ACHIEVING ULTRA-LOW NO_X EMISSIONS WITHOUT EFGR IN BURNER RETROFIT APPLICATIONS

Rex K. ISAACS[1], Director of Burner Products, Rex_Isaacs@zeeco.com
Vance T. VARNER[2], Heat Transfer Expertise Area Leader, vtvarner@dow.com
Liesl LEWIS[3], Manufacturing Rep, lalewis@dow.com
Scott BARTLEBAUGH[3], Process Engineer, sabartlebaugh@dow.com
[1]Zeeco, Inc., Broken Arrow, Oklahoma, USA
[2]Dow Chemical Company, Plaquemine, Louisiana, USA
[3]Dow Chemical Company, Pittsburg, California, USA

1. INTRODUCTION

Retrofitting low NO_x burners into existing applications can be an economical solution to achieving low NO_x emissions levels from existing fired equipment. Typically, low NO_x burners require either External Flue Gas Recirculation (EFGR) or Selective Catalytic Reduction (SCR) to achieve NO_x emissions of 9 ppmv and 50 ppmv of CO or less. Designing a low NO_x burner footprint that fits into an existing burner cutout while properly operating within firing length limitations and meeting emission targets without EFGR has been an industry challenge. The Dow Chemical Company in Pittsburg, California, was faced with this challenge when their Dowtherm® Heater furnace was required to operate with less than 9ppmv NO_x and 50 ppmv CO emissions. Zeeco supplied Dow with a patented next generation GLSF Free-Jet Burner retrofit delivering a small mechanical footprint, a compact flame profile, and shorter flame lengths.

The Zeeco® Next Generation Ultra-Low NO_x Free-Jet Burner technology can produce NO_x emissions of less than 9 ppmv without EFGR. The GLSF Free-Jet Burner produces a flame profile with very limited flame-to-flame interaction for burner installations, while also achieving shorter flame lengths. The burner design utilizes the “free jet” mixing theory to maximize the amount of inert internal products of combustion (flue gas) mixed with the fuel gas in the combustion chamber to produce a reconditioned fuel mixture of gas and flue gas. The resulting mixture then burns in the combustion process with a lower adiabatic flame temperature and produces inherently lower NO_x emissions.

A secondary industry concern for the end user operating company is the overall cost of ownership for next generation ultra-low NO_x burners. Some designs in the marketplace have had higher maintenance costs versus conventional emission burners. Offsetting these costs is the reduced use of expensive EFGR or SCR systems to achieve the desired NO_x reduction.

Zeeco will review the engineering details of the Free-Jet burner used in the Dow application, how the design addresses both emissions and cost of ownership challenges, and discuss verified successful field results.

2. DESCRIPTION OF THERMAL NO_X CREATION AND REDUCTION

In order to understand why the Zeeco® GLSF Free-Jet design was appropriate, 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

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

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 together 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 1 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 equipment without adding expensive external components or processes.

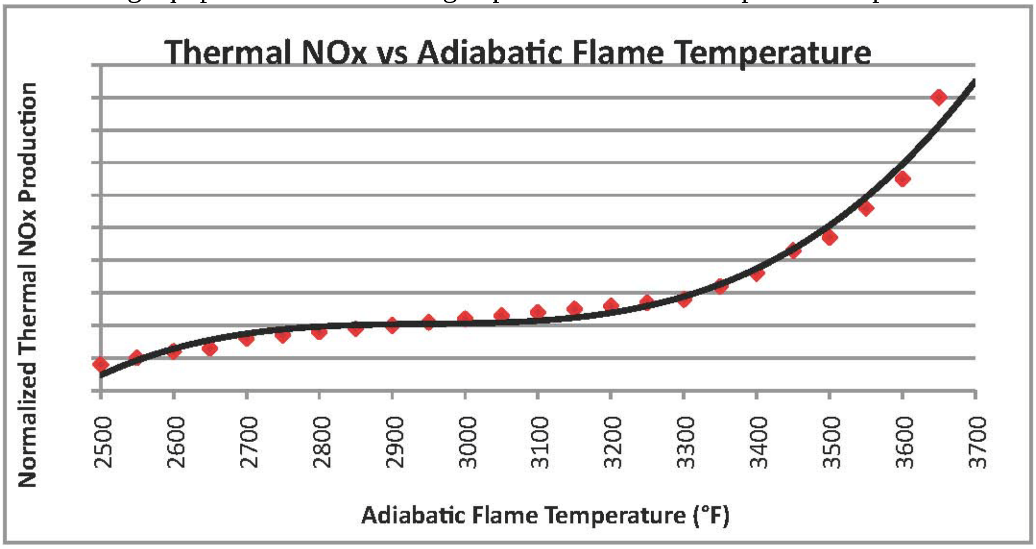

Figure 1. Calculated Peak Flame Temperature vs. Thermal NO_x Production

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 combustion chamber, the fuel gas is introduced along the outside perimeter of the burner tile in an area where flue gas is present while the equipment 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 80 to 90% 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 Free Jet Theory, maximizing IFGR while maintaining flame stability and flame length can become a challenge.

3. A DISCUSSION OF FREE JET TECHNOLOGY

Zeeco's GLSF Free-Jet Burner technology conditions the fuel by mixing the fuel and flue gas together before combustion can occur. This fuel conditioning allows for reduction of the peak flame temperature of the fuel mixture and lowers thermal NO_x emissions. As illustrated in Figure 2, the Free Jet Theory entrains inert flue gas with fuel gas in order to generate less thermal NO_x. In contrast, traditional raw gas burners must employ additional technology such as EFGR or SCR to achieve low NO_x emissions levels.

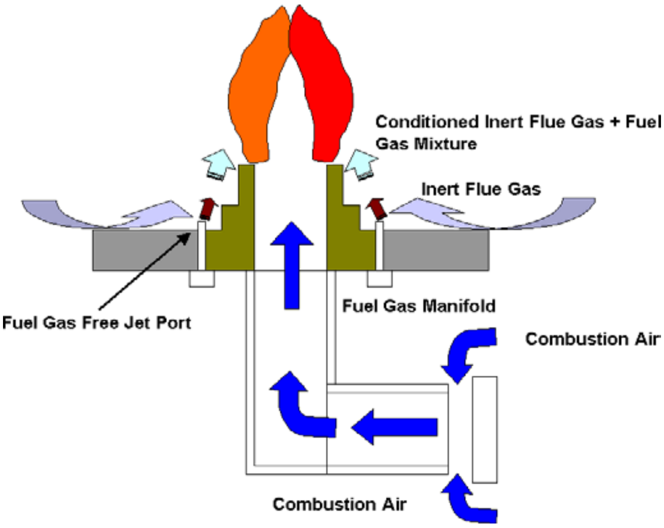

Figure 2. Free Jet Schematic

In the past, the majority of traditional burners were designed to direct a small portion of the fuel gas to a low-pressure area where combustion could be initiated and stabilized. This portion of the gas is commonly referred to as ignition gas. The remaining fuel gas was directed toward the combustion air stream. This traditional burner (Figure 3) uses a stabilization zone with a sufficient temperature to ignite the remaining fuel gas once it contacts the combustion air stream. Combustion then proceeds at high temperatures, and high levels of thermal NOx are produced.

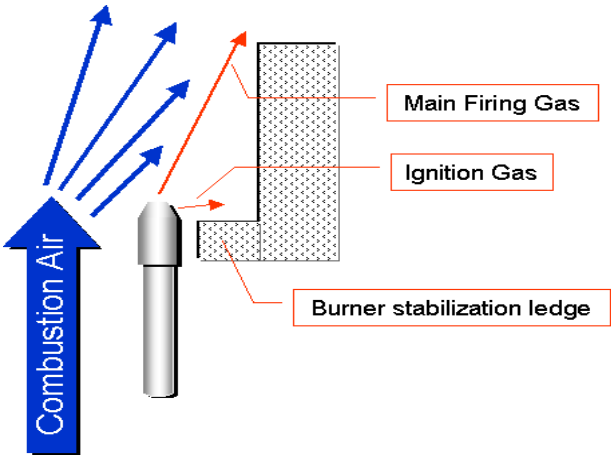

Figure 3. Traditional Burner Stabilization Technique

Typical raw gas burners have one or more ignition and firing ports on each tip. The ignition port directs gas to a low-pressure area where combustion is initiated and stabilized. The firing port is used to shape the flame. This method of fuel gas introduction has been common practice for over fifty years and has proven a very effective means of providing burner stability. In this tradition, the Zeeco® Second Generation Min-Emissions Ultra-Low NO_x burner was designed with both ignition and firing ports. In order to achieve lower NO_x emissions than that of the second-generation designs in the marketplace, it was determined that both the ignition gas and the main fuel gas must be conditioned with inert flue gas by means of Free Jet mixing.

In order to fully utilize the Free Jet Theory, Zeeco devised a method to stabilize the burner flame with a highly inert fuel gas/flue gas mixture. This type of combustion is achieved when the flame is stabilized in a low-pressure area created on a series of specially designed hot refractory ledges. As combustion occurs, the refractory ledge retains heat and flame stability is enhanced. Thus, to achieve improved stability and extreme thermal NO_x reduction, the Free-Jet Technology:

- Mixes inert flue gas through free-jet methods with all of the fuel gas before combustion occurs, lowering flame temperature.
- Stabilizes the flame on a series of refractory ledges, improving flame characteristics.

Before combustion is initiated, a furnace is typically filled with air, containing 21% oxygen. Once the burner is ignited, the oxygen content inside the furnace decreases until the burner achieves maximum duty. At this point, the oxygen content in the firebox is normally 2% to 3%. To maintain burner stability throughout the transition from start-up with 21% oxygen to maximum duty with 2% to 3% oxygen, Zeeco developed a series of stabilization ledges as shown in Figure 4.

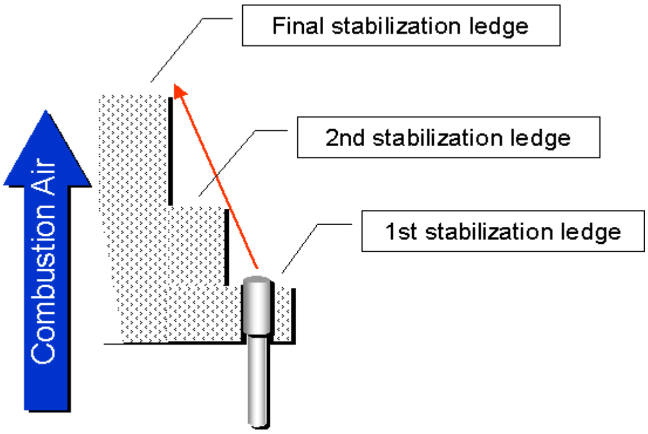

Figure 4. Free Jet Stabilization Technique

The 100% Free Jet Concept: All of the fuel gas is mixed with inert flue gas before combustion occurs. When none of the fuel gas is directed through an enclosed passageway, more energy is available to entrain the surrounding inert flue gas. The conditioned fuel gas can be more than 90% inert and NO_x levels of 5 ppmv (0.006 lb/MM Btu) can be achieved with a 1,650^{o}F (899^{o}C) furnace temperature, 2% excess oxygen, 35% hydrogen and 65% natural gas fuel composition.

Zeeco developed a new tip design for the Free-Jet series that reduces the plugging and coking generally associated with most burner stability issues. Figure 5 shows the resulting Free-Jet tip on the right, featuring less mass and less exposed area, thereby reducing temperature gain and coking. In addition, the probability of plugging is reduced because there is only one port drilled in the Free-Jet compared to two to six ports in the typical tip shown on the left. In addition, Zeeco engineers created a shape that enhances the mixing of inert gases with the fuel gas ejected from the gas tip. The "air foil" shape increases the flow of inert products of combustion around the tip, conditioning the flow, which reduces NO_x emissions. With only one port on the tip, the turndown is enhanced to greater than 10:1, in contrast to the 3:1 to 5:1 range of low NO_x burners of the past. In summary, the new tip enables the Zeeco Free-Jet burner design to achieve Next Generation NO_x emissions (less than 15 ppmv), more than doubles the life of the burner parts, and increases turndown. Furthermore, since each tip does not require an ignition port, more tips can be evenly positioned around the burner tile enabling the burner to more evenly mix the gas and air, allowing the burner to operate with lower excess air.

Figure 5. Zeeco's airfoil tip design (shown right) has less mass and less exposed area, reducing temperature gain and coking.

4. DESCRIPTION OF APPLICATION

The Dow Chemical Company in Pittsburg, California was faced with a challenging emissions application requiring less than 9 ppmv NO_x emissions for their Dowtherm® Heater furnace. The furnace required a single burner designed to achieve a maximum heat release of 26 MM Btu/hr (6.55 MM Kcal/hr). The furnace was a vertical cylindrical-type design, with a two pass helical coil. Combustion air was supplied to the burner at ambient temperature via a forced draft supply system. At maximum duty, the combustion air system was designed to supply 3" H_2O (76.2 mm H_2O) air pressure to the burner. The furnace height was 21.6 ft (6,584 mm) with a furnace tube circle diameter of 9.5 ft (2,896 mm). The furnace volume was approximately 1,530 ft^3 (43.3 m^3) and was designed for a flue gas temperature of 1,700°F (926.7°C). The heat release per floor area was approximately 350,945 Btu/ft^2 (994,964 Kcal/m^2). Applications with the heat release per floor area above 350,000 Btu/ft^2 are typically considered difficult since the temperature where most thermal NO_x formation occurs is at or above 1,600°F.

Burner retrofits in applications where NO_x emissions are required to 9 ppmv or less are challenging projects because they typically require either the use of External Flue Gas Recirculation (EFGR) or Selective Catalytic Reduction (SCR). Providing a next generation low NO_x burner footprint that fits into the existing burner cutout is another concern. Next generation low NO_x burner flame patterns or profiles that can operate properly within the firing length limitations have also proven to be an industry challenge. Zeeco's GLSF Free-Jet Burner was designed to use approximately 0.6lb steam/lb fuel gas injected into the air stream for increased NO_x reduction if needed since EFGR was not planned for this application. The use of a small amount of steam was less expensive than reworking the furnace to add the approximately 25% to 35% EFGR, or an SCR system typically needed to achieve the required NO_x emissions level.

To summarize in detail the conditions of this application, a table is shown below with the key design information:

Units:	English
Type of Heater	Hot Oil Heater, Two Pass Vertical Helical Coil
Basic Flame Shape	Round Flame
Firing Direction	Vertical, Up
Mounting Location	Floor
Refractory Thickness (in)	7.5
Heater Steel Thickness (in)	0.25
Heater Height to Convective (ft)	21.6
Tube Circle Diameter (ft)	9.5
Quantity of Burners	1
Max HR Gas (MMBtu/hr)	26.0
Fuel Gas Pressure (psig)	35
Type of Draft	Forced
Pressure Drop at Burner (in H_2O)	3.0
Air Temperature (°F)	70
Percentage of Excess Air Gas	15%
Furnace Temperature (°F)	1,700
Pilot	Electric Ignition
Approximate Furnace Volume, (ft^3) =	1,530
Approximate Furnace Floor Area, (ft^2) =	70.88
Total Heat Release of Furnace, (MM Btu/hr (LHV)) =	26.00
Volumetric Heat Released, (Btu/ft3 (LHV)) =	16,995
Heat Release per Floor Area, (Btu/ft2 (LHV)) =	350,945
Approximate Floor Temp. at Max. H.R. (Degrees °F) =	1,800
Heat Release per Floor Area at Norm. H.R. (Btu/ft^2) =	202,468
Approximate Floor Temp. at Normal H.R. (degrees °F) =	1,380
Heat Release per Floor Area at 1/2 Rare (Btu/ft^2) =	175,472
Approximate Floor Temp. at 1/2 Rate (degrees F) =	1,290
Heat Release per Floor Area at Min. H.R. (Btu/ft^2) =	70,189

Units:	Metric
Type of Heater	Hot Oil Heater, Two Pass Vertical Helical Coil
Basic Flame Shape	Round Flame
Firing Direction	Vertical, Up
Mounting Location	Floor
Refractory Thickness (mm)	191
Heater Steel Thickness (mm)	6.35
Heater Height to Convective (mm)	6,584
Tube Circle Diameter (mm)	2,896
Quantity of Burners	1
Max HR Gas (MM Kcal/hr)	6.55
Fuel Gas Pressure (kg/cm^{2}g)	2.46
Type of Draft	Forced
Pressure Drop at Burner (mm H_2O)	76.2
Air Temperature (°C)	21.1
Percentage of Excess Air Gas	15%
Furnace Temperature (°C)	926.7
Pilot	Electric Ignition
Approximate Furnace Volume, (m^3) =	43.3
Approximate Furnace Floor Area, (m^2) =	6.59
Total Heat Release of Furnace, (MM Kcal/hr (LHV)) =	6.55
Volumetric Heat Released, (Kcal/m^3 (LHV)) =	151,242
Heat Release per Floor Area, (Kcal/m^2 (LHV)) =	994,964
Approximate Floor Temp. at Max. H.R. (Degrees °C) =	982
Heat Release per Floor Area at Norm. H.R. (Kcal/m^2) =	574,018
Approximate Floor Temp. at Normal H.R. (degrees °C) =	749
Heat Release per Floor Area at 1/2 Rare (Kcal/m^2) =	497,482
Approximate Floor Temp. at 1/2 Rate (degrees °C) =	699
Heat Release per Floor Area at Min. H.R. (Kcal/m^2) =	198,993

5. DESCRIPTION OF DESIGN FUEL GAS COMPOSITION

The Zeeco GLSF-16 Free-Jet Burner retrofit for the Dowtherm® Heater furnace was designed to operate with the following fuel gas shown below:

Composition	GAS 1 % vol
CH_4 (methane)	95.60%
C_2H_6 (ethane)	2.45%
C_3H_8 (propane)	0.18%
C_4H_{10} (butane)	0.03%
C_5H_{12} (pentane)	0.00%
C_4H_8 (butene)	0.02%
C_5H_{10} (pentene)	0.01%
CO_2	0.87%
N_2	0.80%
Total (vol%)	100.0%
Excess O_2	3.00%

6. DESCRIPTION OF EMISSIONS GUARANTEES

The Zeeco GLSF-16 Free-Jet Burner retrofit provided for the Dowtherm® Heater furnace was designed to operate with following emission guarantees:

- Emission guarantees were provided in the heat release range of 15.0 to 26.0 MMBtu/hr.
- The burner is operated at 15% excess air (3% O_2).
- Natural gas as shown in the Description of Fuel Gas Compositions Section of this paper.
- Combustion air temperature of ambient condition.
- NO_x emissions of less than 9 ppmv.
- CO emissions of less than 50 ppmv.
- UHC emissions of less than 15 ppmv.
- Particulate emissions of less than 15 ppmv.
- VOC emissions of less than 15 ppmv.

7. SUMMARY OF FIELD EMISSIONS TESTING

The Dowtherm® Heater furnace was tested for emissions by a third party and achieved the following results:

- Emissions data was recorded in the heat release range of 23.55 MMBtu/hr.
- Natural gas was the fuel gas.
- Combustion air temperature of ambient condition.
- NO_x emissions measured at 5.94 ppmv corrected to 3% dry O_2.
- CO emissions measured at 2.51 ppmv corrected to 3% dry O_2.

8. CONCLUSION

The Dow Chemical Company in Pittsburg, California, installed a single Zeeco GLSF-16 Free-Jet Burner to meet a less than 9 ppmv NO_x emissions requirement for their Dowtherm® furnace. Applications requiring less than 9 ppmv are typically achieved using external flue gas recirculation (EFGR) or Selective Catalytic Reduction (SCR). However, for this retrofit project, Zeeco supplied Dow with patented Next Generation Ultra-Low NO_x Free-Jet Burner technology featuring a very small mechanical footprint, compact flame profile, and shorter flame lengths. Once installed in the field, the emissions were verified by a third party to be less than 6 ppmv NO_x emissions with less than 3 ppmv CO emissions. The ability to meet the emissions requirements without the use of expensive External Flue Gas Recirculation (EFGR) or Selective Catalytic Reduction (SCR) systems was beneficial to Dow.