Developments in Low NOx Incineration Technologies

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John Zink Hamworthy Combustion

The overall combustion industry continues to design and develop new low NOx and ultra-low NOx technologies across many applications. In general incineration design and requirements have lagged other technologies like process heaters and boiler burners. This is due to many factors but there is new focus on making similar gains in NOx combustion performance for the incineration sector.

"Ultra low NOx" technologies can achieve significantly lower emissions as compared to traditional designs with the implementation of flue gas recirculation (FGR), fuel staging, and other techniques to control the adiabatic flame temperature to maintain ultra-low NOx emissions (<10 ppmv). This is key because NOx increases rapidly with the adiabatic flame temperature as demonstrated in Figure 1 and Figure 2. These design principles have led to operation of burners at 0.01 lb/million Btu and less. However, the use of flue gas recirculation is not an option in most incineration applications and requires additional equipment and control scheme considerations.

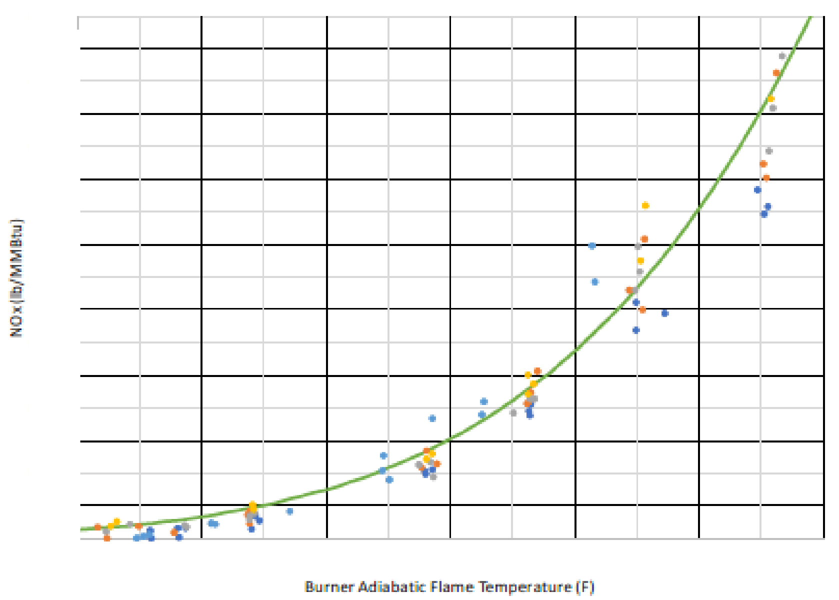

Figure 1: NOx levels as they relate to a burner adiabatic flame temperature.

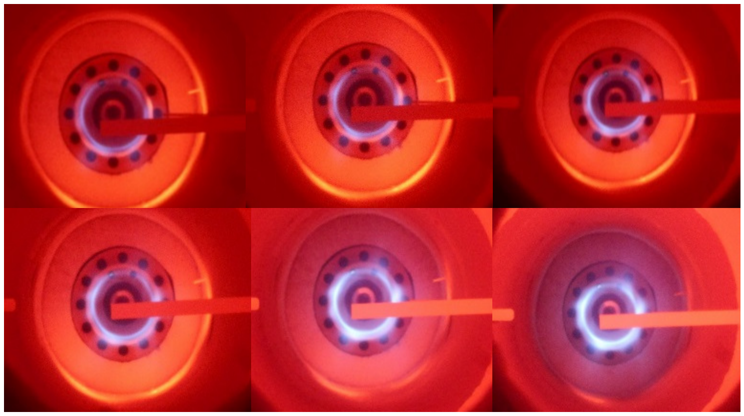

Figure 2: Flame shape as adiabatic flame temperature increases.

In most current conventional incineration applications, NOx limits range from 0.1-0.2 lb/MMBtu fired. However, with the implementation of a new generation of a Rapid Mix Burner (RMB®) design John Zink Hamworthy Combustion (JZHC) have achieved incinerator designs with NOx emissions of 0.02 lb/MMBtu fired, with proven operation of <9 PPM (3% O2 dry) at several facilities without implementation of flue gas recirculation (FGR).

The RMB burner, as depicted in Figure 3, achieves ultra-low NOx by rapidly mixing the fuel and air that 'simulates' lean pre-mix which control the adiabatic flame temperature. Pre-mixture of fuel and air can lead to potential flashback and instability, however, for the RMB® adapted design it does not completely mix prior to the ignition source in order to limit the potential for flashback while also maintaining stability.

While the RMB burner has been used successfully for many years in boiler burner applications the use in incinerators requires additional design considerations. This is due to the variable composition, flow rate changes, and poor conditions that are often involved with sulfur incinerated waste gases. Without the use of flue gas recirculation, other process conditions must be considered to help reduce elevated heat zones in the flame. JZHC has developed two primary strategies that can be used depending on the specific incinerator application. Each design centers around the strategic injection method of waste gases around the RMB burner. These designs can be used to support ultra-low NOx combustion of exothermal waste, heavy CO_2 steams, tail gas streams, among others.

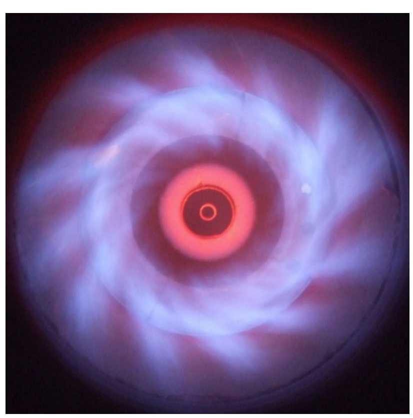

Figure 3: Photo of an RMB burner in operation.

The use of simulated lean pre-mix in the RMB burner helps to reduce two forms of NOx formation: prompt NOx and thermal NOx. Prompt NOx is governed by the Fenimore mechanism and results from reactions between hydrocarbon fragments and molecular nitrogen in the combustion air. Figure 4 shows the different possible reaction pathways for prompt NOx. In general, the hydrocarbon radicals react with molecular nitrogen to form hydrogen cyanide (HCN), which is then converted to NO through various other chemical interactions.

Prompt NOx formation is more prominent in fuel-rich zones, which are minimized in the RMB burner. The rapid mixing of fuel and excess combustion air creates a fuel-lean zone throughout the flame, and suppresses the formation of prompt NOx. Although prompt NOX is a relatively small contributor to total NOx, tightening emission requirements are beginning to push for further reductions of even this smallest source.

By contrast, thermal NOx has typically been the largest contributor to total NOx production in combustion. Governed by the Extended Zeldovich Mechanism[1], it occurs at high temperatures when molecular nitrogen and oxygen in the combustion air dissociate and react to form NOx.

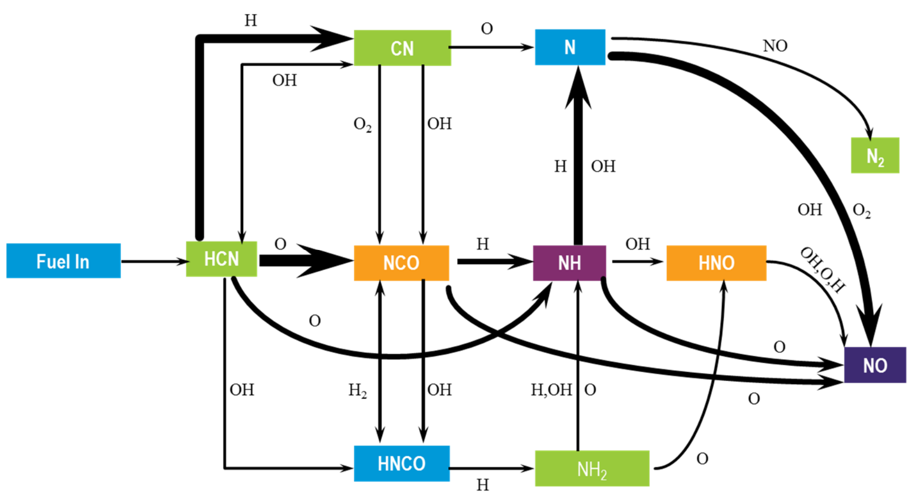

Figure 4: Expected nitrogen compound formations as considered in the Fenimore Mechanism.

For the RMB burner the primary design approach is to reduce both the adiabatic flame temperatures and any peak flame temperatures. The use of rapid fuel and excess combustion air mixing in the burner creates a lower, more consistent flame temperature that eliminates hot zones, and significantly reduces thermal NOx production.

Where exothermic waste is present, these streams can be used to control flame temperature and limit thermal NOx generation. In conjunction with a staged center-firing flame for stability endothermic streams are injected into specially oriented injection tips staged near the primary burner flame. Integral swirl vanes introduce tangential component to the velocity stream, swirling air then expands through the throat and "folds" over forming a zone of recirculation simulated in Figure 5, which result in large scale recirculation and brings hot products back to the face of the spinner reigniting the fuel/air mixture[2]. These injection points depicted in Figure 6 help develop more uniform temperature and minimize hot spots.

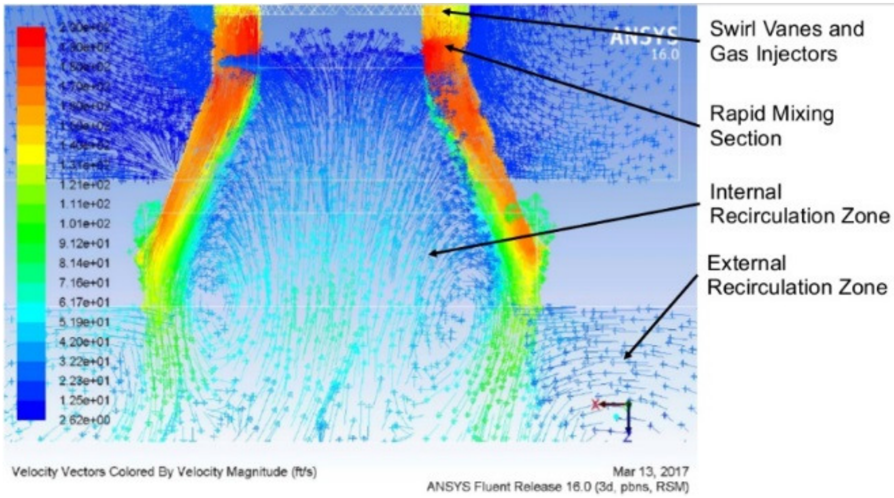

Figure 5: CFD depiction of the mixing zones created by the RMB.

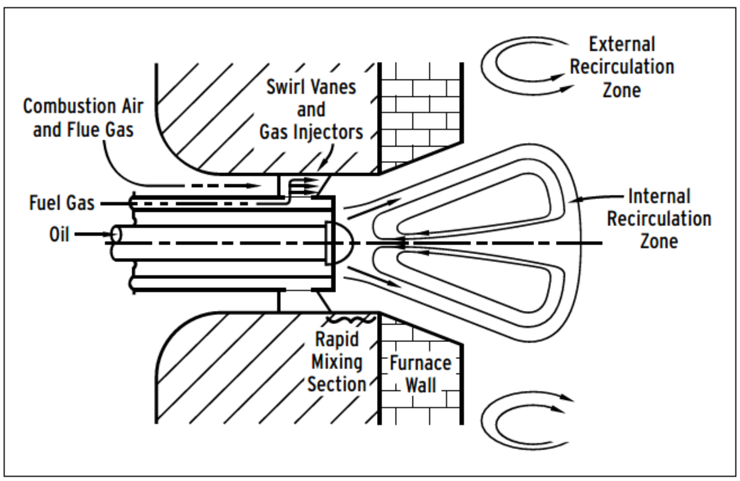

Figure 6: Demonstration of recirculation zones within the RMB burner.

For endothermic streams that may have high levels of inerts, such as CO2, additional considerations must be made to ensure stability. In general, low NOx burners tend to operate near the limits of stability as this operation point tends to produce the least amount of thermal NOx. This does not present significant problems when dealing with exothermic fuels as they help to stabilize the flame, whereas highly exothermic streams require additional stability techniques to maintain flame stability while achieving low NOx levels. Key features used to control this are use of high stability mechanical points on the burner in conjunction with a stable pilot anchoring system. Additionally, the combustion chamber itself must facilitate complete combustion in a controlled environment with the design of key chamber sizing ratios and refractory choke. These strategies allow for stable combustion while still maintaining the benefits of low thermal NOx generation.

The successful implementation of the RMB burner system in incineration design has led to the operation of systems far below what was once achievable with regards to NOx performance. This is a promising step for continued improvement in incinerator designs but there continues to be the potential for further growth and development with regards to incineration design and reduced emissions performance.

References

1. Y.B. Zeldovich, P.Y. Sadovinikov, and D.A. Frank-Kamenetskii, Oxidation of Nitrogen in Combustion, Academy of Science, USSR Institute of Chemical Physics, Moscow-Leningrad, Russia 1947.
2. S.J. Bortz, Apparatus and method for reducing NOx, CO and hydrocarbon emissions when burning gaseous fuel, U.S. Patent No: 5,407,347.