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Low NO_x Combustion System Solutions for Wall Fired, T-Fired and Turbo Fired Boilers

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LOW NO_x COMBUSTION SYSTEM SOLUTIONS FOR WALL FIRED, T-FIRED, AND TURBO FIRED BOILERS

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ABSTRACT

The need to develop cost effective combustion controlled solutions for reducing NO_x emissions in coal fired utility boilers has been a high priority for many years at Riley Power Inc., a Babcock Power Company. Solutions have varied anywhere from burner component modifications only to complete burner replacement combined with an advanced air staging system.

This paper discusses the application and results of various combustion related technologies for reducing NO_x emissions on a wide variety of boiler designs including traditional wall fired and T-fired furnace designs as well as a more unique furnace design, the Riley Turbo Furnace. NO_x reductions of 40-70% have been demonstrated using advanced combustion controlled equipment with improved overall boiler operation.

In these applications, computational fluid dynamic (CFD) modeling was used to refine the design of low NO_x combustion systems and to identify the initial startup settings to minimize commissioning time. Results of the modeling will be discussed making comparisons to actual field measurements.

INTRODUCTION

Reducing NO_x emissions from utility coal fired boilers continues to be a primary goal of environmental authorities. Since the early 1990's nearly all-large utility boilers have installed some form of low NO_x burner technology and/or overfire air (OFA) as a primary means or first step to controlling NO_x emissions. The cost is typically much less than implementing SCR systems and the level of NO_x reduction can range from 40-70% from uncontrolled levels. When combined with an SCR system, LNB & OFA will lower the SCR inlet NOx and save on ammonia consumption cost. So, the cost of LNB & OFA can often be justified by this savings as well.

With NO_x emission requirements becoming more and more stringent, recent years have focused on either replacing first or second generation low NO_x burners or upgrading existing burners with newer more advanced low NO_x combustion technology. Not only will the newer burner technology decrease NO_x emissions an additional 10-15% or more, the equipment will provide greater operating longevity. This paper discusses several recent experiences at Riley Power Inc., (RPI) where earlier vintage low NO_x burners were replaced or upgraded with the newer burner technology. These experiences include the application of low NO_x technology to a wide range of boiler types such as traditional or more common wall fired and tangentially fired (T-fired) furnaces as well less common or unique Turbo fired boilers, a proprietary boiler design of RPI.

In all cases, computational fluid dynamic, CFD modeling was performed to refine the final burner design and further analyze the impact of the modification on furnace and boiler performance.

APPLICATION TO WALL FIRED BOILERS — LNB AND OFA

RPI supplies low NO_x Controlled Combustion Venturi, CCV Burners and overfire air systems as a mean for controlling NO_x emissions from wall fired boilers firing pulverized coal. To date, RPI has supplied over 2000 low NO_x CCV Burners on 150+ utility boilers. Figure 1 shows a schematic of RPI's dual air zone low NO_x CCV Burner.

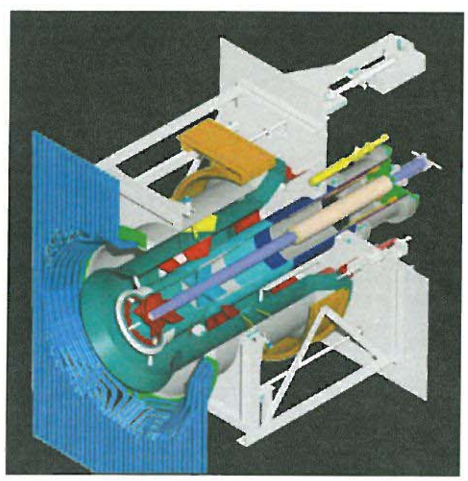

Figure 1. RPI CCV DAZ Low NO_x Coal Burner

Unique key features of this design for controlling NO_x include:

- Independent control of secondary and tertiary air streams to control near field stoichiometry
- Patented low NO_x CCV type coal nozzle for fuel rich combustion with excellent flame attachment and flame length control
- 50-60% NO_x reduction for burners only

Overfire air, (OFA) systems provide additional staging of the combustion air to further reduce the NO_x beyond levels achievable by only LNB's. In most cases, 20-25% of the total combustion air is introduced at a designated distance above the top elevation of burners to "stage" the lower furnace.

When supplied, OFA ports are installed above each burner column utilizing a 1/3-2/3-nozzle concept, as shown in Figure 2. The design is based on extensive modeling and testing performed by RPI for EPRI in the mid 1980's (Reference 1). Separate on/off dampers are used to control the penetration and mixing of overfire air over a wide range of operating loads. The result is low NO_x while maintaining low CO and flyash unburned carbon.

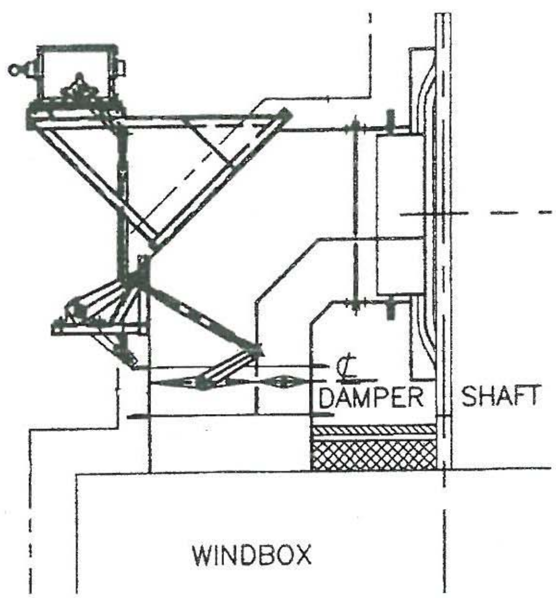

Figure 2. Typical OFA Port Design

A few years ago RPI was approached by a major Southeast utility to improve emissions performance in two (2) wall fired boilers originally supplied by Foster Wheeler and later upgraded with the OEM's low NO_x burners. Both boilers fire various eastern bituminous coals having a wide range of FC/VM ratios (1.3-2.0). Both units also experienced relatively high NO_x emissions (>0.6 lb/mmBtu), unstable CO levels and relatively high-unburned carbon in the flyash.

The first unit, a 500 MW opposed fired design, equipped with 24 burners and 6 HP 863 mills, is shown in Figure 3. The OEM's first generation LNB's were replaced with RPI's CCV DAZ type low NO_x burners without any overfire air to meet NOx requirements. This project was a mechanical design and installation challenge to avoid interference with multiple downcomers inside the windbox. Because of the downcomer issues, the burner was supplied in multiple parts and assemblies and subsequently connected inside the windbox. CFD modeling of the burner design was used to optimize the design and geometry of the flame stabilizer ring. This was done to establish the best possible internal recirculation zones necessary to produce low NO_x with acceptable CO and UBC per furnace. It was also used to establish the initial burner settings to reduce the time for commissioning to only a 2-week period (Reference 4). A photograph of the installed burner is shown in Figure 4.

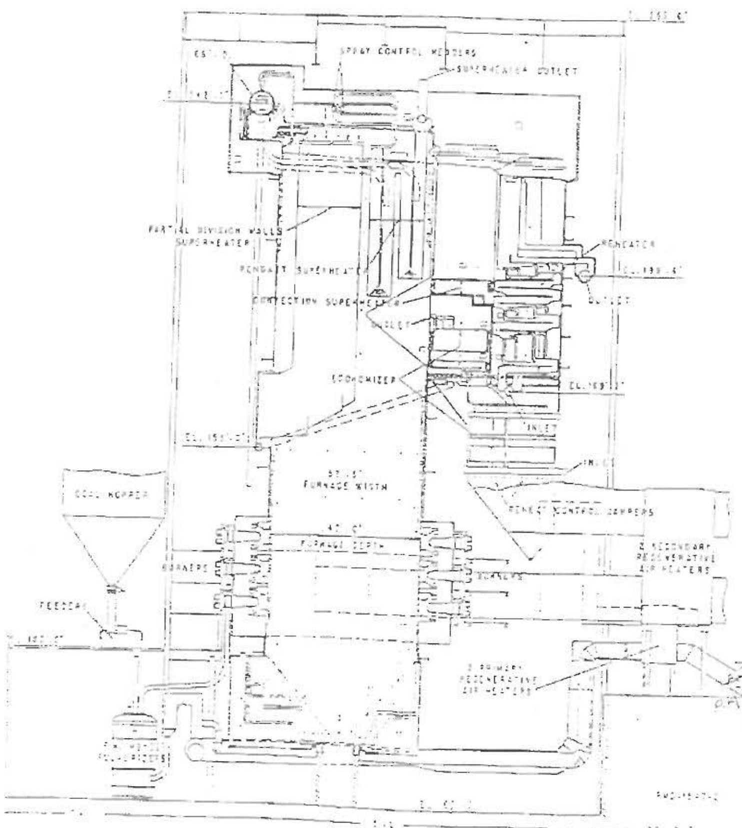

Figure 3. 500 MWg Boiler w/LNB's

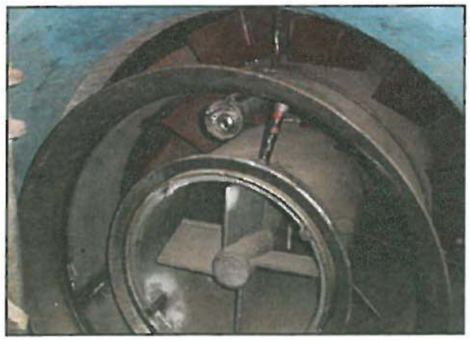

Figure 4. RPI CCV DAZ Burner Installed in 500 MW Utility Boiler

Final results showed a significant reduction in NO_x emissions throughout the load range, (see Figure 5). At full load, NO_x was reduced over 30% while CO emissions were stabilized at < 50 ppm and flyash UBC averaged 5%.

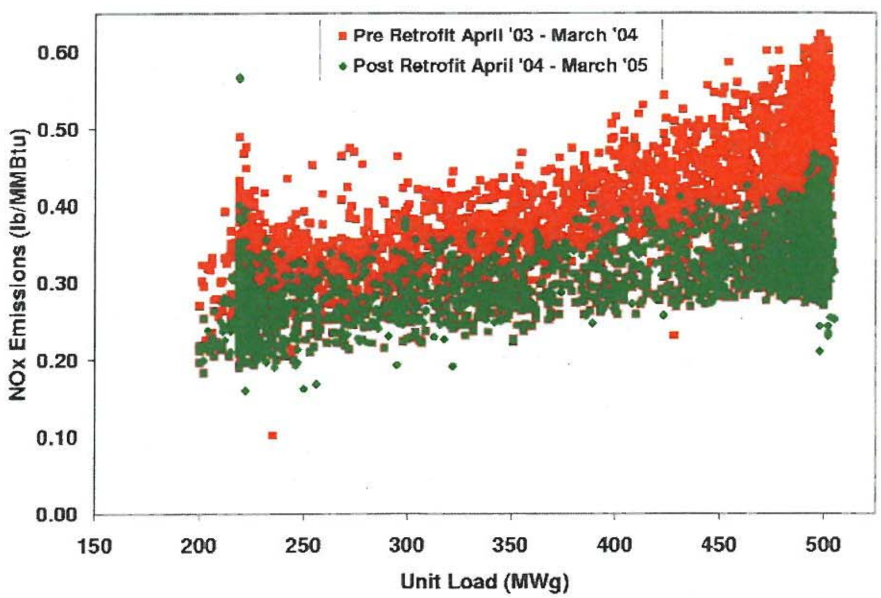

Figure 5. Pre & Post Retrofit NO_x Performance — 500 MWg Boiler

The second unit identified by the same Southeast utility for additional emission reduction and improved performance required a similar installation of new low NO_x CCV DAZ burners but with OFA as well. The challenge for this application was to effectively reduce NO_x while maintaining low CO emissions and low unburned carbon in a unit with abnormally short retention time in the upper furnace for proper carbon burnout. This not only required CFD modeling of the burners but careful CFD analysis of the entire furnace to ensure the OFA would properly mix with the flue gas products. Figure 6 shows a cross section of the 320 MWg unit equipped with 16 front wall mounted burners connected to 4 HP 863 mills. A photograph of the final installed low NO_x burner geometry is shown in Figure 7.

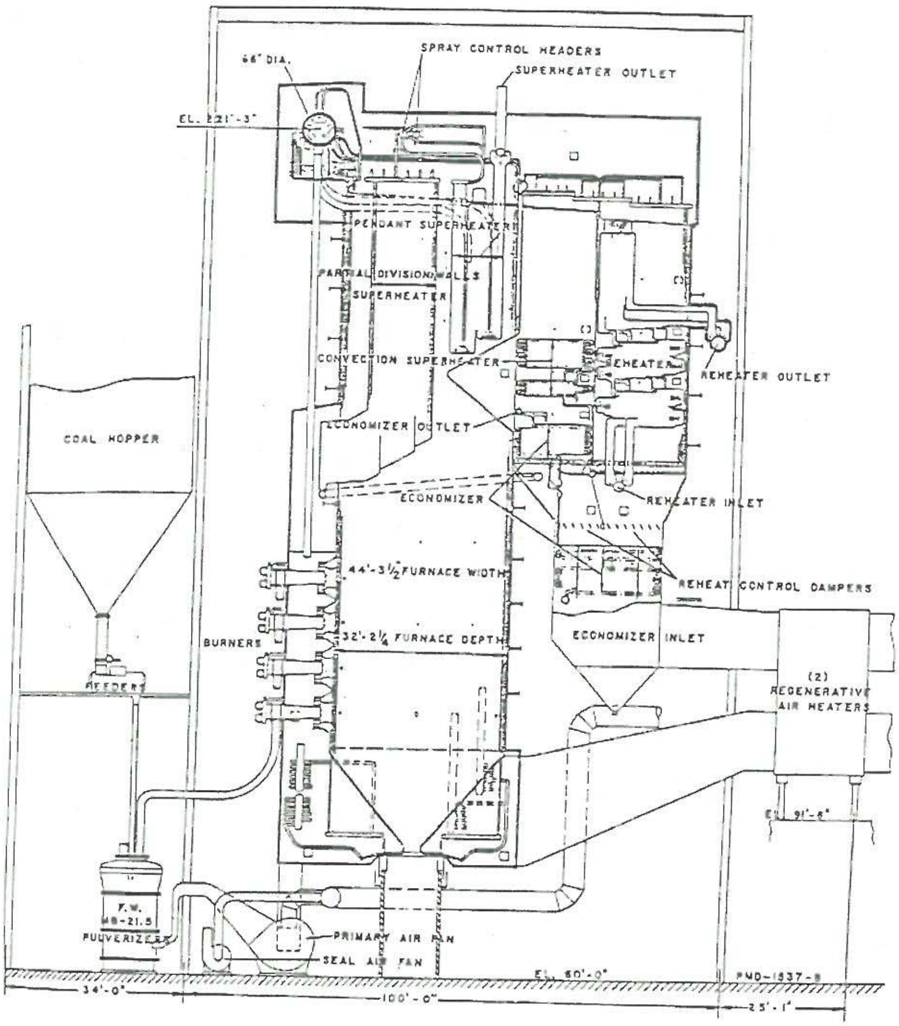

Figure 6. 320 MWg Boiler w/LNB's & OFA

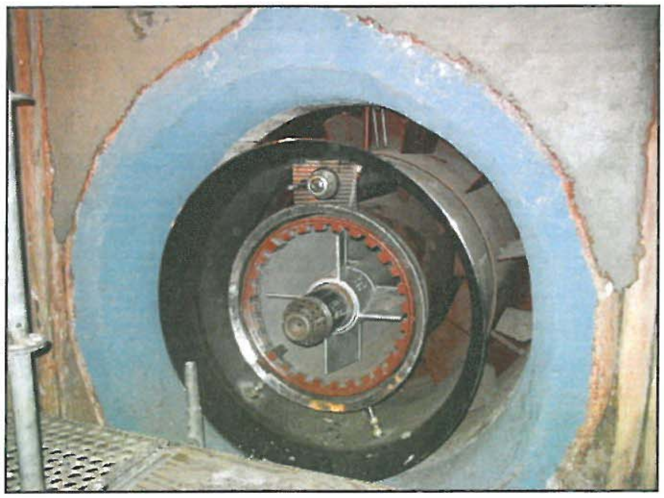

Figure 7. RPI CCV DAZ Burner Installed in 320 MWg Utility Boiler

Start up and commissioning of this 320 MWg unit, with LNB's and OFA, was completed in 2 weeks again because of the careful design of the CCV DAZ burner and the use of CFD analysis in identifying the initial "optimum" burner and OFA settings. Final performance demonstrated a NO_X reduction of 40% from 0.58 to 0.34 lb/mmBtu, which subsequently was reduced further to <0.30 lb/mmBtu at 40% boiler load. This is graphically depicted in Figure 8.

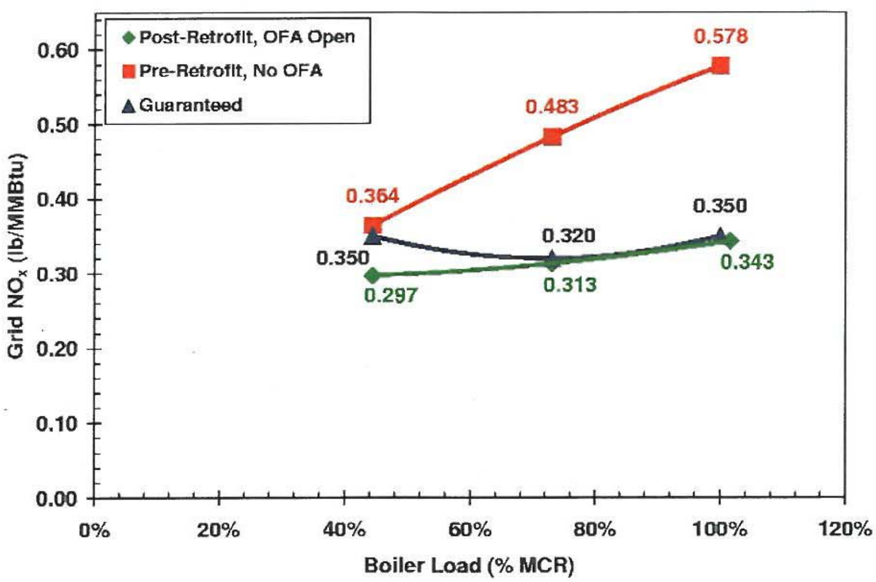

Figure 8. Pre & Post Retrofit NO_X Performance — 320 MWg Boiler

APPLICATION TO WALL FIRED BOILER — LNB COMPONENTS AND OFA

Another Southeastern utility was experiencing combustion related problems following the installation of another OEM's first generation low NO_x burners in the late 1990's. Two (2) years ago RPI was approached by this utility with the intent on reducing NO_x, CO, unburned carbon and to improve flame attachment and eliminate any flame carryover into the backpass. The boiler, originally designed and built by RPI in the late 1960's, shown in Figure 9, is a 270 MWg boiler with 18 opposed fired burners and EL Mills. Several options, including the installation of completely new burners, overfire air and various combinations of both were considered. However, since the existing low NO_x burners were only five (5) years old and in reasonably good working condition, a more cost effective approach was to simply modify or upgrade the existing burners with critical CCV burner components and to add an overfire air system. The material cost would be about 50% of that estimated for completely new burners and OFA plus shorter outage duration (Reference 2). The burners were modified as shown in Figure 10 with CCV coal nozzles, burner heads, and air diverters.

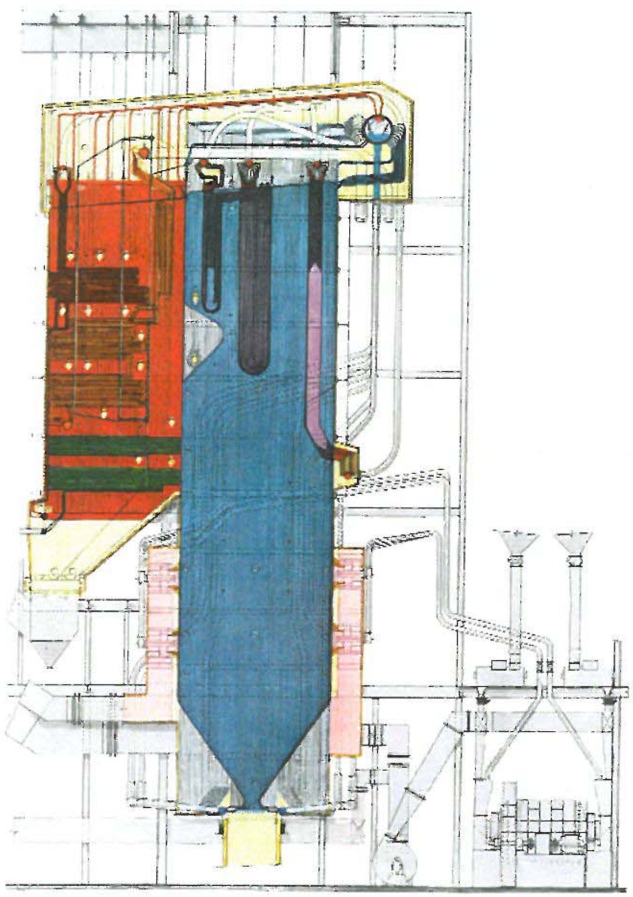

Figure 9. 270 MWg Boiler w/LNB's & OFA

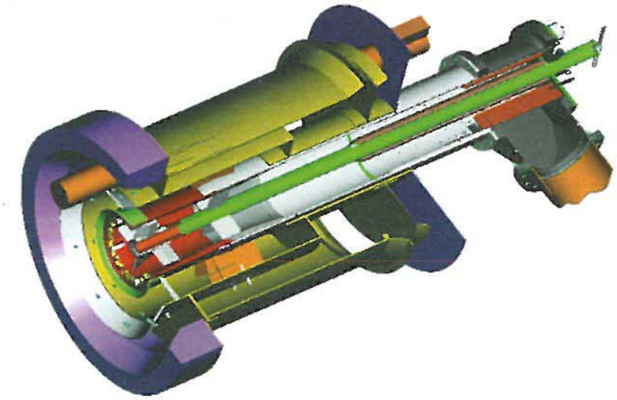

Figure 10. Existing OEM XCL Burner Retrofitted with RPI CCV Components

The entire secondary side of the burner was reused, except an automatic actuator was installed to regulate the positioning of the burner flow disc as a function of the boiler load.

CFD analysis was performed on the burners and furnace systems to ensure proper near and far field mixing patterns were maintained.

The results of this retrofit, as shown in Figure 11, reduced NO_X by over 30% while reducing CO emissions and maintaining the same unburned carbon. The excessive flame carryover was greatly diminished as demonstrated by a 90% reduction in SH attemperator spray flow (Reference 2).

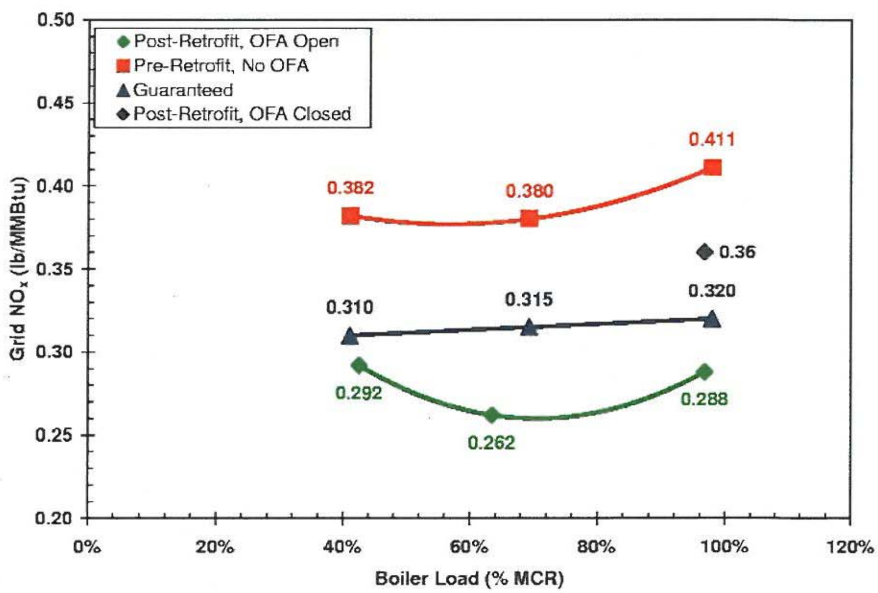

Figure 11. Pre & post Retrofit NO_X Performance — 270 MWg Boiler

APPLICATION TO T-FIRED BOILER — OFA & BURNER RETIPPING

RPI provides overfire air and burner retipping as a means for controlling NO_x emissions on T-fired boilers with tilting coal burners. Overfire air can be provided as close coupled overfire air (CCOFA) — at the top of the main burner windbox, or as separated overfire air (SOFA) — above the main burner windbox. Burner coal and air tips are custom designed for each application to meet the site-specific requirements. NO_x reduction in excess of 50% from uncontrolled levels is possible for most applications when SOFA is combined with burner retipping. RPI experience with two T-fired, low NO_x retrofit applications is presented in this section.

In the first application, RPI was contracted by a Midwestern utility to reduce NO_x on their 125 MWg CE boiler firing a Midwestern bituminous coal. The unit is shown in Figure12, and features four (4) elevations of four (4) burners each, fed by four (4) CE 673 Raymond Bowl mills. RPI selected SOFA and burner retipping as the means to lower NO_x. CFD modeling was used to design one (1) elevation of SOFA ports installed on the front and rear walls with non-tilting, fixed yaw nozzles. The original OEM burner tips were replaced with reduced free area air nozzles and RPI flame attached coal nozzle tips, which are shown in Figure 13.

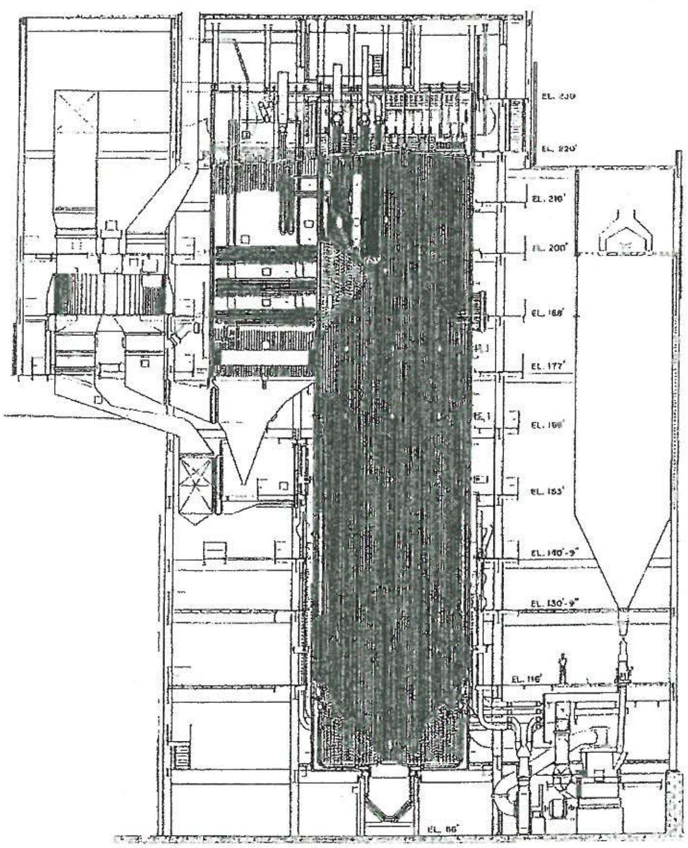

Figure 12. 125 MWg T-fired Furnace w/LNB's & SOFA

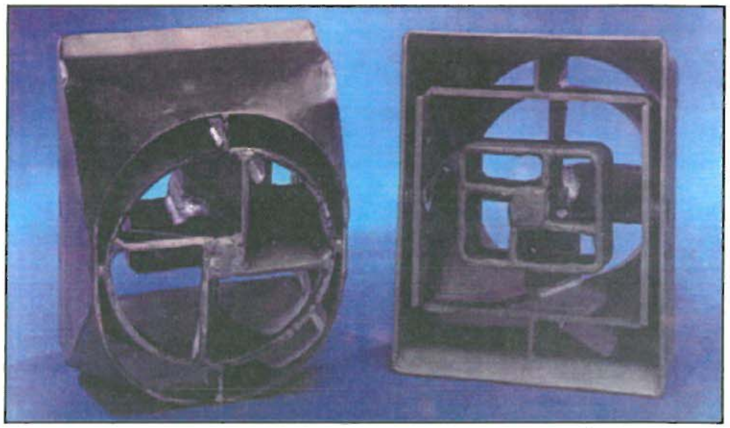

Figure 13. 125 MWg T-fired Furnace Flame Attached Coal Nozzle Tips

Figure 14 indicates NO_x was reduced from a baseline value of 0.68 lb/MMBtu to 0.22 lb/MMBtu at MCR. NO_x reduction in excess of 65% from baseline levels was demonstrated across the boiler load range during acceptance testing, while maintaining flyash UBC and CO emissions below 1.1% and 10 ppm respectively. Superheat and reheat steam temperatures were not adversely impacted, and RPI met the contract boiler efficiency guarantee (Reference 3).

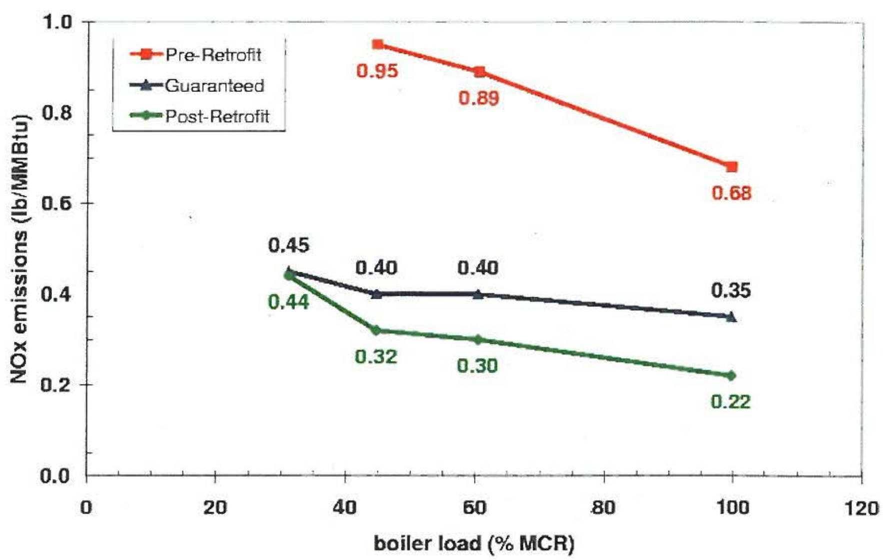

Figure 14. 125 MWg T-fired Furnace Pre & Post Retrofit NO_x Performance

The second T-fired application is an ongoing Babcock Power Environmental, Inc (BPEI) multi-pollutant control contract to control mercury, SO_3 and fine particulate, SO_2, and NO_x on a Midatlantic utility boiler. The NO_x reduction portion of the contract consists of combustion system modifications coupled with a cascading SNCR / in-duct SCR system.

The unit has a peak rating of 114 MWg and is fired with Eastern bituminous coal alone or a combination of coal and up to 10% clean wood waste on a heat input basis. It features four (4) elevations of coal nozzles fed by four (4) 553A Raymond Bowl mills and is shown in Figure 15.

A single elevation of SOFA ports with limited directional control was installed without burner retipping in 1996 as part of a gas reburn system. Natural gas reburning is no longer utilized on this unit, however the SOFA system is used to reduce NO_X emissions. Baseline NO_X emissions exhibit a high degree of scatter due to variations in operator control.

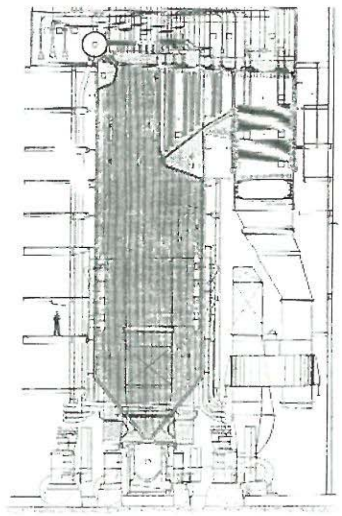

Figure 15. 114 MWg T-fired Furnace w/LNB's & SOFA

RPI's combustion modifications include new SOFA nozzles featuring automatic tilt and manual yaw capability, burner retipping, and compartment damper modifications for improved air flow control. CFD furnace modeling is being used to evaluate the SOFA nozzle design and determine the most beneficial equipment settings for commissioning.

The project features a bimodal NO_X emission guarantee structure which varies from 0.28 lb/MMBtu with the SNCR in non-cascading mode and SCR out of service to 0.10 lb/MMBtu with the SNCR in cascading mode and SCR in service. This is shown in Figure 16 in comparison to the 2005 baseline NO_X emissions and the target NO_X emissions from the burners and SOFA alone. The combustion equipment portion of the project is currently in the design and fabrication phase. The unit outage is scheduled for October 2006 with unit restart in November 2006.

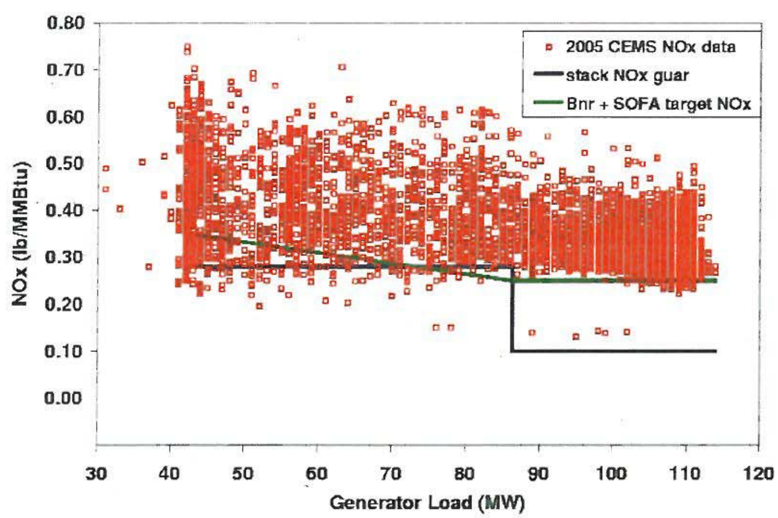

Figure 16. Comparison of Baseline, Target, and Guaranteed NO_X Emissions 114 MWg T-fired Furnace

APPLICATION TO TURBO® FIRED BOILERS — LNB & OFA

The Riley Turbo fired boiler or "Turbo® Furnace" is a unique design developed by RPI in the 1960's for burning low volatile fuels such as petroleum coke and bituminous coal with low volatile content. The boiler design is shaped like an hourglass with a row of burners mounted opposed at only one elevation and aimed to fire downward on a 25 slope. The axial flow burners are called "Directional Flame Burners" with two (2) rectangular coal nozzles/burner with air introduced above, below, and in between the two nozzles. Some Turbo® furnaces have OFA introduced in the narrowest section or throat of the furnace immediately above the burners.

In the 1970's, when NO_x emissions were becoming a concern, it was discovered these furnaces were inheritantly low in NO_x emissions because of the diffusion type of mixing and combustion resulting from the axial flow burners (Reference 5 and 6). Approximately two (2) dozen Turbo® Furnaces are in operation today ranging from 85-600 MWg in capacity firing various fuels from low volatile petroleum coke and bituminous coal to higher volatile sub-bituminous and PRB coal. In the past five (5) years, utilities have expressed interest in reducing NO_x on these Turbo® Furnaces, to meet today's more stringent NO_x emissions requirements at the state and federal level.

Through CFD modeling and physical flow modeling, RPI has developed upgrades to the DF burners to produce lower NO_x emissions. Burner modifications have included new tilting or fixed low NO_x coal nozzles, windbox partitioning and other internal burner modifications. The key factors enabling the lower NO_x focused on better flame attachment, better air flow recirculation patterns and earlier ignition and pyrolysis of the coal in the primary combustion zone. The modifications also provided more independent control of the combustion air within the burner windbox and to the OFA for more precise control of the burner zone stoichiometry.

A recent example of utilizing the upgraded equipment involved two (2) 600 MWg Turbo® Furnaces firing PRB coal. The utility needed to reduce NO_x emissions on these boilers from 0.35 to <0.21 lb/mmBtu to meet state mandated emission requirements. Each of the 600 MWg boilers, shown in Figure 17, has 32 DF burners (16 per side) mounted opposed on a sloped surface and connected to four (4) ball tube mill systems.

Physical flow modeling and CFD analysis were extensively used to analyze and develop the modification details for the DF burners. After a review of numerous designs, the final configuration, shown in Figure 18, included the following key features:

* New burner head inlet vanes
* New patented tilting coal nozzles, FSR's and air diverters
* Windbox partitioning
* Modified center opening plating

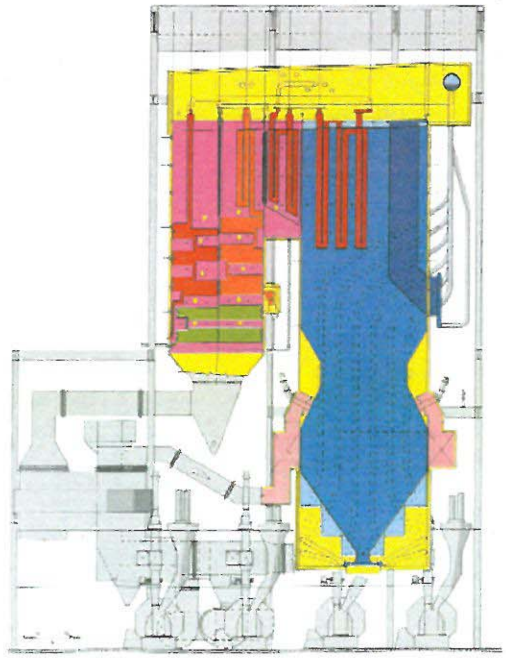

Figure 17. 600 MWg Riley Turbo® Furnace Firing PRB Coal

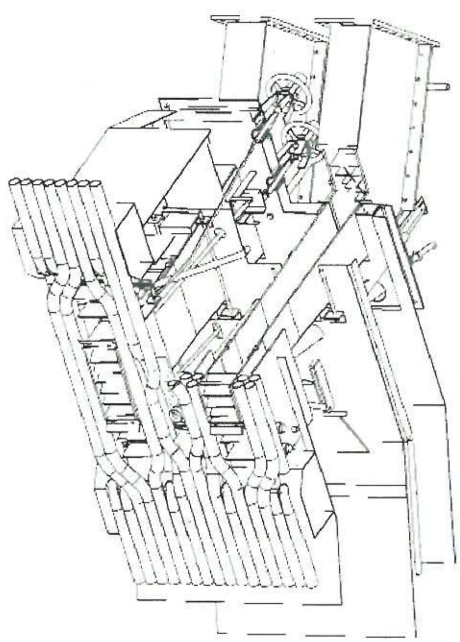

Figure 18. Low NO_X Directional Flame Burner for RPI Turbo® Furnace

The CFD modeling carried further into the furnace to evaluate the use of OFA for additional NO_x control and to ensure proper CO and carbon burnout was maintained. The challenge of this furnace design was short retention time for final carbon burnout and the lack of an arch in the upper portion of the furnace, which aggravated the situation. Results of the modeling defined a need to install additional air injection openings in the four (4) corners of the furnace above the OFA and in the lower furnace below the main burner level to control CO.

With the modified combustion system installed, NO_x emissions were effectively reduced to below 0.2 lb/106Btu (see Figure 19) as required by the state. This represented a 43% reduction from pre-retrofit levels. Flyash unburned carbon was <0.5% and CO emissions averaged <300 ppm which was considered good for this difficult furnace design. Without the additional air injection locations, CO emissions would easily exceed 2,000 ppm.

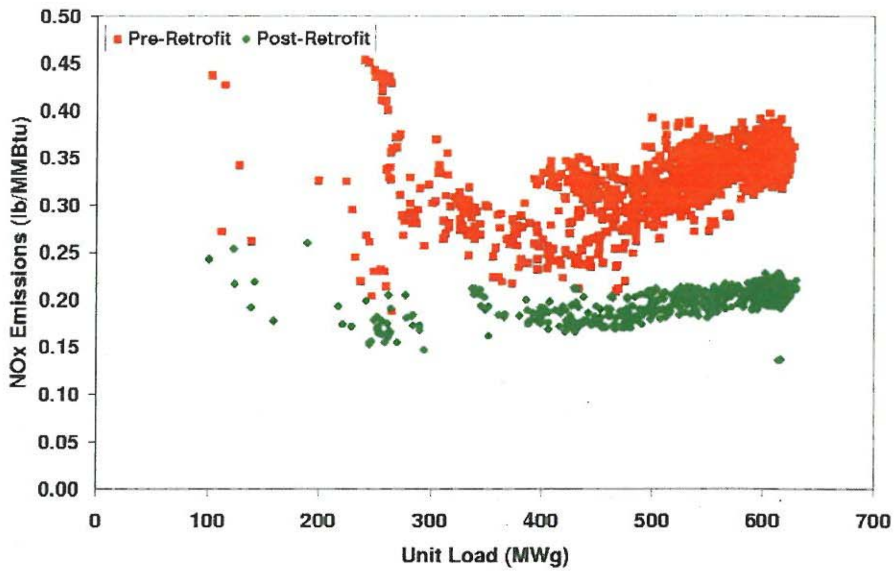

Figure 19. Pre & Post NO_x Performance — 600 MWg Turbo® Furnace Firing PRB Coal

Other significant benefits of the modified combustion system included:

* Improved SH & RH temperature distribution profiles
* Reduced attemperator spray flow
* Improved lower & upper furnace combustion conditions
* Reduced slagging and fouling

SUMMARY

Reducing NO_x emissions from coal fired utility boilers using combustion control only continues to be a cost effective approach for meeting environmental regulations. Recent experiences at Riley Power have primarily involved upgrades to or replacement of existing first and second-generation low NO_x burners with or without overfire air. Actual field performance demonstrated NO_x reductions of 15-65% from pre-retrofit NO_x levels. Overall boiler operation also improved in some cases with reduced CO emissions and lower unburned carbon. In one installation, the superheat attemperator spray flow quantity was reduced 90% because of less flame carryover into the backpass. RPI's experience presented in the paper, covers a wide range of boiler designs and types including wall fired, T-fired, and Turbo fired furnace designs. The low NO_x burner technology included patented designs proprietary to Riley Power. CFD modeling was extensively used in each of the projects discussed to refine the design details and to establish initial equipment settings to shorten commissioning time.

ACKNOWLEDGEMENT

The authors wish to acknowledge the significant contributions by Bonnie Courtemanche, Staff Engineer, Babcock Power in the preparation of this paper. Bonnie was instrumental to the success of implementing low NO_x burner technology on the wall fired and turbo fired boilers discussed in this paper. We are grateful for her dedicated support.

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