Riley Power Inc., a
Babcock Power Inc. company.
www.babcockpower.com

TECHNICAL PUBLICATION

Reducing NO_X Emissions on a Mid-Western Utility Boiler Firing PRB Coal with Low-NO_X Burners and Overfire Air

by
Robert von Hein
Riley Power Inc.
(Formerly Babcock Borsig Power, Inc.)
Worcester, Massachusetts

Presented at
POWER-GEN International 2002
December 10-12, 2002
Orlando, Florida

Riley Power Inc.
5 Neponset Street
Worcester, Massachusetts 01606
www.babcockpower.com

T-181

REDUCING NO_X EMISSIONS ON A MID-WESTERN UTILITY BOILER FIRING PRB COAL WITH LOW-NO_X BURNERS AND OVERFIRE AIR

by

Robert von Hein
Project Engineer
Riley Power Inc.
(Formerly Babcock Borsig Power, Inc.)

ABSTRACT

Riley Power Inc. (RPI), a subsidiary of Babcock Power Inc., recently retrofitted a Mid-Western, 600 MW_N utility boiler with new low-NO_X dual air zone burners and overfire air (OFA). This approach was selected as part of a comprehensive plan to bring the utility's system-wide NO_X emissions into compliance with the EPA's emission requirements. This application represents the use of the most up-to-date low-NO_X coal burner technology, combined with over-fire air, while burning sub-bituminous PRB coal. The objective of this retrofit project is to reduce NO_X emissions to 0.155 lbs / MMBtu while maintaining carbon in ash levels below 2%.

The subject unit is opposed-wall fired, burning a Powder River Basin coal from Wyoming through four elevations of first-generation low-NO_X burners. Baseline NO_X emission levels averaged approximately 0.30 lb / MMBtu and carbon in ash levels were below 1%. Modifications to the existing firing system were necessary to accommodate the addition of OFA. Changes included the reconfiguration of the firing arrangement such that the upper elevation of burners was redistributed throughout the lower three elevations, allowing the OFA to be installed in the uppermost windbox compartment. The new dual air zone low-NO_X CCV® Burners, featuring CCV® coal nozzles, low swirl coal spreaders, and flame stabilizer rings for reducing NO_X emissions, were recently installed during a spring 2002 outage and have completed all commissioning and performance testing.

These target emissions represent nearly a 50% reduction from the levels achieved using first-generation low NO_X burners and represents one of the lowest NO_X emission levels achieved in the industry on a full scale utility boiler firing sub-bituminous coal. This paper reviews the design modifications for this boiler retrofit and presents performance data from the low NO_X burner retrofit.

INTRODUCTION

To reduce NO_X emissions from pulverized coal fired utility boilers, Riley Power Inc. (RPI) developed the Controlled Combustion Venturi (CCV®) burner in the early 1980's. This burner design has evolved throughout the years, and is capable of achieving significant NO_X reduction in various types of applications, new and retrofit. To date, RPI has sold nearly 1,800 low-NO_X CCV® burners with a total electrical generating capacity of 21,700 MW_E. Using the latest CCV® technology, NO_X emissions reductions from uncontrolled levels average more than 60% without overfire air (OFA) and can exceed 70% with OFA.

RPI has supplied forty new coal-fired low-NO_X Dual Air Zone Controlled Combustion Venturi (CCV®) Burners and an overfire air (OFA) system for installation into a 600 MW_N utility boiler. This technology incorporates the latest developments and was selected as an economically viable option for achieving system wide NO_X compliance. The objective of this retrofit project was to reduce NO_X emissions from a baseline of approximately 0.30 pounds/ MMBtu to 0.155 pounds/ MMBtu, while maintaining CO levels below 100 PPM and carbon in ash levels below 2%. A sub-bituminous, PRB coal is burned in this unit.

To install these burners and overfire air nozzles, modifications to the existing firing configuration were needed. These modifications included reconfiguring the burner arrangement such that the upper elevation of burners was redistributed throughout the lower three windbox compartments and the OFA was installed in the uppermost windbox compartment, shown in Figure 1.

Installation of the burners and the OFA system was complete in the spring of 2002 and performance testing was completed during the summer of 2002. This paper discusses the latest design enhancements to the CCV® burner technology for achieving these reduced emission levels and presents results from the start-up and commissioning of this low-NO_X combustion system.

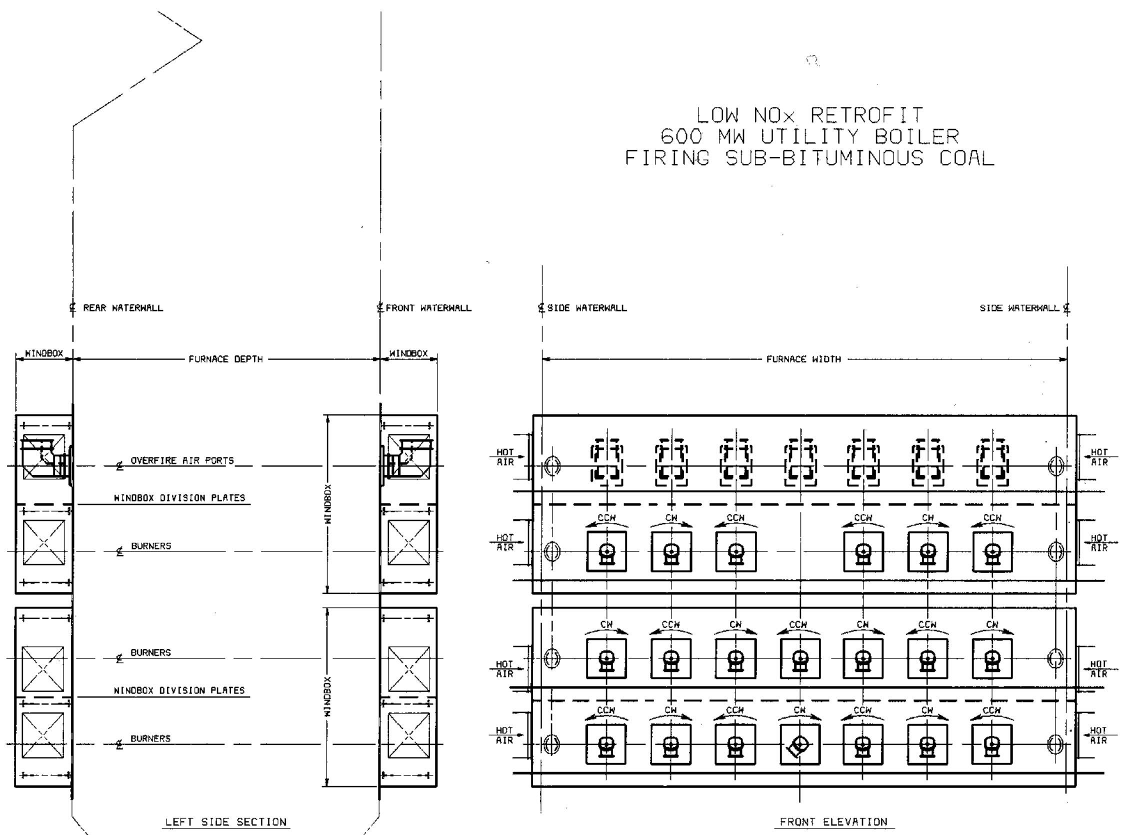

Figure 1 Low NO_X utility boiler retrofit

UNIT DESCRIPTION

The subject utility boiler (Figure 1) is an opposed-wall fired unit burning 100% sub-bituminous PRB coal through up to four elevations of B&W's first generation low-NO_X dual register burners. This unit was originally designed to generate 4,550,000 pounds per hour of main steam flow at 2,650 psig and 1005°F and 4,281,000 pounds per hour reheat steam flow at 602 psig and 1005°F. The original boiler design utilized eight B&W MPS 89 mills to supply pulverized coal to 56 burners. However, because of high furnace heat release rates, sixteen of the burners have been removed from service (two per elevation). Full load boiler operation is 600 MW_N electric power output. Baseline NO_X emissions averaged 0.30 pounds per MMBtu and carbon in ash was typically <0.2%.

BACKGROUND OF RPI's CCV® BURNER TECHNOLOGY

Controlled Combustion Venturi (CCV®) burners are used for reducing NO_X emissions from fossil-fired utility and industrial boilers. Pulverized coal is the primary fuel burned using this design. However, with the proper equipment installed for dual fuel firing capability, oil and gas can also be burned. Figure 2 shows a schematic of the CCV® coal nozzle, which is the basis of RPI's "family" of low-NO_X CCV® Burners. The patented venturi coal nozzle, low swirl coal spreader, and flame stabilizer ring in all of these designs results in a well attached fuel rich flame core, the fundamental condition necessary for minimizing the formation of both fuel and thermal NO_X.

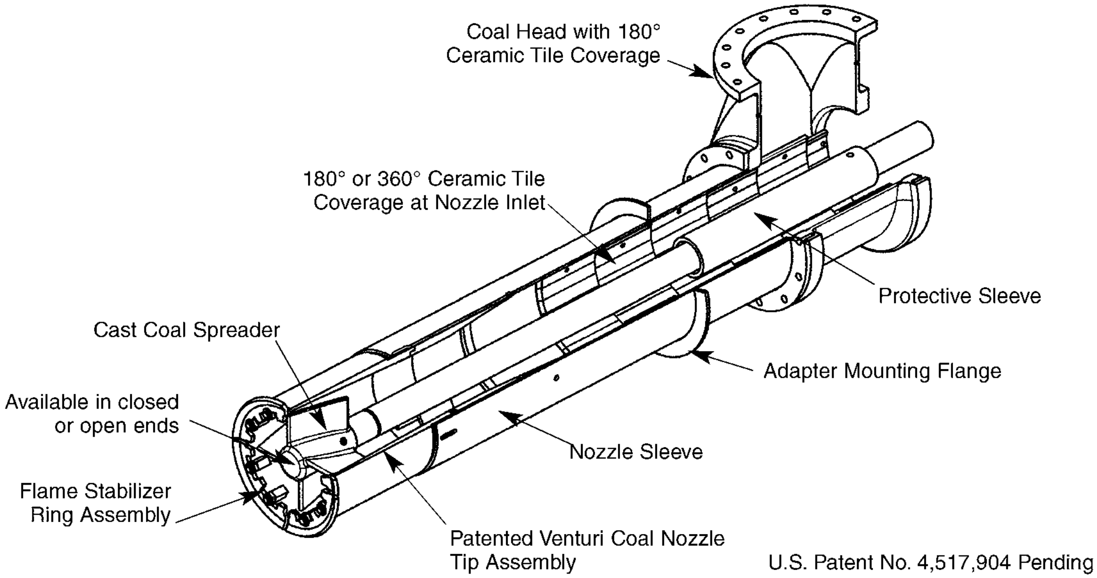

Figure 2 Controlled Combustion Venturi (CCV®) Burner Coal Nozzle

Figure 3 shows schematic drawings of the three low-NO_X coal burner designs incorporating the CCV® coal nozzle. These designs include the single register CCV® , cell CCV® , and dual air zone CCV® burners. For single register burner applications, the secondary air passes through the air register, which imparts swirl, and then through the burner barrel. For the Dual Air Zone CCV® Burner, the main combustion air is further divided into secondary and tertiary air streams. In each of these designs, the combustion airflow is controlled by a movable shroud, which surrounds the air register, independent of the spin vane control. The burner airflow is accurately measured using individual burner airflow probes, supplied by Air Monitor Corporation. CCV® technology can also be applied to cell burners in both single and dual air zone arrangements.

Additional NO_X reduction can be achieved with each of these burners through the use of overfire air to further stage the bulk combustion process. Typically, up to 25% of the combustion air can be diverted from the main combustion zone and introduced above the top elevation of burners. This reduces the stoichiometry at the main burner zone, thus creating a reducing environment for combustion. Airflow measuring devices are used to monitor the desired level of air staging throughout the full range of boiler operation for minimum NO_X formation. Air staging is limited (or not used at all) when applied to boilers burning high sulfur coals and boilers designed for supercritical operation because of the potential concern for lower furnace corrosion.

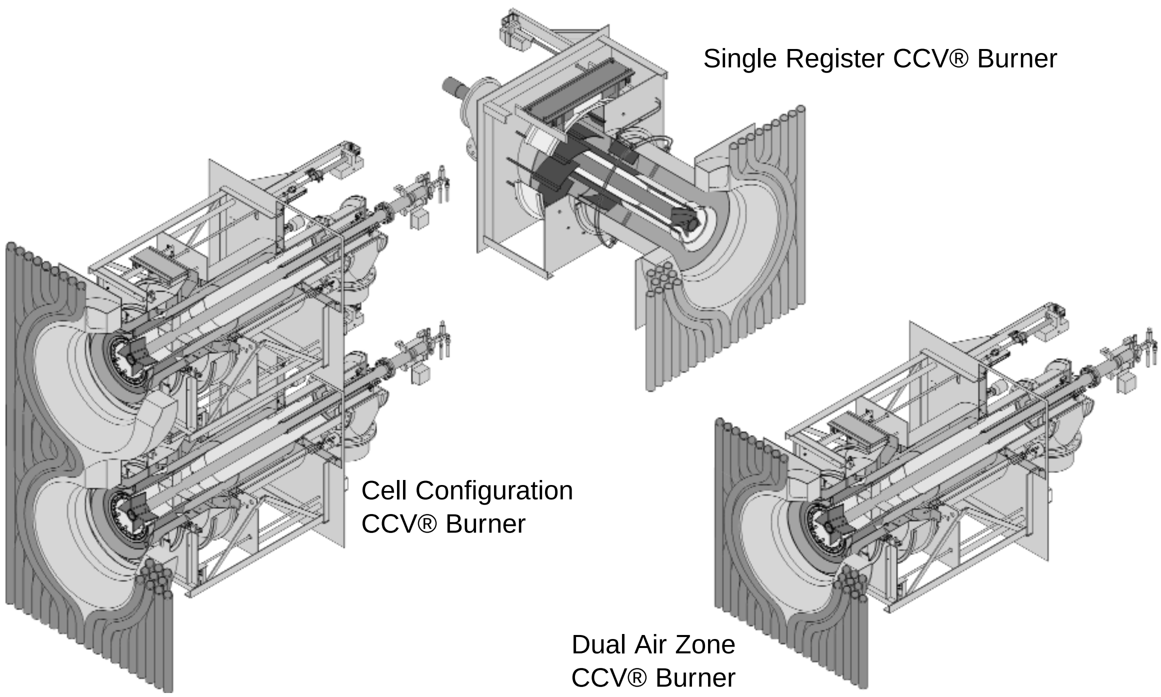

Figure 3 RPI's Low-NO_X CCV® Burners

LOW-NO_X BURNER DESIGN OVERVIEW

The dual air zone low-NO_X CCV® Burners supplied for this retrofit project were designed to meet the emissions target needed to bring this utility into compliance with their system-wide NO_X emissions limits. As previously noted, these burners included the latest technology upgrades. These upgrades focus on maximizing NO_X emissions reductions while extending the wear life for critical burner components.

Enhancements for minimizing the formation of NO_X emissions in this burner design included dual combustion air zones, low-swirl coal spreaders, and flame stabilizer rings. The dual air zones separate the combustion air into secondary and tertiary air passages, each containing swirl vanes for spin control. Each burner includes shrouds and dampers for independent control of the airflow to each passage, providing greater control of the stoichiometry at the burner discharge for additional flexibility in controlling NO_X emissions. The low swirl coal spreader disperses the pulverized coal as individual streams that enter the furnace in a gradual helical flow pattern, producing a longer, low-NO_X coal flame compared to shorter coal flames produced by higher swirl coal spreaders. The flame stabilizer ring produces a well-attached tubular-shaped coal flame for further NO_X emissions reduction. Each of these enhancements has a cumulative effect on reducing NO_X emissions in this burner design.

To meet the requirement of being able to operate the low-NO_X burners maintenance free for up to four years between major plant outages, RPI also focused significant development effort on the design of the burner's wear components. The coal spreader was designed using high-grade cast alloy with a wear resistant weld overlay on the leading edge. The flame stabilizer ring materials are high wear, and were further increased in thickness for added wear life. In addition, ceramics were used to line the burner coal heads and nozzles, along with the coal spreader support tube.

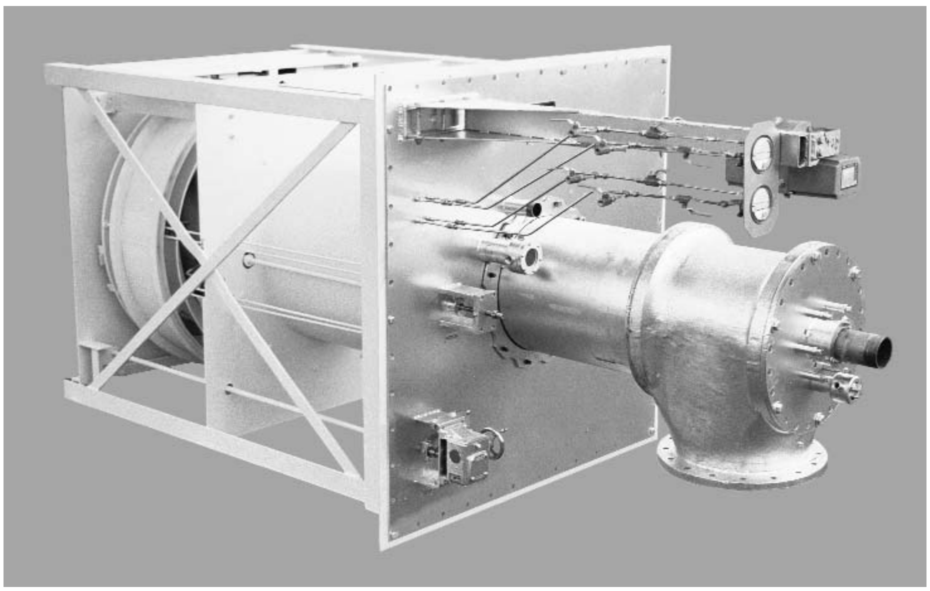

Figure 4 Dual air zone CCV® Burner

A summary of the key design features on this low-NO_X Dual Air Zone CCV® Burner, shown in Figure 4, include:

- CCV® Venturi coal nozzle, cast high temperature/ wear resistant material
- Low-swirl coal spreader, cast high temperature/ wear resistant material with weld overlay on leading edges
- Flame stabilizer ring, cast high temperature/ wear resistant material
- New coal heads, ceramic lined
- Stainless steel secondary and tertiary air barrels
- TA register assembly, including stainless steel swirl vanes
- SA swirl vanes, stainless steel and fixed
- Stainless SA and TA diverters

- Air flow measuring devices with local gauges for indication of burner airflow
- Burner flame observation port

The burner design capacity was 168 MMBtu/ hour heat input, with the design coal shown in Table 1.

In addition to the low-NO_X burners, new oil-fired ignitors and scanners were provided on each burner. The ignitors are located down the center of the coal spreader support tube. The scanners are located in the secondary air annulus.

Table 1 Typical coal analysis

Proximate		**Ultimate**	
Fixed Carbon	40.5%	Carbon	54.3%
Volatile	31.2%	Hydrogen	3.8%
Moisture	24.1%	Nitrogen	0.7%
Ash	4.2%	Oxygen	12.5%
		Sulfur	0.4%
		Moisture	24.1%
HHV (Btu/ lb)	9,550	Ash	4.2%

OVERFIRE AIR SYSTEM DESIGN OVERVIEW

In addition to low-NO_X burners, an overfire air (OFA) system was provided for additional staging of the combustion air, which is needed for achieving further NO_X reduction. In this case, approximately 20% of the total combustion air is diverted from the main combustion zone and introduced through the OFA nozzles, which are located above the top elevation of burners. This results in a reduced lower furnace stoichiometry, which produces lower NO_X emissions by providing a reducing environment for primary combustion to occur.

The OFA nozzles are located above each burner column and are designed using RPI's standard 1/3 – 2/3 nozzle design concept, see Figure 5. Separate on/off dampers are used within each of these sections to control airflow through each of the compartments. This results in better control of the penetration and mixing of the overfire air over a range of operating loads, which is a key factor in achieving optimum combustion and minimizing CO production. The following was also considered when this retrofit OFA system was designed:

- Separation distance between the main burner zone and the overfire air to reduce NO_X
- Overfire air velocity for complete mixing and efficient burnout of the remaining fuel
- Separation distance between the overfire air and the furnace exit to provide adequate residence time for complete combustion
- Independent control of the overfire air from the burner air and independent control of each overfire air port

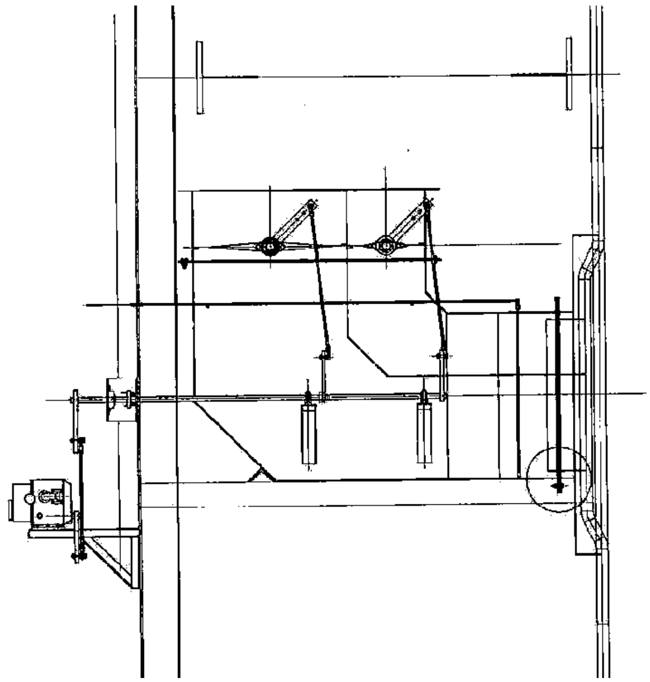

Figure 5 Schematic of OFA damper layout

CFD MODELING

Computational Fluid Dynamic (CFD) modeling of this Dual Air Zone CCV® Burner design was performed using FLUENT. The purpose of this modeling was to evaluate the near field mixing patterns at the burner to both aid in the design and to establish starting points for the various burner component settings during burner optimization. The results from this modeling indicated good separation between the primary air/ coal stream and the combustion air stream, along with recirculation in this separation zone. These flow patterns, shown in Figure 6, are required for good flame attachment and NO_X control.

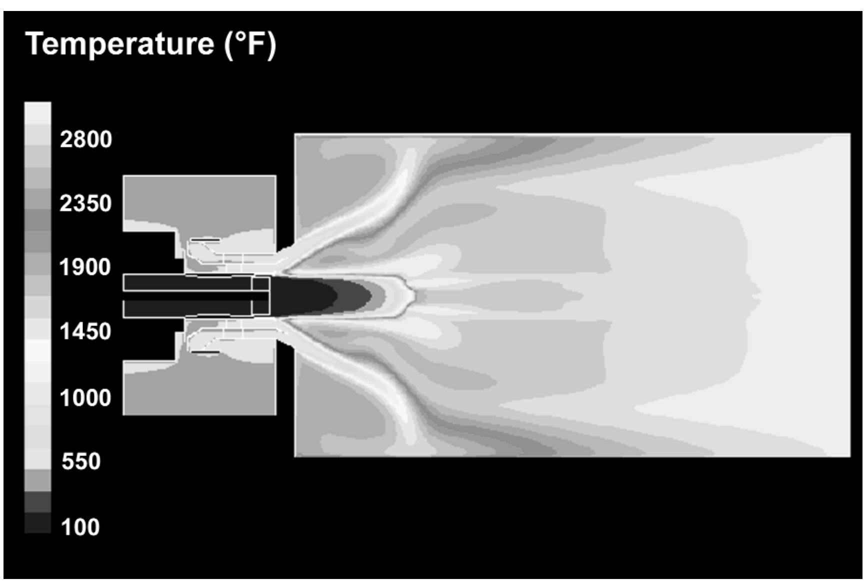

Figure 6 Predicted temperature contour of dual air zone CCV® Burner

RESULTS

The low-NO_X burners and OFA were installed during the spring 2002 outage. During this period, the burners were pre-assembled on the ground and hoisted to the burner deck for installation into the windbox as a "one-piece" design, minimizing the construction effort inside the windbox. The burners were sized to fit within the existing burner throat openings, avoiding additional pressure part modifications to the boiler.

Start up and commissioning of these burners was performed between June and July 2002. Once the unit achieved full load operation, coal line balancing was performed using variable orifices installed in each of the coal lines during the unit outage (no additional testing for coal fineness was performed.) Once this coal line balancing was complete, optimization testing was performed and was completed over a fairly short period of time. This was facilitated by the CFD modeling, which provided starting point settings for the burner that were reasonably close to the settings finally determined at the completion of the burner tuning. This is demonstrated in Table 2, which compares the burner design settings based on the CFD model and the actual burner settings used for the performance test. Because of system load demand requirements, all post-retrofit burner optimization and performance testing was performed at 600 MW_N.

Table 2 Comparison of CFD model and performance test burner settings.

Burner Operating Parameter	CFD Predicted	Post-Retrofit
Excess Air (%)	17	17
SA Flow Control Damper (inches open)	1.25	1.25
Average Shroud Open (%)	59	63
TA Swirl Vane (degrees)	30	35
PA Coal Spreader Retract (inches)	1	1
Average SA/ TA Flow Ratio	0.50	0.58
Windbox/ Furnace ΔP (inches wc)	4.0	4.2

All performance targets were achieved with these new Dual Air Zone CCV® Burners and OFA, as shown in Table 3. This testing was performed at full load operation with seven mills in service.

Table 3 Comparison of performance targets and test results.

	Pre-Retrofit Baseline	Performance Target	Performance Test
Unit Load (MW_N)	600	600	600
Overfire Air (%)	7	20	14
CEM NO_x Emissions (lb/ MMBtu)	.30	< 0.185	0.158
CO Emissions (ppmdv)	10	< 100	40
Flyash Unburned Carbon (%)	0.06	< 2.0	0.1

A comparison of more pre- and post- retrofit performance testing at full load is summarized in Table 4. For this testing, Fossil Energy Research Corporation (FERCO) performed flue gas emissions measurements and isokinetic flyash sampling at the economizer outlet ducts. As shown in this table, the NO_X emissions were reduced by nearly 50% with the new Dual Air Zone CCV® Burners and OFA. These reductions were achieved with NO_X levels that were initially low because of first generation low NO_X burners.

Table 4 Summary of baseline operating conditions

Operating Parameter	Pre-Retrofit	Post-Retrofit
Gross Generation (MW_N)	600	600
Feedwater Flow (lb/ hour)	4,308,500	4,066,000
Main Steam Temp (°F)	1,001	1,012
Main Steam Spray (lb/ hour)	0	162,000
Reheat Steam Temp (°F)	1,003	1,006
Reheat Steam Spray (lb/ hour)	78,000	31,000
Coal Flow (lb/ hour)	664,000	648,000
Total Air Flow (lb/ hour)	6,145,000	5,983,000
Average FEGT (°F)	2,337	2,315
Economizer O_2 (%)	3.10	3.10
CEM NO_x Emissions (lb/ MMBtu)	0.3	0.158
CO Emissions (ppmdv)	10	40
Carbon in Ash (%)	0.06	0.09
Opacity (%)	4.0	0.9

Carbon-in-ash - Although carbon-in-ash (CIA) levels typically increase during low-NO_X combustion conditions, the NO_X emissions reduction achieved for this project was accomplished with minimal impact to CIA levels. Typically low for PRB sub-bituminous coals, the CIA levels on this unit were typically less than 0.1% with the pre-retrofit burners. Post-retrofit CIA levels during the optimization testing were also typically less than 0.1% with the new Dual Air Zone CCV® Burners and overfire air. A summary of the average results for the pre- and post-retrofit CIA levels is shown in Figure 7.

Effect of OFA flow – Figure 8 shows NO_X emissions as a function of % OFA for the burner optimization testing. As expected, the NO_X emissions decrease as the amount of OFA increases. With an OFA flow ratio of 20%, average NO_X emissions of around 0.155 lbs/MMBtu and as low as 0.138 lbs/MMBtu were achieved. On average, the NO_X emissions increased by approximately 16% when the OFA flow ratio was reduced from 20% to 10%, but typically remained under 0.185 lbs/MMBtu.

Effect of excess air – Figure 9 shows NO_X emissions as a function of excess air for the burner optimization testing. Although there is significant scatter in this data, it is noted that there is only a minor increase in the NO_X emissions as the excess O_2 level increases. Instead, the scatter is more likely associated with different burner settings and/or mill firing configurations.

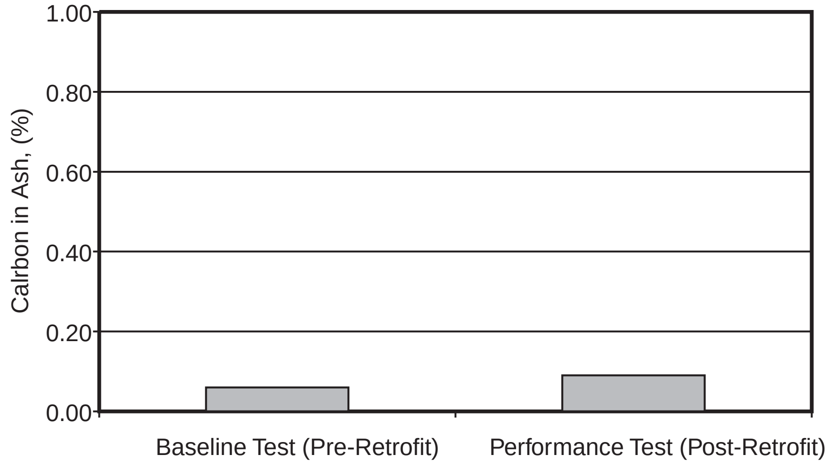

Figure 7 Summary of carbon-in-ash

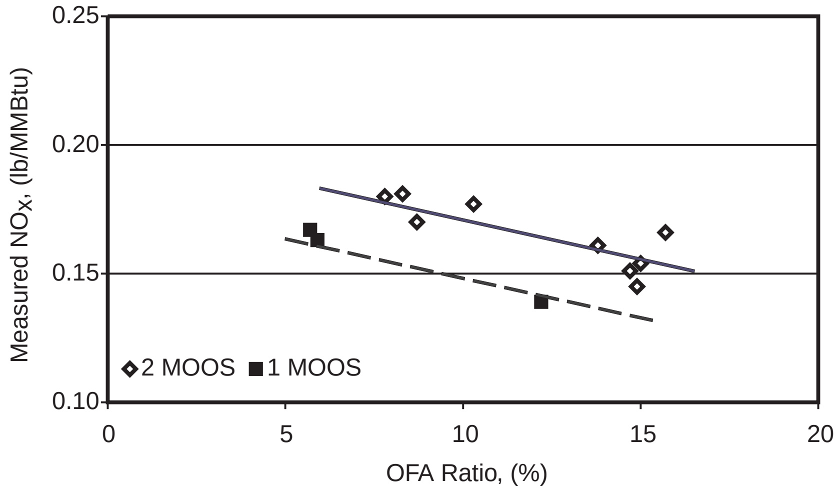

Figure 8 Effect of overfire air on NO_X emissions

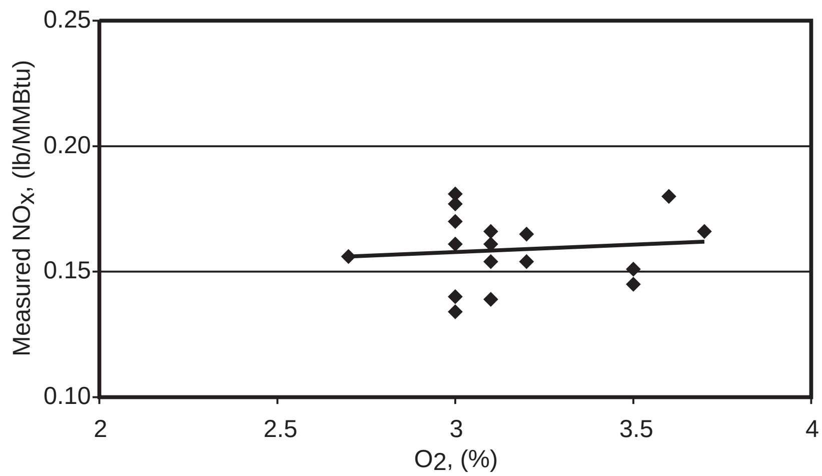

Figure 9 Effect of excess air on NO_X emissions.

Effect of mill firing configuration – Figure 10 shows NO_X emissions as a function of different mill configurations. All of these tests were performed at full load operation with various combinations of either six or seven mills in service. It was also performed with an OFA flow ratio of 20%. As shown in this graph, there was no significant difference in NO_X emissions between these different firing configurations, with all values remaining below the target emissions level. In addition, the CIA levels were all less than 0.1% for each of these tests.

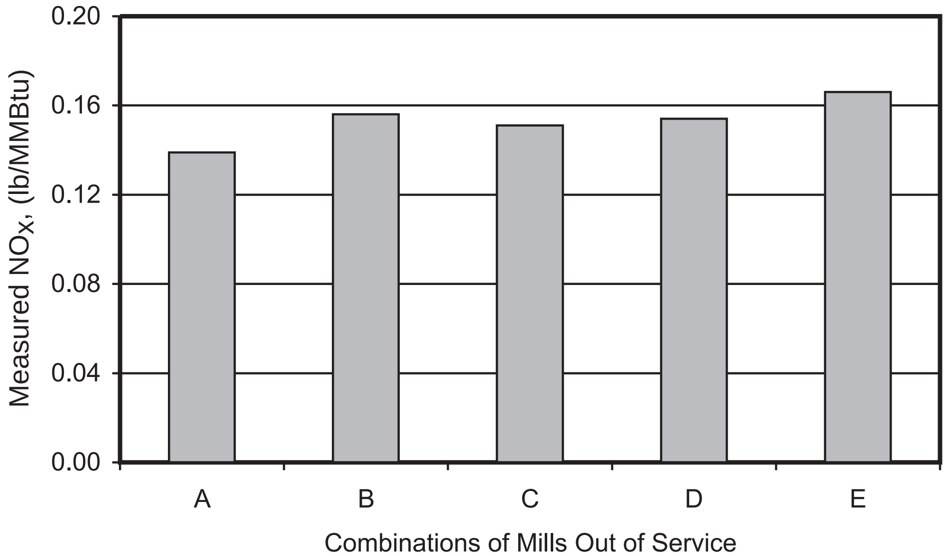

Figure 10 Effect of mill firing configuration on NO_X emissions.

GENERAL OBSERVATIONS

Based on the experience with retrofitting this unit with new Dual Air Zone CCV® Burners and overfire air, the following general observations and comments can be made:

- Balancing of primary airflow between coal lines was performed before burner optimization testing was done. This was done simply with variable orifices, which were installed in each of the coal lines during the outage. Other than this primary airflow balancing, no additional pulverizer testing, such as coal fineness, was needed.
- A slight increase in furnace exit gas temperature was noted; however, this was managed with spray attemperators and no significant change in furnace slagging between pre- and post- retrofit burner operation was experienced.
- No significant change in economizer gas temperature was measured during testing with this new low-NO_X combustion system.
- CFD modeling provided a good starting point for post-retrofit burner optimization, reducing the commissioning time of the new burners.
- These Dual Air Zone CCV® Burners even without OFA are likely to produce significant NO_X emissions reductions with a PRB sub-bituminous coal.
- The lowest NO_X emissions recorded during this testing was 0.138 pounds per MMBtu, which are some of the lowest levels achieved in the industry with only combustion control.

SUMMARY AND CONCLUSIONS

Low-NO_X CCV® burner technology has been used more than twenty years to reduce NO_X emissions from pulverized coal fired utility boilers. With the latest design enhancements incorporated into the low-NO_X Dual Air Zone CCV® Burner, combined with the use of an overfire air system, NO_X emission levels below 0.15 pounds per million Btu were achieved while burning a sub-bituminous coal in an opposed-wall fired boiler. This reduction is approximately 50% over the levels achieved with the first generation low-NO_X burners. Furthermore, these NO_X emission reductions were achieved with minimal impact to CO emissions and carbon in ash.

ACKNOWLEDGEMENTS

The author of this paper would like to thank Dr. Ali Yilmaz and Mr. Craig Penterson for their review and contribution to this technical paper.

REFERENCES

1. Penterson, C., "Development of an Economical Low-NO_X Firing System for Coal-Fired Steam Generators." Presented at the 1982 International Joint Power Generation Conference, Denver, CO, October, 1982
2. Penterson, C., Ake, T., "Latest Developments and Application of DB Riley's Low NO_X CCV® Burner Technology." Presented at the 23rd International Technical Conference on Coal Utilization & Fuel Systems, Clearwater, FL, March 1998
3. Early, D., Penterson, C., "Accurate Burner Air Flow Measurement for Low NO_X Burners." Presented at the International Joint Power Generation Conference, Baltimore, August 1998.