APPLICATION OF ULTRA-LOW NOX EMISSIONS TECHNOLOGY UTILIZING INTERNAL FLUE GAS RECIRCULATION IN A LOOSELY WOUND HELICAL COIL FIRED HEATER

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ABSTRACT

A case study on the use of refinery style fired heater designs in a gas processing facility. The use of ultra-low NOx burners and fired heaters designed using API specifications has been historically limited to the refinery and petrochemical industries. With environmental regulations becoming stricter, and the continued growth of the gas processing industry, an effort has been made to introduce more ultra-low emissions technologies into the industry.

NOx emissions along with VOCs are precursors to ground level ozone. In nonattainment areas, very strict NOx emission plans are typically administered by state environmental agencies as part of a SIP (State Implementation Plan) for new plant construction. Most of the recent (within the last eight years) gas processing plant investments are not located in nonattainment areas but there continues to be a desire by plant owners to utilize ultra-low NOx fired equipment.

NOx is mostly formed within the high temperature zones of a flame. Free nitrogen and free oxygen combine to form NO and to a lesser degree NO_2.

$N_2 + O_2 \rightarrow NO + NO_2$ (at high temperatures)

Equilibrium levels of NO at varying levels of oxygen are as follows:

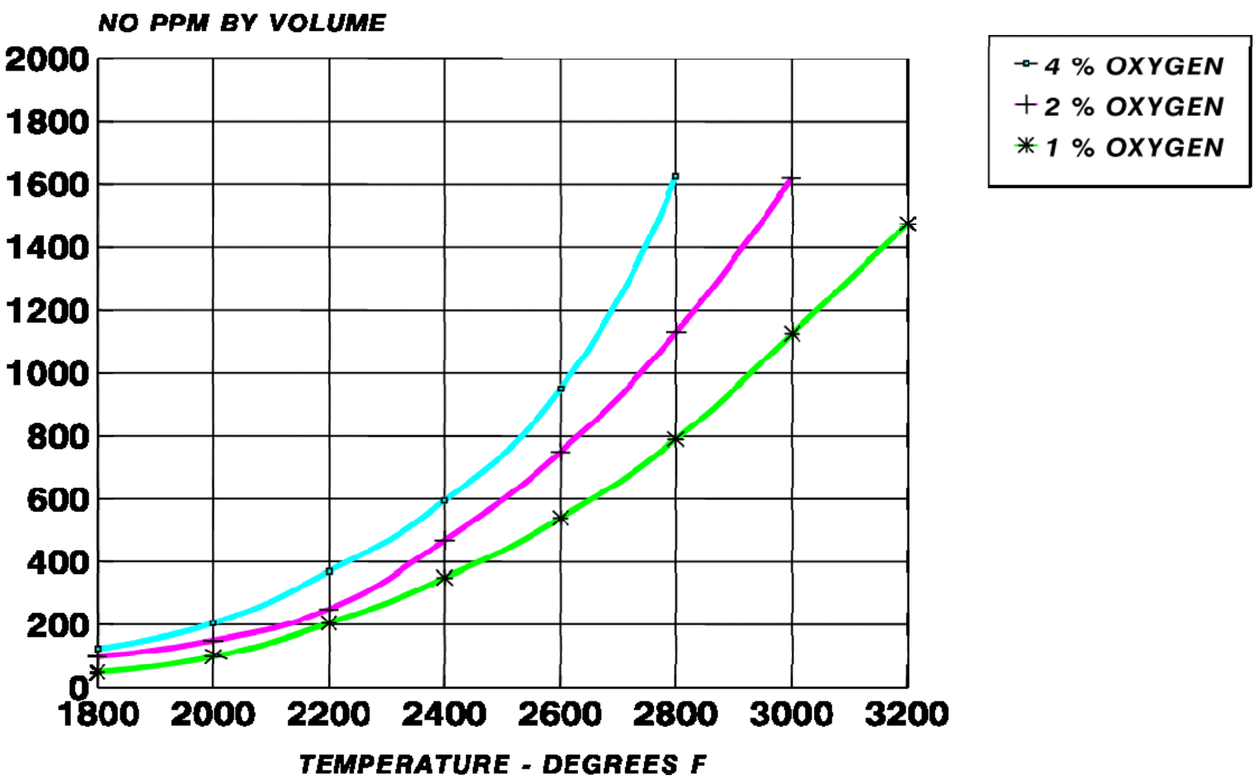

Fig. 1 (Courtesy of Callidus Technologies)

Very little NOx is formed outside of the high temperature flame envelope because the temperatures are not high enough. Equilibrium conditions of NOx, N2, and O2 are never reached in a furnace because of the short residence times, especially within the flame zone. Because NOx levels produced from a flame are a fraction of the equilibrium concentration at the same temperature, NOx predictions (and guarantees) become dependent on tested technology with test facility applied variables like fuel gas composition, heat release, arch temperature and others. To suppress NOx formation, one can remove the nitrogen from the reaction or lower the flame temperature. Removing the nitrogen can be very expensive, since air is used as the oxidant. Limiting oxygen to form NOx is achieved by operating at lower excess air levels but there are limits to this when excessive CO formation or burner instability are experienced. It has also been found that high levels of excess air when mixed intimately with the fuel and using the certain burner technology can suppress NOx formation due to a reduction in flame temperature.

Historically, heaters used in the refining and petrochemical industry were equipped with conventional type burners. The main goal at the time was to burn the fuel and to transfer the released heat as efficiently as possible to the process. However, the flames exhibited in conventional type burners are compact and very temperature intense, which result in high NOx emissions. Through the years, different techniques were used to reduce NOx to meet lower emission requirements. Such techniques included steam injection into the combustion zone, external flue gas recirculation into the air stream or the fuel, and staged air combustion. Each one of these techniques had advantages and disadvantages, but they all had limitation on how low they could reduce NOx emissions. During the 90's, the staged fuel combustion emerged and was accepted as the most effective and promising technology in drastically reducing NOx emissions. This technique reduces emissions by injecting the fuel in different stages of the air stream. Although the delayed combustion of the fuel results in longer flames, it also results in reduced flame temperatures, which greatly reduces the NOx emissions. Recognizing the capabilities of the staged fuel burner technologies, the heater vendors started adapting their equipment to accommodate longer flames.

As heater manufacturers and owners continued to either retrofit or replace older heaters, the burner manufacturers continued to advance staged fuel burner technology during the early 2000's to what is known today as "Next Generation" or "Ultra-Low NOx" burner technology. In addition to delaying combustion of the fuel by fuel staging, the new technologies utilize the fuel jets to entrain flue gases into the combustion zone. Because of the temperature gradients in the radiant section of a heater, internal recirculation patterns of combustion exhaust or flue gases are established. These flue gases consist mostly of inert products of combustions, such as carbon dioxide, water, nitrogen, and a relatively small amount of excess oxygen. The new generation burner technologies position the burner tips strategically to entrain these recirculating flue gases into the fuel jet and subsequently inject both fuel and inert gases into the combustion zone. This technique reduces the flame temperatures to even lower levels than could be achieved with a staged fuel technique alone. The Ultra-Low NOx burner technologies can achieve reduction in NOx emissions by as much as 80% or more compared to the conventional type burner technologies. The "Next Generation" burner technologies have been used to ultimately fulfill many of the NOx reduction plans committed to by major refiners and petrochemical companies in the early 2000's known as Consent Decrees.

The original "Next Generation" technology was envisioned for floor fired refinery furnaces with mostly natural draft applications. This technology works extremely well with the natural flue gas patterns of floor fired heaters. There is a natural upward flow of combustion air, flames and hot flue gases in the center of the furnace and a downward flow of cooler flue gases near the wall and tubes of the furnaces. See Figure 2 on the right:

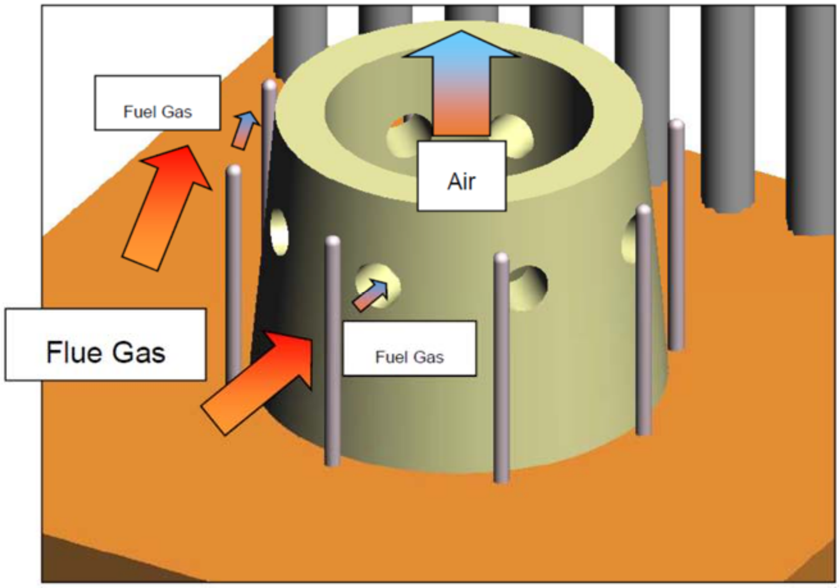

Fig. 2 (Courtesy Callidus Technologies)

Optimal Furnace Flow Patterns

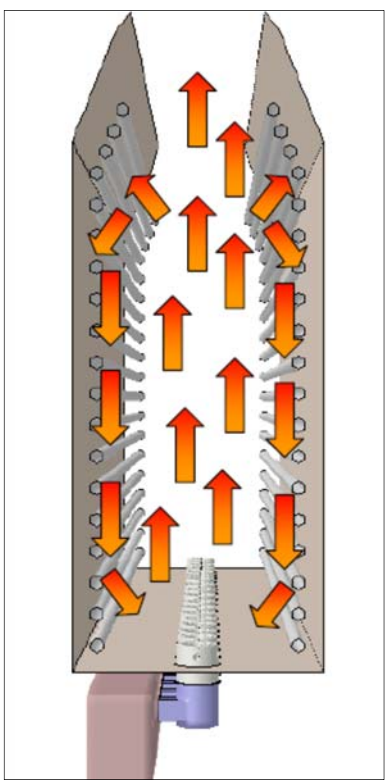

Fig. 3 (Courtesy Callidus Technologies)

It was found through application this technology that the furnace "density" was a factor in successful application and ultimately NOx performance. It works very well in generously sized radiant sections while tight furnace geometries tended to exhibit higher than predicted NOx emissions. It was found through application and CFD modeling that extremely tight radiant geometries (or high density furnaces) set up plug flow with very little recirculation except down low (just above the floor) and with very high temperature gases as opposed to the zoned upward/downward flow regimes shown above. This tight, plug flow is graphically represented in Figure 4 below:

Plug Flow Furnace Patterns

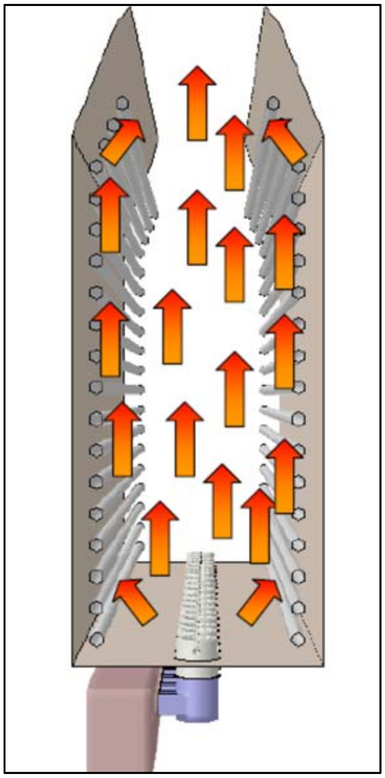

Fig. 4 (Courtesy Callidus Technologies)

This leads to high NOx emissions and poor flame patterns. A "short circuiting" pattern is experienced and sometimes produce flame impingement on tubes.

Besides the heat density consideration, other learnings with ultra-low NOx technology during the development and application of the technology in refineries and petrochemical plants were:

- Susceptibility to burner to burner flame interaction
- Instability in cold furnaces
- Necessity for clean fuel
- Poor NOx performance in leaky furnaces

In anticipation of upcoming lower emission and permit requirements of its customers, Exterran put forward in 2011 the collaborative challenge to Tulsa Heaters to meet the customer's demands and provide a heater that would:

- Meet NOx emissions of 0.04 lb/MMBtu (~30 ppm)
- Retain the horizontally fired heater configuration and relative compact heater size
- Require no special operating procedures or additional/special controls
- Retain a good turndown and stable operation
- Provide a safe, robust design with a long heater and coil life
- Be economical

Tulsa Heaters went to work designing a heater that would meet the requirements set forth by Exterran and the end user. The SHO (**S**tandard **Ho**rizontal) line of heaters by Tulsa Heaters is designed using the basic principles from API 560 – regularly used to design refinery and petrochemical heaters around the world – but scaled back slightly to meet the expectations of the gas processing industry. Some of the key design elements incorporated into the SHO heater line include:

- Horizontally fired
- Adequate burner-to-tube spacing
- Tube-to-tube spacing, and associated flux rate calculations, done per API 560 & 530
- Thermal design and heater rating using globally accepted heat transfer models
- Basic mechanical design
- Burner designed using API 535

While the above items give the SHO heater line a certain robustness in design, a couple of the points, working together, allow the heater to meet the stringent emissions requirements needed for the mentioned project.

One of the most critical design aspects included in the API specifications concerns the design of the coil itself, and much research has been done to determine design criteria. Based on this research, API recommends that tubes in the radiant section of the heater be placed approximately 2 diameters (measured centerline to centerline) from each other, and 1.5 diameters from the refractory wall of the heater (also measured from the tube centerline). The spacing of the coil apart from each other allows two things to happen inside the heater.

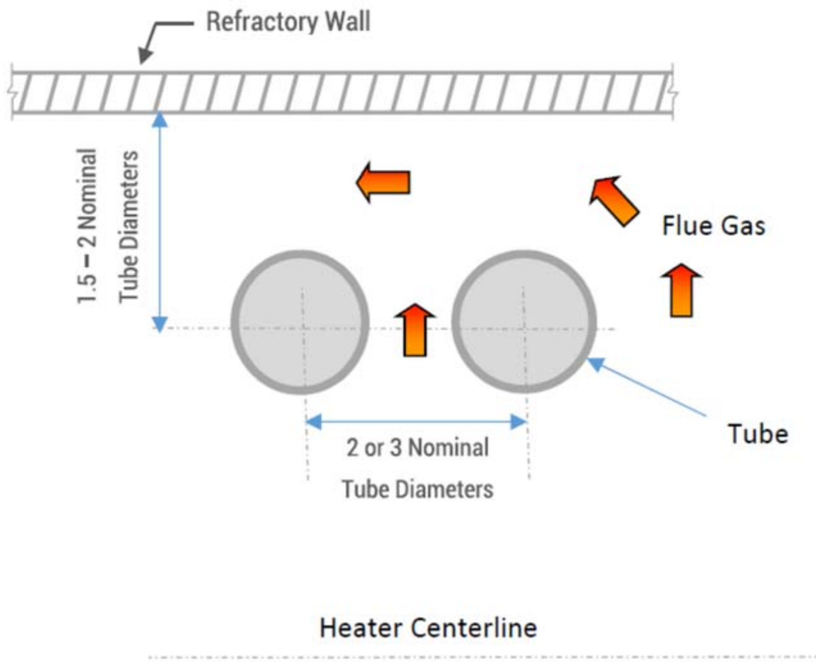

Fig. 5

First, the spacing allows for more even heat distribution on each coil. Studies have shown that, given adequate tube-to-tube spacing, approximately 60% of the radiant heat is transferred in a 30 degree wedge on the burner side of the tube. The other 40% of the radiant heat is transferred to the tube indirectly around the rest of the tube, reflecting off of the refractory wall to get the "back side" of the tube. Without adequate spacing between each coil, a disproportionate amount of the radiant heat is transferred in that same 30 degree wedge. API 530 provides a calculation method that translates this tube spacing to the maximum peak flux rate that the radiant coil will see. This flux rate can then be used to help determine film temperatures for your process fluid. In general, the closer the tubes are to each other, the higher the peak radiant flux rate goes, and the higher the process fluid film temperature will be. This is critical in the design of heaters so that the process fluid is not degraded or made to coke inside the coil.

The second thing that having the coils spaced allows the SHO heater to do is use Next Generation Ultra-Low NOx process burners. As mentioned above, these burners have been traditionally used in larger process heaters (designed to API specifications), and until 2012 had rarely been used in the gas processing industry. One of the main reasons they have not been used in gas processing industry is because the typical furnaces in that industry are horizontally fired, use tightly wound coils (pipe tangents touching or even welded together – see figure below) and have very high heat density geometries. None of which is conducive to internal flue gas recirculation. If internal flue gas technology is applied to this style of tightly wound coil and high heat density, poor flame patterns and high NOx levels would be experienced. A loosely wound coil and adequate cross sectional areas are needed to allow the backwards flow of flue gas to the root or base of the burner flame. This is accomplished with the spacing of the SHO heater tubes and standard geometries for the basic sizes.

Tightly Wound Coil Configuration

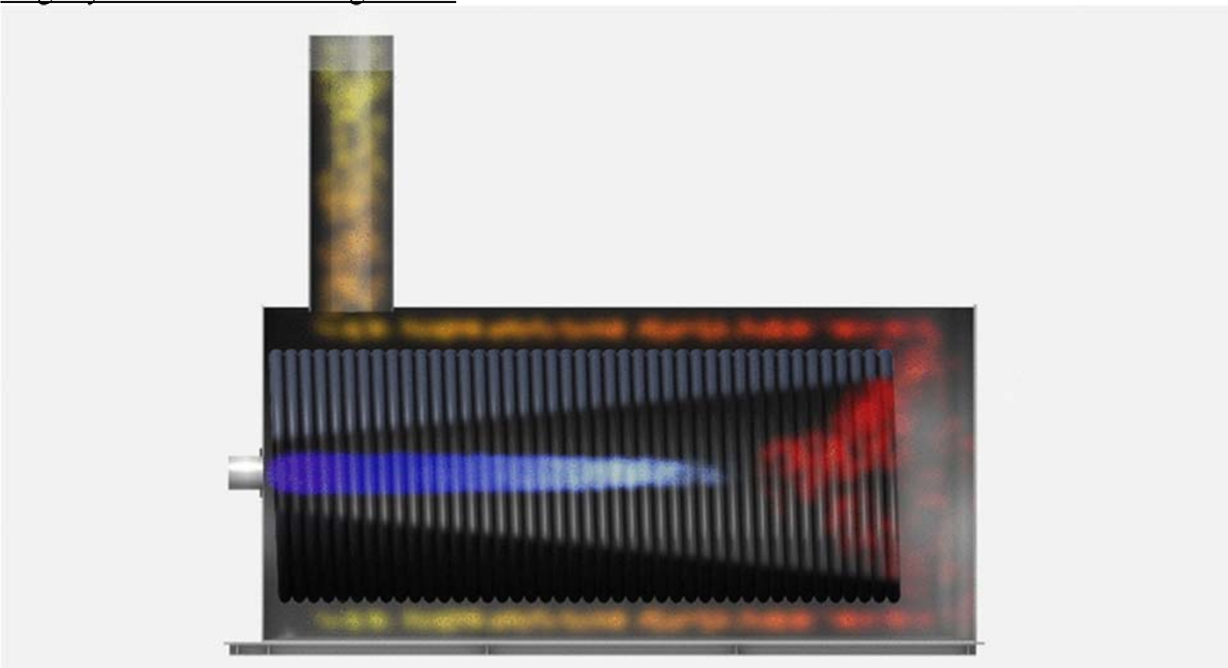

Fig. 6

Loosely Wound Coil Configuration

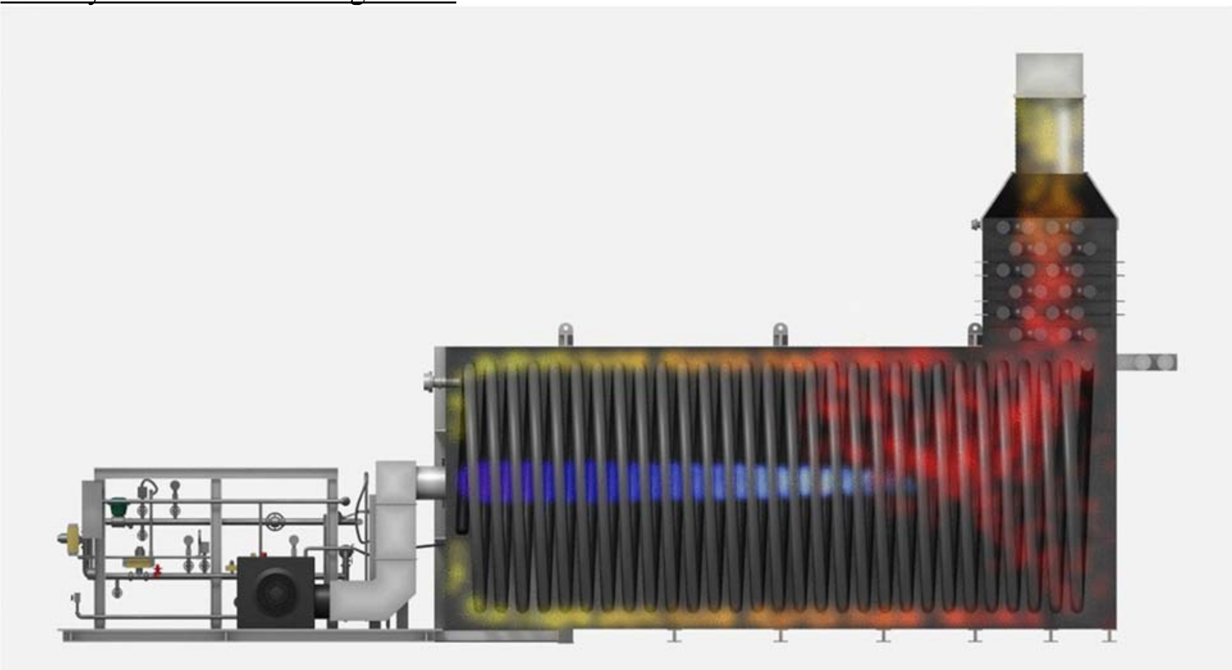

Fig. 7

Tulsa Heaters supplied SHO heaters with Ultra Low NOx Emissions burners for several of Exterran supplied plants (>30 plants). The heaters supplied were intended for different applications, including regeneration gas heaters for dehydration units in cryogenic plants, hot oil heaters for both cryogenic amine plants applications, and hot oil heaters for stabilizer units. Field data were taken for two heater installations in West Virginia. One was a regeneration heater and the other was a hot oil heater.

They are both horizontally fired with a loosely wound coil with 2 diameter tube spacing. The also both use a single forced draft burner mounted on the furnace centerline and both are fired using natural gas. The burners are from two different manufacturers but both are Ultra Low NOx burners and operate utilizing internal flue gas recirculation. Both burners are fired at their normal duty and both are operated within normal or typical excess air levels. The burner duties are matched to the heater sizes. The two heaters tested represent a relatively large difference in duty (size) and service with one being a gas heater and the other an oil heater. Also indicated is the cross sectional heat density. This number is an indication of the ability of a radiant box or section in combination with the burner to allow for "cool" gases to be recirculated back to the base of the flame for use in NOx reduction. High heat densities mean that the recirculated gases will be higher in temperature and yield higher NOx levels. The density itself is simply a ratio of the heat release to the cross sectional area of the radiant box. Levels exceeding 300,000 Btu/hr-ft2 can make this type of burner technology less effective in NOx suppression or produce unacceptable flame patterns (tube impingement).

Heater	Radiant Coil Dia. (ft)	Radiant Box Length (ft)	Cross Sectional Heat Density (Btu/hr-ft2)	Design Absorbed Duty (MMBtu/hr)	Design Fired Duty (MMBtu/hr)	Average Radiant Flux (Btu/hr-ft2)	Design BWT (°F)
Hot Oil	6.5	13	103,000	5.0	5.8	11,370	1450
Regen	9.0	24	165,400	14.2	16.5	11,200	1470

Below is data taken from the field for these two furnaces. As can be seen in the data, the recirculated gases at the burner firing wall are low in oxygen and low in temperature. The reason they are low in temperature is the fact that the gases return in a backwards direction in the furnace in proximity to the tubes both on the backside of the tubes and the front side. These low temperature, inert gases are entrained into the base of the flame and suppress NOx emissions. The target wall temperature is many times referred to as the bridgewall (think vertical furnace) or arch temperature. This an important temperature for burner suppliers for use in calculating their predicted NOx emissions. The NOx emissions requested by THM from the burner suppliers was 30 ppmv and is significantly higher than what was produced in the field operation. It is a somewhat surprising observation that the NOx emissions from two different burner suppliers using slightly different technologies are so close to each other in NOx performance. The flame lengths are somewhat difficult to estimate in the field due to the location of the sight ports but appear to be of proper length and matched to the heater geometry.

Regen Heater

O2 (%)	NOx @ A (ppmv)	Target Wall B Temp (°F)	Firing Wall C Temp (°F)	Flame Length (ft)
2	13	-	-	-
3	15	1469	878	17
4	15	-	-	-
5	17	-	-	-

Hot Oil Heater

O2 (%)	NOx @ A (ppmv)	Target Wall B Temp (°F)	Firing Wall C Temp (°F)	Flame Length (ft)
2	13	-	-	-
3	14	1473	913	11
4	14	-	-	-
5	15	-	-	-

It is concluded that with proper tube spacing and radiant furnace geometries, internal flue gas recirculation technology (ultra-low NOx) in a horizontally fired furnace can achieve:

- NOx emissions of 13 ppm (note: This should not be used for guaranteed or permit purposes as proper engineering evaluation for each specific application should always be utilized)
- Stable burner operation over a wide range of duties
- Flame dimensions that fit the heater and yield long coil life