TECHNICAL PUBLICATION

Achieving over 50% NO_x Reduction on a Utility Boiler Orginally Equipped with Circular Burners and NO_x Ports Using CCV® DAZ Burners and Advanced OFA

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ACHIEVING OVER 50% NO_X REDUCTION ON A UTILITY BOILER ORIGINALLY EQUIPPED WITH CIRCULAR BURNERS AND NO_X PORTS USING CCV® DAZ BURNERS AND ADVANCED OFA

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ABSTRACT

In 2007 Riley Power Inc., a Babcock Power Inc. company, retrofitted a 365 MW balanced draft, opposed fired boiler, with new low NO_x CCV® Dual Air Zone (DAZ) burners and an advanced OFA system. This unit, located in the western United States, has thirty-two (32) burners, sixteen (16) on the front and sixteen (16) on the rear wall and is designed to burn pulverized Powder River Basin (PRB) coal to generate 2,498,500 lb/hr of steam at 1005°F. The unit has four (4) MPS 89 roll-wheel style pulverizers. The OEM circular burners and NO_x port system produced NO_x emission levels of approximately 0.35 lb/MBtu at full boiler load.

The retrofit performance goal was to obtain NO_x emissions less than 0.15 lb/MBtu throughout the boiler load range. The combustion system modifications achieved NO_x emissions as low as 0.135 lb/MBtu but generally around 0.15 lb/MBtu at full boiler load and reduced load operation. Testing demonstrated that the installation of advanced CCV® DAZ low NO_x burners resulted in over 50% NO_x reduction from a system already equipped with NO_x ports. This is a substantial NO_x reduction for an opposed fired unit that originally featured circular burners with OFA.

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 (LNB) technology and/or overfire air (OFA) system 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's & OFA will lower the SCR inlet NO_x level reducing ammonia consumption and thereby lowering SCR operating cost. So, the cost of LNBs & OFA can often be justified by this savings as well.(1)

With NO_x emission requirements becoming increasingly stringent, efforts in recent years have focused on either replacing first or second generation LNBs 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.(1) This paper discusses recent experience from an application where another OEM's earlier vintage circular burners and overfire air system were replaced with RPI low NO_x CCV® DAZ burners and an OFA system.

RPI retrofitted a 365MWg unit, located in the western United States, with low NO_x CCV® DAZ burners and an advanced OFA system. The unit was designed to fire Powder River Basin (PRB) coal and still fires this coal today. The unit is opposed fired, balanced draft, and equipped with 32 burners receiving pulverized coal from four (4) Roll Wheel Pulverizers. The objective of this combustion system retrofit was to reduce NO_x emissions from approximately 0.35 lb/MBtu to 0.15lb/MBtu while maintaining current boiler performance.

This retrofit application featured extended wear protection on key burner components within the primary airflow path. Conforma Clad® tungsten carbide coating was applied to RPI's patented (U.S. Patent No. 6,474,250) Flame Stabilizer Ring (FSR) and coal spreader for each burner. In addition to these applications, ceramic lining was also provided for protection of the coal spreader support tube, the new RPI receiving chambers, variable coal pipe orifices, and new low NO_x coal nozzles.

Computational fluid dynamic (CFD) modeling was performed to refine the final FSR design, further analyze the impact of the modification on furnace and boiler performance, and to determine the final location of the new advanced OFA system. Previous RPI retrofit applications have been used for case-specific parameters.(2)

Application to Wall Fired Boilers — LNBs and OFA

RPI supplies low NO_x Controlled Combustion Venturi, CCV® Burners and OFA systems as a means for controlling NO_x emissions from wall fired boilers firing pulverized coal. To date, RPI has supplied over 2,100 low NO_x CCV® Burners on more than 150 utility boilers. Figure 1 shows a schematic of RPI's low NO_x Dual Air Zone CCV® Burner.(1)

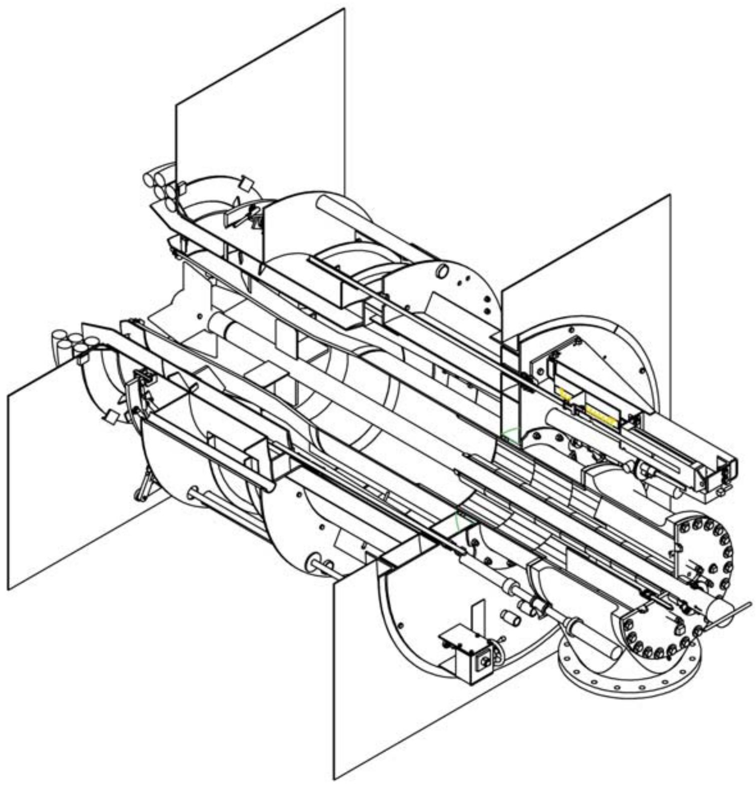

Figure 1. RPI CCV® DAZ Low NO_x Coal Burner

Key unique features of this design for controlling NO_x include(1):

* 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 (U.S. Patent No. 6,474,250)
* 50-60% NO_x reduction for burners only, 50-70% NO_x reduction for burners and OFA

OFA systems provide additional staging of the combustion air to further reduce the NO_x beyond levels achievable by only LNBs. 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. RPI's design features OFA ports 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.(3) Separate on/off dampers are used to control the penetration and mixing of overfire air over a wide range of operating loads.(1)

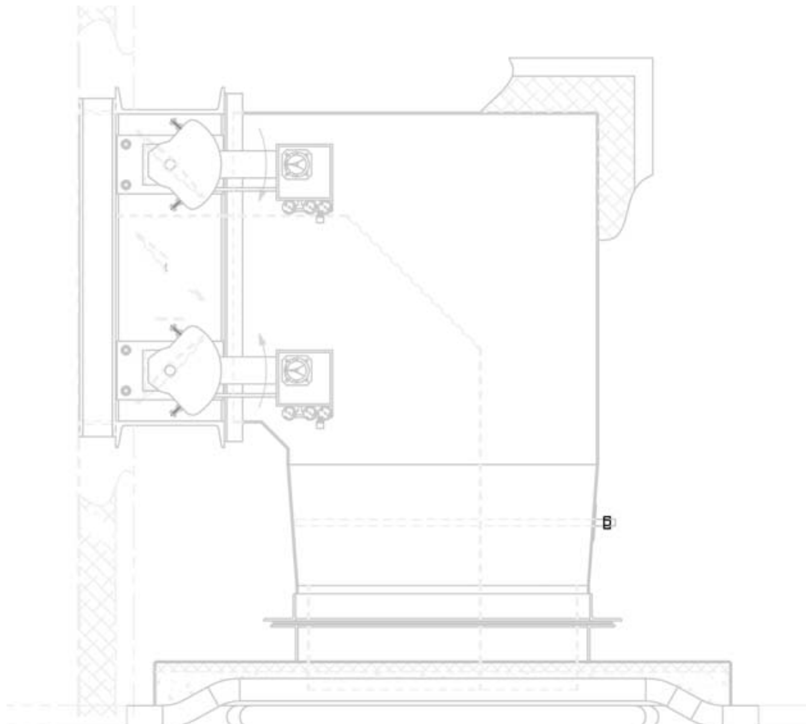

Figure 2: Typical OFA Port Design

Computational Fluid Dynamic (CFD) Modeling

Burner Modeling

As stated earlier, CFD modeling was performed utilizing RPI's in-house CFD resources to refine the final FSR design and initial burner settings, further analyze the impact of the modification on furnace and boiler performance, and to determine the final location of the new advanced overfire air system.

An aerodynamic burner model was constructed to determine the burner geometry and initial burner settings required to establish the best possible recirculation zones necessary to produce good low NO_x combustion. The single burner model is a 2-D simulation using aero-dynamics only, i.e. no combustion. The burner model was specifically used to optimize the design of the flame stabilizer ring, which promotes proper burner flame attachment and reduces NO_x formation approximately 10-15% in comparison to CCV® burner applications without them. Figures 3 and 4 show the burner model simulation results, velocity magnitude, and streamline plots for pre-retrofit and post-retrofit burner designs respectively for this application.

Figure 3 shows that the existing circular burner has a relatively wide flame core, with low velocities and minimal recirculation. This type of recirculation shown in Figure 3 contributes to poor flame attachment, and elevated NO_x formation. Figure 4 shows the more pronounced recirculation zones associated with the CCV® DAZ burner. Streamlines in Figure 3 with the highest magnitude are on the outside, with streamlines of low magnitude on the inside. Streamlines forming loops in Figure 4 show combustion air interaction and recirculation, which are important for flame attachment, controlling the mixing of devolatilizing coal and secondary air oxygen, and thus the formation of NO_x. The first zone shown in Figure 4 streamline plot represents interaction between the burner's primary air and secondary air. This zone helps produce better flame attachment, and lower NO_x formation. The recirculation zone shown is produced from the reaction between air from the secondary and tertiary air zones. This recirculation zone is well defined and developed, which helps with lowering NO_x formation.

It can be seen that the velocity magnitude of the burner core changes substantially from the circular burner to the CCV® DAZ burner. The CFD predictions for the original circular burners show a relatively large, low velocity core. The CFD predictions for the new CCV® DAZ burners show a higher core velocity that is more well defined, indicating improved primary air stream separation and the potential for lower NO_x emissions.

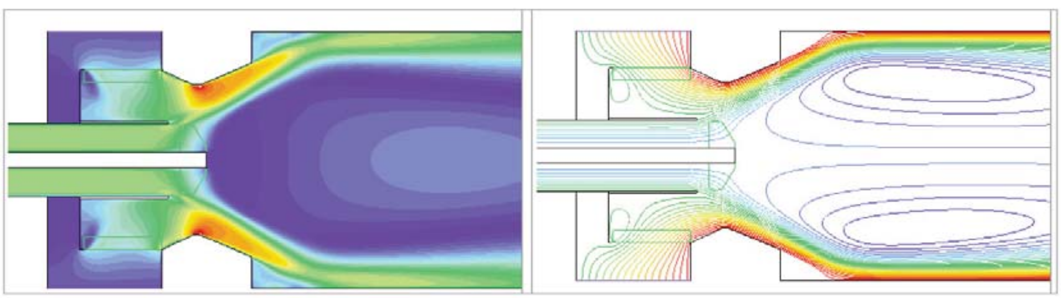

Figure 3. CFD Predictions (Velocity Magnitude-Left, Streamlines-Right) for the OEM circular burners

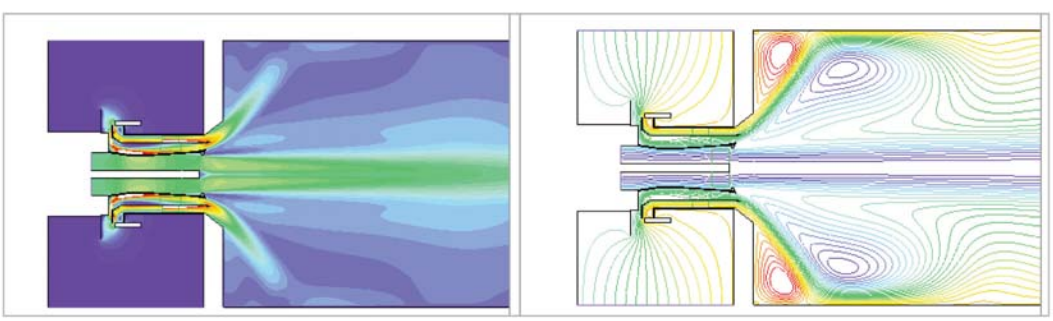

Figure 4. CFD Predictions (Velocity Magnitude-Left, Streamlines-Right) for the new low CCV® DAZ burners

Furnace Modeling

Furnace CFD modeling was used to evaluate OFA port location and determine the impact on O_2 and CO distribution and furnace exit gas temperature (FEGT). Two (2) different OFA elevations were evaluated for this application. The results of the burner aerodynamic model were used as an input for the furnace models.

In, Case 1, the new, advanced OFA ports were located at an elevation similar to the elevation of the OEM OFA ports or one (1) burner elevation above the top burner now. Figure 5 shows the furnace geometry used and advanced OFA port locations for this case.

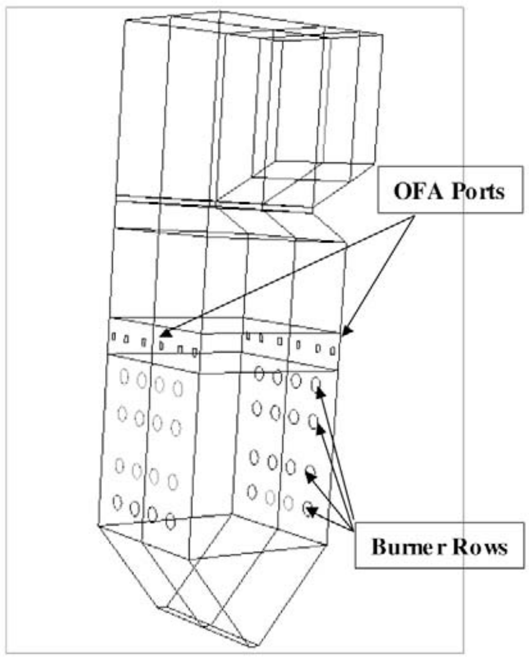

Figure 5. Furnace Geometry and Location of New Advanced OFA Ports Within the Existing Windbox, Case 1

The predicted O_2 distribution for Case 1 is shown in Figure 6. This distribution is important for several reasons. It can be used to infer zones of relatively high or low NO_x concentrations, depending on the O_2 concentration of the area being considered. Generally, a low O_2 concentration corresponds to a low NO_x level in the area of interest, and high O_2 concentration corresponds to a high NO_x level. Distribution of O_2 can also help to determine the amount and location of mixing in the furnace. The new, advanced OFA ports are designed to deliver a certain penetration velocity of combustion air into the furnace. The O_2 distribution can show if the design penetration velocity provides adequate mixing for low NO_x combustion. In this case, Figure 6 shows that the OFA jets generate a considerable amount of mixing in the upper furnace yielding a fairly uniform O_2 distribution.

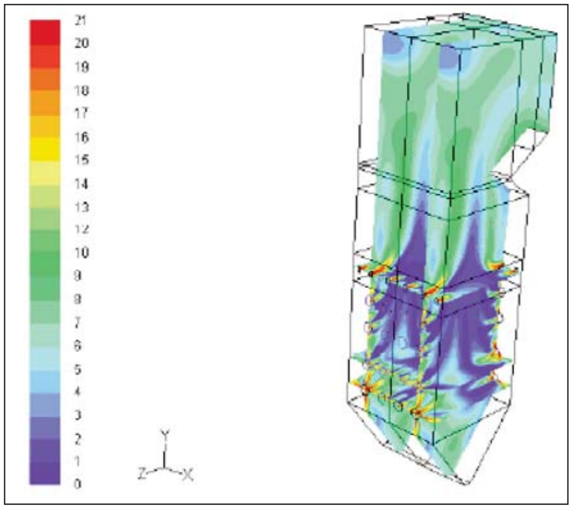

Figure 6. Furnace O_2 Distribution, Case 1

The Furnace Exit Gas Temperature (FEGT) was also predicted for this case using the CFD furnace model. Figure 7 shows the FEGT prediction for Case 1. The highest temperatures are in the middle of the exit plane. The average pre-retrofit FEGT determined from CFD modeling was 87ºF lower. Case 1 shows the FEGT has increased as compared to the pre-retrofit CFD FEGT, which would tend towards lower boiler efficiency.

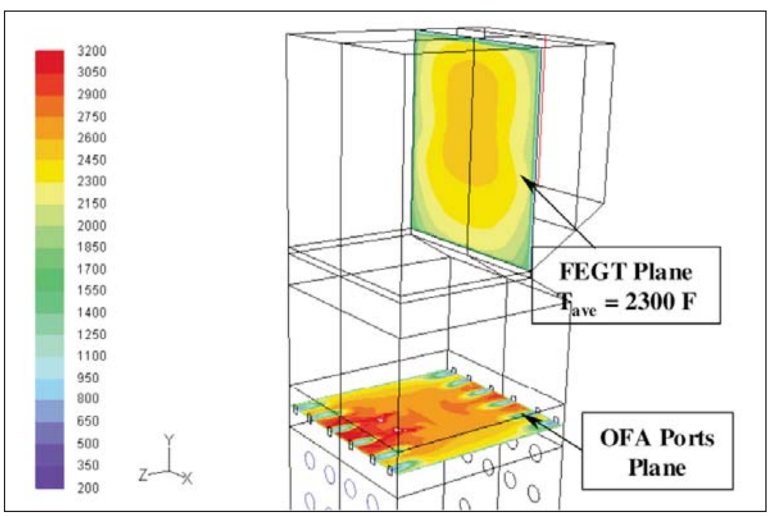

Figure 7. FEGT Plane, Case 1

In Case 2, the new, advanced OFA ports were located two (2) burn elevations above the top burner now. This elevation allows for a longer residence time between the top elevation of burners and the new, advanced OFA ports creating a larger reducing zone, which favors lower NO_x emissions. Figure 8 shows the furnace geometry used and advanced OFA port locations for this case.

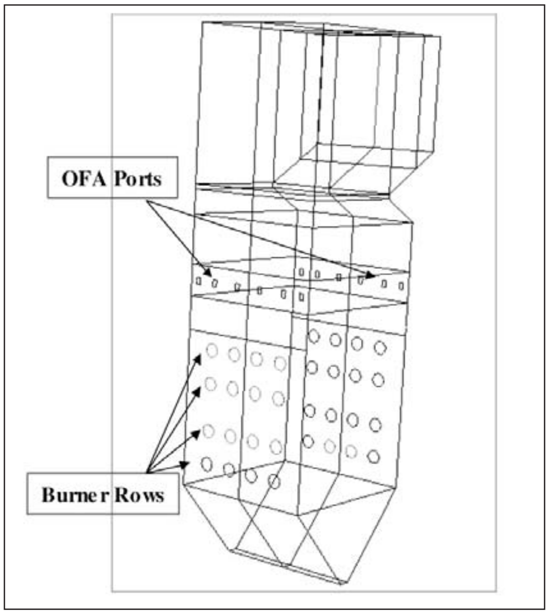

Figure 8. Furnace Geometry and Location of New Advanced OFA Ports Outside the Existing Windbox, Case 2

Figure 9 shows the Predicted for O_2 distribution for Case 2. This also shows, as the Case 1 model did, that the OFA ports provide an adequate penetration velocity for mixing in the upper furnace.

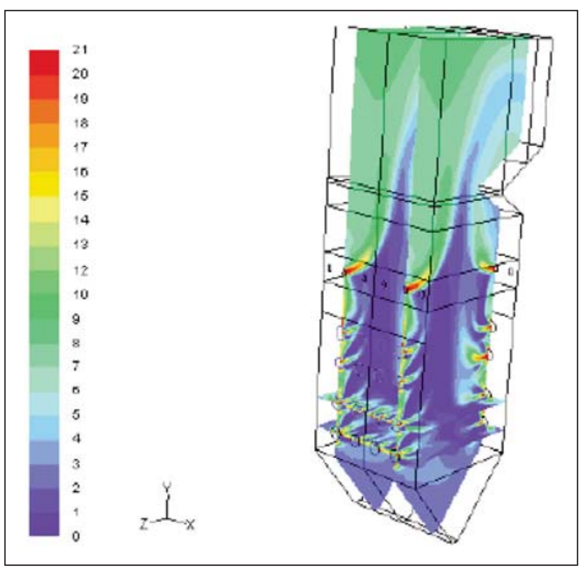

Figure 9. Furnace O_2 Distribution Case 2

FEGT predicted for Case 2 is shown in Figure 10. The highest temperatures are in the lower, middle of the exit plane. This temperature is lower than the average pre-retrofit FEGT by 79 ºF determined from CFD modeling. The Case 2 OFA configuration was selected as the more favorable geometry and was applied to the unit because of the potentially greater NO_x reduction as well as the predicted reduction in FEGT, which tends to favor increased boiler efficiency.

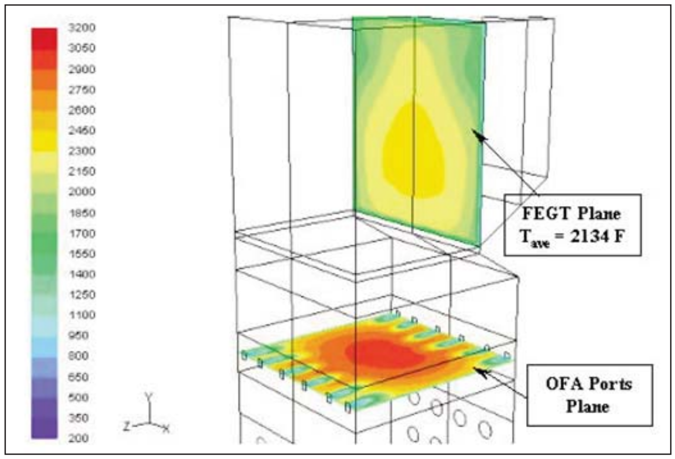

Figure 10. FEGT Plane, Case 2

Windbox Modeling

An aerodynamic windbox model was also completed to investigate combustion airflow distribution to the new CCV® DAZ burners. Existing windbox dampers balance combustion airflow. The model showed that existing windbox dampers could be used to adequately balance combustion airflow to burners on the front and rear of the unit.

Post Retrofit Data and Results

Table 1 shows the proximate and ultimate analysis for the design PRB coal. The Fixed Carbon to Volatile Matter Ratio for this fuel is 1.12, which is typical for a sub-bituminous coal.

Table 1

Proximate and Ultimate Fuel Analysis for Performance Coal

Proximate Analysis		Ultimate Analysis	
Fixed Carbon (%)	35.22	Carbon (%)	50.79
Volatile Matter (%)	31.39	Hydrogen (%)	3.19
Moisture (%)	28.90	Nitrogen (%)	0.70
Ash (%)	4.49	Ash (%)	4.49
Sulfur (%)	0.26	Sulfur (%)	0.26
HHV (Btu/lb)	8603	Oxygen (%)	11.67

The post retrofit results showed a significant NO_x reduction for the unit's full load operation. The unit performance for full load operation during the optimization testing demonstrated a NO_x reduction of over 50 %, from approximately 0.35 lb/MBtu to 0.135 lb/MBtu. Figure 11 shows a chart of pre-retrofit NO_x emission levels with respect to unit load. The NO_x emissions for full load operation ranges from 0.25 lb/MBtu to 0.40 lb/Mbtu, with an average of 0.35 lb/MBtu. This is a wide variability in NO_x emissions.

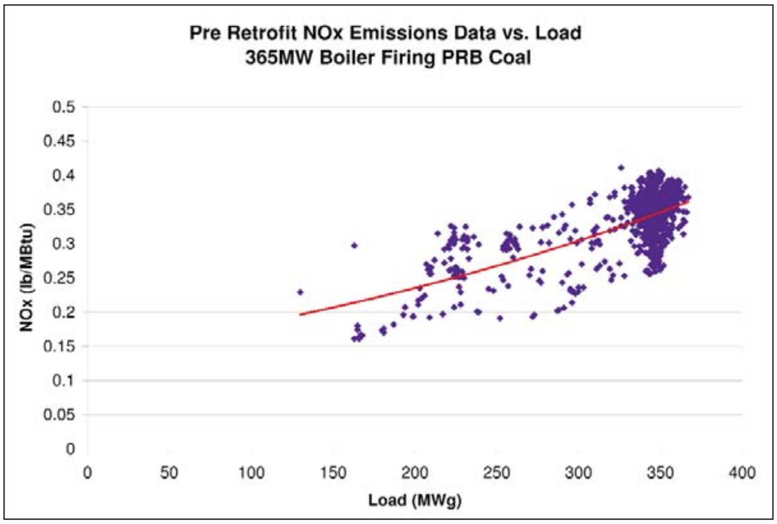

Figure 11. Pre-Retrofit NO_X Emissions Data versus Unit Load

Figure 12 shows the pre-retrofit NO_x emissions compared to emissions recorded during post retrofit testing. For full load operation, the NO_x average was approximately 0.15 lb/MBtu. Data is also shown at other loads. The pre-retrofit data shows a linear relationship between NO_x and boiler load. The sensitivity of NO_x with boiler load has been minimized with the installation of new CCV® DAZ burners and advanced OFA. The NO_x emission levels remain low, as compared to pre-retrofit levels, throughout the boiler range for normal operation. Also the variability in NO_x emissions is minimized significantly.

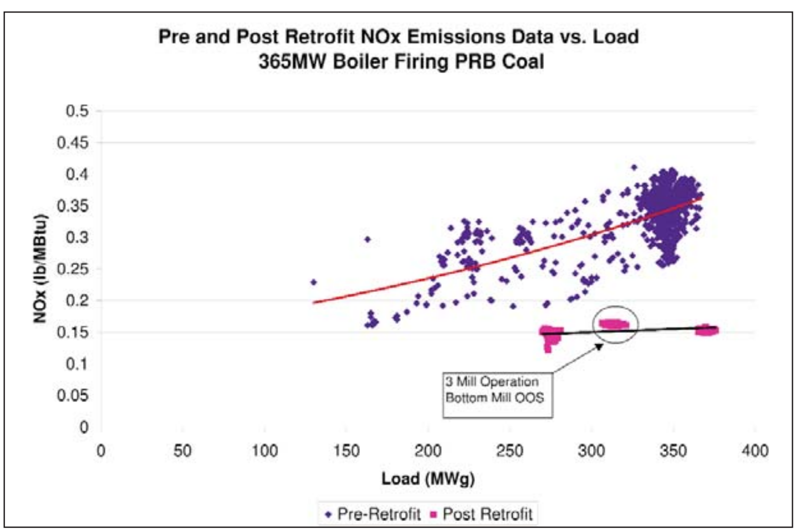

Figure 12. Pre and Post Retrofit NO_X Emissions Data

Other boiler performance parameters were also measured, and are shown in table 2 in comparison with pre-retrofit baseline values for full load operation.

Table 2

Summary of Pre-Retrofit and Post Retrofit Boiler Performance Parameters at Full Load

Performance Parameters	Units	Pre-Retrofit	Post-Retrofit Actual	Post-Retrofit Range
Main Steam Outlet Temperature	°F	999	992	(989-1,013)
Reheat Steam Outlet Temperature	°F	931	999	(972-1,015)
Boiler Efficiency	%	85.34	85.79	N/A
Flyash Unburned Carbon	Wt %	0.03	0.42	N/A
NO_x	Lb/MBtu	0.35	0.153	(0.135-0.153)

Main Steam outlet and reheat steam outlet temperatures both exhibited a range of approximately 25°F and 45°F respectively, and demonstrated the ability to achieve the original design steam outlet temperature of 1005°F, at full load depending upon the actual outlet steam temperature set point and corresponding amount of attemperating spray used.

The increase in reheat outlet steam temperature was due primarily to mechanical cleaning of the external convective surfaces during the retrofit outage, i.e. — after the pre-retrofit baseline performance test. Mechanical cleaning of the convective surfaces also resulted in lowering economizer outlet gas temperatures below pre-retrofit levels and was a primary contributor to the boiler efficiency improvement. Boiler efficiency increased from 85.40% to 85.87%.

The post retrofit FEGT determined through back calculation of actual performance test data, was within 1% of the corresponding pre-retrofit value.

Flyash UBC increased over pre-retrofit baseline levels as expected for a large NO_x reduction of this magnitude, but remained below 0.50 wt %. The UBC ranged from 0.28 to 0.42 wt % over the boiler load range.

Figure 13 illustrates the relationship between burner zone stoichiometry and NO_x emissions as measured on this unit. NO_x emissions are strongly influenced by the level of air staging and resultant burner zone stoichiometry. Typically NO_x emissions decrease with decreasing burner zone stoichiometry, but it was interesting to observe a minimum level of NO_x was produced at a certain level of staging. As shown in Figure 13, there is a point at which reduction in burner zone stoichiometry causes late combustion that actually increases the overall exit NO_x emissions. It is speculated that this increase in NO_x production is due to late burn out aided by the introduction of additional combustion air above the main burner zone, such is the case for separated OFA used on this installation. The inflection point of the curve may vary based on the type of fuel fired and furnace geometry.

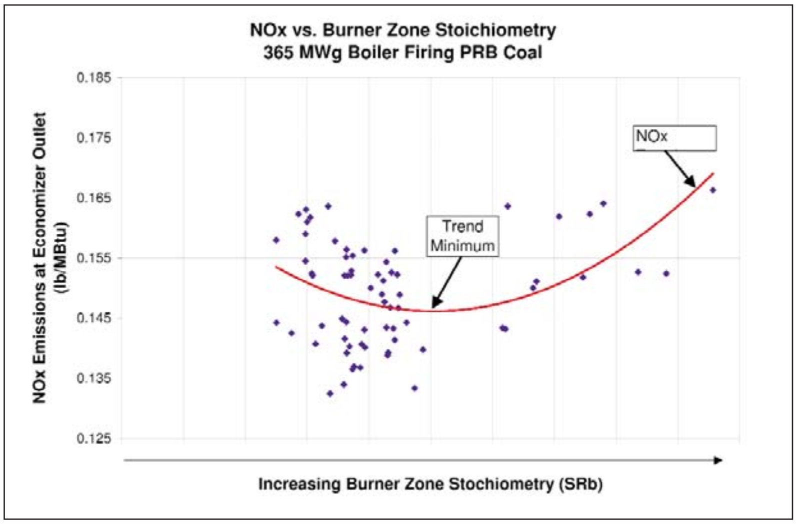

Figure 13. Post Retrofit NO_x Emissions vs. Burner Zone Stoichiometry

The pre-retrofit CO levels for full load operation with four (4) mills in service, was approximately 760 ppm @ 3% O_2. This is a high CO level particularly for pre-retrofit NO_x levels of 0.35 lb/MBtu. Post-retrofit CO for full load, four (4) mill operation was variable and ranged from approximately 420 to > 1000 ppm @ 3% O_2 for a corresponding NO_x range of 0.135 to 0.153 lb/MBtu at the final operating conditions. The CO emissions exhibited similar trends as a function of boiler load for both the pre-retrofit and post-retrofit cases; CO increased with boiler load. The abnormally short furnace retention time for final burnout of the CO emissions contributed to the elevated levels experienced during both pre and post-retrofit operation.

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.[1] The recent experience discussed in this paper involved replacing existing circular burners and OFA system with new RPI CCV® DAZ burners and an advanced OFA system to lower NO_x emissions while firing PRB coal. Burner, windbox, and furnace CFD modeling were used extensively to refine the final low NO_x system design. NO_x emissions were reduced by over 50%, while simultaneously improving boiler performance using Riley Power's patented low NO_x combustion system design.

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