DETERMINING OPTIMUM COMBUSTION SOLUTIONS TO EMISSIONS CONCERNS FOR NEW AND EXISTING BOILERS

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ABSTRACT

The reduction of emissions through the design and implementation of the appropriate combustion system for each particular application is the key to offering maximum operational benefits. To accomplish this, one must have the ability to design and implement systems that produces the best emissions performance and operational flexibility on both new boiler and retrofit applications. The ability to offer emissions reduction through the use of the latest burner technology gives users a method to achieve maximize emissions reduction and avoids the cost and complexity of back-end cleanup systems. Choosing the right burner system based on the operating conditions, furnace design, fuel supplies, and other mitigating factors is critical to implementing a successfully operating system. In this paper we will discuss three radically different burner replacement projects, which were designed and implemented based on the specific requirements of the applications, and resulted in significant reductions in NOx and other pollutants.

In many applications suitable emissions reductions can be achieved without a complete burner replacement. In these cases you can employ an engineered solution that allows users to achieve their required emissions reductions through the use of a building-block approach. By addressing all the aspects of the combustion process; the fuel, the air, and the burner design, the entire combustion system can be optimized to produce the lowest possible emissions for any given configuration. The ability to implement these techniques on both new and existing burners, and regardless of the original manufacturer, gives this technology a widespread applicability. In applications ranging in size from firetube boilers to utility boilers, these techniques provide the same consistent emissions performance and operational benefits. In this paper we will provide an example of this patented technology and how it was utilized to provide over 90% NOx reduction on a boiler retrofit project without affecting capacity or requiring replacement of ancillary components.

INTRODUCTION

In order to discuss NOx reduction techniques, it is first necessary to briefly review the basic theory behind NOx formation. Burning natural gas, and other fuel gases with no bound nitrogen, produces NOx through two main routes. The first is a thermal route where high flame temperatures cause nitrogen molecules from the combustion air to break apart and combine with oxygen to form nitric oxide. The sequence is complicated, but the following two steps represent the essential features.

$$N + O_2 = NO + O$$
$$\underline{O + N_2 = NO + N}$$
$$N_2 + O_2 \rightarrow 2\ NO$$

As the name implies, thermal NOx formation can be reduced through control of peak flame temperature. While thermal NOx is dependent to some extent on oxygen availability, if the temperature can be lowered enough, thermal NOx emissions from a natural gas flame can be reduced to less than 1 ppm.

Another mechanism that produces NOx is the prompt mechanism. Under fuel-rich conditions, particularly when stoichiometry is under 0.6, both HCN and NH_3 can be formed through the rapid reaction of CH with N_2 to form HCN and N. Below a stoichiometry of 0.5, almost all NOx formed is prompt NOx. Although prompt NOx is temperature-sensitive, the temperature sensitivity is not as great as with thermal NOx. The rate of formation is very rapid, being complete in 1 ms. Under fuel-rich conditions and a temperature of just 2,400°F, approximately 20 ppm of prompt NOx still remain.

In the drive to reduce NOx emissions, methods were implemented to lower peak flame temperatures and oxygen availability through the addition of various diluents to the combustion process. Two of the most popular methods have been through the use of recirculated flue gases from the boiler outlet and through the use of steam injection. Both of these methods reduce the flame temperature and help to reduce thermal NOx formation. Another method to lower NOx is through burner designs that utilized staged combustion, delaying the mixing of fuel and air. By creating an initial fuel-rich combustion zone, with air added downstream to complete combustion, oxygen availability is limited, peak flame temperature is lowered, and thermal NOx formation is reduced. Another staging method is to create a fuel-lean primary combustion zone, with lower flame temperatures and lower thermal NOx formation, then inject additional fuel downstream to consume the excess oxygen and complete the combustion process. However, some burner designs employ an extreme degree of fuel-air staging that can result in unacceptably long flames and reduced flame stability, especially at lower load rates. It is when these various NOx reduction methods are combined that the lowest NOx emissions can be achieved, with the maximum operating flexibility. In the following sections we will discuss three different applications that were solved using three different burner technologies.

LOW NOx BURNER UTILITY RETROFIT

The Dynaswirl Low NOx burner was developed to provide the maximum degree of flexibility in achieving low NOx emissions, high burner turndown, and improved flame shaping capability. The basis of the design is to develop a stratified flame structure with specific sections of the flame operating fuel rich and other sections operating fuel lean. The burner design thus provides for the internal staging of the flame to achieve reductions of NOx emissions while maintaining a stable flame. Controlling combustion stoichiometry to fuel rich conditions inhibits NOx production especially in the burner's flame front. Operating the flame fuel rich also reduces burner NOx emissions dependence on the burner zone heat release (BZHR) characteristics of the furnace. In addition to controlling NOx formation, operating under fuel rich conditions results in the production of combustion intermediates that can result in the destruction of previously formed NOx. In a reducing environment, NO can act as an oxidizer to react with these combustion intermediates resulting in the reduction of NO to N2. As such, NO necessarily formed to satisfy the requirements of establishing a strong flame front can be scavenged by the processing of this NO. To achieve complete fuel burnout at minimum excess O2 the burner design provides for fuel lean zones to directly interact with the center fuel rich sections. This ensures that the "rich" products of combustion from the center flame pass through the oxidizing zone for complete fuel burnout. The burner design allows control of the stoichiometry of the oxidizing zone from being pure air to having varying degrees of excess oxygen. This controls NOx formation by causing the fuel burnout to occur in the form of a premixed flame rather than a diffusion flame.

The basis of the burner design is the Dynaswirl low excess air burner. The venturi air sleeve for the burner provides for the primary and secondary airflow in the Dynaswirl-LN burner. To increase the flexibility of combustion staging and flame shaping capabilities, the burner is equipped with a tertiary air sleeve assembly. This is installed at the outer periphery of the burner throat. The tertiary air is mixed in the furnace with the bulk furnace gas to achieve complete fuel burnout. This provides for the complete burnout of the fuel in the post combustion zone where NOx formation is inhibited by lower combustion temperature and reduced O2 concentration. The gas injection is done through multiple gas “pokers” located and oriented around a curved-bladed swirler, and a center-fired gas injection assembly.

In the Spring of 2000, a 340 MW Babcock and Wilcox “El Paso” style, opposed wall fired, natural circulation, forced draft utility boiler in Southern California was retrofitted with twenty-four Dynaswirl-LN burners. The combustion equipment for this unit consists of burners with advanced fuel gas injection techniques, a separated over-fire air port system, and flue gas recirculation of approximately 25%. The burners are fired with natural gas and combustion air is supplied with a 480°F pre-heat temperature. The configuration is comprised of three elevations of four burners each, below one elevation of four over-fire air ports, on both the boiler front and rear walls. The separated over-fire air ports route pure combustion air through the ports, in lieu of air mixed with flue gas. The intent of this modification was to make the flue gas recirculation system more effective by achieving a lower windbox O2 for a given amount of FGR. Utilizing all these NOx reduction techniques in concert allowed this unit to achieve NOx levels at full load of 19.8 ppm and CO levels of 300 ppm, while operating at excess oxygen levels of approximately 1.0%. The reliable performance of the Dynaswirl-LN has resulted in this project achieving the lowest NOx emissions of any utility gas burner retrofit project ever, and has resulted in over 8,000 MWe of installed capacity.

ULTRA LOW EMISSIONS BURNER

The relationship between temperature, stoichiometry and NOx forms the basis of the Ultra Low Emissions Rapid Mix Burner (RMB) designed for natural gas or other gaseous fuels. NOx formation fundamentals were used to design a gas injection and mixing system that was radically different from all other commercially available low NOx burners. The new gas mixing approach was incorporated into an established burner geometry that had been optimized to provide an extremely stable flame. The solution avoids fuel-rich regions by rapidly mixing gaseous fuel and air near the burner exit. The rapid mixing results in a nearly uniform fuel/air mixture at the ignition point, which virtually eliminates prompt NOx formation. Thermal NOx is then minimized by using FGR, mixed with combustion air upstream of the burner, to control flame temperature. In effect, the Rapid Mix Burner acts like a pre-mixed burner with one important distinction: since the fuel is added just upstream of the burner throat, the extremely small pre-mixed volume eliminates possibility of flashback.

The RMB consists of a two-zone parallel-flow air register with no moving parts. Combustion air pre-mixed with FGR enters the register, and the entire mixture then passes through the two air sleeves. The inner sleeve contains swirl vanes, which are attached to a central gas reservoir, and have hollow bases that are drilled for gas injection. Thus, the swirl vanes actually are the gas injectors, which provides the RMB's near perfect fuel/air mixing. The outer sleeve contains a second set of gas injector vanes attached to an outer gas reservoir. These vanes do not impart any swirl to the airflow, however. Airflow through the inner and outer burners is designated "primary" and "secondary" airflow, respectively. Both the primary/swirled and secondary/axial zones operate with the same, near perfect mixing. Swirler geometry, burner internal geometry and quarl expansion are matched to promote internal recirculation of a large amount of hot combustion gases. This enables the burner to operate at lower flame temperatures than other burners and consequently lower NOx levels, with a "blow off" point of about 3 ppm NOx. In fact, the RMB flame remains stable at 60% FGR; therefore, the 25-30% FGR rates currently necessary for single digit NOx do not begin to approach the burner's performance limits.

In the Fall of 1994, a 100,000 lb/hr D-type Nebraska watertube boiler at a tomato cannery in California was retrofitted with a 130 MMBtu/hr Rapid Mix Burner. This system utilized induced flue gas recirculation, combined with the proven burner design, to achieve single digit emissions of both NOx and CO. The burner operates with natural gas supplied at a pressure of less than 10 PSIG and ambient combustion air with a register draft loss of only 8 inches W.C. The NOx emissions of the burner was maintained at less than 8.5 ppm across the entire load range, and achieved a turndown of 6:1. The CO emissions were also kept to less than 1 ppm across the load range. The flue gas rate required to achieve these emissions ranged from 28% in the lower half of the load range to 23% at full load. The boiler excess oxygen was 4% at minimum load and ranged down to 3.2% at full load. The compact flame dimensions of this burner (less than 10 feet at full load), which is characteristic of the Rapid Mix design, allowed the boiler capacity to be increased to a maximum rate of 110,000 lb/hr. This type of performance has resulted in making the Rapid Mix Burner the burner of choice for natural gas fired single burner applications requiring single digit NOx and CO emissions, and has resulted in over 50 successful applications of this burner to boiler installations.

FUEL DILUTION FOR NOx REDUCTION

The properties of the fuel being burned have a direct impact on the emissions of the combustion system, and now a technology exists for conditioning gas fuels to reduce emissions. Through the use of this patent-pending COOL*fuel* system, inert gases are induced and mixed with the existing gas fuel to generate a low BTU gas, which results in substantially reduced emissions. COOL*fuel* gas conditioning technology reduces thermal NOx by reducing the flame temperature and lowering the local oxygen concentration. Since it also increases the fuel mass flow, it improves fuel-air mixing, reduces the residence time under NOx forming conditions, and homogenizes the flame, which serves to further lower the peak flame temperature. Conventional flue gas recirculation, which returns some flue gas to the air-side of the combustion zone acts to reduce thermal NOx by reducing available O2. However, this does not increase the fuel mass flow and improve the fuel-air mixing, so it is not as effective in reducing thermal NOx as gas conditioning. Moreover, since it does not affect the fuel side of the combustion, it also should have no effect in reducing prompt NOx. Because gas conditioning technology reduces the carbon radical concentrations in the combustion zone, it thereby reduces prompt NOx formation in addition to thermal NOx. This has resulted in the ability to achieve higher NOx reductions with COOL*fuel,* than with conventional flue gas recirculation system using the same mass flow of flue gases.

COOL*fuel* uses the motive force of the fuel gas to aspirate flue gases and mix them with the fuel. This allows the system to provide emissions reductions without the requirement of additional fan horsepower to move the flue gases, resulting in lower operating costs, and eliminates the maintenance issues involved with hot flue gases contacting rotating fan parts. Any recycling of flue gases increases mass flow through the boiler, increasing convective section pressure drops and increasing superheat temperatures. However, since gas conditioning is more effective in reducing NOx than conventional flue gas recirculation, it requires less flue gas for the same amount of NOx reduction. This results in a much lower impact to the boiler operation. In addition, steam injection can be incorporated easily into this system. Steam serves a dual role of providing additional NOx reduction through its added mass flow, and also providing a motive force for inducing more flue gases. This results in large increases in NOx reduction while using only small amounts of steam.

In the Spring of 2000, four 125,000 lb/hr Riley field erected watertube boilers at a refinery in California were retrofitted with five 40 MMBtu/hr LCF burners each. This system utilized a COOL*fuel* gas conditioning system, induced flue gas recirculation, and steam injection to allow the user to meet their emissions requirements. These burners operate with refinery fuel gas that contains approximately 25% hydrogen by volume, and utilize combustion air with a pre-heat temperature of 440°F. The goal of this retrofit project was to allow the plant to bring the boilers into compliance with a new permit requirement of 25 ppm NOx. The existing burners operated with NOx emissions of between 400 and 450 ppm. After replacing the existing register type burners with new LCF burners, which had been designed specifically for the use of COOL*fuel,* the NOx was reduced to 350 ppm as a function of the improved burner design. Once the COOL*fuel* system was utilized NOx on these units the NOx dropped to 70 ppm, an 80% reduction from the baseline. The addition of steam injection to the system resulted in lowering the NOx to 24 ppm, and achieved compliance with the permit requirements. Since the existing forced-draft combustion air fans had some additional spare capacity, and in order to provide more operational flexibility, 2-3% induced flue gas recirculation was added and the NOx was lowered to 22 ppm. This resulted in a total NOx reduction of 93.7% from baseline levels with the new burners, and over 95% reduction from the existing burners. This system has allowed NOx compliance without requiring replacement or modification of the existing forced draft fans, induced draft fans, airheaters, steam superheaters, or economizers. The units have also demonstrated that they are capable of firing to a maximum steam rate of 140,000 lb/hr while still staying in compliance with the 25 ppm NOx limit.

CONCLUSION

The continued drive to reduce NOx and other emissions is a fact that industry must struggle with daily. In order to provide the most cost effective solution, and have the smallest impact on existing systems operation, the appropriate combustion system for each particular application needs to be engineering and supplied. Above we have outlined solutions to three different boiler applications, each of which allowed the units to be operated with NOx emissions below 25 ppm. Choosing the proper burner design, such as the Dynaswirl-LN or the RMB, in addition to applying to best NOx reductions system gives users an economical custom-engineered solution to emissions compliance. NOx reduction system like COOL*fuel,* can be added to new burners as well as any manufacturers existing burner for superior NOx reduction. This add-on NOx reduction technology has been implemented on units ranging from 250 HP firetube boilers to 165 MWe tangentially fired utility boilers, with the same successful results. This novel approach to using flue gases for NOx reduction has the proven benefit of being more effective, and reducing both the operating cost and operational impact on the system. By optimizing all aspects of the combustion process, the entire combustion system can be designed for the lowest possible emissions. It is through this building-block approach that the best combustion system for any particular application can be designed, installed, and implemented.