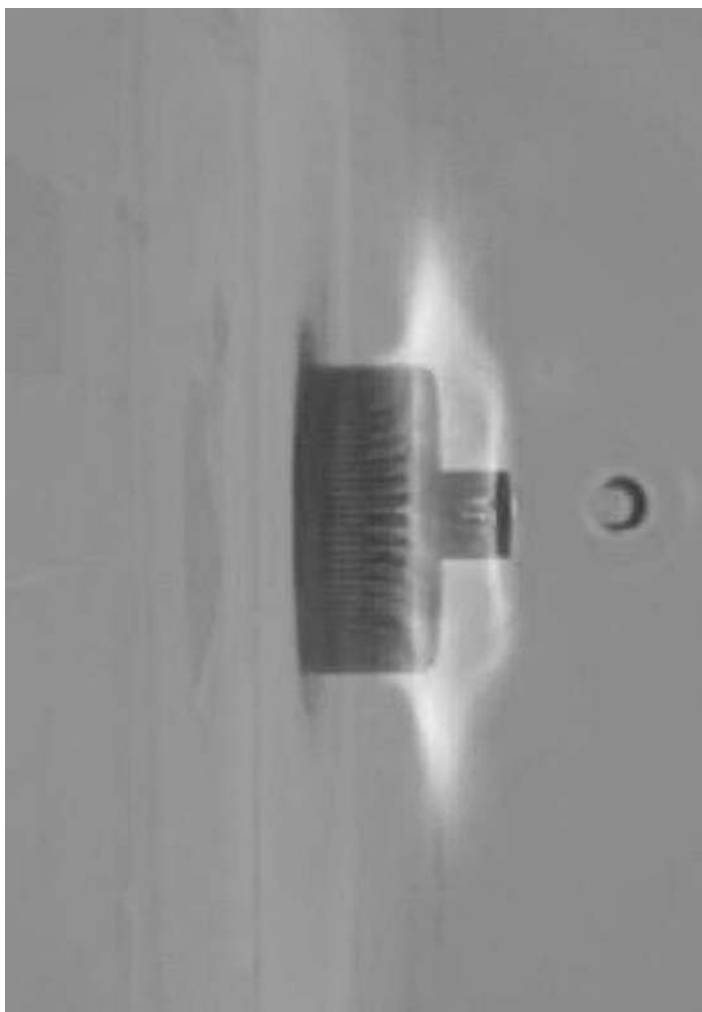


FIGURE 16.11 Wall-fired burner (side view). (Courtesy of John Zink Co., LLC.)

convection section, arbor or wicket type, and single-row/double-fired. Six basic designs were also given for horizontal tube fired heaters: cabin, two-cell box, cabin with dividing bridgewall, end-fired box, end-fired box with side-mounted convection section, and horizontal-tube/single-row/double-fired.

Many commonly used process heaters typically have a radiant section and a convection section. Burners are fired in the radiant section to heat up the tubes. Fluids flow through the tubes and are heated to the desired temperature for further processing. The fluids are preheated in the convection section and heated to the desired process temperature in the radiant section. Radiant heat transfer from the flames to the tubes is the most critical aspect of this heater because overheating of the tubes leads to tube failure and shutdown of the heater.²⁸ The tubes may be horizontally or vertically oriented, depending on the particular heater design.

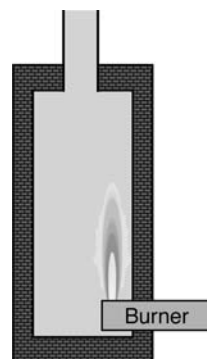


FIGURE 16.12 Sketch of a horizontally-mounted, vertically-fired burner configuration. (Courtesy of John Zink Co., LLC.³)

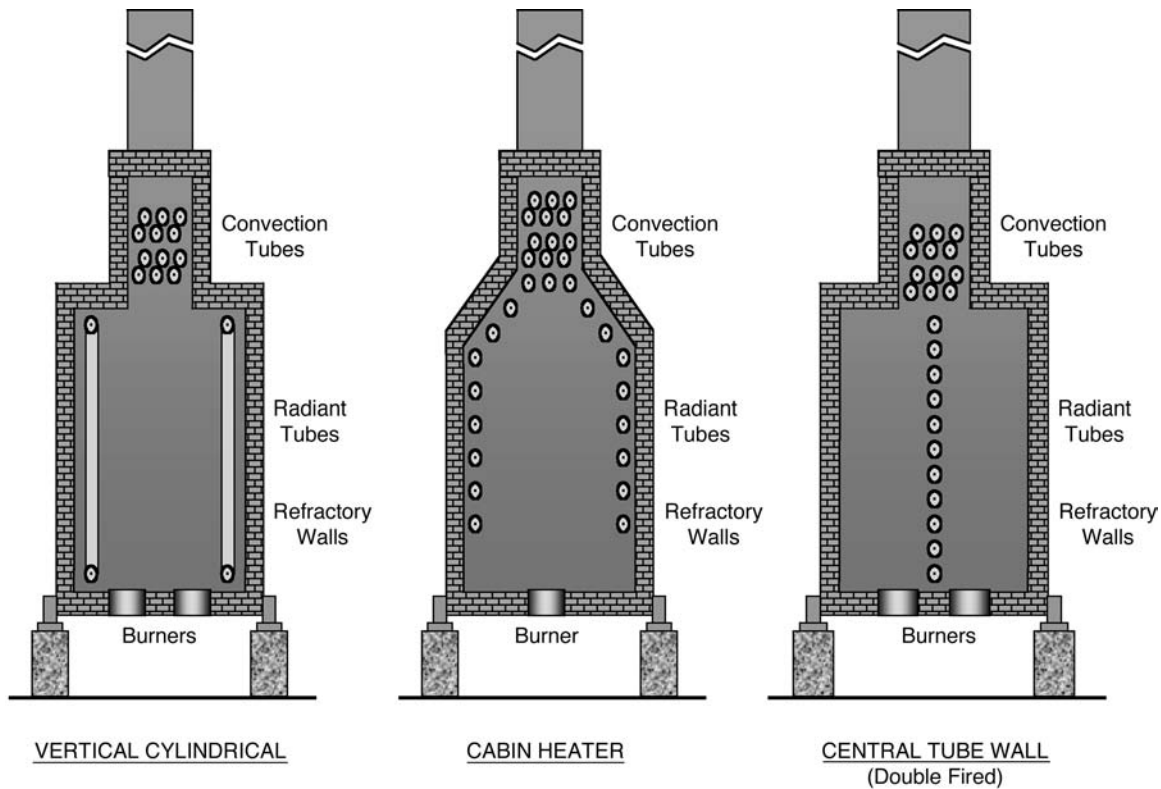


FIGURE 16.13 Examples of process heaters.²⁶

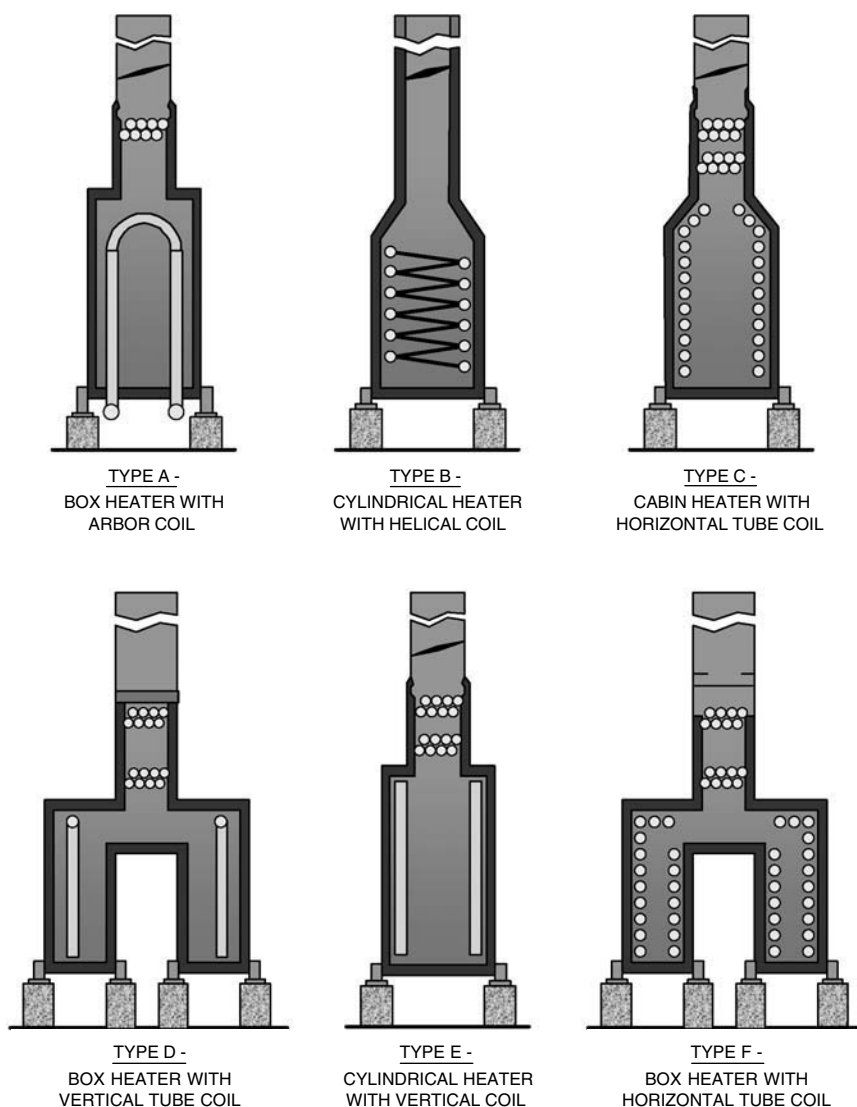


FIGURE 16.14 Typical heater types.²⁶

A unique aspect of process heaters is that they are often natural draft. Another unique aspect of these heaters is the wide range of fuels that are used, which are often byproducts of the petroleum refining process. These fuels may contain significant amounts of hydrogen, which has a large impact on the burner design. It is also fairly common for multiple fuel compositions to be used, depending on the operating conditions of the plant at any given time. In addition to hydrocarbons ranging up to C_5 , the gaseous fuels may also contain hydrogen and inerts (such as CO_2 or N_2). The compositions can range from gases containing high levels of inerts to fuels containing high levels of H_2 . The flame characteristics for fuels with high levels of inerts are very different than for fuels with high levels of H_2 . Add to that the requirement for turndown conditions and it becomes very challenging to design burners that will maintain stability, low emissions, and the desired heat flux distribution, over the range of conditions that are possible. Some plants use liquid fuels, like no. 2 to no. 6 fuel oil, sometimes by themselves and sometimes in combination with gaseous fuels. So-called



FIGURE 16.15 Cabin heater. (Courtesy of John Zink Co., LLC.³)



FIGURE 16.16 Crude unit burners. (Courtesy of John Zink Co., LLC.³)

combination burners use both a liquid and a gaseous fuel, which are normally injected separately through each burner. The various aspects of natural-draft burners are considered next.

16.4 BURNER DESIGN

The burner is the device used to combust the fuel with an oxidizer to convert the chemical energy in the fuel into thermal energy. A given combustion system may have a single burner or many burners, depending on the size and type of the application. For example, in a vertical cylindrical

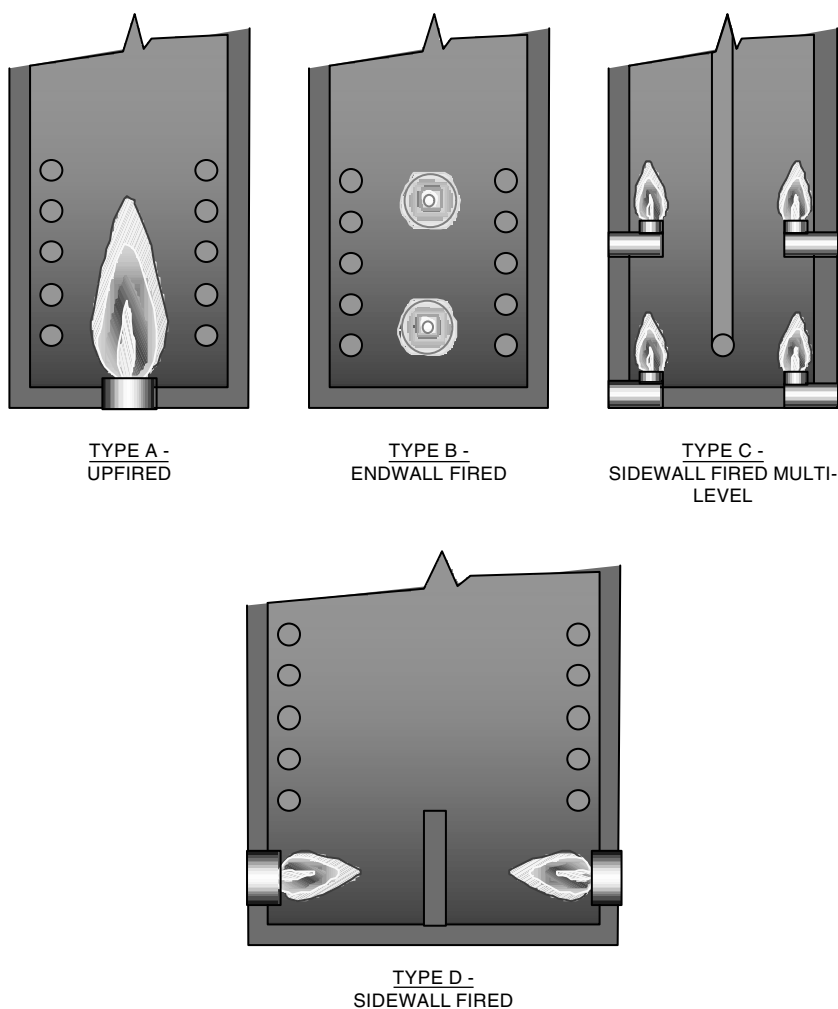


FIGURE 16.17 Typical burner arrangements. (Courtesy of John Zink Co., LLC.³)

furnace, one or more burners are located in the floor of a cylindrically shaped furnace (see [Figure 16.18](#)). The heat from the burner radiates in all directions and is efficiently absorbed by the tubes. Another type of heater geometry is rectangular (see [Figure 16.19](#)). This type of system is generally more difficult to analyze because of the multiplicity of heat sources and because of the interactions between the flames and their associated products of combustion.

Specialization of processes and furnace designs to meet the demands of those processes has resulted in the necessity for specialized burners. A burner is designed to provide stable operation and an acceptable flame pattern over a specific set of operating conditions. In addition, there may be a specified maximum level of pollutant emissions that can be generated through the combustion process. The American Petroleum Institute gives some guidelines for burners used in fired heaters.⁵ Specifications of operating conditions include:

- Specific types of fuels
- Specific range of fuel compositions
- Maximum, normal, and minimum heat release rates

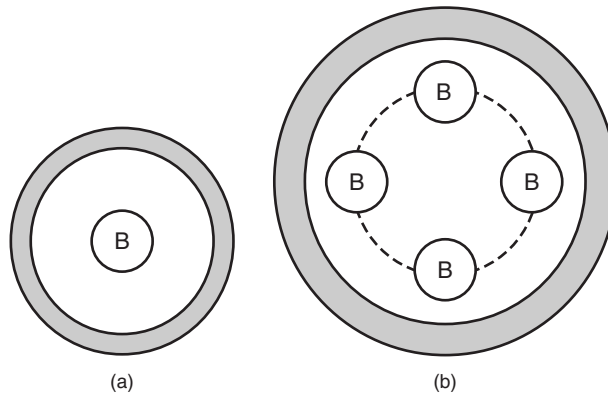


FIGURE 16.18 Burner (B) arrangement in the floor of vertical cylindrical furnaces: (a) small-diameter furnace with a single centered burner and (b) larger-diameter furnace with four burners symmetrically arranged at a radius from the centerline. (Courtesy of John Zink Co., LLC.³)

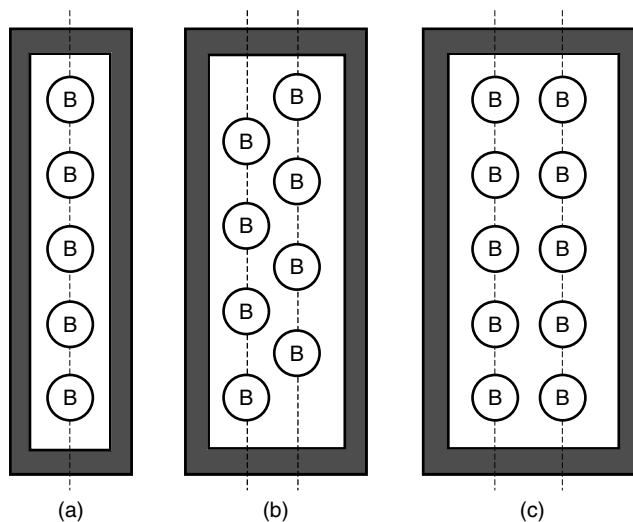


FIGURE 16.19 Burner (B) arrangement in the floor of rectangular cabin heaters: (a) single row of burners in a narrower heater, (b) two rows of staggered burners in a slightly wider heater, and (c) two rows of parallel burners in an even wider heater. (Courtesy of John Zink Co., LLC.³)

- Maximum fuel pressures available
- Maximum atomizing medium pressures available for liquid firing
- Fuel temperature
- Oxidant source, either ambient air, exhaust gases, or enriched
- Available combustion air pressure, whether forced (positive) or induced (negative)
- Combustion air temperature (ambient or preheated)
- Furnace firebox temperature
- Furnace dimensions for flame size restrictions
- Type of flame (configuration or shape)

To provide acceptable operation, the burner must be designed to perform the 5-Ms:

1. Meter the fuel and air into the flame zone
2. Mix the fuel and air to efficiently utilize the fuel
3. Maintain a continuous ignition zone for stable operation over the range
4. Mold the flame to provide the proper flame shape
5. Minimize pollutant emissions

16.4.1 METERING THE FUEL

Typically, the furnace operating system is able to monitor only the total flow of fuel to a furnace. A typical process heater has multiple burners installed to provide the proper heat distribution. The fuel system must then be designed to ensure that the fuel is properly distributed to all burners, because there are not typically individual fuel controls to each burner. Uniform fuel pressure to each burner is critical to the proper operation of the burners. The burner designer then ensures that each burner takes the correct amount of fuel from the system. Controlling the proper amount of fuel flow is accomplished through a system of metering orifices designed for each burner. These ports are specifically designed to act as metering and limiting orifices, passing a specified and known amount of fuel at a given fuel pressure.

16.4.1.1 Gaseous Fuel

A fuel capacity curve is developed for a burner based on the number and size of ports or orifices in the burner. This curve specifies the heat release vs. pressure for a given fuel composition and temperature. For gaseous fuels and compressible or incompressible flow, the calculations for the mass flow through a given orifice depends on:

- P_o the fuel pressure immediately upstream of the orifice
- P_a downstream pressure, generally atmospheric pressure
- T_o fuel temperature upstream of the orifice
- K fuel's ratio of specific heats, which depends on the composition of the fuel and is a factor used in calculating the compressibility of the fuel gas
- A area of the port
- C_d discharge coefficient, which depends on the design of the orifice port

The equations for calculating the flow through an orifice are given in Chapter 3.

The fuel metering orifices for gaseous fuels in raw-gas burners are typically installed at the point where the flame is formed. This is generally located in a region of the burner tile often termed the "burner throat." The fuel injector tips with the fuel orifices may be centered in the burner throat, located on the periphery, or a combination of both. [Figure 16.20](#) shows typical raw gas burner tips.

For premix or partial premix burners, the metering orifice serves two functions: to meter the fuel and to entrain combustion air into the venturi. This orifice is generally a single port located at the entrance of a venturi eductor. A typical premix metering orifice spud and air mixer assembly is shown in [Figure 16.21](#).

Fuel capacity curves are generally presented in terms of heat release vs. fuel pressure. The heat release is calculated from the mass (or volume) flow of the fuel multiplied times the heating value per unit mass (or volume) of the fuel. [Figure 16.22](#) shows a typical set of gaseous fuel capacity curves for three different heating values.

16.4.1.2 Liquid Fuel

Liquid fuels must be vaporized in order to burn efficiently. Burners designed for firing liquid fuels include an atomizer designed to produce a spray of small droplets that enhances the vaporization of the fuel. The design of the atomization system will have a significant impact on the liquid fuel flow

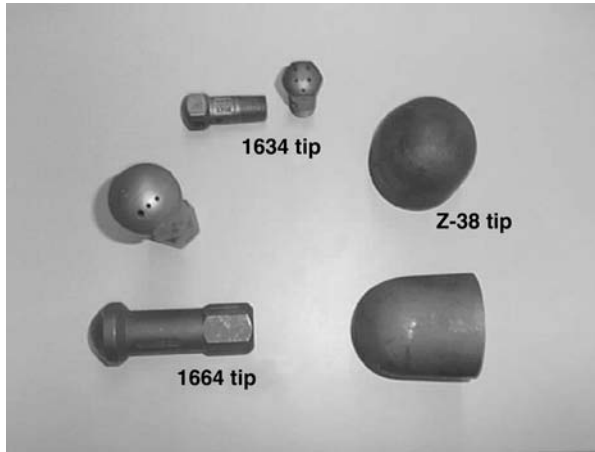


FIGURE 16.20 Typical raw gas burner tips. (Courtesy of John Zink Co., LLC.⁴)

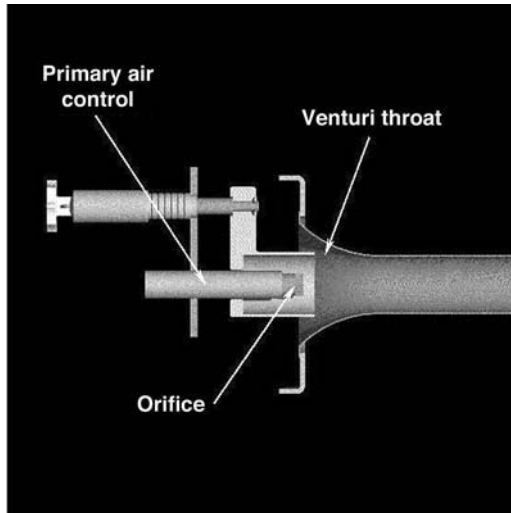


FIGURE 16.21 Typical premix metering orifice spud and air mixer assembly. (Courtesy of John Zink Co., LLC.⁴)

metering of the burner. With liquid fuels, the metering design is more complicated because of the need to “mix” the oil with an atomizing medium, such as steam or compressed air. This results in fuel metering orifices and atomizing media metering orifices in combination with orifices designed to flow the mixture. Figure 16.23 shows three typical liquid fuel atomizer/spray tip configurations.

Many factors are important in a liquid fuel atomization system. Variations in any of a number of factors must be considered when designing the system of ports for the metering of flow for a liquid fuel; those factors include:

- Viscosity as a function of temperature for the fuel
- Atomization medium and its temperature
- Fuel/atomizing medium pressure ratio
- Vaporization temperature for the fuel

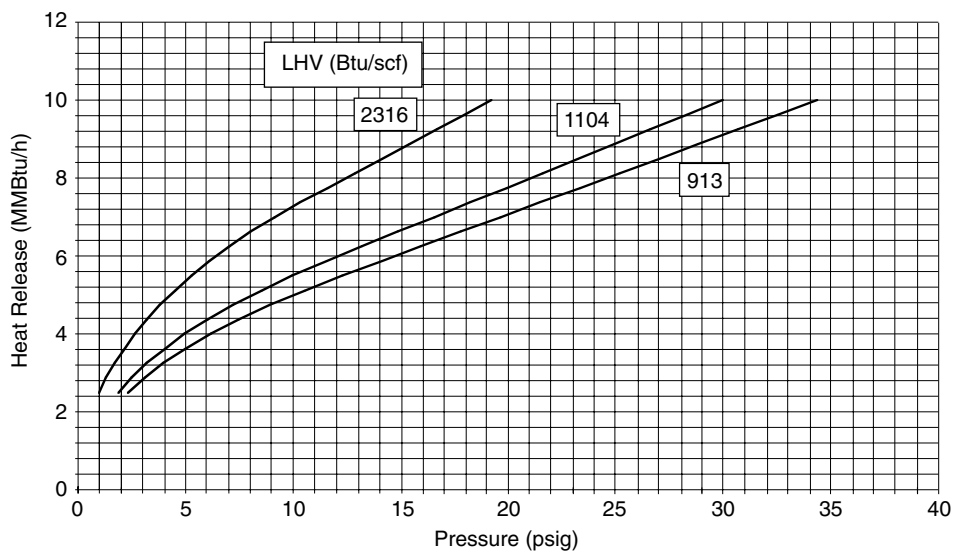


FIGURE 16.22 Typical gas fuel capacity curve. (Courtesy of John Zink Co., LLC.⁴)

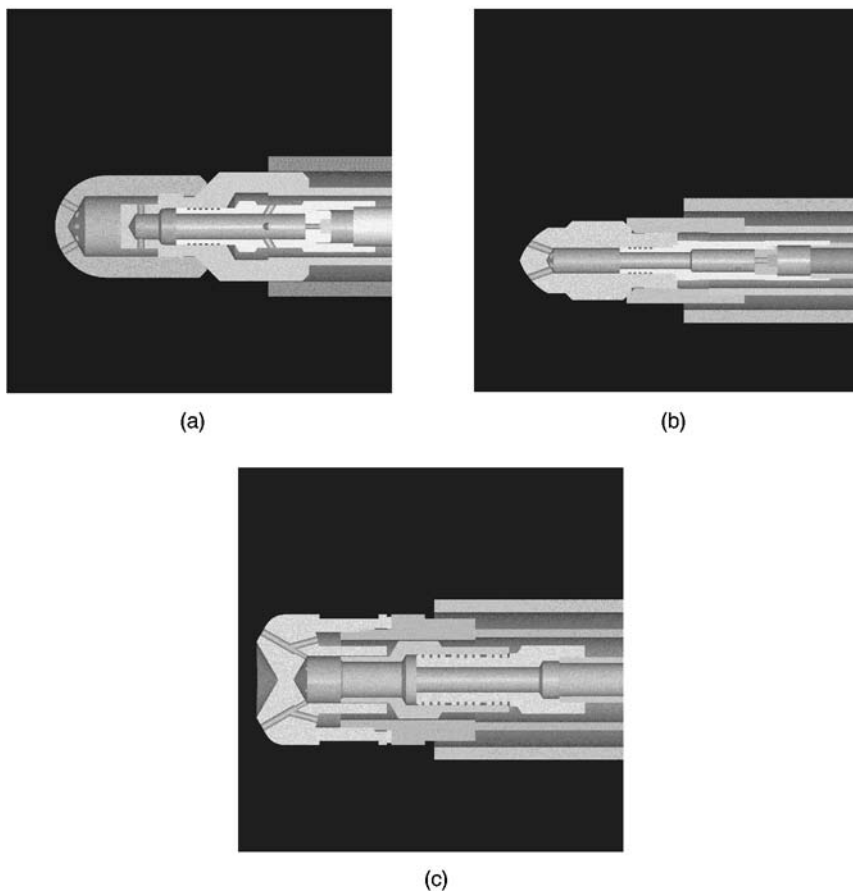


FIGURE 16.23 Typical liquid fuel atomizer/spray tip configurations. (Courtesy of John Zink Co., LLC.⁴)

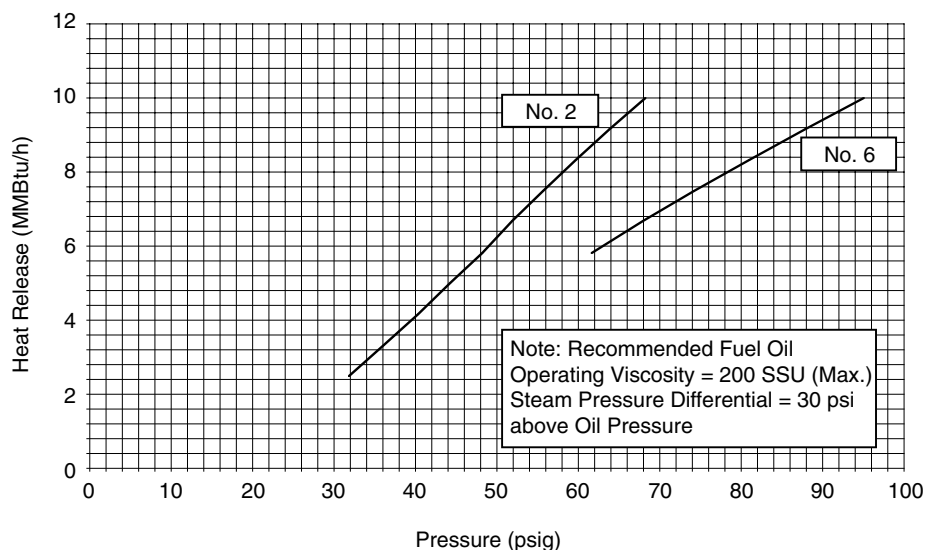


FIGURE 16.24 Typical liquid fuel capacity curve. (Courtesy of John Zink Co., LLC.⁴)

Fuel capacity curves are generally presented in terms of heat release vs. fuel pressure. The heat release is calculated from the mass/volume capacity of the system times the heating value per unit mass of fuel. Figure 16.24 shows a typical liquid fuel capacity curve.

16.4.2 METERING THE AIR

The burner must be designed for the required air flow for the operating conditions, particularly the air pressure that is available. The design of the burner throat is critical for two independent reasons. First, the throat must be capable of achieving the proper flow of combustion O_2 to meet the demands of the fuel. Second, the burner throat is designed to control the shape of the flame.

The primary air flow metering point where most of the available air pressure drop occurs is designated as the “throat.” In most burners, especially raw-gas or nozzle-mix and liquid fuel burners, it is the point at which the fuel is first injected into the air stream. In a premix or partially premixed burner, it is the point at which the fuel/air mixture is injected and, if necessary, secondary or completion air is introduced. In all cases, it is the location at which the initiation of combustion, or ignition, occurs. Figure 16.25 shows the throat for a typical raw-gas (pure diffusion or non-premixed) burner.

Natural-draft burners use the natural suction created in a furnace as the motive force for drawing combustion air through the burner. This negative pressure is typically less than 1 inch water column (<1.0 in. w.c.) at the burner location. Draft is naturally created in a furnace due to the buoyant forces of the hot and lighter combustion products compared to the cool and heavier ambient air outside the furnace (see Chapter 3). This draft is slightly more complicated in process heaters and furnaces used in the chemical and petrochemical industries that have a convection section near the outlet. This convection section is designed to further extract energy out of the combustion products before they are exhausted to the atmosphere. It typically consists of a band of tubes where the fluid is some type of hydrocarbon. There is some pressure drop across this band of tubes that must be taken into account when determining the available draft at the burner. The available draft at the burner is a function of the height of the combustor, the average temperature inside the combustor, and the pressure drop across the convection section. The burner must be adequately sized for the given available draft to induce enough ambient air for the maximum heat release.

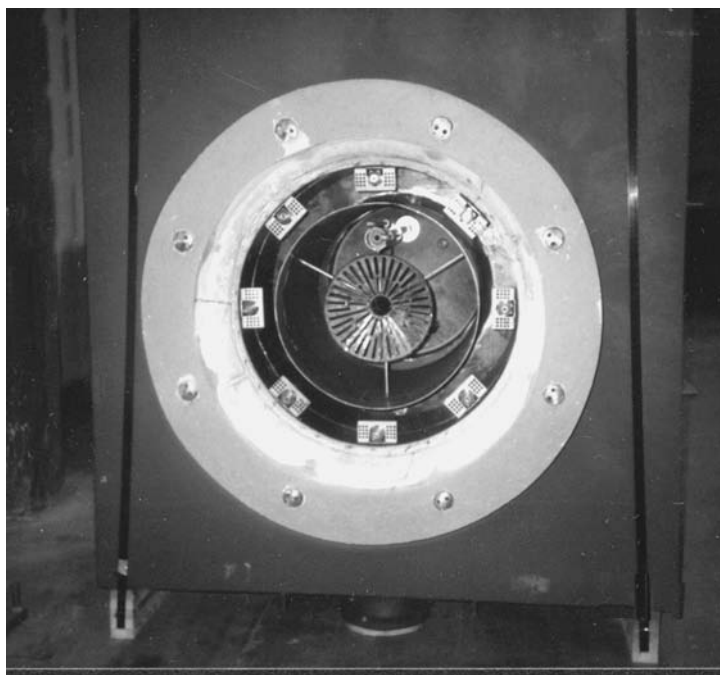


FIGURE 16.25 Typical throat of a raw gas burner. (Courtesy of John Zink Co., LLC.⁴)

In raw-gas (diffusion or nonpremixed) or liquid fuel burners, the principle combustion air flow metering point is the burner throat. In partially premixed burners, the secondary or completion air metering point is the burner throat. As a primary metering restriction, the majority of the pressure loss is expected to be taken across the throat. Engineering groups such as the American Petroleum Institute (API),^{5,6} process design companies, and some furnace manufacturers provide burner design guidelines that define the use of the available airside pressure drop at that point. These guidelines often require that 75 to 90% of the available draft be taken across the burner throat to enhance air control. There are practical limitations to the control range for natural-draft burners. The percentage of available draft utilized for throat metering can leave little room for an adequate air control mechanism.

Example 16.1

Given:

Fuel gas:	1200 Btu/scf (47.27 MJ/Nm ³ , 11,300 kcal/Nm ³)
Maximum design duty:	10.0×10^6 Btu/hr (2.93 MW, 2.52×10^6 kcal/hr)
Normal duty:	8.0×10^6 Btu/hr (2.3 MW, 2.0×10^6 kcal/hr)
Minimum design duty (turndown):	2.0×10^6 Btu/hr (0.586 MW, 0.504×10^6 kcal/hr)
Available furnace draft:	0.5 in. w.c. (120 Pa, 1.25 mbar, 12.7 mm H ₂ O)
Excess air:	20% design, 10% operation
Design standards:	API 560 and 535

API 560 Section 10.1.12 states that “The burner shall be selected to use no less than 90 percent of the maximum draft available for the maximum specified heat release.” API 560 Appendix A (Equipment Data Sheets), Section b (Burner data sheets, Sheet 3 of 3), Note 1 states that “At design condition, minimum of 90% of the available draft with the air register fully open shall be utilized across the burner. In addition, a minimum of 75% of the airside pressure drop with the air registers full open shall be utilized across burner throat.” API 535 Section 8.2 (Dampers and Registers) states

that “Dampers and burner registers shall be sized such that the air rate can be controlled over a range of at least 40–100% of burner capacity.” Assume that the burner requires between the specified 90% to 100% of the available draft, and that the specified 75% is measurable as static loss across the throat. [Table 16.5](#) and [Table 16.6](#) (developed for Example 16.1) indicate the:

- Operating heat release (1)
- Desired operational excess air (2)
- Required pressure loss across the throat (3)
- Required pressure loss across the register or air control device (4)
- Ratio percentage of register or damper opening required (5)

[Table 16.5](#) shows the theoretical percentage of air control opening based on no change in control flow coefficient and 3% leakage in the full closed position. [Table 16.6](#) is based on 6% leakage. These tables assume that the variable orifice, which is the air control mechanism (often referred to as an air register or damper), has a constant discharge coefficient throughout its full range of operation. This is a simplification that is not strictly correct in practical application. These tables provide insight into the problem of excess design capacity. Many who specify combustion equipment seek to provide excess capacity as a cushion against reduced operation with burners out of service, upset operation, process design contingencies, and future desired capacity. The problem is the ability to control excess air and utilize the available pressure drop for the normal operation. At lower firing rates, the air and fuel pressures are both reduced in the mixing zone and the resulting flame quality often suffers because of the reduced control.

16.4.3 MIXING THE FUEL AND AIR

“Mixing” is a general term used to describe the function of bringing the fuel (reactant) in close proximity with the air (oxidant). The higher the level of turbulence and shear between the streams, the more uniform the fuel and air mixture, which makes the combustion reaction more rapid and complete. It is generally accepted that the higher the level of mixing, the more intense, complete, and enhanced the combustion. However, there are a number of conditions and factors that should be considered, including flame shaping and control of pollutant emissions that lead to some exceptions to this rule. Intimate mixing does not always produce the most desirable results.

Designing a combustion system for special applications such as high inert composition fuels can also set limitations on the desired level of mixing. All combustion reactions have a rate at which they will proceed and a minimum temperature that is required to initiate or sustain that reaction. The introduction of inert components to the fuel can generate two conditions that will affect burner stability. First, the inert components slow the reaction, which slows the flame speed and can result in the stabilization point being moved out of the desired position (e.g., at the flameholder). Second, the inerts introduce a heat absorption component that narrows the flammability limits and reduces the flame temperature. Quenching of the flame to extinction is an important consideration when inert components are present in the fuel or the combustion O_2 stream.

Many combustion oxidant streams with greater inert compositions than ambient air are often the result of some type of flue gas recirculation process and are typically at an elevated temperature. This elevated temperature will often partially offset the potential quench effect of the elevated inert levels.

An effective form of emissions control is through the delaying of the combustion process. Highly mixing the fuel and the oxidant in the proper proportions will generate the maximum flame temperatures. This enhances the formation of large quantities of oxides of nitrogen (NO_x), which is a highly regulated pollutant. Certain burner designs reduce the level of fuel and air mixing, sometimes referred to as delayed mixing, which extends the reaction zone to achieve reductions in these emissions. Fuel and air staging are well-known techniques for delaying mixing to reduce NO_x emissions.

TABLE 16.5

Theoretical Air Control Opening, Based on No Change in Control Flow Coefficient and 3% Leakage at the Full Closed Position

Heat Release (1) MMBtu/hr	Percent Design %	Percent X-Air (2) %	Throat Drop		Control Drop		Total dP In. wc	Percent Control Open	
			90% Total	100% Total	90% Total	100% Total		90% Total	100% Total
			(3) in. wc		(4) in. wc			(5) % (w/3% leakage)	
10.0	100	15	0.338	0.375	0.162	0.125	0.50	86.3	Full open
10.0	100	10	0.309	0.343	0.191	0.157	0.50	75.9	83.8
9.0	90	10	0.250	0.278	0.250	0.222	0.50	59.4	63.1
8.0	80	10	0.198	0.220	0.302	0.280	0.50	47.7	49.6
7.0	70	10	0.151	0.168	0.349	0.332	0.50	38.6	39.6
6.0	60	10	0.111	0.124	0.389	0.376	0.50	31.0	31.6
5.0	50	10	0.077	0.086	0.423	0.414	0.50	24.5	24.8
4.0	40	20	0.059	0.065	0.441	0.435	0.50	20.7	20.9
3.0	30	40	0.045	0.050	0.455	0.450	0.50	17.6	17.7
2.0	20	80	0.033	0.037	0.467	0.463	0.50	14.7	14.8
0	0	3	0.00031	0.00034	0.49969	0.49966	0.50	Full closed	Full closed

Courtesy of John Zink Co., LLC.⁴

TABLE 16.6

Theoretical Air Control Opening, Based on No Change in Control Flow Coefficient and 6% Leakage at the Full Closed Position

Heat Release (1) MMBtu/hr	Percent Design %	Percent X-Air (2) %	Throat Drop		Control Drop		Total dP In. wc	% Control Open	
			90% Total	100% Total	90% Total	100% Total		90% Total	100% Total
			(3) in. wc		(4) in. wc			(5)% (w/6% leakage)	
10.0	100	15	0.338	0.375	0.162	0.125	0.50	84.8	Full open
10.0	100	10	0.309	0.343	0.191	0.157	0.50	74.4	82.3
9.0	90	10	0.250	0.278	0.250	0.222	0.50	57.9	61.6
8.0	80	10	0.198	0.220	0.302	0.280	0.50	46.2	48.1
7.0	70	10	0.151	0.168	0.349	0.332	0.50	37.1	38.1
6.0	60	10	0.111	0.124	0.389	0.376	0.50	29.5	30.1
5.0	50	10	0.077	0.086	0.423	0.414	0.50	23.0	23.3
4.0	40	10	0.059	0.065	0.441	0.435	0.50	19.2	19.4
3.0	30	40	0.045	0.050	0.455	0.450	0.50	16.1	16.2
2.0	20	80	0.033	0.037	0.467	0.463	0.50	13.2	13.3
0	0	6	0.0012	0.0014	0.4988	0.4986	0.50	Full closed	Full closed

Courtesy of John Zink Co., LLC.⁴

16.4.4 MAINTAINING IGNITION

The most important function that a burner performs is to provide for the continuous and reliable ignition of the fuel and air passing through the burner over a specified range of operating conditions. Failure to do so could potentially lead to an explosion. Each burner is designed to provide a specific location in which a portion of the fuel and air is continuously introduced in near-stoichiometric proportions at velocities at or below the mixture flame speed, allowing for a continuous ignition zone. The fuel orifices in the burner designed for this purpose are often referred to as ignition ports. In the ignition zone, a steady flame is maintained that continuously ignites the fresh fuel/air mixture as it is introduced. The ignition zone is designed to operate over the specified range of operation of the burner. The flame from this ignition zone is then used to ignite the remainder of the fuel and air mixture. In natural-draft burners, the ignition zone is often situated in the eddy formed downstream of a step or ledge in the burner tile (see Figure 16.26), or in the wake of a bluff body “flame stabilizer” or “flame holder” (see Figure 16.27) located in the center of the combustion airstream.

Safe ignition of the fuel/air mixture depends on the compositions of the fuel and oxidant, which affect the flammability limits, ignition temperatures, and stoichiometry of the mixture. The flame speed is controlled by the stoichiometry and composition of the mixture. The ability to sustain a single point of ignition for a fuel/air mixture is controlled by both the stoichiometry and the velocity of the mixed stream. Wide ranges in capacity, excess air requirements, and fuel compositions make strict dependence on the mixed stream for stability unreliable. The development of low-velocity zones and recirculating eddies ensures a single point for maintaining an ignition zone over a broad range of operating conditions. Each burner is designed for a limited range of fuel and oxidant compositions and flow rates, and the burner should not be operated outside this range.

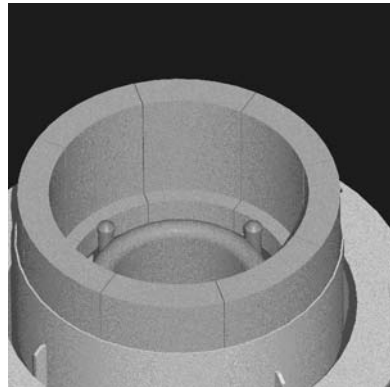


FIGURE 16.26 Ledge in the burner tile. (Courtesy of John Zink Co., LLC.⁴)

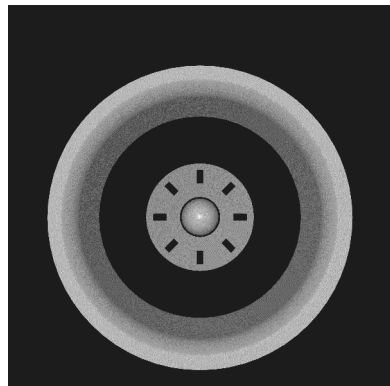


FIGURE 16.27 Flame stabilizer or flame holder. (Courtesy of John Zink Co., LLC.⁴)

“Stability” is a widely used term when describing combustion and burner performance. This term is applied to the range of conditions under which burners maintain their ignition. Outside those conditions, the burner may become unstable and therefore potentially dangerous. A condition may be created where the flame pulsates. There is no strict measurement of or unit for stability, and it is somewhat subjective unless the flame is obviously pulsing, for example.

16.4.5 MOLDING THE FLAME SHAPE

Many industrial applications have strict restrictions on the shape, size, and consistency of the flames in the combustor. The furnace chamber and burner flame in every process furnace are designed to provide for the efficient transfer of heat to the process load. Flame size and shape for the natural-draft burners used in the hydrocarbon processing industries is especially critical due to the sensitivity to overheating for the hydrocarbons being processed. The rate of heat transfer to the process tubes must be limited to prevent overheating of the process tubes leading to the formation of carbon or coke inside the process tubes. As a result, there are generally strict guidelines for the flame dimensions. Typical specifications for flames include maximum flame lengths and maximum flame widths. In some cases, there may even be some minimum flame dimensions specified. The number, heat release, and layout of the burners in the furnace are designed to provide the proper heat transfer pattern.

Controlling the air flow through the incoming ambient air approach distribution, tile throat sizing and shape, and the tile exit configuration provides the most reliable method for flame shape control. Introduction of the fuel into the established airflow streams provides the primary function in a raw-gas burner. The proper flame pattern is generated by the combination of fuel injection pattern provided by the fuel injectors and the burner tile and flame holder that controls the air flow. The fuel injectors are also often called *spuds* or *tips*. The injectors have fuel injection ports or orifices that introduce the main portion of the fuel into the air stream in a manner that generates the desired flame pattern or shape. The number, size, and orientation of the ports are critical for determining the overall flame shape. In conjunction with the fuel injectors, the air stream must be shaped in an appropriate manner by the airflow passages provided by the shape of the tile and flame holder.

In most cases, the flame cross section is round (see Figure 16.28). The fuel is normally injected symmetrically to maintain the round shape. In the hydrocarbon and petrochemical industries, round-flame burners are used in a wide variety of applications. They are typically fired vertically upward in the middle of the floor or hearth of the furnace between rows of tubes. The flames radiate their heat to the tubes containing hydrocarbon fluids.



FIGURE 16.28 Round-shaped flame. (Courtesy of John Zink Co., LLC.⁴)



FIGURE 16.29 Flat-shaped flame. (Courtesy of John Zink Co., LLC.⁴)

Some applications require a fan-shaped or rectangular cross section (see [Figure 16.29](#)). This shape is often termed a “flat flame;” it typically has a fairly high aspect ratio (ratio of the longest side to the shortest side) and is rarely square in shape. In flat-flame burners, the burner tile (block or quarl) is generally rectangular and the fuel is injected in a manner to produce a flame that is essentially rectangular or “flat,” rather than round. In many cases, these flat-flame burners are fired along a refractory wall or floor (see [Figure 16.10](#)) to heat the wall so it can radiate to the load. These are commonly used in cracking-type applications, such as in the production of ethylene.

16.4.6 MINIMIZING POLLUTANT EMISSIONS

Because of increasing concern for the environment, pollutant emissions from most industrial combustion processes are highly regulated. A wide range of strategies has been used in natural-draft burners to minimize pollution emissions, particularly NO_x. The most popular techniques include air and fuel staging and internal furnace gas recirculation. A more recent technique is the use of ultra-lean premix, which has achieved very low levels of NO_x emissions.²⁹

16.5 BURNER TYPES

Natural-draft burners are typically classified based on the type of fuel being burned and how the fuel and air are mixed:

- Gas: premix and partial premix
- Gas: raw gas or nozzle mix
- Liquid
- Combination gas and liquid: raw gas and oil (typically)

The combining of any two or more burners is simply a matter of basing the design on the most difficult of the fuel types and adapting the other fuel distribution systems to the base design.

16.5.1 PREMIX AND PARTIAL PREMIX GAS

“Premix” is a term applied to burners where the fuel and the combustion air are completely mixed together prior to reaching the ignition zone. This type of burner usually provides for intimate mixing of the fuel and combustion O₂ prior to the ignition zone. However, it is also possible for the fuel

and air to be relatively unmixed before reaching the ignition zone, depending on the burner design. This may be deliberate or simply poor design, depending on the objectives of the combustion process. Partial premix burners mean that some but not all of the fuel and air are mixed prior to reaching the ignition zone.

In natural-draft burners, the motive energy to inspire the combustion air is supplied by the low-mass, high-potential-energy-stream fuel. The fuel gas is metered through one or more orifices at the entrance to a venturi or mixer. The entrained air stream is made available at zero, or virtually zero, velocity at the same location. The conversion of the potential energy from the pressure of the fuel stream to kinetic energy in the form of velocity is completed within the air supply zone. The free fuel jet expands and decelerates. Conservation of momentum requires that the reduction in velocity be balanced by an increase in the mass of the moving stream. This additional mass is the entrained ambient air.

Burners designed with an inspiring arrangement typically require fewer adjustments to the air control. The utilization of the fuel momentum determines the amount of air inspired, which is proportional to the gas flow. Therefore, reducing the fuel mass momentum reduces the amount of air entrained. The efficiency of the venturi and the restriction imposed by the fuel/air distribution nozzle are the limits to the capacity (volume) of air that can be inspired.

Another benefit to this design is the flame volume created. If the air inspiration design is efficient, the resulting flame volume of this premixed burner will be much smaller than that of other low air pressure drop burners. Conversely, if this premixing is inefficient, the flame may actually be larger than a raw gas burner due to the reduction in the secondary air mixing energy. By utilizing the majority of the available energy of the fuel stream to achieve the primary premix, the remaining energy for any required secondary air mixing is reduced to only that available from the air due to the draft loss.

Fuel metering is a further benefit of this burner style. Because all of the fuel is typically metered through a single orifice for each venturi, the size of the orifice is maximized. Larger diameter orifices, as long as they do not jeopardize the function of the burner, are a benefit because they minimize the chances of plugging from dirty fuels.

One of the basic limitations to this type of burner is the burning characteristic of fuels. Each fuel composition has a different reaction rate, which is dependent on the concentrations of the fuel, the oxygen, and any inert components. This rate also depends on the temperature of the mixture. The reaction rate is often quantified in terms of flame speed, which is the velocity at which the flame will propagate. The design of the injection system into the ignition and combustion zones depends on this same burning characteristic of the design fuel. Changes in the firing rate or the fuel will result in a change in the flame volume, velocity, and burning characteristics at the distribution tip. If the fuel/air mixture is within combustible limits, and the velocity is not maintained above the flame propagation speed, the flame front moves back toward the incoming fuel/air flow streams. In the worst case, this flashback condition may result in flames being translated completely outside the designed ignition and flame zone causing mechanical and structural damage. If this mis-positioned flame actually establishes itself outside of confining equipment, major safety problems may occur.

16.5.2 RAW-GAS OR NOZZLE-MIX

Raw-gas (diffusion or nozzle-mix) burners are designed to introduce the fuel and air separately into the ignition zone. The mixing of the fuel and combustion air is done at or after the ignition point of the burner. Typically, these burners provide for the major, or metering, pressure drop for both the fuel and air immediately prior to the ignition zone.

By separating the fuel from the combustion air prior to the ignition zone, there is no possibility of flashback. Therefore, the raw-gas style of design can effectively handle a wide range of fuels without concern for equipment damage or personnel safety. Turndown on a raw-gas burner is limited only to the method of stabilization, the flammability limits of the fuel, and the controllable and safety lower pressure limits of the fuel system.

Because the combustion air is supplied through and metered by the throat of the burner, the air flow must be adjusted as the fuel flow rate changes, for efficient operation. The incoming air flow rate depends primarily on the furnace draft rather than on inspiration by the fuel. Unlike venturi operation, where the air flow rate is proportional to the fuel flow rate, in raw-gas burners the air flow rate is not proportional to the fuel rate. This can mean an excessive amount of combustion air when the firing rate is reduced, unless the air flow is adjusted. The ability to efficiently combust the fuel and transfer the heat is directly related to the amount of excess air. Therefore, it becomes necessary to control the air with every change in fuel flow or fuel composition or there will be a related change in efficiency. This is typically done with an individual burner damper or register. In a limited number of applications, a common inlet air header is used and the air flow rate to an entire furnace can be controlled with a single damper.

Another problem intrinsic to the raw-gas design condition comes from the fuel distribution system. Multiple fuel injection points are often required to shape the flame, distribute the fuel into the combustion air stream, and mix the fuel with the air. Breaking the fuel flow into multiple metering orifices while maintaining high potential energy (pressure) can lead to small fuel injection ports or orifices. These small orifices are highly subject to fouling problems due to dirty fuel quality and foreign material in the piping.

Natural-draft burners utilize quiescent zones for stabilization. These low-flow, low-pressure zones can be generated through the use of flow stream disruption. Cones or bluff bodies located in the throat of the burner are a common form of flow stream disruption. Flow disrupters or shields around fuel tips and ledges or sharp changes in the burner block (tile or quarl) profile are also common. In all cases, these mechanisms are basically designed to prevent a portion of the combustion air from leaving the designed ignition zone prior to the introduction of fuel. They provide pockets of a continuously renewing combustible mixture at a location where the velocity is lower than the flame propagation speed.

16.5.3 OIL OR LIQUID FIRING

Oil firing is more complicated than fuel gas firing because the oil must be atomized and vaporized before it can be properly burned. Atomization involves producing a relatively fine spray or mist of droplets that will vaporize quickly. Industrial natural-draft oil burners typically utilize twin fluid atomizers and employ steam as the atomizing medium. Compressed air or even high-pressure fuel gas, rather than steam, can be utilized in some applications.

Some internal mix, twin fluid atomizers form a gas/liquid emulsion, which then issues from the fuel tip. This type of atomizer is shown in Figure 16.30. The oil issues from a single port at the entry to the atomizer section. Steam is injected into the oil stream through multiple ports forming

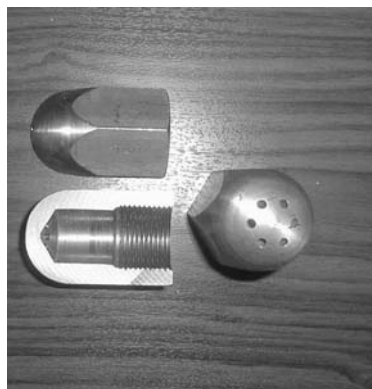


FIGURE 16.30 Internal mix twin fluid atomizer.
(Courtesy of John Zink Co., LLC.⁴)

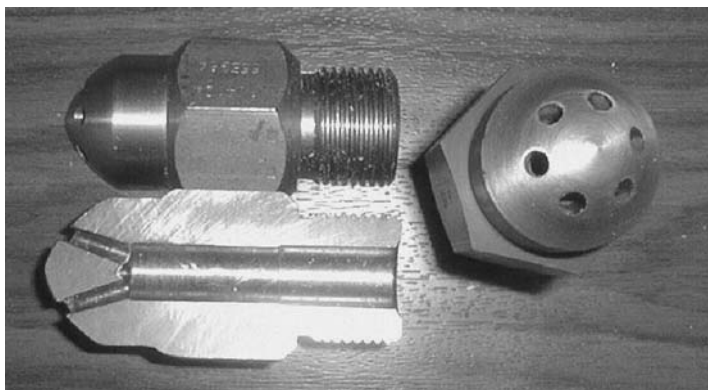


FIGURE 16.31 Port mix twin fluid atomizer. (Courtesy of John Zink Co., LLC.⁴)

the emulsion. This oil/steam emulsion then travels to the chamber between the atomizer section and the exit ports. Multiple exit ports are placed on the tip, which allows for enhanced mixing of the spray and the combustion air, flame shaping, and stabilization. Internal mix atomizers often utilize a steam pressure that is maintained at 10 to 30 psig (70 to 210 kPa) above the oil pressure over the operating range of the burner. The oil pressure may be 100 to 120 psig (700 to 800 kPa) at the maximum firing rate.

Port mix, twin fluid atomizers (see [Figure 16.31](#)) use the atomizing media to form a thin liquid annulus on the inner surface of the port. The high velocity of the atomizing media pushes the liquid along the length of the port shearing and stretching the liquid into a thin film. These atomizers generally operate with a constant steam pressure, typically 120 to 150 psig (800 to 1000 kPa) over the entire operating range of the burner. The oil pressure may be 100 to 150 psig (700 to 1000 kPa) at the maximum firing rate.

In each case, internal mix or port mix, droplets are formed as the liquid forms a sheet as it exits the port and this sheet then breaks up as it expands. The size of the droplets formed depends on the relative velocity of the liquid sheet and the surrounding media. It also depends on the viscosity, surface tension, and density of the liquid, size of the port, momentum of the fuel, and ratio of fuel to atomizing media.

16.5.3.1 High-Viscosity Liquid Fuels

Most of the industrial liquid fuels fired are high viscosity or heavy fuel oils, including no. 6 fuel oil, bunker C oil, residual fuel oil, pitch, tar, and vacuum tower bottoms. Most heavy fuel oils are the residue from the oil refining process and are considered low-value byproducts. Some of these high-viscosity fuels can be solid or nearly solid at room temperature. Nearly all high-viscosity liquid fuels must be heated in order to be efficiently atomized. Typically, for best atomization, the viscosity of the oil should be in the range of 100 to 250 SSU. This often requires the heavy oil to be heated to the range of 200 to 250°F (90 to 120°C). However, a heavy pitch may require a temperature of 600°F (320°C) to achieve the proper viscosity for atomization.

Heavy fuel oils have high boiling points and are therefore difficult to vaporize. Many heavy oil burners have special refractory tiles, sometimes called regenerative or *regen* tiles (see [Figure 16.32](#)), that redirect the intense flame radiation back to the root of the spray to enhance vaporization rates and help stabilize the oil flame. Some other heavy oil burners utilize swirlers to promote internal recirculation of the hot combustion products back into the flame root to enhance heating of the spray (see [Figure 16.33](#)).

FIGURE 16.32 Regen tile for enhancing oil flame stabilization. (Courtesy of John Zink Co., LLC.⁴)

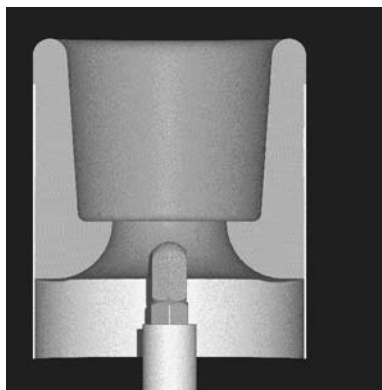
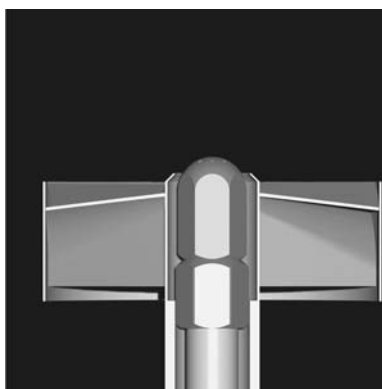


FIGURE 16.33 Swirler for enhancing oil flame stabilization. (Courtesy of John Zink Co., LLC.⁴)



16.5.3.2 Low-Viscosity Liquid Fuels

Low-viscosity liquid fuels include light oils such as no. 2 fuel oil, naphtha, and byproduct waste liquids containing a variety of hydrocarbon byproducts such as alcohols. These liquids are also typically fired using twin fluid atomizers. However, care must be taken to avoid overheating low-boiling-point fuels. Vaporization of the liquid within the oil gun can cause disruption in the flow within the atomizer, leading to unsteady operation. Many light liquid fuels require compressed air rather than steam atomization. The air serves not only as the atomizing medium, but also as a source of combustion air. Because light oils generally have lower boiling points compared to heavy oils, they are easier to vaporize. Their flames can often be stabilized using simple bluff body stabilizers instead of swirlers or special tiles that are typically needed for heavy oils.

16.6 BURNER CONFIGURATION

Burners can be mounted in the furnace or heater floor to fire vertically upward, in the heater wall to fire horizontally, or in the roof to fire vertically downward. The major consideration required for burner design is to ensure the proper support for the burner tile. Burner blocks for floor-mounted service can typically be simply placed on the furnace steel or burner mounting plate. Burner blocks for horizontal mounting must be supported by tile case assemblies and must be held in place so that they do not move if subjected to vibration. Roof-mounted tiles must have support surfaces cast into them so that they can hang from steel supports in the furnace roof.

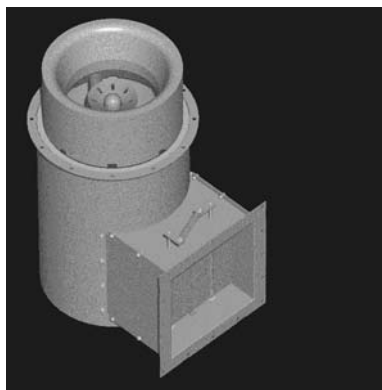


FIGURE 16.34 Typical conventional raw-gas burner.
(Courtesy of John Zink Co., LLC).⁴

16.6.1 ROUND-FLAME BURNER

The following figures illustrate the different types of burners that are typically used in refinery and petrochemical furnaces. The round-flame burner is the most universal design and used in many applications. Figure 16.34 illustrates a typical raw gas conventional burner. This burner is used where NO_x emissions are not a primary concern and a short flame is desired.

Figure 16.35 shows a typical premix gas burner. A premix round-flame burner is useful when a short heater does not have enough draft to supply the required combustion air. The premix burner uses the fuel jet as a motive force to allow the burner to pull in part or all of its combustion air. However, there may be other considerations such as flame shape that will influence the choice of burner style as premix flames are often shorter than raw gas (diffusion) flames.

Figure 16.36 shows a typical round/conical flame combination oil and gas burner. This burner can be used to burn gas or liquid fuels. This versatility is desirable in applications with liquid fuels or where gas fuels may be in short supply at various times throughout the year and an alternative fuel must be fired to maintain a process. Figure 16.37 shows a typical round/conical flame, high-intensity combination oil and gas burner. This burner is used in applications where a high heat release per burner is required, but also a short flame length is required.

16.6.2 FLAT-FLAME BURNER

Some applications require a flat- or fan-shaped (rectangular) flame due to the close proximity of process tubes or due to the fact that the burner is fired along a wall. Figure 16.38 shows a typical staged-fuel flat-flame gas burner. This burner produces a free-standing flame and is used in applications where the process tubes are close to the centerline of the burner.

The advantage in using this particular burner is that the fuel staging can significantly reduce NO_x emissions. Based on fired capacity, they can utilize single or multiple primary and staged injectors to affect the proper fuel distribution to produce the desired flame pattern. A flat-flame burner can be fired in two basic configurations, wall-fired or free-standing.

16.6.2.1 Wall-Fired Flat-Flame Burners

A wall-fired, flat-flame burner is similar to a free-standing flat-flame burner except that it is installed and fired against a refractory wall (e.g., see Figure 16.12). By directing the fuel jets toward the wall, the flame heats the refractory wall, which, in turn, radiates heat to the process tubes facing the wall. Wall-fired burners are typically used in ethylene furnaces.

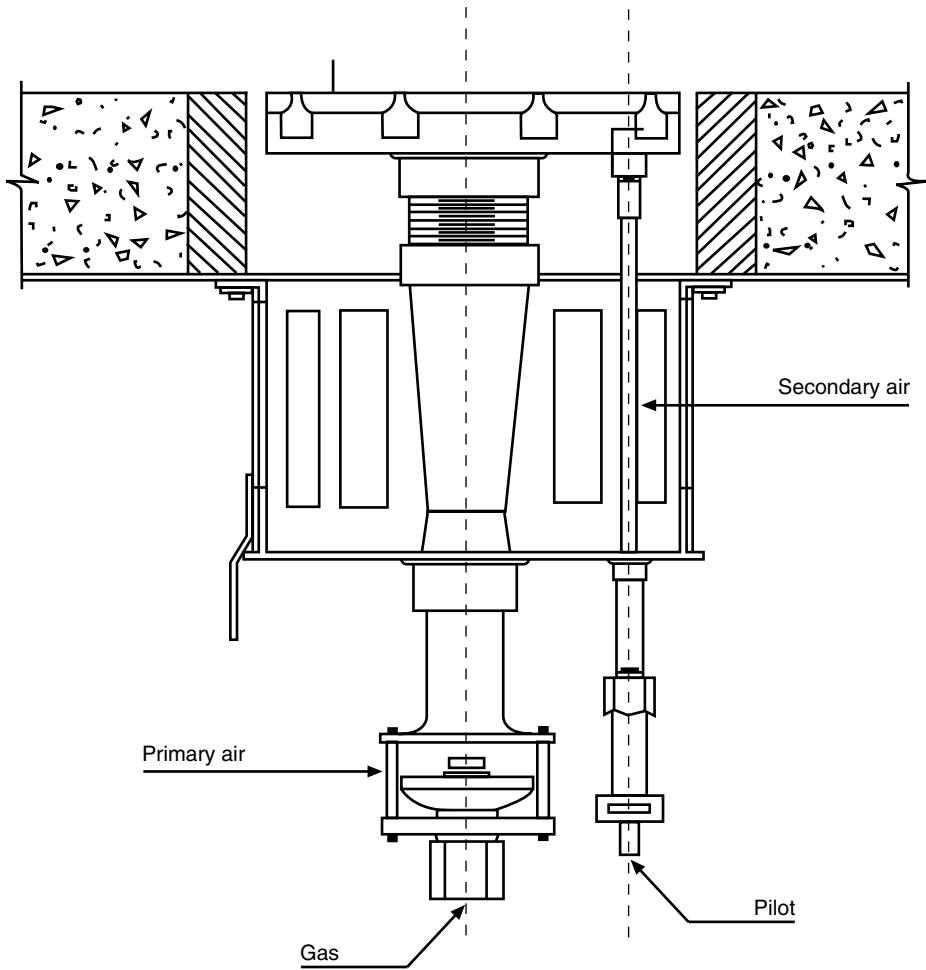


FIGURE 16.35 Typical premix gas burner. (Courtesy of John Zink Co., LLC.³)

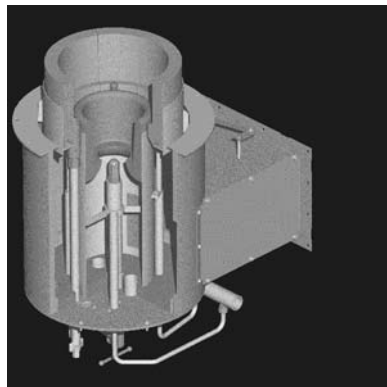


FIGURE 16.36 Typical round-flame combination burner. (Courtesy of John Zink Co., LLC.⁴)

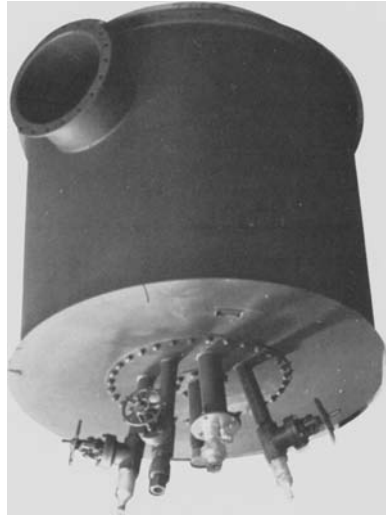


FIGURE 16.37 Typical round-flame, high-intensity combination burner. (Courtesy of John Zink Co., LLC.⁴)

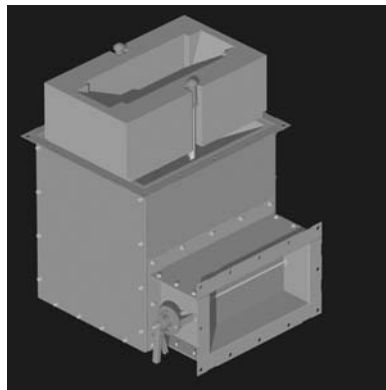


FIGURE 16.38 Typical staged-fuel, flat-flame burner. (Courtesy of John Zink Co., LLC.⁴)

16.6.2.2 Free-Standing Flat-Flame Burners

A free-standing flat-flame burner (see [Figure 16.29](#)) is used in applications where it is necessary to fire a burner in a narrow space between two sets of process tubes. The tube spacing often requires the use of a flat-flame burner, instead of round-flame burners that are normally used in these applications. A staged-fuel, flat flame is shaped by firing staged fuel jets opposite one another. This makes the flame shape into a fan. The flame thickness is typically less than or equal to the burner tile width. The fuel injectors are specifically designed to produce a relatively narrow flame width to avoid flame impingement on the nearby process tubes.

16.6.3 RADIANT WALL BURNERS

Radiant wall burners (see [Figure 16.11](#)) are used in cracking furnaces. These burners are mounted through the furnace wall and produce a thin, flat, circular disk of flame adjacent to the wall. There are typically multiple rows of burners equally spaced in a grid pattern on walls. The burners from row to row may be staggered or aligned (see [Figure 16.39](#)). The burners uniformly heat the walls, which radiate heat to the process tubes on the centerline of the furnace. [Figure 16.40](#) shows a drawing of a typical radiant wall burner.

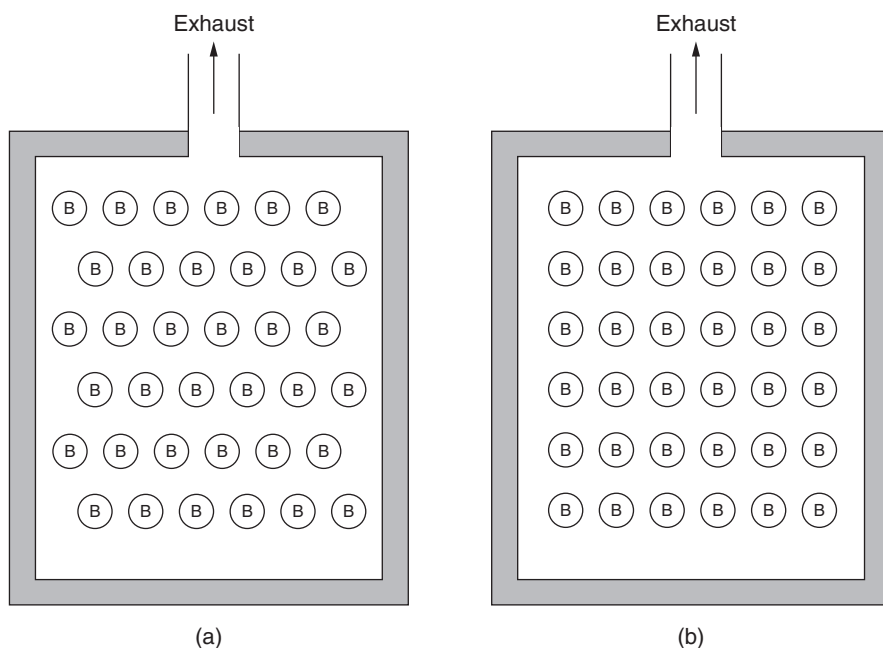


FIGURE 16.39 Elevation view of radiant wall burner arrangements: (a) staggered and (b) aligned.

Many applications, such as reformers and cracking furnaces, require high furnace temperatures in the radiant section of the heater to produce the required high process temperatures. In addition, very uniform heat transfer to the process tubes is needed. In such operations, a flat-flame burner that fires adjacent to a refractory wall, is utilized in conjunction with radiant wall burners.

16.6.4 DOWN-FIRED BURNERS

A down-fired burner is a burner that is fired vertically into a furnace from the ceiling (see Figure 16.4). Typically, these burners produce a flame that is round (conical) in shape. These burners are utilized in applications such as hydrogen reformers or ammonia reformers. Down-fired burners are often dual-fuel burners firing a make-up fuel and a waste gas. The make-up fuel can be gaseous, such as natural gas or a propane/butane blend. The make-up fuel may also be a liquid such as naphtha, no. 2 fuel oil, or diesel oil.

16.7 MATERIALS SELECTION

Burner materials are selected for strength, corrosion resistance, and, in many cases, temperature resistance. Carbon steel is used for most metal parts unless temperature or corrosion considerations require more resistant alloys. Cast iron or carbon steel can be utilized for fuel gas manifolds. The fuel gas riser material between the manifold and the fuel injector tip is generally carbon steel for ambient air service and 304 SS for parts in contact with air temperatures greater than 700°F (370°C). Fuel injector tips for premix burners may be cast iron. Cast steel or cast stainless steel may be required for fuel gases containing appreciable levels of hydrogen (typically >50 vol%) due to hydrogen embrittlement of carbon steel. Raw-gas burners typically use 300 series stainless steel gas tips. Tips for oil burners are normally 416 SS. For oils containing erosive particles, T-1 tool steel is generally used. Atomizers for oil service are normally brass for lower sulfur oils and 303 SS

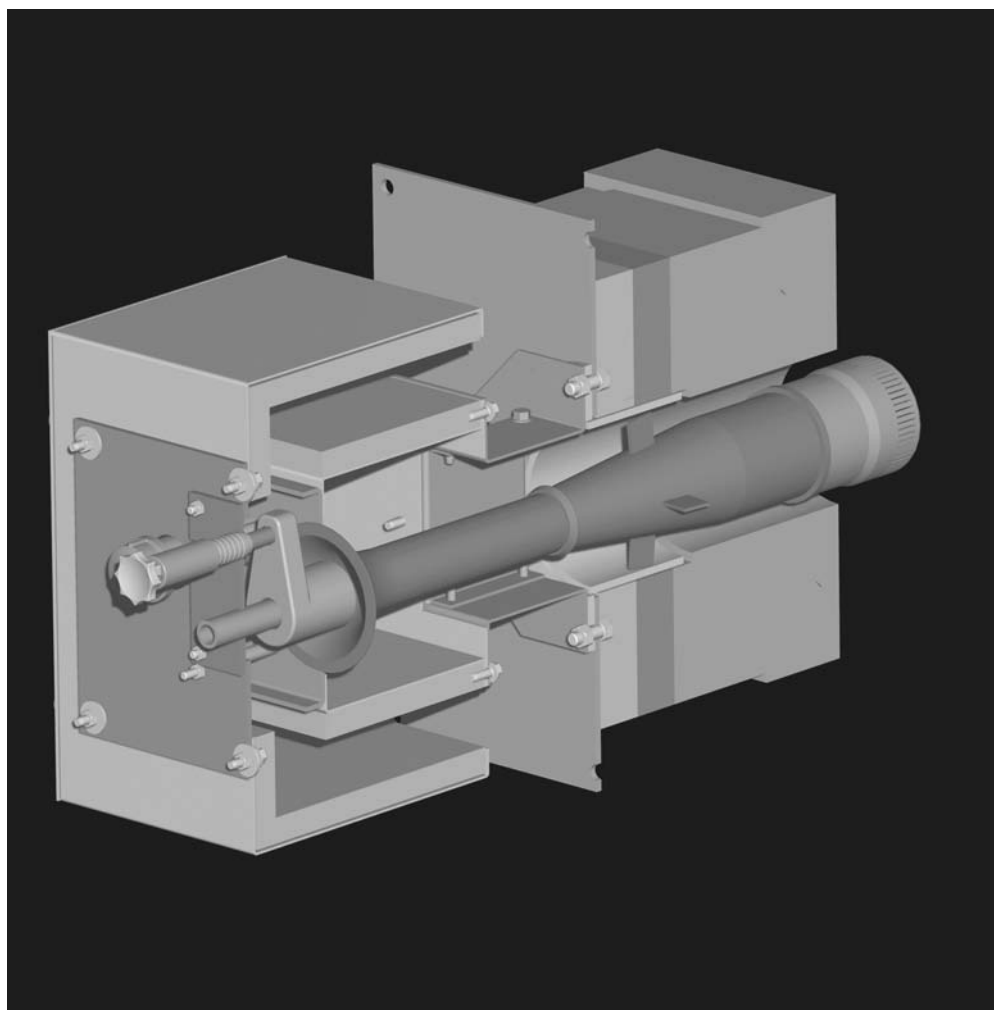


FIGURE 16.40 Typical radiant wall burner. (Courtesy of John Zink Co., LLC.⁴)

for oils containing higher sulfur contents. Other oil injector parts are carbon steel, although nitride-hardened parts may be used for erosive liquids. Flame stabilizer cones and swirlers are normally 300 series stainless steel.

Mineral wool is commonly used for noise reduction in the burner air inlet plenums. The burner block (tile) material is typically 55 to 60% alumina refractory with a 3000°F (1650°C) service temperature. Primary oil tiles may require 90% alumina refractory if the combined vanadium and sodium in the oil is greater than 50 ppm by weight.

16.8 CONCLUSIONS

Natural-draft burners are not commonly used in most industrial combustion applications, but are used extensively in the hydrocarbon and petrochemical industries. In this burner design, the combustion air is drawn into the burner rather than being supplied by a blower or fan, as is the case with forced-draft burners. One method for drawing in the air is by using the energy of a high-pressure fuel (>20 psig), which is usually widely available in refineries and petrochemical plants.

There, the fuel is typically a byproduct of the chemical production process of refining hydrocarbon fluids and is under some pressure by virtue of the transport through the plant piping. However, high fuel pressures are often not available in most other industries, which is one of the reasons natural-draft burners are not commonly used elsewhere. Another method for drawing in air is by the suction created by the draft in the furnace. Therefore, the conditions needed to practically use natural-draft burners for high heat release rates in furnaces and heaters are present in some industries but not others. While there are some cost savings associated with not having to buy a combustion air fan and the operating costs to run it, there are also some other factors to be considered. For example, natural-draft burners are typically larger than forced-draft burners for a given heat release rate, so the burner cost may be higher. Natural-draft burners are somewhat subject to weather conditions, particularly to the wind, which may adversely affect both the air flow into the burner and the furnace draft that may fluctuate as wind gusts flow over the exhaust stack outlet. This shows the importance of proper burner selection and design to ensure adequate performance for a given application.

REFERENCES

1. R.D. Reed, *Furnace Operations*, third edition, Gulf Publishing, Houston, 1981.
2. C.E. Baukal, Ed., *The John Zink Combustion Handbook*, CRC Press, Boca Raton, FL, 2001.
3. C.E. Baukal, Chapter 1: Introduction, in *The John Zink Combustion Handbook*, C.E. Baukal, Ed., CRC Press, Boca Raton, FL, 2001.
4. R.T. Waibel and M. Claxton, Chapter 11: Burner Design, in *The John Zink Combustion Handbook*, C.E. Baukal, Ed., CRC Press, Boca Raton, FL, 2001.
5. American Petroleum Institute, Burners for Fired Heaters in General Refinery Services, API 535, first edition, Washington, D.C., July 1995.
6. American Petroleum Institute, Fired Heaters for General Refinery Services, API 560, Washington, D.C., November 1996.
7. R. Hayes, C.E. Baukal, P. Singh, and D. Wright, Fuel Composition Effects on NO_x, *Proc. Air & Waste Management Association's 94th Annual Conf. & Exhibition*, Orlando, FL, June 24–28, 2001.
8. U.S. Dept. of Energy, Office of Industrial Technology, Petroleum — Industry of the Future: Energy and Environmental Profile of the U.S. Petroleum Refining Industry, U.S. DOE, Washington, D.C., December 1998.
9. U.S. Dept. of Energy, Office of Industrial Technology, Industrial Combustion Technology Roadmap, U.S. DOE, Washington, D.C., April 1999.
10. W.L. Nelson, *Petroleum Refinery Engineering*, second edition, McGraw-Hill, New York, 1941.
11. G.R. Martin, Heat-flux imbalances in fired heaters cause operating problems, *Hydrocarbon Processing*, 77(5), 103–109, 1998.
12. R. Nogay and A. Prasad, Better design method for fired heaters, *Hydrocarbon Processing*, 64(11), 91–95, 1985.
13. A. Garg and H. Ghosh, Good heater specifications pay off, *Chem. Eng.*, 95(10), 77–80, 1988.
14. H. Futami, R. Hashimoto, and H. Uchida, Development of new catalyst and heat-transfer design method for steam reformer, *J. Fuel Soc. Japan*, 68(743), 236–243, 1989.
15. H. Gunardson, *Industrial Gases in Petrochemical Processing*, Marcel Dekker, New York, 1998.
16. J.D. Fleshman, FW Hydrogen Production, in *Handbook of Petroleum Refining Processes*, 2nd edition, R.A. Myers, Ed., McGraw-Hill, New York, chap. 6.2, 1996.
17. J.S. Plotkin and A.B. Swanson, New technologies key to revamping petrochemicals, *Oil & Gas J.*, 97(50), 108–114, 1999.
18. D.Q. Kern, *Process Heat Transfer*, McGraw-Hill, New York, 1950.
19. N.P. Lieberman, *Troubleshooting Process Operations*, PennWell Books, Tulsa, OK, 1991.
20. H.S. Bell and L. Lowy, Equipment, in *Petroleum Processing Handbook*, W.F. Bland and R.L. Davidson, Eds., McGraw-Hill, New York, 1967, chap. 4.
21. E.B. Sanderford, Alternative Control Techniques Document — NO_x Emissions from Process Heaters, U.S. Environmental Protection Agency report EPA-453/R-93-015, February 1993.
22. L.A. Thrash, Annual Refining Survey, *Oil and Gas Journal*, 89(11), 86–105, 1991.

23. S.A. Shareef, C.L. Anderson, and L.E. Keller, Fired Heaters: Nitrogen Oxides Emissions and Controls, U.S. Environmental Protection Agency, Research Triangle Park, NC, EPA Contract No. 68-02-4286, June 1988.
24. H.L. Berman, Fired heaters. II. Construction materials, mechanical features, performance monitoring, in *Process Heat Exchange*, V. Cavaseno, Ed., Chem. Eng., McGraw-Hill, New York, 1979, 293–302.
25. A.J. Johnson and G.H. Auth, *Fuels and Combustion Handbook*, first edition, McGraw-Hill, New York, 1951.
26. G.L. Shires, Furnaces, in *The International Encyclopedia of Heat & Mass Transfer*, G.F. Hewitt, G.L. Shires, and Y.V. Polezhaev, Eds., CRC Press, Boca Raton, FL, 1997 493–497.
27. H.L. Berman, Fired heaters. I. Finding the basic design for your application, in *Process Heat Exchange*, V. Cavaseno, Ed., Chem. Eng., McGraw-Hill, New York, 1979, 287–292, .
28. V. Ganapathy, *Applied Heat Transfer*, PennWell Books, Tulsa, OK, 1982.
29. W. Bussman, R. Poe, B. Hayes, J. McAdams, and J. Karan, Low NO_x burner technology for ethylene cracking furnaces, *Proc. 13th Ethylene Producers' Conf.*, New York: American Institute of Chemical Engineers, Vol. 10, 714–740, 2001.