Designing near-zero-NOx boiler burners

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Nitrogen Oxides (NOx) emissions are regulated not only because they are highly reactive gases, but also due to the fact they react with VOC and Sunlight to form ground-level ozone and smog.

The allowable emissions set by the EPA and local regulators have continuously been reduced and boiler burner technology has had to keep pace. NOx regulations vary across the country based on the measured NOx and ozone levels. Any areas not meeting the requirements are designated as non-attainment areas and must implement a plan to bring levels into compliance. This typically involves establishing lower emission concentration thresholds for equipment within affected regions.

Some Air Pollution Control Districts in California require as low as sub-2.5 ppm NOx for boilers firing higher than 20 MMBtu/h while smaller sized equipment as well as other regions in California can require sub-5 ppm NOx. Other regions around the nation are currently considering lowering NOx for minor and major combustion sources to similar levels in their non-attainment areas. Until recently NO_x emissions this low required the use of a Selective Catalytic Reduction (SCR) unit. These systems eliminate the NO_x from the boiler flue gas by reacting it over a catalyst with ammonia. The size of the units is significant compared to the space available in most boiler rooms, ammonia handling and storage on site is required, and periodic catalyst reloads are required. It is much more efficient to prevent the formation of NOx by implementing combustion technology.

The current regulatory environment has necessitated flexibility in boiler burner designs to enable compliance with wide ranging emissions requirements while also maintaining efficiency, performance, and stability. Additionally, beyond emissions, there are also customer requirements for increased boiler efficiency, fuel flexibility for alternative fuels like biogas, propane, hydrogen, or the need to add air-preheat for increased overall efficiency. Rogue Combustion has successfully applied ClearSign's Core^{TM} burner technology capable of meeting near-zero NO_x emissions across diverse applications in firetube boiler burners without the use of ammonia, catalyst or any external flue gas recirculation.

The technology

Most ultra-low-NOx burners employ some level of air-fuel premixing and utilize higher levels of excess air and external flue gas recirculation (EFGR) to achieve lower NOx. ClearSign's Core burner technology also utilizes premixed technology but in addition incorporates several other design features and approaches to tailor NOx emissions per regional and specific customer requirements. These features and approaches include burner airside pressure drop, internal flue gas recirculation, varying levels of air-fuel premixing, premixed fuel staging, burner mixing length and control system modifications.

The Rogue burner with ClearSign Core^{TM} technology incorporates a flameholder positioned downstream from the fuel-air injection plane. Fuel and air are thoroughly mixed before reaching the flameholder. The airside pressure drop created by the blower generates high air momentum at the burner that enables high levels of inert flue gases – N_2, CO_2, H_2O – to be

entrained into the fuel-air stream. The effect is lowered flame temperature and less thermal NOx formation in the flame zone. The mixture is then ignited by the flame anchored at the flameholder location where the bulk of the combustion occurs.

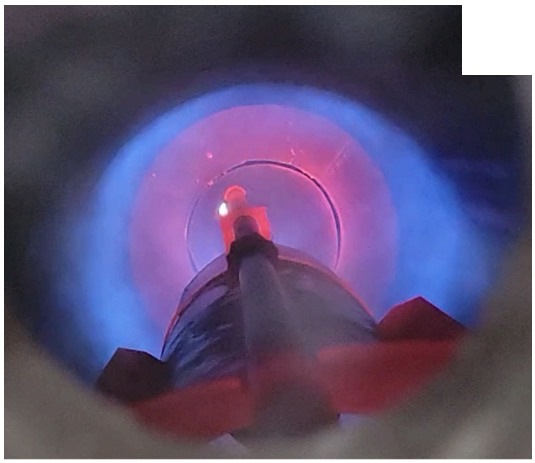

Figure 1 - Flame on a Rogue burner with ClearSign Core technology

The strongest dependence of NOx in premixed burners is on the operating O_2 level. As the excess air increases, NOx reduces because of lower flame temperatures. This behavior is shown in Figure 2 (left). This flexibility of the burner to both dial in NOx compliance at different required levels while also considering maximization of efficiency is an important feature.

The burner combustion air nozzle determines the burner pressure drop. The higher the pressure drop, faster the velocity of air exiting the nozzle, and higher is the entrainment of flue gases. The nozzle size can thus be tailored to meet the required level of NOx emissions. Smaller sized blowers can be specified when NOx emissions requirements are higher while operation at near-zero NOx levels (<2.5 ppm) requires larger blowers.

NOx is a strong function of air-fuel premixing. Larger distances from the location of the air and fuel injection to the location of the flame allow for larger mixing residence times prior to burning thus lowering peak flame temperatures (Figure 2 - right). Additionally, the premixing can be enhanced by introducing a second fuel circuit in the burner windbox prior to the combustion air nozzle.

Figure 2 - NOx dependence on operating O_2 in premixed flames (left). Effect of mixing length and burner airside pressure drop on NOx (right).

In addition to lab and field testing, ClearSign utilizes computational fluid dynamics (CFD) tools to develop and optimize its burner designs. Steady-state, full-scale reacting flow models of

the burner are simulated using commercial software. The combustion is modeled using a reacting species transport model for chemical kinetics specialized for methane-air combustion. The CFD provides a powerful tool to evaluate the flow fields in the burner, air-fuel mixing, heat transfer to the boiler as well as NOx formation. Some exemplar plots from CFD are presented in Figures 3 and 4.

Figure 3 - CFD profiles of methane concentration and velocity

Figure 4 - Pilot flame stabilization

ClearSign and Rogue recently introduced new burner lines for different levels NOx requirements – NZN or "near-zero-NOx" for sub-2.5 ppm operation, S5 for sub-5 ppm, and S9 for sub-9 ppm NOx capability. The burner design is simplest for the S9 line while additional features are added to the S5 and NZN models. The design of the burner is such that the components can be upgraded in the field to allow customers to "future-proof" their boiler to meet more stringent NOx requirements. The NZN, S5, and S9 all have a footprint similar to other fire tube boiler burners.

Case studies

Two recent installations of the Rogue burner with ClearSign Core™ technology were a 500 HP NZN burner and a 300 HP S5 burner (Figure 5). The S5 burner was a 300 HP retrofit project in a Superior Mohican 4-pass wetback firetube boiler in the California Central Valley. The customer was a medical waste recycling facility whose existing conventional ultra-low-NOx burner had challenges in reliably meeting the 5 ppm NOx permit. The new Rogue Combustion burner with ClearSign Core Technology was installed and successfully source tested to 3.6 ppm NOx (corrected to 3% O_2). This was a good application to test the robustness of the burner as the boiler operated in a highly cyclical mode with the transition from light off to low fire to high fire occurring inside of two minutes. The burner was able to maintain its NOx and CO emissions within permit levels throughout the range.

The S5 Model fit easily into the existing space without relocation of the boiler or other ancillary equipment. The S5 blower was positioned 90-degrees to the centerline of the boiler. That made the burner footprint slightly wider but had a shorter length than the existing burner assembly that used an inline blower. The external FGR ducting was removed, opening the space above the burner.

A new Rogue control panel was installed that uses a familiar operator interface. The tuning and operation of the burner would be intuitive to any boiler operator. Startup and tuning were made simpler with the elimination of external FGR controls. The S5 burner's flow of the internal FGR is inherent to the design of the burner and automatically varies with the combustion air flow. Commissioning of sub-5 PPM NOx burners has always been challenging, but much less so for the Rogue S5, as the capabilities of the burner leave margin for error. There was no impact related to the diameter or corrugations of the furnace, which is a feature of ClearSign technology. The end user was impressed with how quietly the system operated.

To facilitate the installation of the 300 HP Rogue-Clearsign burner retrofit, a 500 HP trailer-mounted rental boiler was installed to provide steam to the facility for continuing operations. This Cleaver-Brooks boiler was equipped with a Rogue-ClearSign 500 HP NZN burner. The system had been successfully independently source-tested to 1.9 ppm NOx (corrected to 3% O_2). Due to the facility's permit, the 500 HP rental boiler had to be derated to 300 HP. By adjusting the fuel and combustion air settings only, without any component changes, the burner was reset for 300 HP operation at sub-7 ppm NOx as required by the permit. Sub-2.5 ppm NOx operation was also achievable on this burner, demonstrating the versatility and flexibility of the burner system.

Figure 5 - Rogue-ClearSign NZN 500 HP system (left), Rogue-ClearSign S5 300 HP flame (right).

Figure 6 - NOx emissions (corrected to 3% O_2) for the S5 300 HP and NZN 500 HP burners.

Utilization of CFD, lab and field testing resulted in an innovative burner design that showcases a significant advancement in meeting stringent NOx emission requirements. ClearSign Technologies and Rogue Combustion have introduced firetube boiler burner lines catering to extremely low NOx emission requirements, from near-zero (sub-2.5 ppm) to sub-5 ppm to sub-9 ppm. Recent field installations have demonstrated the flexibility of these burners in achieving unparalleled NOx reduction while ensuring reliable, efficient operation, even in challenging applications.

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