Flame interaction and rollover solutions in ethylene cracking furnaces

During plant expansion or construction of new facilities for olefins plant, it is important to keep in mind the interactions of flame, fuel and lower emissions

REX K ISAACS
Zeeco

Due to an increasing supply of North American shale gas feedstocks, many petrochemical companies are restarting once-idled olefins facilities or planning plant expansions. Since these facilities may have been out of commission for several years, operators should be aware that existing ethylene furnace equipment might not meet today's emissions requirements. This article will discuss the challenges facility operators face when retrofitting furnaces with the latest burner technology to achieve required emissions levels.

Retrofitting ethylene furnaces with the latest burner technology can be difficult due to burner spacing issues and their resulting effect upon burner flame quality. As existing furnaces are upgraded to achieve higher capacities, more floor burners are added. The addition of more burners can result in smaller distances between burners and more potential for adverse flame conditions, such as burner-to-burner flame interaction and flame rollover.

Flame interaction between burners can cause flame impingement upon the process tubes and increased emissions. Flame impingement can also be problematic for prolonged ethylene production, resulting in shorter run lengths and higher tube metal temperatures, which can cause premature coking and lead to shorter periods between decoking, reducing ethylene production and outputs.

One of the other primary concerns for the end user operating company is flame rollover. When the momentum of the hot gases moving upwards from the burner becomes less than the momentum of the colder gases moving down the furnace tubes, flame rollover occurs. One product developed to address these concerns is the patented ultra-low NOx GLSF Min-Emissions Enhanced Jet Flat Flame burner. In this article, we will review the design details for this type of burner, provide specific retrofit installation details in a case study format, review lessons learned during the retrofit, and include results for several of the retrofit applications.

An inherent design aspect of the burner is the fact that the fuel gas is introduced between the furnace wall and the air stream. Consequently, flame interaction between burners is minimised due to the location of the burner tip and the very compact design. Since the gas does not cross the air stream, the tip drilling design can be modified to achieve better heat flux profiles without adversely effecting the thermal NOx emissions.

Application background

Since the early 2000s, Zeeco and a petrochemical facility have worked together on many ethylene furnace revamp applications where the number of floor burners increased and the burners had to be moved closer. Even in these situations, using the right technology helps avoid problematic occurrences such as flame rollover and interaction.

To achieve improved flame quality without any flame rollover or flame interaction, the customer selected Zeeco's

GLSF Min- Emissions floor-mounted burners. As Figure 1 shows, this burner is designed to entrain the unburned gas next to the wall to prevent flame rollover as the furnace currents pull the air and products of combustion towards the tubes. As the unburned gas moves up the wall, it mixes with the inert flue gas products of combustion, burning directly below the unburned gas. As the mixture of unburned gas and products of combustion continues to move up the wall, it combines with air and burns. Since the unburned gas is mixed with some of the products of combustion before burning, the peak flame temperature is lowered, producing lower thermal NOx emissions. Therefore, not only are flame rollover and flame interaction problems solved, but ultra-low emissions can be achieved.

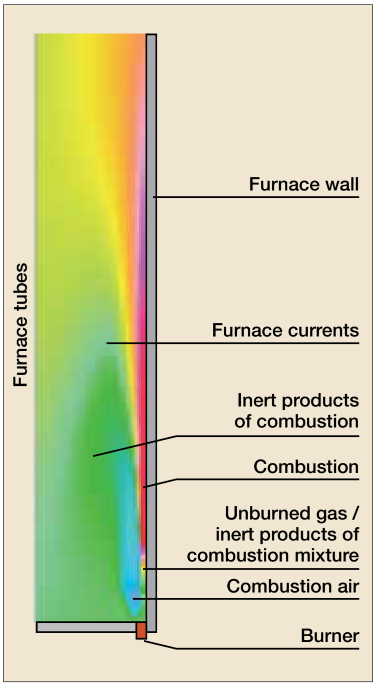

Figure 1 Computational fluid dynamics (CFD) model of GLSF burner

Comparison to low emission burners

Low emission burners found in ethylene cracking units typically use staged fuel technology. These particular burners have staged fuel tips strategically positioned for fuel to exit the orifices and pass over the combustion air stream before reaching the furnace wall. In order to modify the flame pattern to achieve an even heat flux in the lower portions of the flame envelope, the orifices must be drilled at increasingly abrupt angles towards the furnace wall. These orifice angles cause the air and fuel gas to mix at a faster rate, thus increasing thermal NOx and requiring a compromise between the heat flux profile and thermal NOx production. As the heat flux profile is made more uniform, with an average above 90%, the NOx emissions typically increase along with the increase in flux percentage. In the same respect, as the NOx is decreased, the heat flux percentage is also decreased.

It is important to note that the location of the staged gas tips also affects the flame quality of the burner. For example, if the burner is required to make very low NOx emissions, the staged orifices must be aimed in a more vertical direction. This vertical direction, coupled with the combustion air stream located in between the unburned gas and the furnace wall, increases the likelihood of flame impingement. The mixing of the fuel gas energy becomes so reduced at higher elevations that the furnace currents can easily influence the flame towards the tubes. In general, the lower the NOx emissions when the staged gas has to pass completely over the combustion air opening, the higher the tendency for flame impingement or hot spots on the tubes.

The latest in low emission burner technology, such as the GLSF Min- Emissions burner, incorporates staged gas tips with gas ports aimed towards the wall in a pattern that provides a very uniform heat flux profile in the middle to upper regions of the flame envelope. The mounting of the burner's flame-shaping tips on the side of the combustion air stream allows the gas to avoid passing directly over the combustion air stream. The primary gas tips and gas lance provide the necessary heat distribution in the lower regions of the flame envelope. Since the burner mixes internally inert flue gases, the flame is stretched over a longer distance, enabling a more uniform heat flux distribution on the furnace wall. With the flame-shaping tips located on the side of the combustion air stream, the burner heat flux profile can be changed without adversely affecting NOx or causing flame impingement on the tubes. The burner can then evenly transfer heat to the process tubes and reduce the possibility of localised hot spots while producing lower NOx emissions.

Figure 2 shows a comparison between the Min-Emissions burner and a typical staged fuel burner. The typical staged fuel burner, with staged gas tips that normally comprise 70% of the heat release positioned on the back side of the tile, requires that the unburned gas cross the combustion air stream before reaching the furnace wall. The Min-Emissions burner illustrates that the staged gas does not directly cross the combustion air stream. This type of burner design allows the angle of the staged gas port to be changed without adversely affecting the thermal NOx emissions. Since the volume of air can be around nine times greater than gas, it is very important that the gas be injected between the furnace wall and the combustion air stream to keep furnace currents from affecting the flame quality.

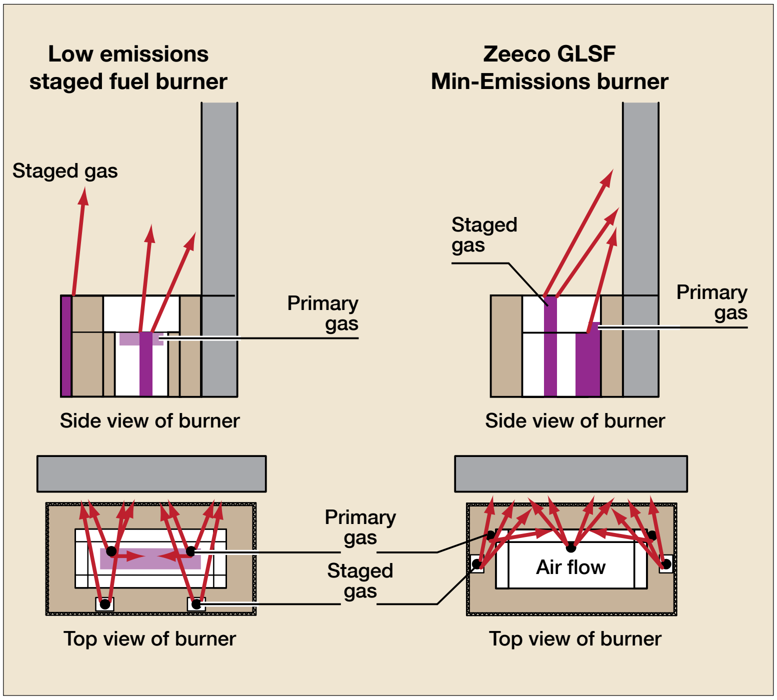

Figure 2 Comparison of a low emissions staged fuel burner and the GLSF burner

Small burner size for retrofit applications

Another critical design detail when retrofitting for emissions control without sacrificing flame quality is the compactness of the burner design. Operators should seek a combustion company that engineers a burner which is compact in design with no metal located in the throat of the burner, excluding the gas tips. Gas tips are required on each burner to distribute the fuel and mix it with the combustion air stream so that it burns completely. Eliminating any other metal from the burner throat results in a design with fewer items that can fail and require replacement. In addition, by simply eliminating metal from the burner throat, the burner can be designed with a smaller external dimension. When the external dimensions of the burner are smaller, it can normally replace conventional NOx and staged fuel NOx burners with only minor furnace modifications. This compact footprint allowed the petrochemical plant operator to install more burners mounted more closely together in revamped furnace applications without adverse flame impact or major modifications to the furnace (see Figure 3).

Thermal NOx creation and reduction

In order to understand why the Min-Emissions burner design was successful in this application, the formation of thermal NOx emissions must first be examined. For gaseous fuels with no fuel-bound nitrogen (N_2), thermal NOx is the primary contributor to overall NOx production. Thermal NOx is produced when flame temperatures reach a high enough level to "break" the covalent N_2 bond apart, allowing "free" nitrogen atoms to bond with oxygen to form NOx.

A stoichiometric equation describing typical combustion in a natural gas-fired burner (methane and air with excess air) is as follows:

$$2CH_4 + 4\,(XA)\,O_2 + 15\,(XR)\,N_2 \rightarrow 2CO_2 + 4H_2O + (XA)\,15N_2 + (XR)\,O_2$$

Natural air is comprised of 21% O_2 and 79% N_2. Combustion occurs when O_2 reacts and combines with fuel (typically hydrocarbon). However, the temperature of combustion is not normally high enough to break all of the N_2 bonds, so a majority of nitrogen in the air stream passes through the combustion process and remains diatomic nitrogen (N_2) in the inert

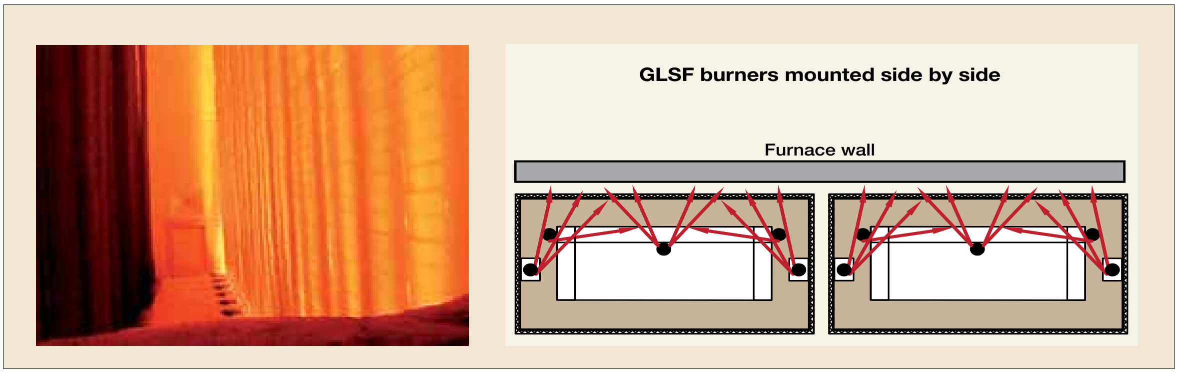

Figure 3 Left: the GLSF burner in operation with no flame rollover or flame interaction issues. Right: a diagram depicting the close proximity of the burners in the petrochemical plant revamp application

combustion products. Very little N_2 is able to reach high enough temperatures in the high-intensity regions of the flame to break apart and form free nitrogen. Once the covalent nitrogen bond is broken, the free nitrogen is available to bond with other atoms. Basic chemistry dictates that free nitrogen, or nitrogen radicals, will react with other atoms or molecules that can accept them to create a more stable atom. Of the possible reactions with the products of combustion, free nitrogen will most likely bond with other free nitrogen to form N_2. However, if another free nitrogen atom is not available, the free nitrogen will react with the oxygen atoms to form thermal NOx. As the flame temperature increases, the stability of the N_2 covalent bond decreases, allowing the formation of free nitrogen and subsequently increasing thermal NOx. Burner designers can reduce overall NOx emissions by decreasing the peak flame temperature, which can reduce the formation of free nitrogen available to form thermal NOx.

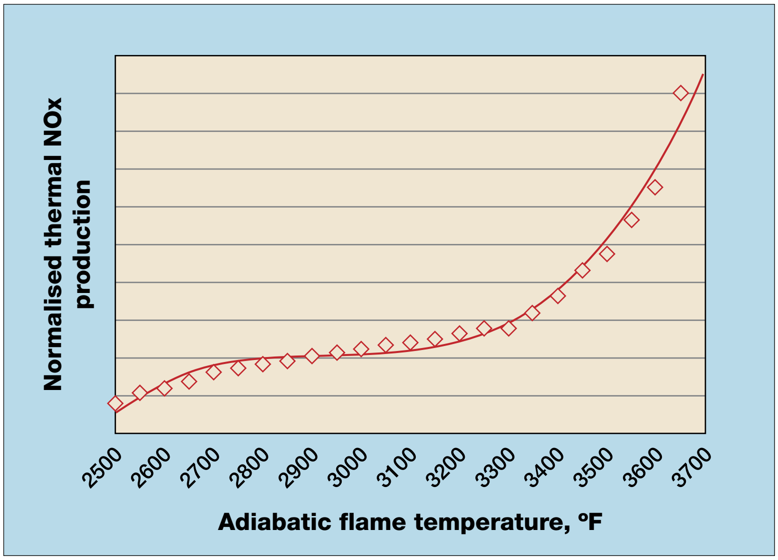

Figure 4 Calculated peak flame temperature vs thermal NOx production

The varied requirements of refining and petrochemical processes entail the use of numerous types and configurations of burners. The method utilised to lower NOx emissions can differ by application. However, thermal NOx reduction is generally achieved by delaying the rate of combustion. Since the combustion process is a reaction between oxygen and fuel, the objective of delayed combustion is to reduce the rate at which the fuel and oxygen mix and burn. The faster the oxygen and the fuel gas mix, the faster the rate of combustion and the higher the peak flame temperature.

Figure 4 plots peak flame temperature against thermal NOx created. NOx emissions increase as the adiabatic flame temperature increases. Slowing the combustion reaction reduces the flame temperature, which results in lower thermal NOx emissions. The challenge in achieving lower thermal NOx emissions is not the theory; however, the challenge is in retrofitting the latest burner technologies into older existing furnaces without adding expensive external components or processes.

The industry's standard method to reduce thermal NOx is to mix the fuel gas together with the inert products of combustion to recondition the fuel before combustion occurs. Since the reconditioned fuel is mainly comprised of inert components, the resulting composition burns at a lower peak temperature. To best utilise the inert products of combustion (flue gas) within the furnace, the fuel gas is introduced along the outside perimeter of the burner tile in an area where flue gas is present while the furnace is in operation. As the fuel gas passes through the inert products of combustion, mixing naturally occurs. This changes the composition of the fuel, and stabilisation occurs at the tile exit. Since the reconditioned fuel mixture is 15-50% inert in most cases, the resulting flame burns at a lower peak temperature and generates less thermal NOx.

The mixing of the fuel gas with flue gas prior to combustion is called internal flue gas recirculation (IFGR). When IFGR is too aggressive, it can result in an increased blower power usage, decreased burner turndown and increased flame destabilisation. Through min-emissions theory, maximising IFGR while maintaining flame stability and flame length can become a challenge.

Summary information for bottom burners

Summary details	
Number of burners	2 furnaces x 24 per furnace (= 2 rows × 12 per side)
Type of burner	GLSF Min-Emissions burners with internal fuel gas recirculation
Type of fuel (gas/oil/dual oil gas)	Gas only
Location in furnace (roof/floor/side wall)	Floor
Firing orientation (down-firing/upshot/radiant wall/against wall)	Upshot (against wall)
Flame shape(round flame/flat flame)	Flat flame gas burner assembly
Air supply system (natural/forced/induced/balanced/GTE)	Induced draft fan with natural draft burners
Maximum available combustion air pressure at burner, KPa(a)	Atmospheric
Ambient temperature (minimum/normal/maximum), °C	-40.2/+4.5/+36.6
Relative humidity, %	70% at 4.5°C
Ambient pressure, KPa(a)	99.3
Altitude above sea level, m	Not applicable
Atomisation (mechanical/steam/air)	Not applicable
Firebox data	
Flue gas temperature at cross-over, °C	1143
Average flue gas temperature in firebox, °C	1252
Firebox volume, m3	568
Firebox dimensions (L× W × H), m	2 boxes, each 10.21 x 2.8 x 9.93

Table 1

Application and results

The petrochemical plant chose to retrofit GLSF Min-Emissions burners in the following cracking furnace design. Each heater required 24 hearth (bottom) burners per furnace. Twelve burners were mounted on each side of the tubes located in the centre of the furnace. The floor burners were designed to fire up the furnace wall, which, in turn, radiates heat to be absorbed by the furnace tubes (see Table 1).

The hearth burners were mounted in the floor of the heater and fired up the firebrick wall. Since the burners fired directly onto the firebrick wall, the wall transferred heat to the process tubes that are located in the centre of the cracking heater. The furnace has two rows of tubes and burners located on each side of the tubes.

The radiant wall burners, or "trim" burners, were located in the upper regions of the furnace wall. Each radiant wall burner was mounted in the furnace wall horizontally and produced a radial flame pattern on the wall. The radiant wall burners are a pre-mixed design, where air and gas mix together before combustion occurs.

The hearth burners provide most of the heat, while the radiant wall burners are the remaining heat release. In order for the heater to work properly, the hearth burners must provide an even heat flux profile for where the tubes are located.

Conclusion

As petrochemical companies continue to revisit their olefins facilities through plant expansion or construction of new facilities, it is important to keep in mind the complex interactions of flame, fuel and lower emissions. Zeeco has provided GLSF Min-Emissions burners for ethylene cracking applications for over 200 cracking furnaces worldwide, with NOx emission guarantees as low as 44 ppmv. As described in the example petrochemical plant installation, using a compact design burner technology to achieve challenging emissions levels without sacrificing flame quality is possible through a retrofit, but it does require careful consideration of options and possible pitfalls.

Rex K Isaacs is the Director of Burner Products for Zeeco, Inc, a combustion equipment manufacturer based in Broken Arrow, Oklahoma, USA. He has over 20 years' experience in the industry and is listed on five patents for combustion equipment. He holds a BS in mechanical engineering from Oklahoma State University.