TECHNICAL PUBLICATION

Reducing NOx Emissions on Riley Turbo® Furnaces Latest Results and Experiences

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ABSTRACT

For the past five (5) years, Riley Power Inc., a Babcock Power Inc. company, has been actively retrofitting coal fired Turbo® furnaces with low NO_x system technology. The Riley Turbo® furnace is a unique design originally developed by Riley Power in the 1960's for burning low volatile coals and petroleum coke. It is shaped like an hourglass with a row of burners installed opposed at only one elevation and fire downward below the furnace "throat". The boilers, retrofitted by Riley Power for reducing NO_x emissions, have ranged in size from 85 to over 600 MWg in electrical generating capacity. NO_x emission reductions from 10% to nearly 50% from previous operating levels have been demonstrated with no degradation, or in some cases, improvements in boiler operating performance. The low NO_x technology, developed by Riley Power Inc. includes various combinations of equipment depending on the NO_x reduction levels desired. Some projects utilized minor modifications to the coal nozzles and secondary air chamber. Other projects were retrofitted with completely new burners, overfire air, underfire air and boundary air systems. The key factors enabling reduced NO_x emissions focus on better flame attachment, better airflow recirculation patterns and early ignition and pyrolysis of the coal in a more controlled primary combustion zone.

This paper describes the low NO_x equipment design that Riley Power has developed for these coal fired Turbo® furnaces and the application of this equipment to various installations. Emissions results and the impact on boiler performance are discussed in detail. The use of computational fluid dynamic (CFD) modeling to assist in the design and evaluation of these low NO_x systems is also described.

INTRODUCTION

Since 2004, Riley Power Inc. (RPI) has retrofitted several utility boilers having Riley Turbo® Furnace designs with low NO_x combustion system technology. The boilers have ranged in size from 85 to 600 MWg. Depending on the level of NO_x reduction desired, the scope of combustion equipment supplied has varied from simple burner modifications to a combination of completely new burners with staged air systems. This paper discusses the results of five (5) low NO_x retrofit projects, which can be categorized in regard to % NO_x reduction, the level of retrofit scope supplied, and boiler capacity as noted below.

% NO_x Reduction	Retrofit Scope	Boiler Capacity (MWg)		
10-25	Minimal	85		
15-35	Moderate	200	365	540
35-50	Complex	600		

In all cases, the emissions results and impact on boiler performance is presented in this paper.

TURBO® Furnace Design History

The Riley Turbo® Fired boiler or "Turbo® Furnace" is a unique boiler design developed by RPI in the 1960's. It was designed primarily to burn low volatile fuels such as petroleum coke and bituminous coal with low volatile content. As shown in Figure 1, the boiler design is shaped like an hourglass with a single row of burners at only one (1) elevation, aimed to fire downward on a 25º slope. There are over two (2) dozen dry bottom Riley Turbo® Furnaces installed in the U.S. ranging in electrical generating capacity from 25 to over 600 MWg. The number of burners installed on a Turbo® Furnace ranges from as little as four (4) to as many as thirty-two (32).

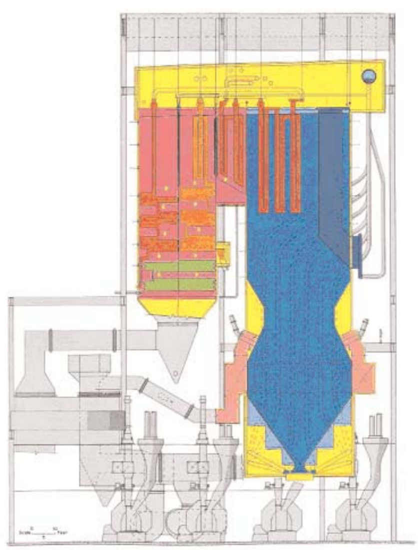

Figure 1. Riley Turbo® Furnace Design

The burners used on these furnaces are axial flow type "Directional Flame" or DF burners. Each burner has two (2) rectangular coal nozzles for introducing the primary air/coal mixture into the furnace. Secondary air is introduced through openings above and below each of the coal nozzles, the direction is controlled by tilting directional air vanes. Staged air or overfire air is introduced through waterwall openings in the furnace throat section immediately above the burners.

In the 1970's, when NO_x emissions were starting to become a concern, it was discovered these furnaces were inheritantly low in NO_x emissions [1, 2] when compared to more traditional wall fired boiler technology. This was due to the diffusion type of mixing and combustion resulting from the axial flow burners, which was much slower mixing than highly swirl stabilized burners typically used on wall fired boilers. NO_x emissions from these Turbo® Furnaces averaged 0.5-0.7 lb/mmbtu and 0.35-0.50 lb/mmbtu for bituminous and sub-bituminous type coals, respectively. This performance was acceptable for meeting the NO_x emission regulations in the 1980's and 1990's. However, the NO_x emission levels were not low enough to satisfy today's more stringent NO_x regulations.

Through CFD modeling and physical flow modeling in the early 2000's, RPI developed upgrades to the DF burner to produce lower NO_x emissions the details of which are described in the next section.

Design and Development of TDF Low NO_x Burner

To further reduce NO_x emissions the DF burner was upgraded to include several design features, learned from our experience with reducing NO_x emissions on wall fired units that we felt were critical to success of the low NO_x DF design. These key features included the addition of:

* New burner head inlet vanes to produce more uniform top to bottom coal distribution within the coal nozzle

* New patented (5,623,884) tilting coal nozzles with air diverters to promote better flame attachment and early pyrolysis of the coal in a reducing zone. By having the ability to position the fireball within the furnace, it enables greater utilization of the complete furnace envelope for controlling the NO_x emissions

* Windbox partitioning for better control of secondary air distribution passing through upper vs. lower half of the burner

* Modified center opening perforated plate to reduce amount of air in this section of the burner

CFD analysis was extensively used to analyze and develop the modification details for the TDF (Tilting Directional Flame) burners as well as for the firing configurations used in the full furnace modeling. Benefits from the modeling include demonstrating the ability of the TDF burner technology to create burner near-field flow behavior that increases flame attachment to the burner tip, decreases NO_x emissions and produces effective flame length in the lower furnace, which in turn reduces lower furnace wall corrosion potential. In addition, the benefits of good nozzle design on improved furnace hopper O_2 content for reduced wall wastage and reduced impingement of coal flames on the lower furnace wall were observed. A typical Riley Turbo® Furnace application for which CFD modeling was used for burner as well as furnace design is shown in Figure 2a. A typical CFD model of the TDF burner is shown in Figure 2b.

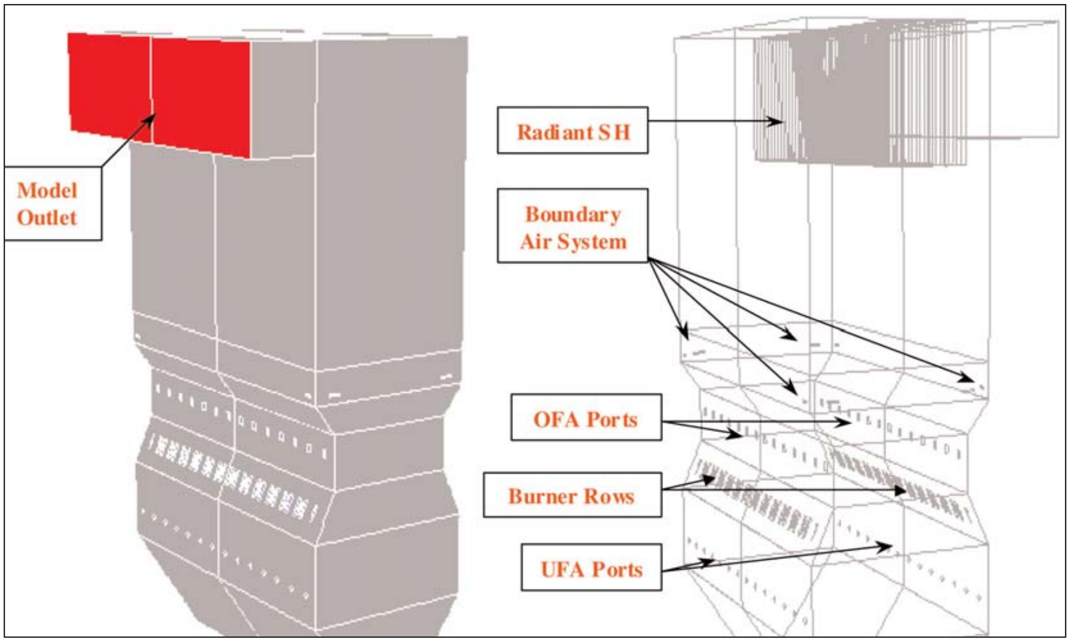

Figure 2a. Typical Riley Turbo® application where CFD analysis is utilized

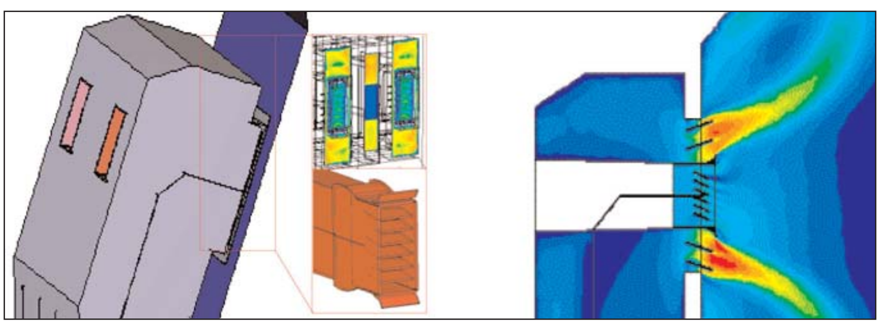

Figure 2b. CFD Model of the TDF

The final design for the TDF burner is obtained after an iterative process for each low NO_x application. The final design configuration typically used is shown in Figure 3 and is referred to as the low-NO_x TDF (Tilting Directional Flame) burner design.

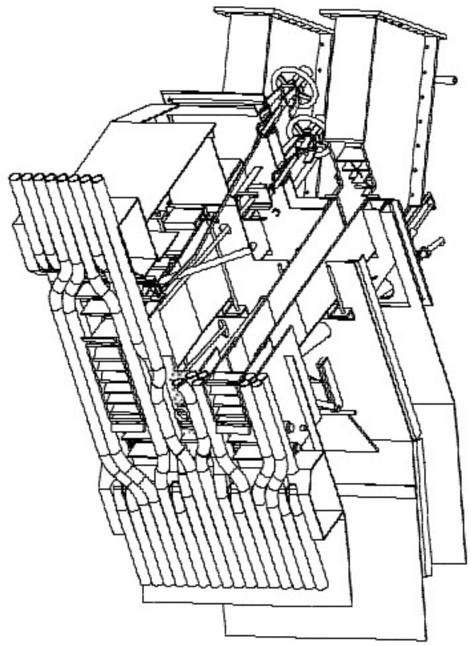

Figure 3. Low NO_x TDF Burner Design

As mentioned earlier, the key factors enabling reduced NO_x emissions focus on better flame attachment, better airflow recirculation patterns and early ignition and pyrolysis of coal in the primary combustion zone for which the CFD burner modeling effectively evaluated. Other important modifications where CFD furnace modeling was used to enhance the low-NO_x systems include the addition of advanced overfire air (OFA), underfire air (UFA) and boundary air (BA) systems. The addition of a boundary air system in combination with the RPI tilting nozzle technology proved beneficial in controlling the CO emissions in the upper furnace. In many cases, aside from CFD modeling, burner setting optimization and field tests are used to balance O_2 distribution within the furnace to control CO emissions and flyash unburned carbon at low NO_x levels.

Application Examples

Turbo® fired units with NO_x reductions ranging from 10% to 25% from pre-retrofit levels included the following components and modifications:

* Fixed Low NO_x Directional Flame (DF) coal nozzles with secondary air diverters, integrated flame stabilizer ring and fixed exit turning vanes

* Inlet adjustable turning vanes installed in the existing coal head

* Perforated plate for the center opening design to minimize the "tramp" air exiting this opening, which enhances the flame attachment at the coal nozzles

Figure 4 illustrates the pre and post retrofit NO_x performance for the first of three (3) identical Turbo® units, located in the Midwest Region of the United States. Each unit has a generating capacity of 85 MWg, burning PRB Coal through eight (8) DF burners fed by two (2) Ball Tube Mills. The other two (2) units experienced the same level of NO_x reduction. There were no operational issues with any of the boilers following the retrofit. In anything, the flyash UBC levels actually decreased.

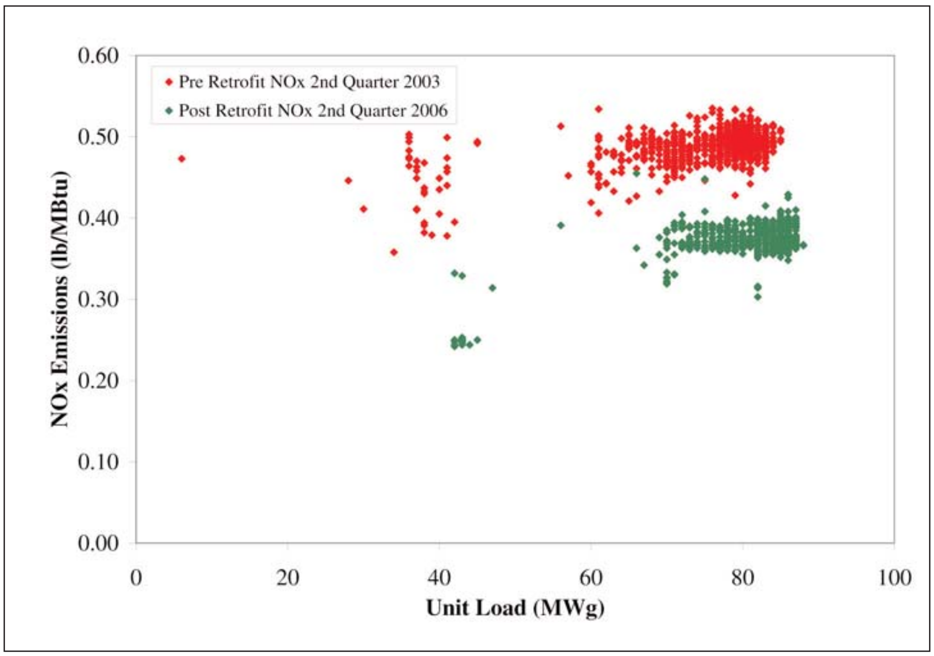

Figure 4. Pre- and Post-retrofit NO_x performance for 3 Turbo® 85MWg Fired Units

RPI's Turbo® fired experience with reducing NO_x emissions by 25% to 35% includes three (3) units ranging in size from 200 MWg to 540 MWg. The first retrofit was completed in 2005 on a unit located in the Midwest. This unit fires an eastern bituminous coal through twenty-four (24) DF burners, fed from three (3) Ball Tube Mills. The scope of equipment supplied included the following:

* New Tilting Directional Flame (TDF) coal nozzles, with fixed exit vanes, secondary air diverters and abrasion resistant plate or cladding throughout
* New adjustable turning vanes installed in the burner head
* Perforated plate designed to minimize the air exiting the center of the burner
* Extension tubes for the scanners and igniter
* Modified OFA dampers and linkages for the existing OFA system

Figure 5 shows the pre and post retrofit NO_x emission results for this unit under normal operating conditions.

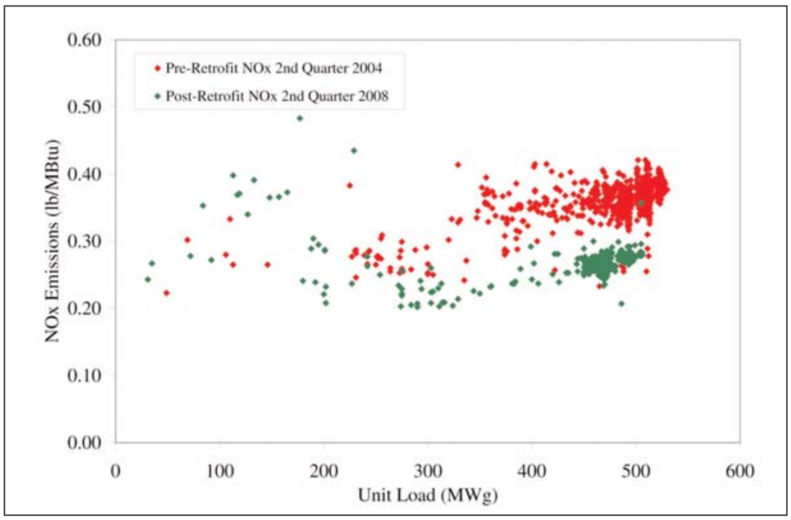

Figure 5. Pre- and Post-retrofit NO_x performance for a Turbo® Fired 540 MWg

The second Turbo furnace low NO_x retrofit is also located in the Midwest. This unit fires pulverized PRB sub-bituminous coal through eighteen (18) directional flame burners supplied by three (3) Ball Tube Mills. The scope of equipment supplied for this retrofit included:

* New Burner Air Chamber assemblies to direct and control the secondary airflow similar to the original equipment
* New TDF coal nozzles, with fixed exit vanes, secondary air diverters and abrasion resistant inlet protective sleeve and wear protection on the exit vanes
* New windbox assemblies including a new front plate assembly, division plate and manual actuators for the coal nozzles and the directional vane tilts
* New perforated plate for the center burner opening
* New divided secondary air damper assemblies with electric drives
* Maintained the existing underfire air system for improved lower furnace performance

Overfire air was not used on this retrofit application. A more detailed discussion of this low NO_x retrofit is presented in reference 4. However, Figure 6 illustrates the final NO_x emissions after the retrofit compared to the pre-retrofit baseline NO_x emissions.

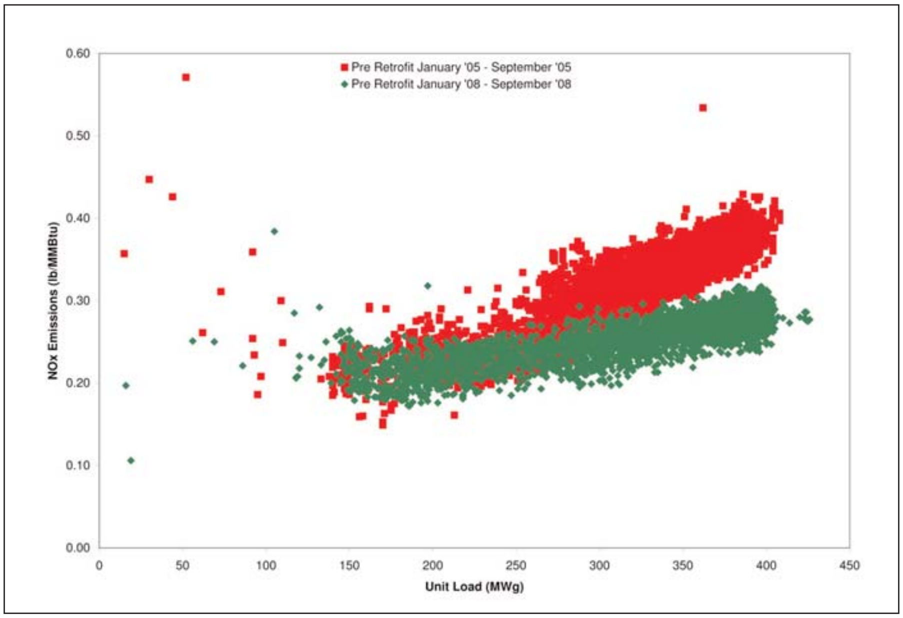

Figure 6. Pre- and Post-retrofit NO_x performance for a Turbo® Fired MWg

The third Turbo® unit to discuss is located in the Southwest region of the United States. This unit fires a sub-bituminous coal through twelve (12) directional flame burners fed by three (3) Ball Tube Mills. The units generating capacity is 200 MWg. This unit had directional flame burners with an underfire air (UFA) system and a small separated overfire air (OFA) system. RPI's modification of this unit included the following equipment:

* New Fixed Low NO_x coal nozzles with integrated air diverters and fixed vanes
* New perforated plate for the center burner opening
* Inlet turning vane assemblies
* New larger OFA system including additional waterwall openings for the "wing" OFA ports

The final NO_x performance pre vs. post retrofit is shown in Figure 7. In addition, a summary of the final performance data is summarized in Table 1.

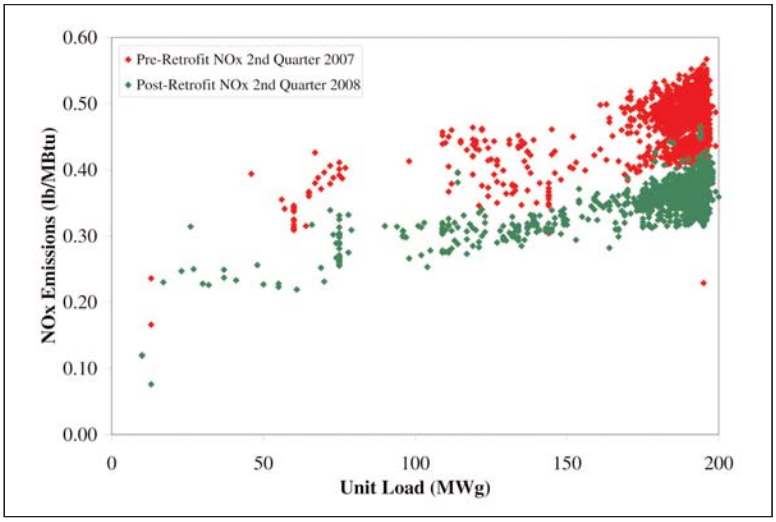

Figure 7. Pre- and Post-retrofit NO_x performance for the a Turbo® Fired 200 MWg

Table 1

Summary of Final Performance for the third Turbo® Unit (200 MWg)

Test		Pre-Retrofit	Post-Retrofit
Gross Load	MWg	194	195
Feed water Flow	pph	1,262,737	1,297,548
Main Steam Flow	pph	1,323,276	1,354,827
SH Spray Flow	pph	60,539	57,279
RH Spray Flow	pph	35,770	23,882
Feed water Temp.	°F	477	316
SH Steam Temp	°F	1,000	1,000
RH Temp.	°F	1,011	1,003
AH Inlet Gas Temp.	°F	671	671
AH Outlet Gas Temp.	°F	271	257
Avg. Local O_2 @ Econ. Outlet	% Vol. Wet	2.46	2.73
CEMS NO_x	Lb/MBtu	0.53	0.39
Local Grid CO @ Economizer	ppm	2.84	27
%LOI at the Precipitator	% wt	0.96	0.75

Note that the flyash % LOI actually decreased from pre-retrofit levels and the CO emissions remained relatively low, which is contrary to that experienced with most low NO_x retrofits.

For units with a generating capacity greater than 600 MWg, RPI's Turbo® experience regarding low NO_x retrofit also includes two (2) units installed in the Southeast region of the US. The first unit experienced NO_x reductions of 45% or more from pre retrofit levels but required more substantial modifications to ensure compliance with CO emissions and UBC along with reducing the NO_x. RPI has since retrofitted a second unit at the same site; both units achieved similar results utilizing the following combustion system equipment:

* New TDF coal nozzles, with fixed exit vanes, secondary air diverters and abrasion resistant inlet protective sleeve and wear protection on the exit vanes
* New OFA system complete with control dampers and electric drives
* New windbox division plate
* New Boundary Air System for controlling CO levels
* Maintained the existing underfire air system for improved lower furnace performance

A summary of the performance for the units greater than 600 MWg is shown in Table 2 below. The pre-retrofit and post-retrofit NO_x emissions for these units are presented in Figure 8.

Table 2

Summary of Performance for the Turbo® Units with a capacity greater than 600 MWg

Test		Pre-Retrofit	Post-Retrofit
Gross Load	MWg	614	611
Net Load	MWn	578	577
No. Mills in Service		4	4
Feedwater Flow	kpph	4,158	4,082
SH Spray Flow	kpph	458	524
RH Spray Flow	kpph	0	0
Feedwater Temp.	°F	475	472
SH Steam Temp.	°F	1005	1005
Hot RH Temp.	°F	1006	1004
AH Outlet Gas Temp. (diluted)	°F	300	302
Avg. CR O_2	% Vol. Wet	2.80	2.63
Avg. local O_2 @ Econ. Outlet	% Vol. Dry	3.5	3.20
CEMS NO_x	Lb/mmBtu	0.35	0.1983
CEMS CO	ppm	251	268
Unburned Carbon	% wt	3.24	0.73

Similar to the previous retrofit discussed the flyash unburned carbon decreased from pre retrofit levels. This benefit is most likely due to much better control of the combustion process and greater utilization of the turbo® furnace envelope for carbon burnout.

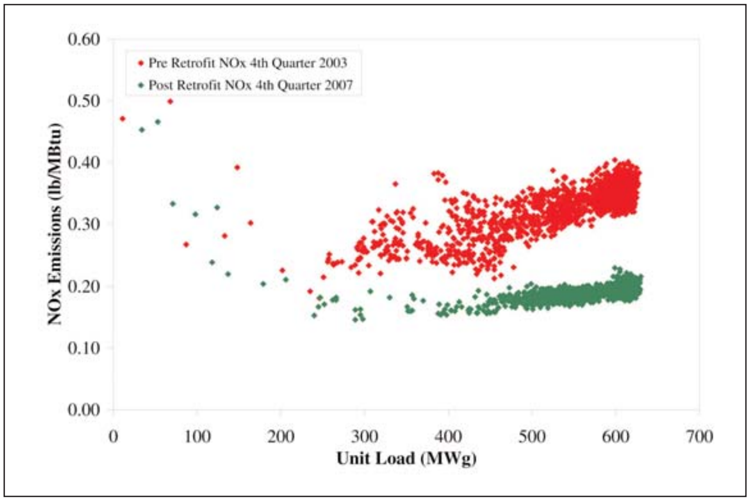

Figure 8. Pre- and Post-retrofit performance for Turbo® Units with a capacity greater than 600 MWg firing PRB Coal

Impact on Boiler Performance & Operations

The actual field performance on these retrofit applications demonstrated NO_x reductions ranging from 10% to nearly 50 % from pre-retrofit levels. Overall boiler operation either remained the same or improved in some cases with reduced CO emissions and lower unburned carbon than the performance experienced during pre-retrofit operation. In several applications, lower furnace waterwall wastage and excessive upper furnace radiant pendant tube metal temperatures were previously minimizing the unit's reliability and capacity factors. Although coal sulfur content was a major factor governing wall corrosion, the local amounts of O_2 in the flue gases at the walls directly impacted waterwall corrosion rates. Near zero local wall O_2 level, high CO content and high local wall heat flux were causing high wall corrosion rates. The CFD furnace models directly showed for that particular case the wall environment (O_2 content, CO content, gas temperature, and heat flux) creating highly corrosive conditions. By identifying the cause of increased corrosion risk in the lower furnace, RPI was able to recommend changes in hardware or operations with respect to improving the lower furnace waterwall conditions. Similarly, in the upper furnace the radiant pendant heat absorption was not uniform from pendant to pendant across the unit width, so that during normal operations tube metal temperatures can exceed limiting values in a number of pendants, which over time leads to tube failures and poor unit reliability. CFD furnace models in this project were instrumental in directly showing the flue gas motion in the upper furnace and hence whether or not specific changes to reduce the tube metal alarm trends were needed. In one installation, the superheat attemperator spray flow quantity was reduced by 90% because of less flame carryover into the backpass.

Overall, the benefits of the combined RPI low NO_x burner technologies and OFA system improvements on furnace performance with respect to FEGT, furnace exit O_2 and CO distributions and radiant pendant heat pickup distributions were demonstrated. In all cases, there were no reported issues or concerns with boiler operation following the installation of RPI's low NO_x combustion system.

FUTURE PROJECTS

Currently RPI has two (2) projects in progress for retrofitting low NO_x combustion system technology on Riley Turbo® Furnaces. One (1) unit is a small industrial furnace/boiler design rated at 25 MWg operating capacity and designed to burn eastern bituminous coal. The other is a larger 400 MWg sub-bituminous coal fired unit that will burn a blend of coals. NO_x emission requirements from the burner equipment are <0.45 and <0.30 lb/mmbtu, respectively for these two (2) installations. The larger unit is scheduled to start up this spring and the smaller unit in the fall, 2009. Both projects will utilize the latest DF burner upgrades and air staging systems. The smaller unit will be equipped with tilting OFA since the furnace residence time for proper carbon burnout is relatively short. The larger 400 MWg unit will utilize our more traditional OFA system design.

SUMMARY

Reducing NO_x emissions from coal fired utility boilers including the Riley Turbo® Furnaces using combustion control only continues to be a cost effective or first step approach for meeting environmental regulations. The key principles learned while reducing NO_x emissions on wall and T-fired boiler installations are also applicable to the Riley Turbo® Furnace / boiler design. Both physical and CFD flow modeling were helpful tools for evaluating different design options. In the past five (5) years several utility boilers were retrofitted by RPI with the latest combustion systems technology for low NO_x emissions. Reductions approaching 50% from levels that were once considered acceptable in the 1980's and 1990's have been demonstrated with minimal impact on boiler performance and operation. Projects are currently on-going at RPI to continue implementing this low NO_x technology on both utility and industrial size boiler designs.

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