
15 Radiant Wall Burners

*Demetris Venizelos, Ph.D., R. Robert Hayes,
and Wes Bussman, Ph.D.*

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15.1 INTRODUCTION

Radiant wall burners, as discussed in this chapter, refer to burners that are typically designed to be installed in several rows along a furnace wall, as shown in [Figure 15.1](#). They typically fire radially outward along the furnace wall providing heat, which is transferred to the process tubes chiefly by thermal radiation from the wall and hot gases. This type of configuration is usually designed to provide uniform heat input to the process from the wall area comprising the radiant wall burner matrix.



FIGURE 15.1 Radiant wall burners (natural draft) firing in an ethylene-cracking furnace. (Courtesy of John Zink Co., LLC.)

Historically, radiant wall burners have been used in many hydrogen-reforming and ethylene-cracking heater applications.¹ These furnaces typically operate in the temperature range between 1900°F and 2300°F. The process fluid is circulated through process tubes, which are usually suspended in the middle of the furnace, and is heated to the required application temperature, with radiative heat transfer from the refractory side walls being dominant. The heat transfer from the furnace to the tubes (and the use of a catalyst in some applications) converts the process fluid to the final product via the appropriate chemical reactions. As one can expect, the product yield efficiency of the process in these furnace operations depends heavily on the heat transfer. Through the years, furnace and burner manufacturers have devoted considerable research efforts to determine the optimum heat flux profiles in various furnace-burner configurations to optimize product yields.

The two most common burner configurations used in furnaces with radiant wall burners are the following: (1) heat input from a combination of hearth burners located on the floor firing vertically upward along the wall, and radiant wall, burners located on the wall above the hearth burner flames, and (2) heat input entirely by radiant wall burners configured in a matrix that extends from the top to the bottom of the furnace radiant section. An illustration of each of these configurations is shown in Figure 15.2. In both burner-furnace configurations described above, the radiant wall burners are arranged in several rows located at different elevations on the furnace wall. The heat release, spacing, and spacing pattern (grid pattern) of the radiant wall burner matrix are designed to suit the radiant heat flux distribution needs of the particular process. Figure 15.3 shows typical heat flux profiles in a furnace operating with hearth (floor) burners only, and with both hearth and radiant wall burners firing.

FIGURE 15.2 Common radiant wall burner application furnace configurations.

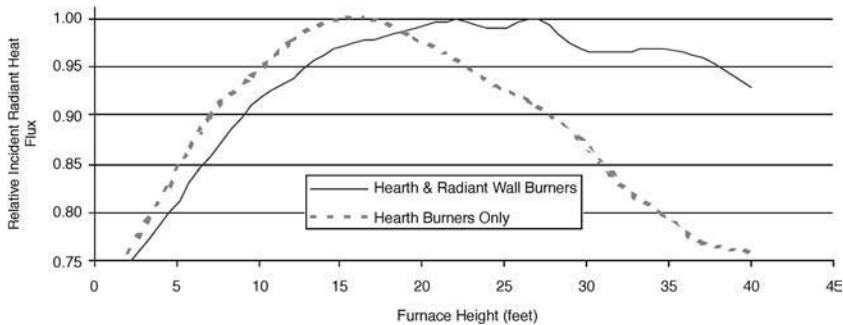
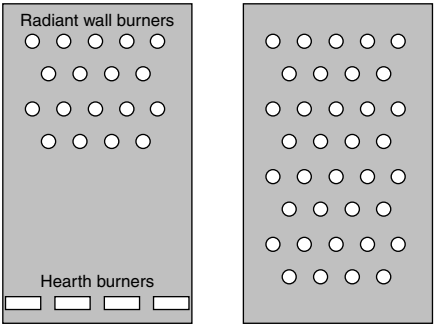


FIGURE 15.3 Heat flux profiles with and without radiant wall burners.



FIGURE 15.4 Forced-draft radiant wall burners in an ethylene-cracking furnace. (Courtesy of John Zink Co., LLC.)

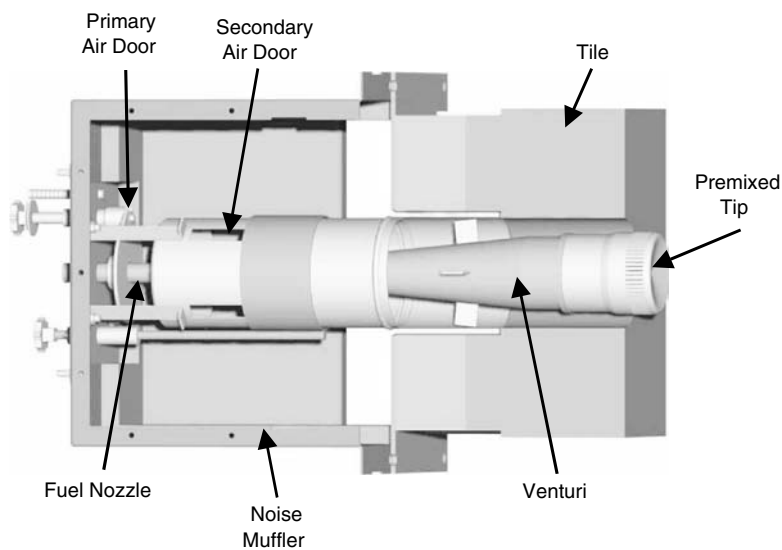
There are many different designs of radiant wall burners, including premix and raw-gas radiant wall burners, as well as forced- and natural-draft burners. A row of forced-draft radiant wall burners in operation is shown in Figure 15.4. The discussion in this chapter focuses mainly on natural-draft, premix, radiant wall burners, as they are the most widely used in cracking and reforming heaters. Descriptions of the components of these burners are given, along with design and operational considerations.

15.2 BURNER DESCRIPTION

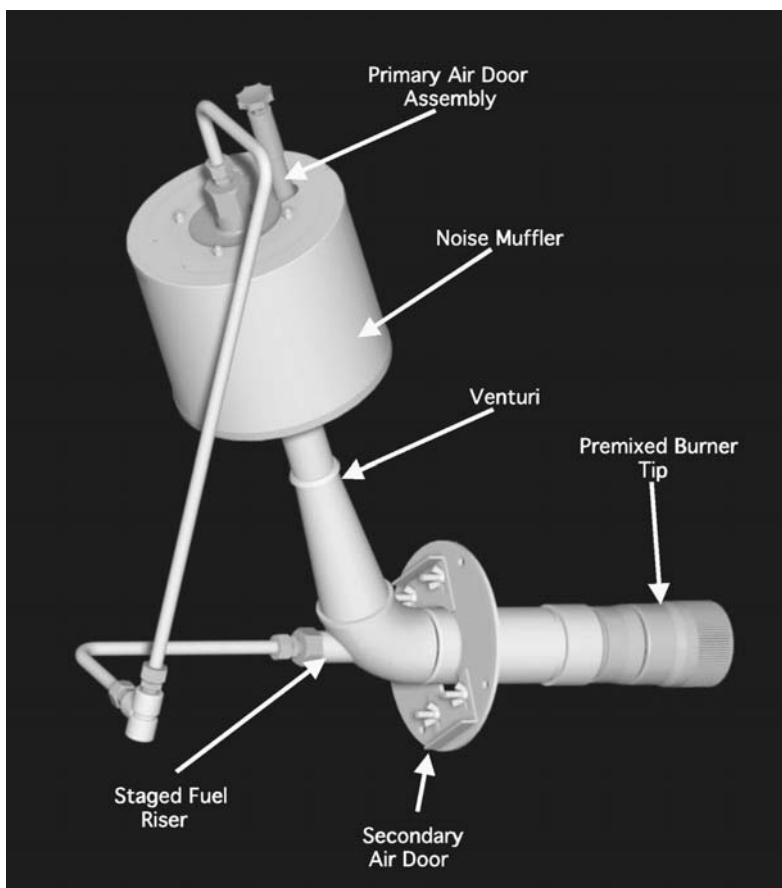
15.2.1 BURNER COMPONENTS AND DESIGN PARAMETERS

[Figures 15.5a](#) and [15.5b](#) illustrate typical radiant wall burners. These types of burners are usually mounted horizontally through the heater steel and burner tile along the furnace wall. The main components of these burners include:

1. Primary fuel nozzle (spud)
2. Venturi section (inlet, throat, and diffuser)
3. Premix burner tip
4. Primary air door assembly
5. Secondary air door assembly
6. Burner tile
7. Muffler/rain shield
8. Staged fuel riser and tip assembly



(a)



(b)

FIGURE 15.5 Solid model illustrating (a) a radiant wall burner and (b) a radiant wall burner with fuel staging. (Courtesy of John Zink Co., LLC.)

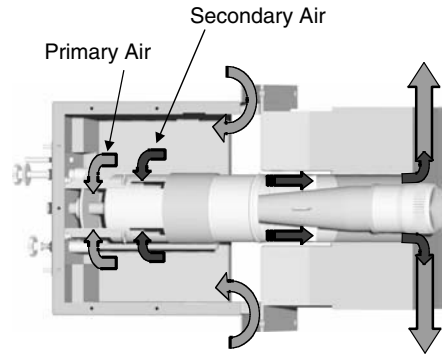


FIGURE 15.6 Illustration of the primary and secondary air flows through a radiant wall burner.

A typical radiant wall burner operates as a premixed burner. The objective in a natural-draft premixed burner is to use the energy from a fuel jet as the motive force to educt combustion air and transfer the fuel/air mixture through the burner and into the furnace where the combustion occurs. Forced-draft burners operate the same as natural-draft burners, with the exception that they can utilize the energy of the forced incoming air stream. Secondary air openings can also be used to inspire air for combustion by means of the furnace draft. A diagram showing pathways of primary and secondary air flow is shown in Figure 15.6.

The fuel is injected at high velocities from a port on the primary fuel orifice (or primary fuel spud) into the venturi throat where it mixes thoroughly with the educted air. The fuel/air mixture then flows through the diffuser and the downstream section before entering the premix burner tip. The flow then turns and exits through openings in the burner tip in a radial direction near the furnace wall. Depending on the burner manufacturer, these openings can have different shapes and sizes.

In a staged fuel radiant wall burner configuration, the stage fuel riser(s) supply(ies) the stage tip(s) with fuel. The location of the staged fuel tip(s) can vary, depending on the manufacturer and type of burner. Each component of this type of burner design, along with many other operating parameters, are important in providing maximum air entrainment and optimum performance. Understanding the importance of the venturi eductor and premix burner tip geometries allows one to design an optimal burner system. The remainder of this section discusses each component in additional detail.

15.2.1.1 Entrainment of an Eductor System

When a fuel exits a port, it will interact with the surrounding gas. The fuel jet will entrain the surrounding gas and mix as it flows downstream of the port. This process is called *free jet entrainment*. A premixed burner simply consists of a free jet with a venturi located just downstream. The fluid dynamic principles that apply to free jet entrainment also apply to an eductor system. However, the amount of surrounding gas entrained is reduced compared to free jet entrainment. The reduction in entrainment performance is due to momentum losses associated with the flow-restricting geometry of the venturi and burner tip system. Minimizing the momentum losses associated with the venturi system is an important aspect of premix burner design. Some premix burners require a design that achieves maximum entrainment performance for successful operation. The challenge in many instances is to optimize the burner design that will maximum entrainment performance.

15.2.1.2 Venturi Inlet Bell

The inlet to the venturi is typically designed as a well-rounded bell entrance. A well-rounded inlet bell helps minimize momentum losses through the venturi system. Idelchik⁷ reports values for the hydraulic resistance for flows through the inlet of a bell entrance. Typically, in the burner industry,

the bell inlet is designed with a radius r with a value that is at least 20% of the hydraulic diameter D_h of the throat ($r/D_h \geq 0.20$). One should keep in mind that the air door, spud holder, and fuel spud will also introduce additional restrictions to the air flow and can reduce entrainment performance.

The position of the primary fuel spud with respect to the venturi inlet bell also affects the entrainment performance. Depending on the venturi design, the entrainment performance is usually optimized when the fuel spud is located near the entrance plane of the inlet bell.

15.2.1.3 Venturi Throat

The area of the venturi throat can have a significant influence on the entrainment performance of a premix burner. The throat diameter required to achieve maximum entrainment performance depends on the overall design of the burner. For example, premix burners that consume a large pressure drop through the tip exit will require a smaller venturi throat diameter to achieve optimum entrainment performance. As the venturi throat diameter increases, for a given burner design, the entrainment performance increases until the throat diameter reaches an optimum value, beyond which any increase in throat diameter will result in a reduction of entrainment performance, as illustrated in Figure 15.7.

The throat length is another important parameter in venturi design. It is generally recommended that the length of the venturi throat should be approximately 7 times the throat diameter for maximum entrainment performance.

15.2.1.4 Venturi Diffuser

Located downstream of the venturi throat is the diffuser. The diffuser is a conical section that provides a gradual transition, increasing in diameter from the throat to the downstream section of the burner. To reduce momentum losses, it is recommended that the total divergence angle of the diffuser section be less than 10° . Designing diffuser angles with larger values will result in the formation of recirculation zones in this section of the venturi that can significantly reduce entrainment performance.

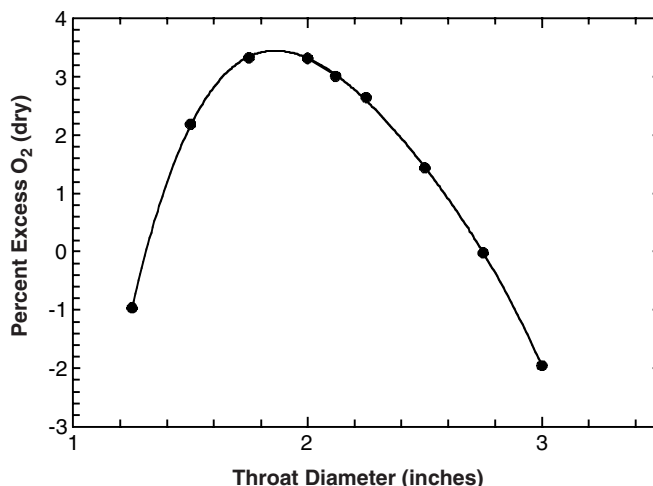


FIGURE 15.7 Effect of throat diameter sizing on air entrainment with other parameters held constant, for a given radiant wall burner design.

15.2.1.5 Downstream Section

The downstream section of the burner is typically a straight pipe that connects the exit of the diffuser section with the burner tip. The length of the downstream section usually varies, depending on the mechanical design requirements. Typically, the downstream section length is determined by the thickness of the furnace wall and mounting or platform requirements.

As shown previously in [Figure 15.5b](#), some premix burners are designed with a bend in the downstream section to accommodate these requirements. The elbow in the downstream section will introduce additional momentum losses. Using long-radius elbows with shallower angles can reduce these losses and improve entrainment performance. After a turn in a pipe, the flow downstream will be highly skewed toward the outer side of the elbow. Depending on the elbow geometry, a longer downstream straight section should be used to allow the gas mixture flow profile to distribute evenly before exiting the burner tip. A nonuniformly distributed flow at the burner tip exit could create problems with flame quality and flashback during operation.

15.2.1.6 Premix Burner Tip and Internal Baffle

As previously shown in [Figures 15.5a](#) and 15.5b, the premix radiant wall burner tip can be comprised of many thin slots or, as shown in [Figure 15.8](#), the tip can utilize fewer larger openings at the exit. A turning baffle located inside the tip to assist in turning the flow can be utilized to help provide more uniform flow profiles at the tip exit and minimize pressure losses.

15.2.1.7 Burner Tile

The burner tile in which the burner insert is mounted provides protective insulation for the burner internals, and the fired tile surface provides a region for flame stabilization and radiant heat transfer

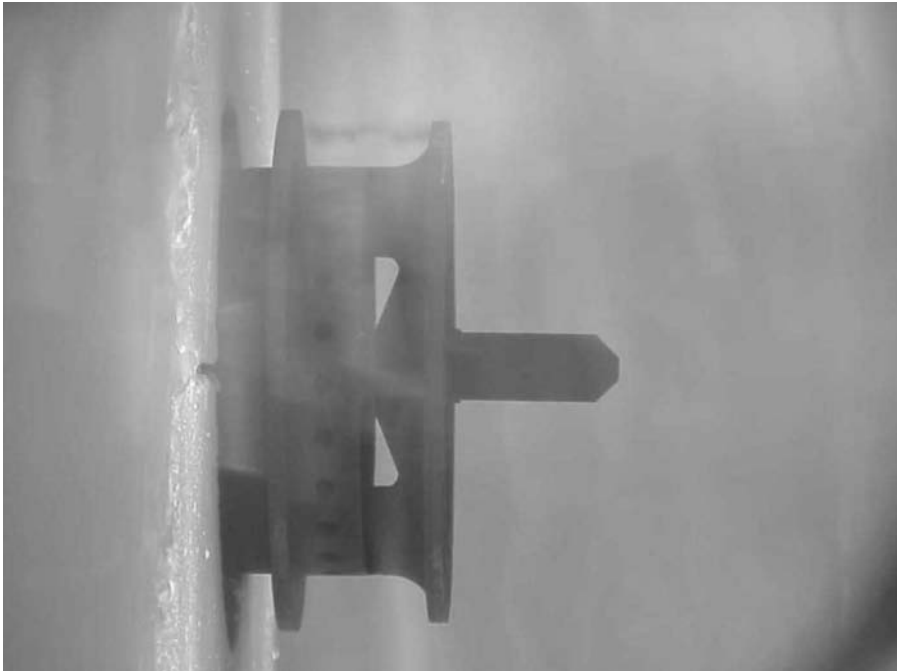


FIGURE 15.8 Photograph of radiant wall burner firing in a test furnace. (Courtesy of John Zink Co., LLC.)

to the process tubes. Tile materials typically consist of hard refractory rated for very high temperatures as the face is exposed to direct contact with the flame.

15.2.1.8 Muffler/Rain Shield

The burner muffler serves the purpose of reducing noise emissions and keeping precipitation and foreign materials from entering the burner inlet. The muffler typically consists of a thin metal liner insulated with noise-attenuating fiber material. The muffler is designed to be large enough so that pressure losses through the inlet and required turns are minimized, to provide maximum capacity for a given venturi system.

15.2.1.9 Air Doors

The primary air doors are used to control the amount of air entrained in the venturi that is premixed with the primary fuel gas. The secondary air door/damper controls the amount of airflow through the burner openings external to the venturi system. The secondary air, inspired by the furnace draft, is not premixed with any fuel prior to entering the combustion zone.

15.2.1.10 Staged Fuel Riser and Tip Assembly

Staged fuel risers and tip assemblies can be utilized in some burner designs. The staged fuel is typically injected at locations where it is allowed to mix with inert furnace gases prior to combustion. The location and method of staged fuel injection varies according to design to reduce NO_x emissions and achieve desired flames shape.

15.3 DESIGN CONSIDERATIONS

Similar to any other combustion system, a successful radiant wall burner design requires understanding of the fundamentals and principles in a wide range of fields, including combustion, fluid dynamics, heat transfer, physics, chemistry, and materials. The importance of some of the different considerations relevant to the design of a premixed radiant wall burner are discussed in this section.

15.3.1 FUELS

An important parameter in the successful design and operation of a radiant wall burner is the available fuel pressure and specified fuel compositions that will be fired. In many petrochemical and refinery applications, the fuel gas composition that a radiant wall burner is required to fire can vary widely because it is made up of various gas streams from different processes that change with time. A burner may be required to operate on both very heavy fuels with high heating value contents and very light fuels containing high levels of hydrogen during periods of start-up, normal operations, or upset conditions. This poses a significant design challenge because the fuel is used as the primary motive force to inspire the required combustion air. Variability in fuel gas compositions can significantly affect the amount of air that can be inspired and premixed. If a wide range of possible fuel compositions is required, the burner should be designed to be optimized for the typical fuel gas composition. This often limits the achievable firing rates for very high or low Btu content fuels. For high Btu content fuels (heavy fuels), the limit is often due to constraints in air education; while for low Btu content fuels (light fuels), the firing rate may be limited due to the maximum available fuel pressure.

15.3.2 FLAME STABILITY

15.3.2.1 Flashback

Flashback is a phenomenon that occurs in premix burners when the flame front propagates through the burner tip and into the venturi, as illustrated in [Figure 15.9](#). This phenomenon occurs when the local flame speed of the burning mixture outside the burner tip exceeds the velocity of the mixture exiting the tip. When a flashback occurs, the flame will typically stabilize inside the burner tip or just downstream of the primary fuel orifice.

Usually, flashback is easily recognized by an intermittent appearance of flame at the fuel orifice and a loud distinct noise. If flashback occurs and is left uncorrected, the venturi and/or burner tip can be quickly damaged due to overheating. When a flashback is detected, the operator should immediately shut off the burner and determine what actions must be taken to eliminate the unsafe operating condition. Several factors governing the flashback potential of a natural-draft premix burner include: (1) fuel composition, (2) air-to-fuel ratio, and (3) tip design.

The fuel gases most susceptible to causing flashback are the ones with higher flame speeds, such as hydrogen or ethylene. These fuels have characteristic flame speeds that are about 5 to 10 times greater than the characteristic flame speed of methane.

In addition, the flame speed of a fuel largely depends on the local air/fuel ratio. For example, the flame speeds of hydrogen for various volumetric air/fuel ratios are listed in Table 15.1.

Notice that the flame speed for hydrogen varies significantly with the air/fuel ratio. For most typical fuel gas components, maximum flame speed levels generally occur near stoichiometric or slightly sub-stoichiometric (fuel-rich) conditions. The local temperature of the flame region also affects flame speed. For example, higher furnace operating temperatures or higher inlet air temperatures result in increased flame velocities.

The design of the premix burner tip is critical in preventing flashback. There are several factors that should be considered when designing the geometry of a premix burner tip to avoid flashback.

TABLE 15.1
Variation of Laminar Flame Speed of Hydrogen

Volumetric Air/ Fuel Ratio	Laminar Flame Speed at 60°F (ft/s)
1.19	5.9
1.70	9.2
2.38 (stoichiometric)	6.9
4.77	1.3

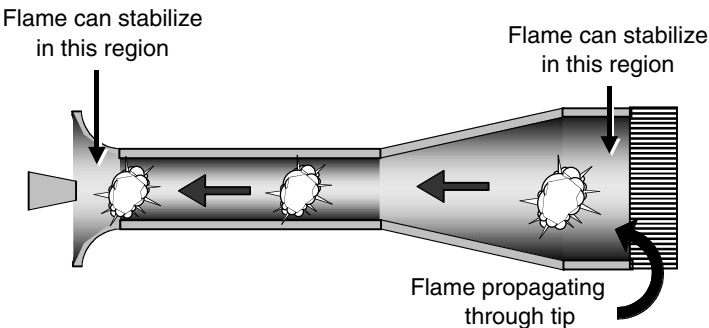


FIGURE 15.9 Illustration of the flashback phenomenon.

These factors include: (1) maximize tip exit velocity of the air/fuel mixture, (2) provide uniform velocity profile of the air/fuel mixture at the tip exit plane, (3) promote laminar flow at the tip exit plane, and (4) provide sufficient quenching distance.

15.3.2.2 Flame Attachment and Liftoff

The flame from a premix burner can be stabilized in a region where it attaches to the tip, as shown in Figure 15.10. This photograph clearly shows that the position of the flame front is located near the burner tip exit plane and is typically referred to as *flame attachment*. In the flame attachment

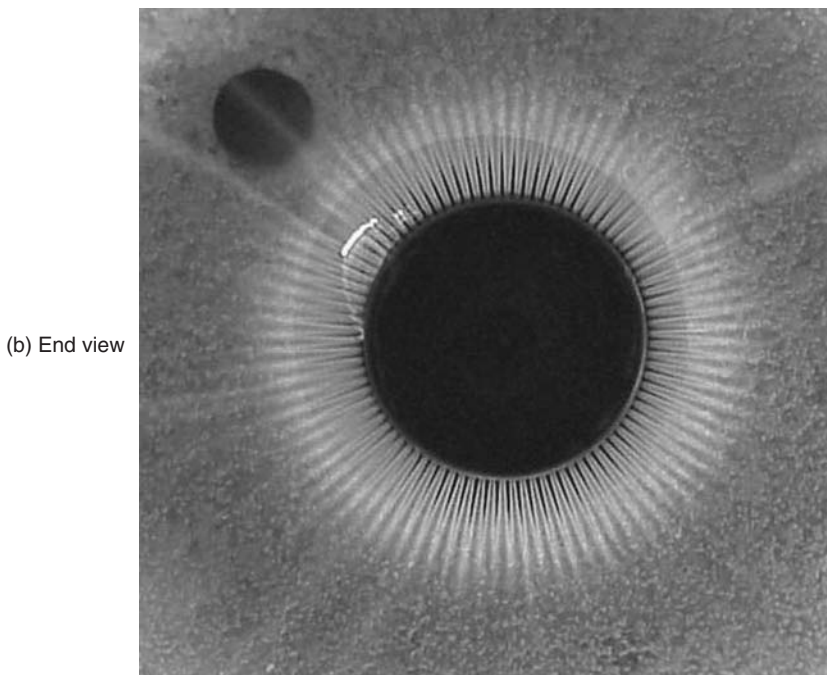
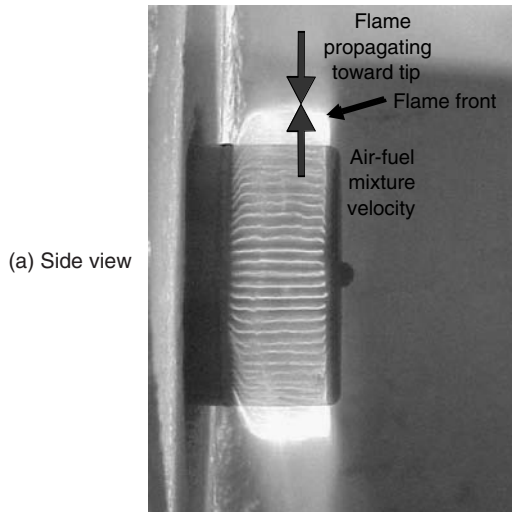


FIGURE 15.10 Photograph of flame attachment on a radiant wall burner tip. (Courtesy of John Zink Co., LLC.)

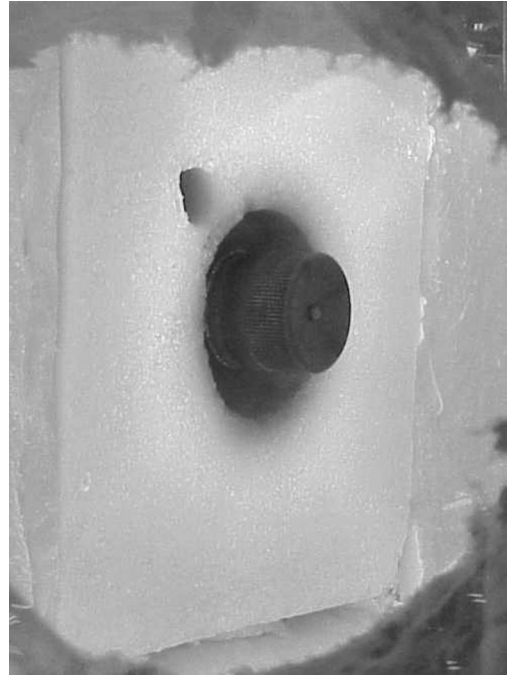


FIGURE 15.11 Photograph of flame detachment on a radiant wall burner tip. (Courtesy of John Zink Co., LLC.)

mode, the velocity of the air/fuel mixture exiting the tip prevents the flame front from propagating through the premix burner tip openings causing a flashback.

Radiant wall burners are also often designed to operate with the flame stabilized in a region some distance away from the premix tip exit along the hot surface of the fired wall. This detached flame is stabilized by radiant heat emitted from the refractory wall. Figure 15.11 shows a burner operating in this detached mode. This mode is typically desirable during hot furnace operation and can result in the reduction of NO_x emissions, as inert furnace gases are entrained into the mixture prior to combustion. However, if local exit velocities of the mixture substantially exceed local flame velocities and/or local temperatures are not maintained at levels high enough to sustain stable combustion, it is possible that the flame could lift off and blow out.

15.3.3 EMISSIONS

Historically, early radiant wall burners were designed with the primary goals of having stable, complete combustion (low CO and unburned fuel emissions), and providing desired heat transfer characteristics. These radiant wall burners were commonly partially premixed burners — meaning that the primary air educted through the burner was not sufficient for complete combustion of the fuel (i.e., fuel-rich mixture). Additional air (secondary air) was supplied through the space between the burner venturi/tip assembly and the tile and was controlled with secondary air doors as previously illustrated in [Figure 15.5a](#). The nitrogen oxide (NO_x) emissions from these previous burner designs are relatively high, due to relatively high peak flame temperatures.

As requirements for lower NO_x emissions arose, radiant wall burners were developed that utilized different fuel staging schemes to lower NO_x emissions. In some configurations, secondary fuel (staged fuel) risers were used to stage the fuel between the primary premixed flame and the furnace wall to reduce NO_x emissions. In other configurations, the fuel was staged on the furnace side, rather than the wall side, of the primary premixed flame. As in other types of burners, staged fuel technology can be used to reduce emissions by reducing the peak flame temperatures in the fuel-rich, staged-flame zones by entrainment of inert furnace gases prior to combustion. Typically, less than 25% of the fuel was staged in these types of radiant wall burners. Although staging a

portion of the fuel is an effective technique to reduce NOx emissions, less fuel is available in the primary zone to entrain the required air for complete combustion. Additional air required for combustion could be supplied through secondary air openings, but this can also result in detrimental increases in flame temperatures and NOx emissions, due to early mixing and reacting of the secondary air with the staged fuel.

In recent years, federal and state regulations in the U.S. have required further reductions in NOx emissions from hydrogen-reforming and ethylene-cracking heaters employing radiant wall burners. New technology employed to achieve these desired emission levels combines a very fuel-lean premixed primary flame with fuel staging.^{4,5} Lean premixed combustion has been the subject of research in academia and industry to successfully reduce NOx emissions. Lean premixed combustion results in very low peak flame temperatures in the primary premixed flame zone as the stoichiometry in this region approaches the limits of flammability, as illustrated in Figure 15.12. Highly efficient venturi systems are employed to achieve the required stoichiometry in the primary fuel/gas mixture. Currently, the best available radiant wall burner technology can achieve entrainment and mixing of 100 to 115% of the total required air for complete combustion with a portion of the fuel. The remainder of the fuel is staged, with little or no secondary air required. Typical NOx levels achievable with the different radiant wall burner technologies discussed are shown in Table 15.2.

	Early Designs with Secondary Air	Staged Fuel Designs	Lean Premixed Designs
Premixed mixture	100% fuel/<100% air	75–90% fuel/<100% air	40–70% fuel/100% air
Secondary air	Yes	Yes	No
Staged fuel	No	Yes	Yes
Typical NOx emissions (1900–2250°F firebox)	75–120 ppm	40–75 ppm	20–35 ppm

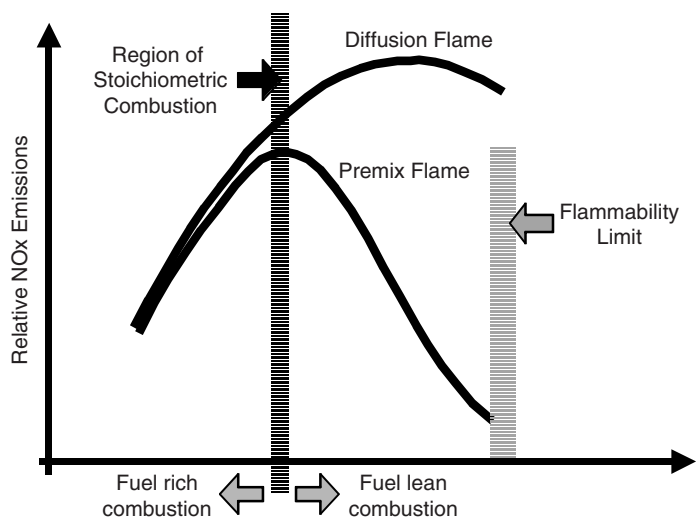


FIGURE 15.12 Effects of stoichiometry on NOx emissions.

15.3.4 BURNER SPACING

Burner location and spacing along the heater wall can play an important role in determining operating performance of the furnace. In typical applications, the desire is to evenly heat the wall to relatively high temperatures without causing local overheating of the process tubes. Overheating can cause fouling or coking of the tubes and decrease product yields and unit run lengths. When burners are spaced too closely together, the burner flames can interact significantly, causing local hot spots and increased NO_x emissions. If they are spaced too far apart, the unit efficiency might be negatively impacted by not providing the maximum levels of heat transfer to the process tubes achievable with the given furnace geometry.

15.4 RETROFIT CONSIDERATIONS

In new heater installations, there is more flexibility for collaboration between the burner and heater manufacturers to provide burner and furnace configurations that complement each other for optimal process performance. However, in existing heaters, many constraints for retrofit with newer burner technologies may be present. This is due to the furnaces being originally designed with geometries optimized for older-technology burners. Several parameters, such as existing burner cutouts, heater dimensions, the distance between the process tubes and the refractory walls, the size of the hole in the tile through which the burner is inserted, the space limitations for personnel access to the burners outside the furnace, or the maximum available fuel pressure, can place many constraints on a burner designed for retrofit to meet new emissions requirements.

15.5 OPERATION AND TROUBLESHOOTING

15.5.1 OPERATION

Proper operation of radiant wall burners during cold light-off, normal operation, and turndown conditions is important in achieving the desired performance. Typically, cold light-off is achieved by inserting a lighting torch near the burner tip exit to provide an ignition source as the fuel gas is opened to flow through the burner. When lighting burners in cold furnace conditions, the air flow is adjusted (typically by positioning the burner air doors or dampers) to provide for a stable flame that is positioned close to the burner tip exit (i.e., attached flame) — see [Figure 15.10](#). As the furnace warms up and the fired wall temperature increases, the burner can be adjusted so that the flame lifts further away from the burner tip and stabilizes along the surface of the hot fired refractory wall. During normal operation, burner air doors should be adjusted appropriately at the different burner elevations to achieve the desired excess air levels locally and globally that optimize combustion efficiency and NO_x emissions. During turndown conditions, fuel flow is reduced, which can lead to flashback conditions if mixture exit velocities become less than the local flame speed at the burner tip exit.

15.5.2 TROUBLESHOOTING

15.5.2.1 Burner Tip Plugging/Coking

Fuel ports can become plugged from particulates in the fuel lines, such as pipe scale, salts, dirt, materials dissolved in liquids in the fuel, or from hydrocarbon liquids in the fuel that crack when they encounter the hot surface of the fuel port, leaving behind coke. If plugging occurs, the firing capacity of the furnace will be reduced for a given fuel pressure. Plugged ports can also create uneven flame patterns within the furnace, flame instability, flashback, or coking of the burner tip.

Coke is a black, solid, carbon-based material that can build up on the inside of a burner tip. Coke buildup usually occurs when fuel containing heavy hydrocarbons, unsaturates, or liquids

comes in contact with the hot metal surface of the burner tip. When the fuel encounters the surface of the tip, and temperatures are elevated above acceptable levels, the fuel gas can crack, creating soot and coke buildup. This buildup can block off the premix burner tip, resulting in a reduction in the entrainment performance of air through the burner. As the coke continues to build up inside the tip, the air flow becomes more restricted, causing the tip temperatures to continue to rise. Eventually, the tip can be destroyed due to the lack of air flowing through and cooling it.

Filtration of fuel stream to remove liquids and/or particulates is recommended to prevent burner tip from plugging/coking. Burner tips should be regularly inspected and cleaned or replaced, if necessary, to maintain optimal burner performance.

15.5.2.2 Furnace Air Leakage

In the typical operation of a heater, the excess air for the entire heater is monitored and appropriately adjusted for the specific process to meet a global target (typically 2 to 3% excess O₂ in reforming and ethylene-cracking applications). If air is unintentionally being pulled into the heater by the furnace draft through openings other than the burners, local air/fuel ratio conditions at the burners and in the flame zones may be very different from those designed (i.e., optimal). This can result in incomplete combustion or increases in NO_x emissions.

15.6 CONCLUSION

Radiant wall burners are an important, widely used component in petrochemical industries. They are utilized to achieve specific heat flux conditions in relatively high temperature furnace applications, such as reformers or ethylene-cracking units. Historically, the design of these burners has changed to meet increasingly stringent emissions requirements. Proper design of the burner components and consideration of a variety of factors are necessary, combined with proper operation, to achieve the best burner performance. This will consequently have a significant impact on heater performance with regard to process efficiency and yield, equipment durability, and emissions.

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Footnote

U.S. Patent No. 4702691 and 5180302, U.S. and International patents pending.