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Flame Interaction and Rollover Solutions in Ethylene Cracking Furnaces

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Abstract

Burner retrofits in Ethylene cracking applications have proven to be challenging projects due to burner spacing requirements and resulting effects upon burner flame quality. As existing furnaces are upgraded to achieve higher capacities, more floor burners are added resulting in smaller distances between burners and more potential for adverse flame conditions such as burner-to-burner flame interaction and flame rollover.

Zeeco has developed a patented ultra low NO_x burner technology, the ZEECO® GLSF Min-Emissions Enhanced Jet Flat Flame Burner, that provides not only a very small mechanical footprint, but also produces a flame profile with very limited burner-to-burner, flame-to-flame interaction and no flame roll-over.

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. An inherent design aspect of the GLSF Flat Flame Burner is the fact that the fuel gas is introduced between the furnace wall and the air stream. Consequently, flame interaction between burners is minimized 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 NO_x emissions.

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. We will review the design details and advantages of the GLSF burner, provide specific retrofit installation details, lessons learned during the retrofit, and include results for several of the retrofit applications.

Introduction

Flame rollover and flame interaction can be problematic in ethylene cracking applications. Flame rollover issues can lead to flame impingement on the furnace tubes, resulting in hotspots. Such localized high temperatures within the tubes can cause premature coking and lead to shorter periods between de-coking and reduced ethylene production. Since the early 2000s, Zeeco and Wison Engineering Ltd. have worked together on many 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.

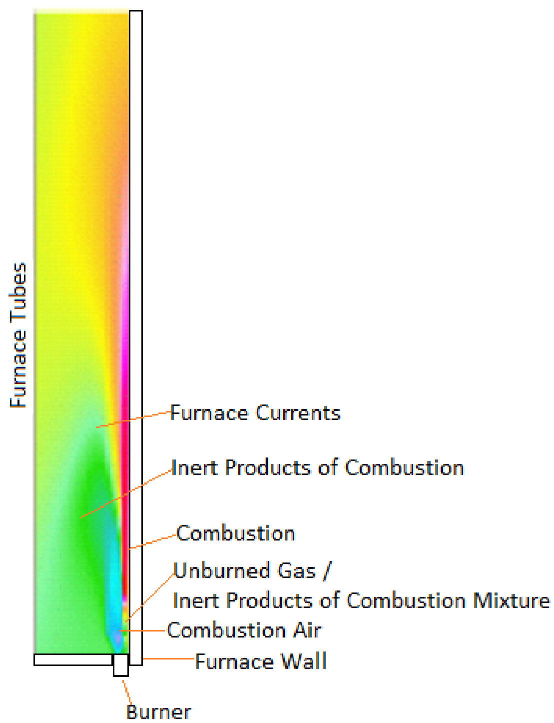


Figure 1: The GLSF burner design entrains the gas next to the wall so when the furnace currents pull the air toward the tubes, the gas and flame stay next to the wall with no flame rollover. The Computational Fluid Dynamics (CFD) Model of GLSF is shown

To achieve the improved flame quality without any such flame rollover or flame interaction, Wison selected Zeeco's GLSF Min-Emissions flat flame floor mounted burners. As shown in Figure 1, the GLSF 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 toward the tubes. As the unburned gas moves up the wall, it mixes with the inert flue gas products of combustion, burned directly below the unburned gas. As the mixture of unburned gas and products of combustion continues to move up the wall, it then combines with air and burns. Since the unburned gas is mixed with some of the products of combustion before burning, peak flame temperature is lowered, producing lower thermal NO_x emissions. Therefore, not only are flame rollover and flame interaction problems solved, but ultra low emissions can be achieved.

Comparison to Low Emissions 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 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 toward the furnace wall. These orifice angles cause the air and fuel gas to mix at a faster rate, thus increasing thermal NO_x, and requiring a compromise between the heat flux profile and thermal NO_x production. As the heat flux profile is made more uniform, with an average above 90%, the NO_x emissions typically increase along with the increase in flux percentage. In the same respect, as the NO_x 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 NO_x 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 toward the tubes. In general, the lower the NO_x 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 Zeeco GLSF Min-Emissions Burner has staged gas tips with gas ports aimed toward 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 NO_x or causing flame impingement on the tubes. Zeeco's GLSF Min-Emissions Flat Flame Burner evenly transfers heat to the process tubes, and reduces the possibility of localized hot spots while producing lower NO_x emissions.

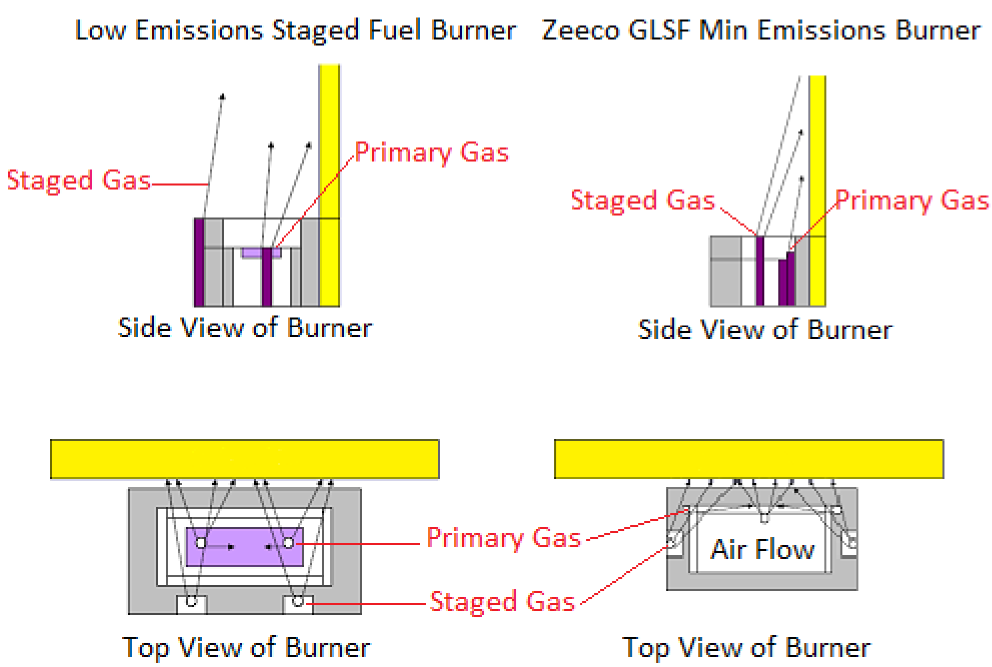
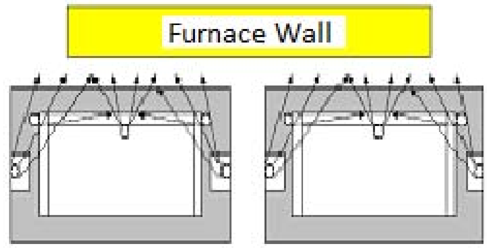


Figure 3: Side-by-side comparison of a Low Emissions Staged Fuel Burner and Zeeco's GLSF Min-Emissions Burner

Figure 3 shows a comparison between the GLSF Min-Emissions burner and a typical staged fuel burner. The typical staged fuel burner shown on the left, 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. Zeeco's GLSF Min-Emissions Burner, shown on the right, illustrates that the staged gas does not directly cross the combustion air stream. Zeeco's design allows the angle of the staged gas port to be changed without adversely affecting the thermal NO_x emissions. Since the volume of air can be around nine (9) 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.

Small Burner Size for Retrofit Applications

The GLSF floor burner is very compact in design with no metal located in the throat of the burner, excluding the gas tips. Typically, the items that require replacing most often are the gas tips and any metal in the throat of the burner that is used for combustion air pressure block or flame stabilization. Gas tips are required on each burner to distribute the fuel and mix it with the combustion air stream so that it burns completely. Zeeco engineers focused on eliminating any metal in the burner throat other than the gas tips and pilot meaning fewer items that can fail and require replacement. Eliminating metal from the burner throat means the burner can be designed with smaller external dimensions. When the external dimensions of the burner are smaller, it can normally replace conventional NO_x and staged fuel NO_x burners with only minor furnace modifications. The compact design allowed Wison to install more burners mounted more closely together in revamped furnace applications without adverse flame impact or major modifications to the furnace.



GLSF Burners mounted side by side.

Figure 4: Zeeco's GLSF Min-Emissions Flat Flame Burner. As shown on the left, the GLSF burner in operation with no flame rollover or flame interaction issues. As shown on the right, a diagram depicting the close proximity of the Zeeco's GLSF burners in Wison's revamp application.

Description of Thermal NO_x Creation and Reduction

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

Stoichiometric Equation describing typical combustion in a natural gas fired burner

Methane & Air with Excess Air

$$2CH_4 + 4\ (XA)\ O_2 + 15\ (XR)\ N_2 \ \text{--->}\ 2CO_2 + 4H_2O + (XA)\ 15N_2 + (XR)\ O_2$$

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 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 to 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 a free nitrogen atom is not available, the free nitrogen will react with the oxygen atoms to form thermal NO_x. As the flame temperature increases, the stability of the N_2 covalent bond decreases, allowing the formation of free nitrogen and subsequently increasing thermal NO_x. Burner designers can reduce overall NO_x emissions by decreasing the peak flame temperature, which can reduce the formation of free nitrogen available to form thermal NO_x.

The varied requirements of refining and petrochemical processes entail the use of numerous types and configurations of burners. The method utilized to lower NO_x emissions can differ by application. However, thermal NO_x 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 5 plots Peak Flame Temperature against Thermal NO_x created. NO_x emissions increase as the adiabatic flame temperature increases. Slowing the combustion reaction reduces the flame temperature, which results in lower thermal NO_x emissions. The challenge in achieving lower thermal NO_x emissions is not the theory; however, it is in retrofitting the latest burner technologies into older existing furnaces without adding expensive external components or processes.

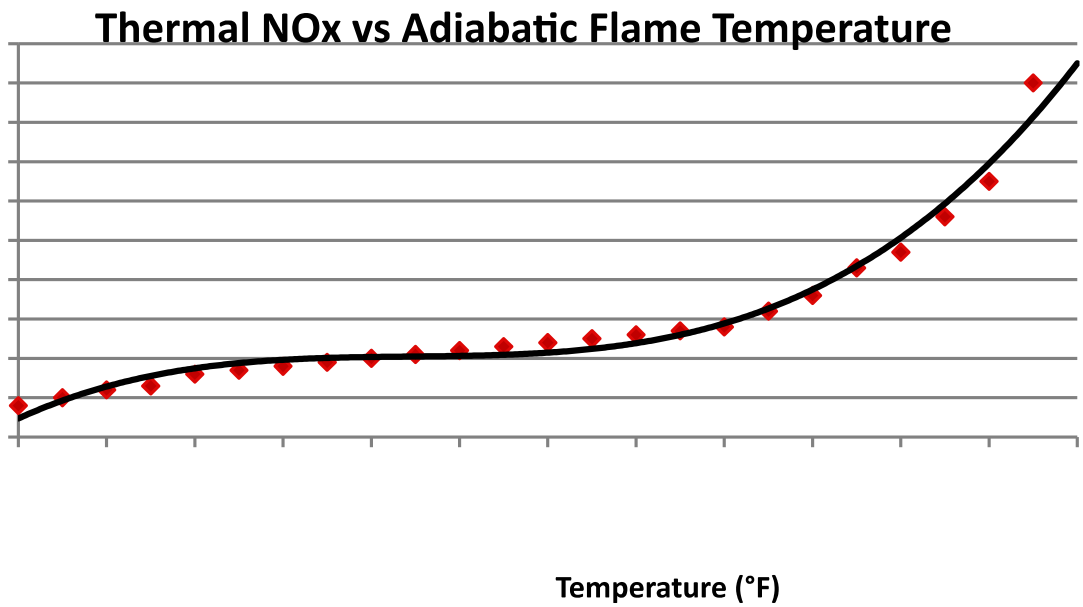


Figure 5: Calculated Peak Flame Temperature vs. Thermal NO_x Production

The industry's standard method to reduce thermal NO_x 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 utilize 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 stabilization occurs at the tile exit. Since the reconditioned fuel mixture is 15 to 50% inert in most cases, the resulting flame burns at a lower peak temperature and generates less thermal NO_x.

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 destabilization. Through Min-Emissions Theory, maximizing IFGR while maintaining flame stability and flame length can become a challenge.

Description of Application

Wison selected Zeeco to perform a burner retrofit application to install GLSF Min-Emissions burners used in the following cracking furnace design. Each heater required 24 hearth (bottom) burners per furnace. Twelve (12) burners were mounted on each side of the tubes located in the center 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.

The hearth burners are mounted in the floor of the heater and fired up the firebrick wall. Since the burners fire directly on the firebrick wall, the wall transfers heat to the process tubes that are located in the center 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 are located in the upper regions of the furnace wall. Each radiant wall burner is mounted in the furnace wall horizontally and produces a radial flame pattern on the furnace wall. The radiant wall burners are a pre-mixed design where air and gas mix together before combustion occurs. For this application, the radiant wall burners are to be provided by others. The first row of sidewall (radiant wall) burners is located at 8.94 meters above the floor location where the bottom burners are installed.

In summary, 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.

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 Minimum Emissions Burners complete 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) □	-40.2/+4.5/+36.6
Relative humidity %	70% at 4.5□
Ambient pressure KPa(a)	99.3
Altitude above sea level m	- Not applicable
Atomization(mechanical/steam/air)	- Not applicable
Fire box data	
Flue gas temperature at cross-over □	1143
Average flue gas temperature in firebox □	1252
Firebox volume m^3	568
Firebox dimension (L× W×H) m x m x m	2 boxes, each 10.21 x 2.8 x 9.93

Description of Emissions Guarantees

Zeeco provided the following guarantees for NO_x, CO, UHC and particulate levels:

1. Zeeco guarantees that the NO_x emissions will not exceed 150 mg/Nm3.

2. Zeeco guarantees that the CO emissions level will not exceed 50 mg/Nm3.

3. Zeeco guarantees that the particulate (PM10) level will not exceed 50 mg/Nm3.

4. Zeeco guarantees that the UHC level will not exceed 50 mg/Nm3.

5. Zeeco guarantees that the burner noise level will not exceed 85 dba.

Conclusion

Wison has retrofitted many ethylene cracking furnaces with Zeeco GLSF Min-Emissions Burners to achieve challenging flame requirements. Even though the burners were mounted closely together, they showed no signs of flame interaction or flame rollover. The compact burner design allowed more burners to be installed more closely together without adversely affecting flame behavior. The GLSF Min-Emissions burner design has been used in over 140 challenging ethylene cracking furnaces, some of which with NO_x emissions guarantees less than 90 mg/Nm3.

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