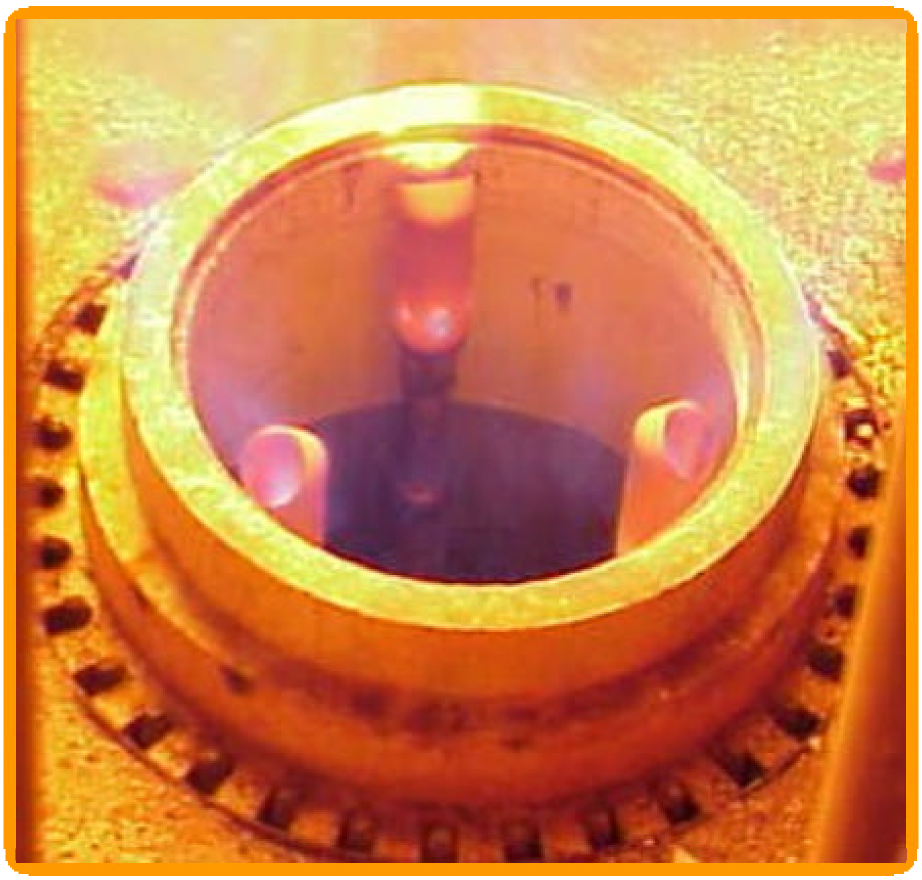
Zeeco Burner Division

Free Jet Burner Technology



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Summary of Zeeco Ultra Low NOx Burner Development

To meet the needs of our customers, Zeeco has developed three generations of ultra low NOx emission burners. In 1994, Zeeco introduced its first generation of ultra low NOx burner, the Model GLSF. This internal flue gas re-circulation burner achieved the objective of ultra low emissions, but required a metal plate in the throat for stabilization. This metal in the throat was prone to failure and caused the overall burner dimensions to be larger than conventional burners of similar capacity making it difficult to retrofit into existing furnaces. Therefore, development was begun on a second generation of burners that would not require any metallic stabilization device.

In 1997, Zeeco introduced its second-generation burner named the GLSF Min-Emission. The Min-Emission burner achieves NOx emissions of 15 to 30 ppmv depending on the operating conditions of the furnace. This burner is offered in both round and flat flame versions. It has been successfully applied in a variety of furnace configurations and chemical plant and refinery processes.

Over the past three years, Zeeco has been developing our third generation of ultra low NOx burner. The result of this effort is our Model GLSF Free Jet burner. The Free Jet technology maximizes the internal flue gas recirculation and fuel gas conditioning methods of NOx reduction. Mixing a maximum amount of internal inert flue gas with the fuel gas before combustion initiates enables the Free Jet burner to achieve NOx emission levels as low as 9 ppmv (with external flue gas recirculation). A detailed description of the Free Jet technology is included in the following sections of this paper.

For very high furnace temperature applications the Free Jet burner can be coupled with external flue gas re-circulation (EFGR). This type of burner system is currently achieving 8 to 9 ppmv (0.012 lb/MM Btu) NOx in a furnace operating in excess of 2100^{o}F (1149^{o}C). The EFGR system uses a blower to redirect a percentage of flue gas from above the convection section to the burner(s). The flue gas is then injected into the burner in such a way that the flue gas mixes with the fuel gas only after entering the combustion zone. Since there is no mixing of the flue gas with the fuel, there is no chance that the fuel gas/flue gas mixture can reach its lower explosive limit prior to discharge into the furnace even in the event of high oxygen levels in the flue gas. In this way, the Zeeco EFGR system is able to achieve very low emissions without sacrificing safety.

Free Jet Design Criteria

When designing new burners, such as the GLSF Free Jet burner, our engineers work hard to make the equipment “user friendly”. To help them do so, design and service criteria that will not only result in low emissions, but also result in a burner that is economical to produce and easy to install, maintain and operate are determined prior to any development work. For the Free Jet burner the following design criteria were established and adhered to.

- **Stable Flame:** The burner shall have a stable flame while operating over a 5:1 or greater turndown range with both natural gas and typical refinery fuel gases.

> **Ultra Low Emissions:** The burner shall achieve less than 6 ppmv NOx emissions with natural gas, 1,600 F furnace temperature and 15% excess air.

> **Improved Heat Flux Characteristics**: The burner shall provide a more even heat flux distribution than past generation ultra low emission burners.

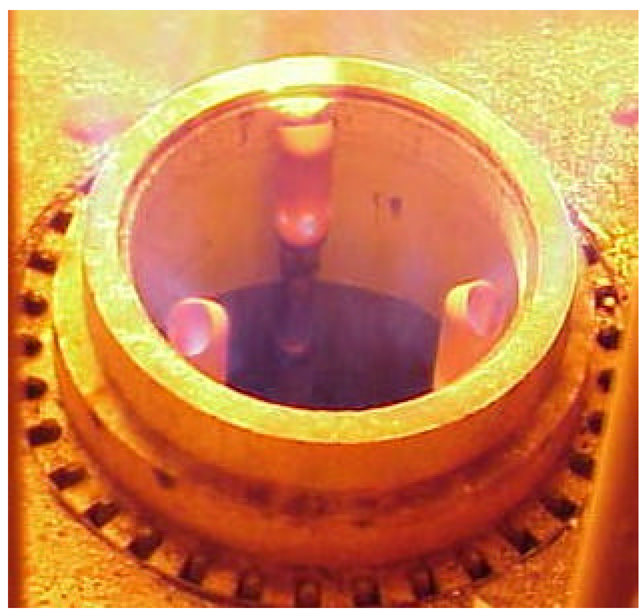
> **Low Maintenance Cost**: The burner shall have no metal in the throat other than the pilot. Typically, items that need to be changed most often are the fuel tips and metal in the throat of the burner that is used for combustion air pressure block or flame stabilization. Since the Zeeco Free Jet burners do not have metal in the throat other than the burner pilot (if required), there is very little that can go wrong with these burners allowing the burner performance to remain constant throughout the furnace run length. In addition, to reduce the chance of fuel tip plugging, Zeeco can include wire mesh screens on the burner main fuel gas connection to prevent foreign objects such as pipe scale from plugging the gas tips.

> **Compact Design / Easy Retrofit**: The burner shall be no larger than conventional or staged fuel burners. Another advantage of eliminating the metal combustion air pressure block or stabilization device from the burner throat is that the burner can be made with smaller external dimensions. Since the external dimensions of the burner are smaller, it can normally replace conventional and staged fuel burners with little or no furnace modification. This allows the end-user to have the option of installing burners "on the run" and reduces costly down time.

> **Low Probability of Flame Interaction**: The burner shall produce a compact flame that will not interact with surrounding burner flames when placed in conventional burner spacing. Since the burner design is very small and can fit in the same location as existing burners, existing burner spacing can be maintained.

> **Reasonable Cost**: The burner shall be economical to engineer and produce. Since the Free Jet burner is smaller than typical burners of ultra low NOx design, the cost of material and labor is less, enabling Zeeco to pass this savings on to our customers.

In summary, the Zeeco Free Jet burner was designed to have very low maintenance cost due to the absence of metal (other than the pilot) in the throat, lower initial cost due to fewer parts and compact size, and the ability to replace older designs with only minor furnace modifications.



Summary of Thermal NOx Formation

Thermal NOx Reduction Methodology

For gaseous fuels with no fuel bound nitrogen, thermal NO_x is the primary mechanism of NO_x production. Thermal NO_x is produced when the flame temperature reaches a high enough level to “break” the covalent N_2 bond apart and the “free” nitrogen atoms bond with oxygen to form NOx.

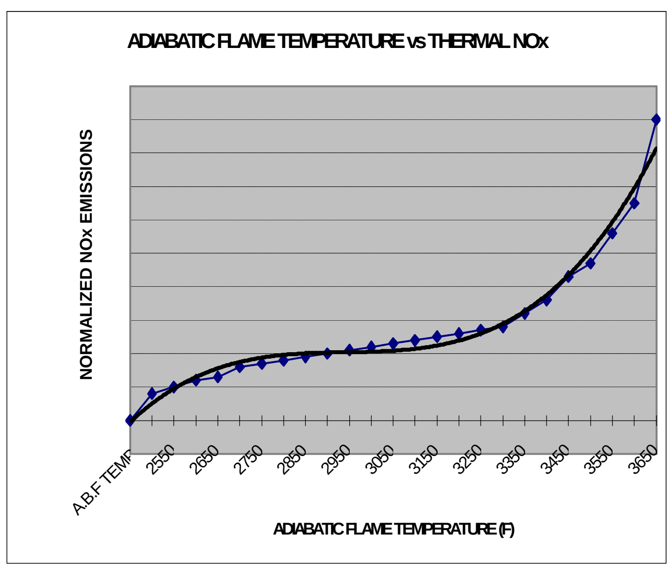
Methane & Air with Excess Air

$$2CH_4 + 4(XA)O_2 + 15(XR)N_2 \text{ ---> } 2CO_2 + 4H_2O + (XA)15N_2 + (XR)O2$$

Combustion air is comprised of 21% O_2 and 79% N_2. Combustion occurs when the O_2 reacts and is combined with the fuel (typically hydrocarbon). However, the temperature of combustion is not normally great enough to break all of the N_2 bonds, so most of the nitrogen in the air stream passes through the combustion process and remains as diatomic nitrogen (N_2) in the combustion products. Some of the N_2 does 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. The free nitrogen, or nitrogen radicals, will react with any other atoms or molecules suitable for reaction. Of the prospects in the products of combustion, free nitrogen will most likely react with other free nitrogen to form N2. However, if another free nitrogen atom is not available, the free nitrogen and oxygen atoms will react to form NOx. As the flame temperature increases, the stability of the N2 covalent bond decreases allowing the formation of more and more free nitrogen and subsequently increased thermal NOx. Burner designers can reduce NOx emissions by reducing the peak flame temperature which in turn reduces the formation of free nitrogen available to form NOx.

The varied requirements of refining and petrochemical processes require the use of numerous types and configurations of burners. The method utilized to lower NOx emissions can differ from application to application. However, thermal NOx reduction is generally achieved by delaying the rate of combustion. Since the combustion process is a reaction between oxygen and a 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 together, the faster the rate of combustion and the higher the peak flame temperature.

The table below plots Adiabatic Flame Temperature vs. Thermal NOx. As you can see, NOx emissions increase as the adiabatic flame temperature increases. Slowing the combustion reaction allows the flame temperature to be reduced, and as the flame temperature is reduced, so are the thermal NOx emissions.



Description of Zeeco Free Jet Technology

The Zeeco GLSF Free Jet series of burners utilize the mixing action of the fuel gas to mix fuel gas and flue gas together before combustion occurs. This mixing, or fuel conditioning, allows the peak flame temperature of the fuel mixture to be reduced and the thermal NOx emissions to be lowered. As illustrated in Figure 1, the Free Jet concept is very simple. The Free Jet burner operates in much the same way as raw gas burners have operated for the last fifty years. The only difference being that the fuel has been conditioned in order to burn with lower thermal NOx emissions.

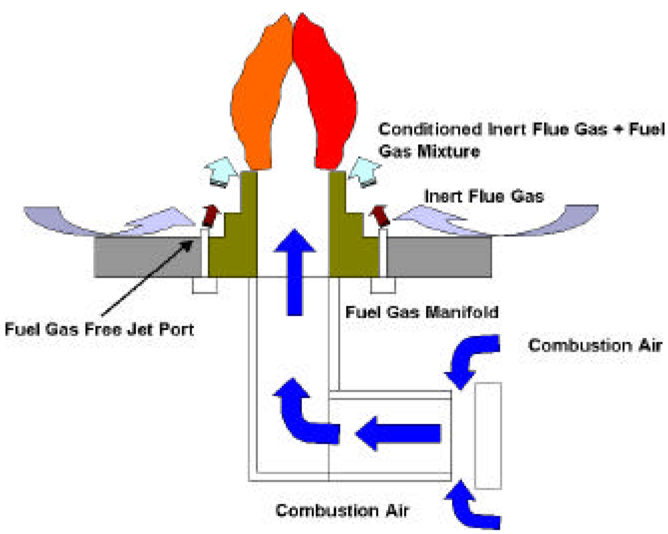


***Figure 1**: Free Jet Schematic*

In the past, the majority of 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 is illustrated in Figure 2. The stabilization zone provided sufficient temperature to ignite the remaining fuel gas once it came into contact with the combustion air stream. Combustion then proceeded rapidly and at high temperature and high levels of thermal NOx were produced, approximately 160 ppmv (0.2 #/MM Btu).

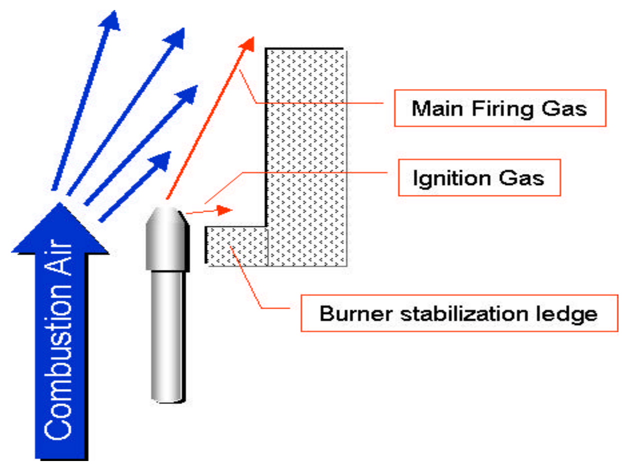
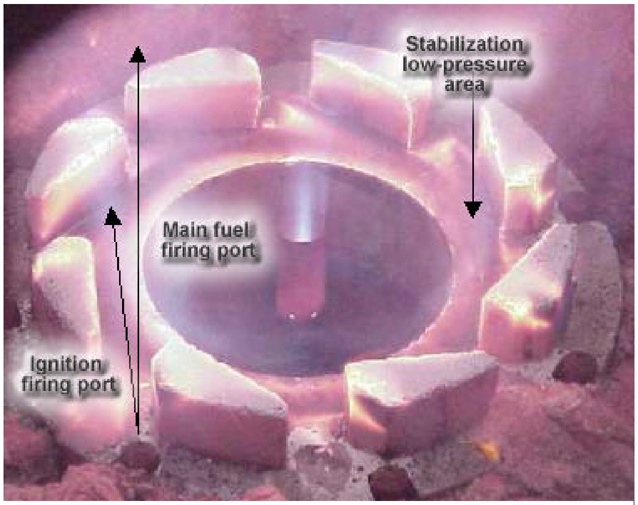


***Figure 2:** Traditional Burner Stabilization Technique.*

When Zeeco engineers began design work on the Free Jet technology, we reviewed our second-generation ultra low emission burner and tried to identify what portion of the flame was producing the majority of the thermal NOx. It was theorized that the ignition and stabilization portion of the flame produced the majority of the burner NOx. Through research in our test furnaces, this hypothesis was proven. For example, in our second-generation ultra low NOx burner, the ignition gas traveled a much shorter path to the combustion air stream than did the main gas stream. Since the distance to the combustion air stream was shorter, less inert flue gas was mixed with the ignition gas and more thermal NOx was produced in the ignition phase than in the main flame.



Zeeco Second Generation Ultra Low Emissions Round Flame Burner Assemblies.
Note that the fuel gas ejected from the main firing port travels a greater distance through inert gas than does the ignition gas. Most of the thermal NOx emissions are produced from ignition and stabilization of the burner flame.

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, Zeeco's second-generation ultra low NOx burner was designed with both ignition and firing ports. In order to achieve lower NOx emissions than that of the second-generation design, 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 mixing technology, Zeeco had to devise a method of stabilizing the burner flame with a highly inert fuel gas/flue gas mixture. We knew that the most stable combustion is achieved when combustion is initiated in a low-pressure area created by a refractory ledge. As combustion occurs, the refractory retains heat and flame stability is enhanced. Thus, for stability and extreme NOx reduction, we needed:

1. To mix inert flue gas through Free Jet methods with all of the fuel gas before combustion occurs.
2. To stabilize the flame on a refractory ledge.

Before combustion is initiated, a furnace is typically filled with air, which contains 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 keep the burner stable 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 3.

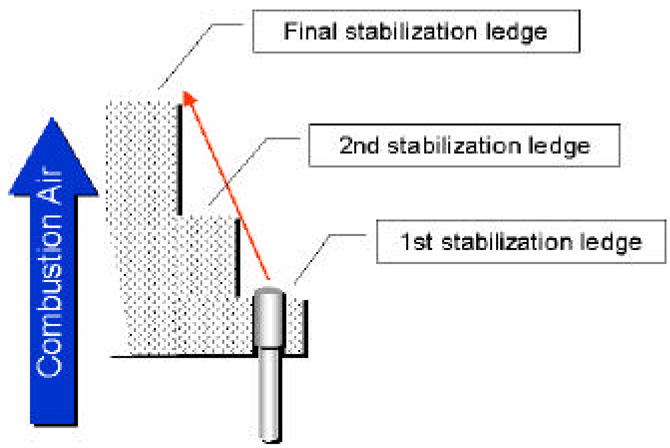


Figure 3: *Free Jet Stabilization Technique.*
100% Free-Jet Concept: All of the fuel gas is mixed with inert flue gas before combustion occurs. When none of the fuel gas is directed through an enclosed passageway, more energy is available to entrain the surrounding inert flue gas. The conditioned fuel gas can be more than 90% inert and NOx levels of 5 ppmv (0.006 lb/MM Btu) can be achieved with a 1,650°F (899°C) furnace temperature, 2% excess oxygen, 35% hydrogen + 65% natural gas fuel composition.

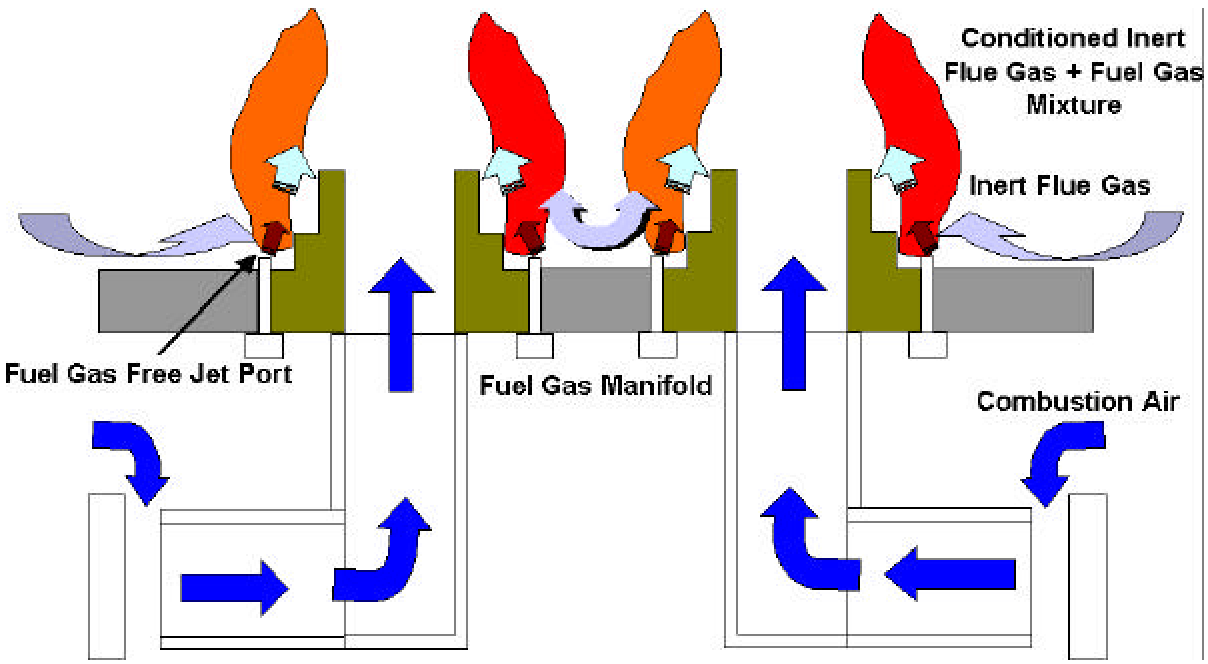


Figure 4: *Free Jet First Stabilization Ledge*

Ignition Process / Start-up with 21% Oxygen in Furnace: Before the burners in the furnace are ignited, the oxygen content in the furnace is 21% since the furnace is filled with air. After the furnace is started-up and the oxygen content is still high, the Free Jet burner operates like a conventional burner and the flame stabilizes on the first stabilization ledge. When the burner is operating with high oxygen levels, the burner produces NOx levels much like conventional raw gas burners. Two Free Jet burners operating with high oxygen levels shown above: Since the burner is capable of operating just as the past conventional burners did with high oxygen contents, it can achieve very high turn-down rates. When operating at high excess air levels, the burner can turndown until pressure is lower than 1 psig which relates to a 10:1 or greater turndown for most cases.

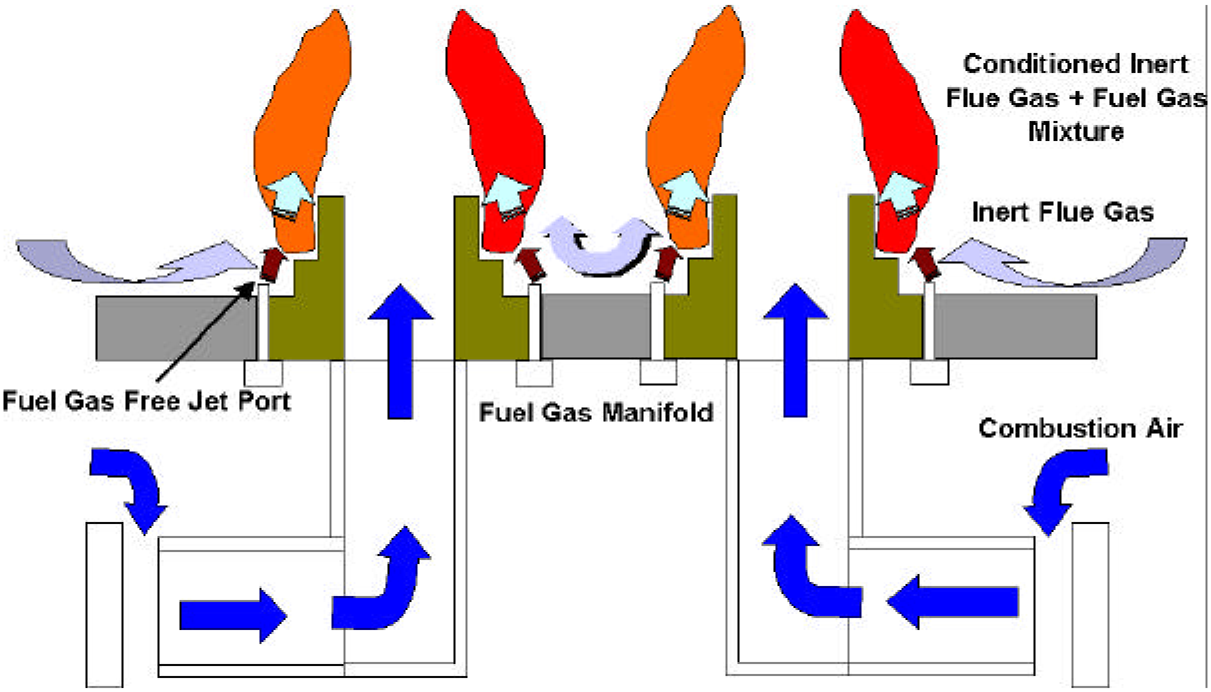


Figure 5: *Free Jet Second Stabilization Ledge*

The transition from high excess oxygen to low excess oxygen: As the excess oxygen content inside of the furnace is lowered from 21% at start-up to the final value of 2% to 3% oxygen, the stabilization point moves from the first ledge to the second ledge. This movement from the first ledge occurs since the flame front is moving toward the combustion air stream flowing through the throat of the burner tile. The diagram below shows two Free Jet burners with flame stabilization occurring on the second stabilization ledge. The mixture of fuel gas and inert products of combustion becomes increasingly inert as the oxygen concentration inside the firebox is reduced.

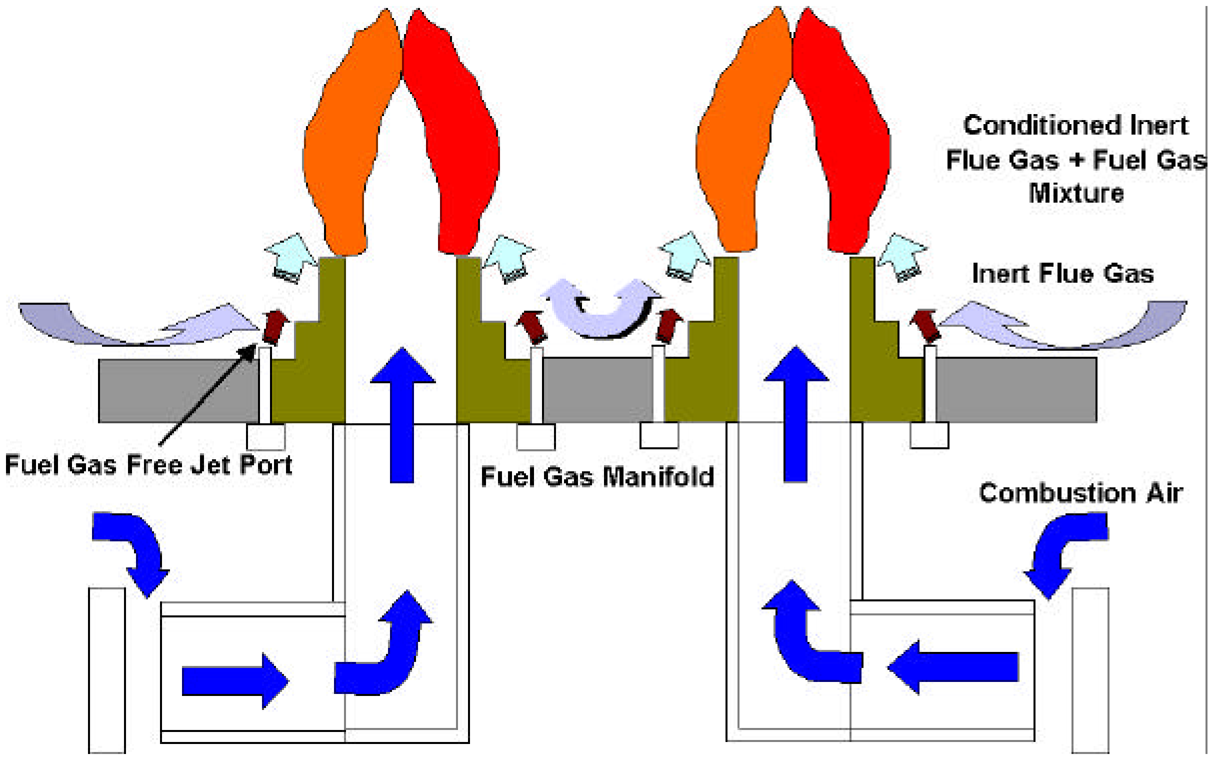


Figure 6: *Free Jet Final Stabilization*

Stabilization on the top ledge of the burner tile: By the time the oxygen content inside of the furnace is at 2%, the flame will stabilize on the top and final ledge of the burner assembly. All of the gas is mixed with flue gas and the thermal NOx emissions are drastically reduced.

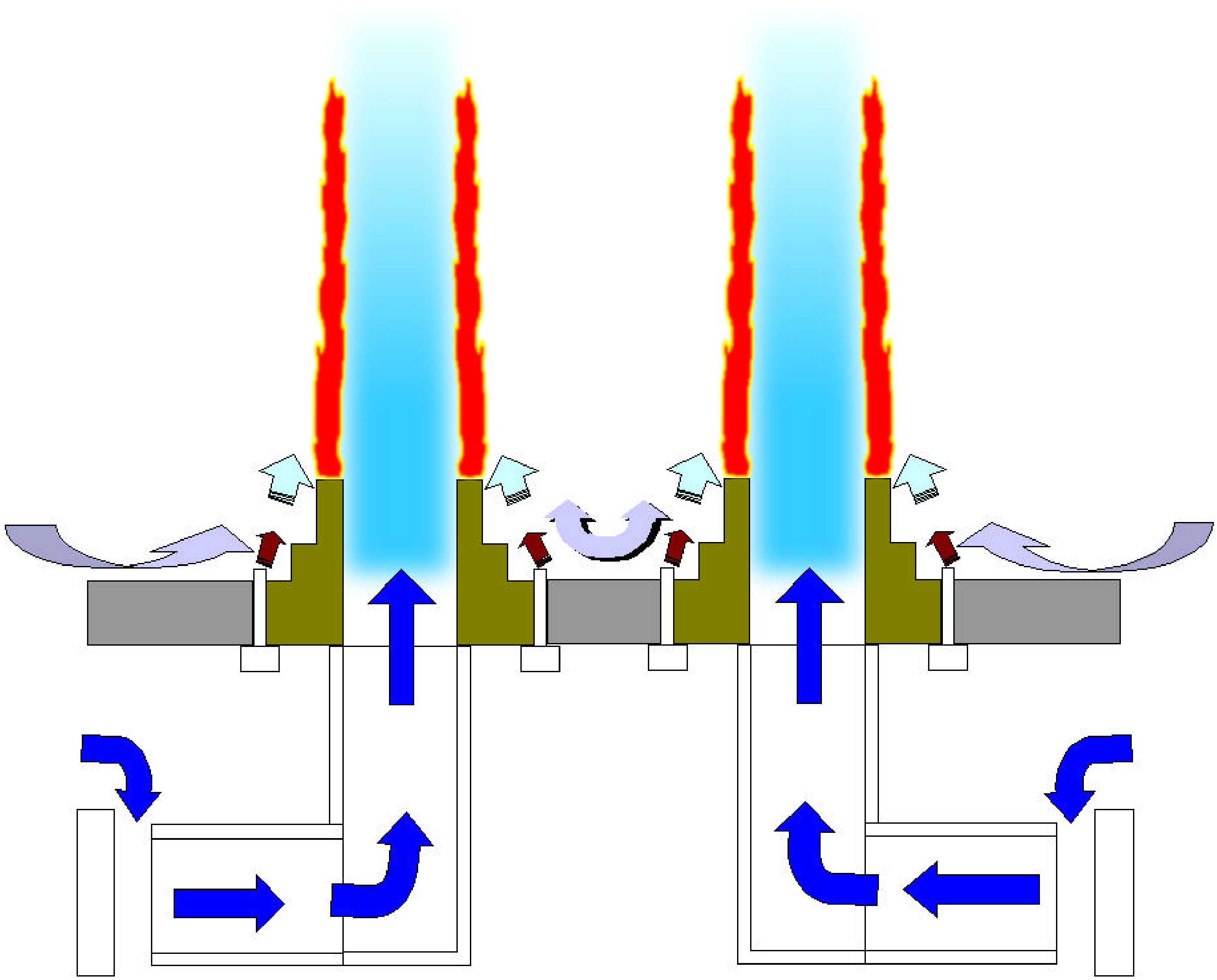
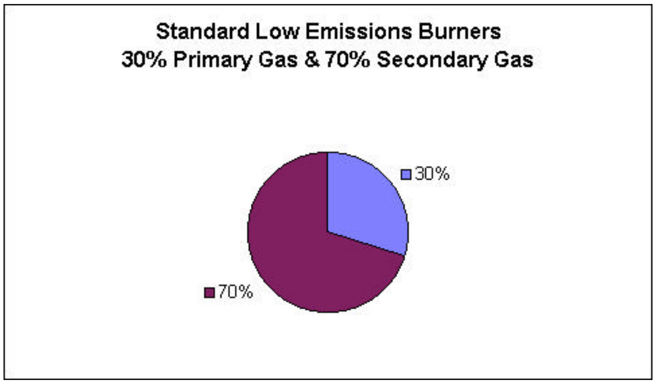
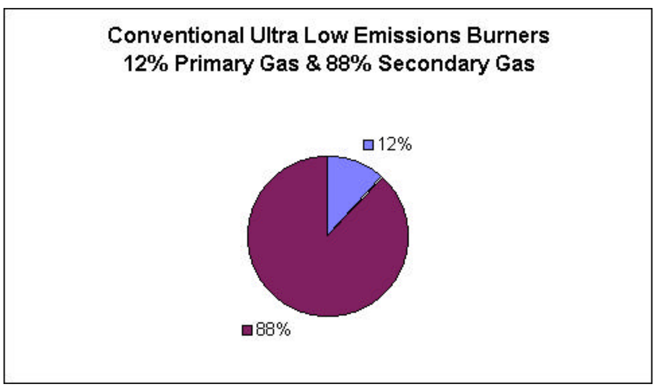


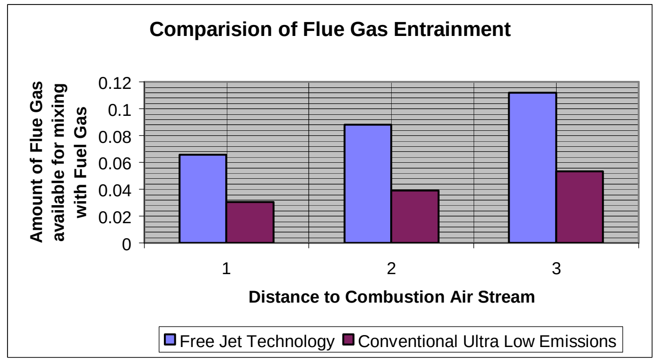
Figure7: *Free Jet Flame Pattern*

The compact size of the Free Jet burner allows the distance between burners to be maximized when placed in conventional spacing. More space between burners decreases the likelihood of flame interaction and decreases NOx. The absence of any flame holder in the burner throat and the fact that the burner does not "swirl" the air allows the momentum of the combustion air to remain in the vertical direction as it exits the tile. This results in a compact flame pattern and minimal flame interaction.

The graphs below demonstrate the proportions of primary and secondary gas in previous low emission burners. The primary gas contributes a significant portion of the total NOx production, therefore, in our Free Jet design we eliminated this phase of combustion. All of the fuel gas utilizes the Free Jet method of mixing inert flue gas with the fuel gas to reduce the peak flame temperature, and reduce the thermal NOx emissions to very low levels.







The advantage of the GLSF Free Jet ignition system is that up to 2.27 times as much flue gas can be mixed with the fuel gas as compared to other ultra low emission burner technologies. Increased flue gas entrainment and mixing with the fuel gas allows the peak flame temperature to be decreased and the NOx emissions to be reduced. In comparison to a standard low emission burner, the GLSF Free Jet entrains 38% more inert flue gas. With respect to a standard ultra low emission burner, the Free Jet method increases the internal flue gas recirculation by 15%. As the test data on the following pages indicates, very low emissions levels can be achieved with a very compact burner design.

Round Flame Emissions Data, English Units (Test Furnace)

Zeeco GLSF Free Jet Round Flame Burner Assemblies (Vertically mounted and vertically fired).

Description of Burner Assembly	Box Temp (F)	Floor Temp. (F)	NOx (ppmv)	Comb. Air Temp. (F)	Hydrogen % vol.	Methane % vol.
GLSF Free Jet Round Flame	1500	1300	7.2	80	35	65
GLSF Free Jet Round Flame	1600	1400	8.0	80	35	65
GLSF Free Jet Round Flame	1700	1500	8.8	80	35	65
GLSF Free Jet Round Flame	1800	1600	9.6	80	35	65

Flat Flame Emissions Data, English Units (Test Furnace)

Zeeco GLSF Free Jet Flat Flame Burner Assemblies (Vertically mounted and vertically fired).

Description of Burner Assembly	Box Temp (F)	Floor Temp. (F)	NOx (ppmv)	Comb. Air Temp. (F)	Hydrogen % vol.	Methane % vol.
GLSF Free Jet Flat Flame	1500	1300	6.0	80	35	65
GLSF Free Jet Flat Flame	1600	1400	7.5	80	35	65
GLSF Free Jet Flat Flame	1700	1500	8.2	80	35	65
GLSF Free Jet Flat Flame	1800	1600	9.0	80	35	65

Round Flame Emissions Data, Metric Units (Test Furnace)

Zeeco GLSF Free Jet Round Flame Burner Assemblies (Vertically mounted and vertically fired).

Description of Burner Assembly	Box Temp (C)	Floor Temp. (C)	NOx (ppmv)	Comb. Air Temp. (C)	Hydrogen % vol.	Methane % vol.
GLSF Free Jet Round Flame	846	704	7.2	27	35	65
GLSF Free Jet Round Flame	871	760	8.0	27	35	65
GLSF Free Jet Round Flame	927	816	8.8	27	35	65
GLSF Free Jet Round Flame	982	846	9.6	27	35	65

Flat Flame Emissions Data, Metric Units (Test Furnace)

Zeeco GLSF Free Jet Flat Flame Burner Assemblies (Vertically mounted and vertically fired).

Description of Burner Assembly	Box Temp (F)	Floor Temp. (F)	NOx (ppmv)	Comb. Air Temp. (F)	Hydrogen % vol.	Methane % vol.
GLSF Free Jet Flat Flame	846	704	6.0	27	35	65
GLSF Free Jet Flat Flame	871	760	7.5	27	35	65
GLSF Free Jet Flat Flame	927	816	8.2	27	35	65
GLSF Free Jet Flat Flame	982	846	9.0	27	35	65