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NO_x Control Solutions and their Impact on CO Emissions for Coal-Fired Utility Boilers

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ABSTRACT

The electric utility industry is facing more stringent NO_x reduction requirements in coal-fired boilers. Available technical solutions range from low-NO_x burner technology and addition of overfire air systems to post-combustion control methods such as SCR, SNCR or a combination of these. In many existing units, application of SCR is cost prohibitive and as a result, there is strong interest for more cost-effective technologies. Also, due to the potential impact of the adopted solution on other parameters such as unburned carbon in fly ash or CO emissions, there is a need for a balanced approach, which can assess the optimum solution.

This paper describes Riley Power Inc's approach to NO_x control and its use of CFD modeling as an integral tool in the design and implementation of NO_x reduction technologies in utility boiler applications. Several examples are presented on how RPI has used CFD modeling to develop design upgrades and modifications for reducing emissions. They involve the staging of furnace combustion through the use of overfire air (OFA) to reduce NO_x emissions while minimizing the impact on CO concentrations and unburned carbon. Furnace simulations were used to optimize the OFA port placement as well as to identify locations of highest CO and O_2 concentration. Plant data for these units confirmed the accuracy of the modeling results for pre-retrofit and post-retrofit operation. The benefits of using CFD modeling to minimize start up and commissioning time as well as the potential impact on CO emissions are discussed.

INTRODUCTION

The electric utility industry is facing more stringent NO_x reduction requirements in coal-fired boilers due to legislation such as the Clean Air Act of 1990 and the CAIR regulations. Available technical solutions range from low-NO_x burner technology and addition of overfire air systems to post-combustion control methods such as SCR or a combination of these. In many existing units, application of SCR is cost prohibitive and as a result, there is strong interest for a more cost-effective technologies. Since the early 1990's most large utility boilers have installed some form of low-NO_x burner (LNB) 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. Also, due to the potential impact of the adopted solution on other operational parameters such as unburned carbon in fly ash and CO emissions, there is a need for a balanced approach, which can fully evaluate the optimum solution.

Riley Power Inc (RPI) has used CFD modeling extensively over the past 20 years to assist in the design process of low-NO_x combustion systems for utility boilers [1-3]. Recent applications have focused on retrofit projects designed to reduce NO_x emissions by applying low-NO_x technology to a wide variety of boiler types such as traditional wall-fired and tangentially fired (T-fired) furnaces as well as unique Turbo® fired boilers, a proprietary boiler design of RPI [4-6]. The design requirements for these applications include burner upgrades, staging and overfire air as well as burning of various fuels. The potential impact of burner and furnace modifications on NO_x and CO emissions, furnace exit gas temperature (FEGT) and waterwall corrosion was evaluated. This paper describes RPI's use of CFD modeling to evaluate and design NO_x reduction strategies applied to three coal-fired utility boilers.

RPI's Burner and OFA System Technology Overview

RPI supplies low-NO_x CCV®-DAZ burners and OFA systems as a solution for controlling NO_x emissions from wall-fired boilers firing pulverized coal. To date, RPI has supplied over 2100 low-NO_x CCV®-DAZ burners on 150+ utility boilers. Figure 1 shows a schematic of RPI's dual air zone low-NO_x CCV® Burner. Unique design features 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 and low swirl coal spreader for fuel rich combustion with excellent flame attachment and flame length control
* 50-60% NO_x reduction for burners only from uncontrolled levels

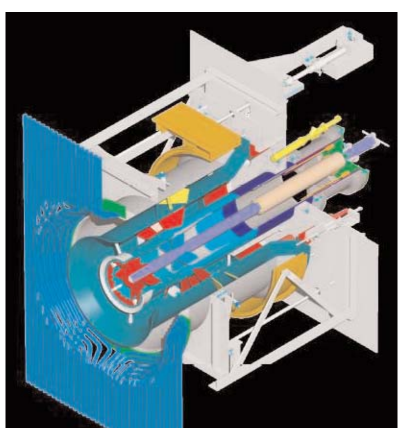


Figure 1. RPI CCV® DAZ Low-NO_x Coal Burner.

In addition to low-NO_x burners, an overfire (OFA) system is typically offered by RPI on units with suitable furnace geometry for additional staging of the combustion air to achieve further NO_x reduction. Overfire air (OFA) nozzles are normally located above the top elevation of the burners and are designed using criteria established during previous in-depth OFA design study conducted for EPRI. Separate on/off dampers are used to control airflow through each of the compartments, which results in better control of the penetration and mixing of the overfire air over a range of operating boiler loads. This represents a key factor used by RPI to achieve optimum combustion and minimize CO emissions. The amount of air diverted to the OFA system results in a reduced burner zone stoichiometry, which produces lower NO_x emissions by providing a reducing environment in which the primary combustion occurs. Key features of the OFA system include:

* OFA jet velocity for complete mixing and efficient burnout of the remaining fuel

* OFA distribution, including the use of wing OFA ports on units with suitable geometry

* Residence time between the main burner zone and OFA system and between the OFA system and furnace exit respectively for NO_x and CO control

* Independent control of OFA from the burner air and of each OFA port

For the applications presented in this paper, the integration of RPI's low-NO_x burner technology and OFA system played a critical role in achieving the targeted NO_x emissions with minimal impact on CO production and unburned carbon in ash.

Application to Front Wall Fired Boilers — LNB and OFA

CFD modeling was used to evaluate the modified furnace design for a low-NO_x retrofit on a 320 MWg unit at a major Southeastern U.S. utility. The unit fired various eastern bituminous coals and experienced relatively high NO_x emissions (>0.6 lb/mmBtu), unstable CO levels and relatively high-unburned carbon in the flyash. The retrofit involved replacement of the OEM's first generation LNB's with RPI's CCV®-DAZ type low-NO_x burners and addition of an RPI-designed OFA system. The challenge for this application was to effectively reduce NO_x while maintaining low CO emissions and low unburned carbon. This required CFD analysis of the burners as well as the entire furnace to ensure adequate mixing by the OFA system in the upper furnace. Basic features of the model are shown in Figure 2. The unit is equipped with 16 front wall mounted burners connected to 4 HP 863 mills, and has five waterwall platens in the upper front furnace, opposite the rear wall nose arch. Included in Figure 2 are: a typical CFD aerodynamic flow pattern of the CCV®-DAZ burner and a photo of an as-installed burner.

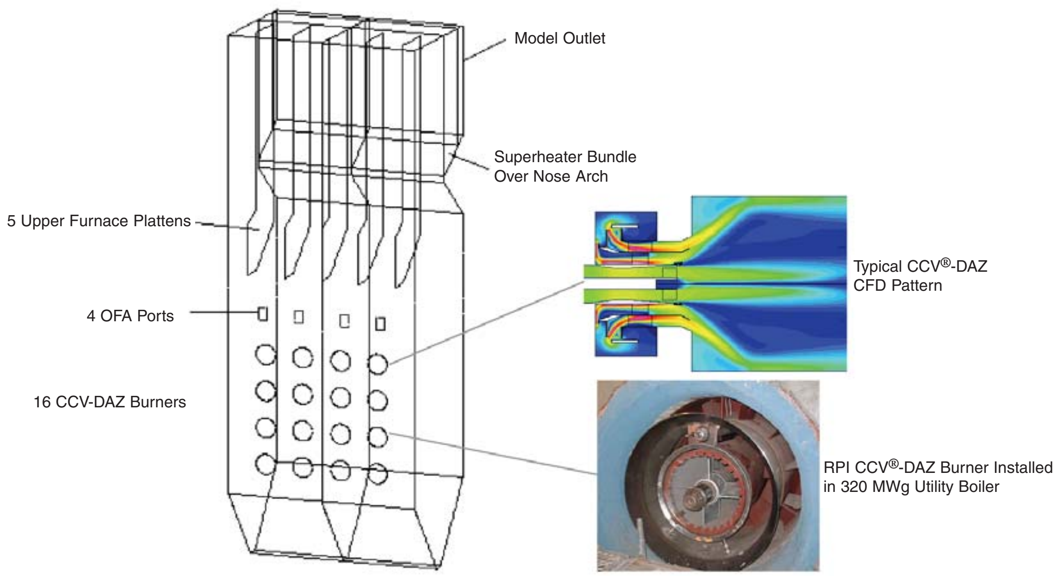


Figure 2. Basic Features of the 320 MWg Boiler CFD Model.

Figure 3 shows the computed temperature distributions for the modified furnace on vertical and horizontal cuts through the burners. It can be seen that the hot flame mass from the burners reaches the rear wall and turns closely around the arch as it flows out the furnace. The flames are well attached across all burner levels with fairly wide base angles. As expected, the flame cores become hotter from the bottom row to the top row due to the greater level of confinement and increase in heat release. The vertical FEGT plane has a very non-uniform temperature distribution with a bulk average of 2320ºF. Figure 4 illustrates the computed CO distributions for the modified furnace on similar vertical and horizontal cuts through the burners and OFA plane. Furthermore, Figure 4 highlights how the lower outer burner flame cores tend to flare out to the sidewalls and rear corners ultimately to find paths of least resistance to exit the furnace. The figure also indicates that, as is common with low-NO_x burners, the flame core penetrates into the furnace and slowly expands with rotation of the combustion air to fill the furnace width and depth. As particles move outward into regions of lower O_2 concentrations, the CO emissions remain high. As a result, a non-uniform CO distribution enters the OFA zone. In the upper furnace, pockets of concentrated CO pass the nose arch elevation in the rear corners, resulting in elevated CO leaving the furnace in small patches, giving an average value of 445 ppm dry at the furnace exit (superheater inlet) dropping to 245 ppm, dry at the model exit after the superheater. The relatively good furnace turbulence through the furnace exit superheater, due to the shape of the nose, reduces the CO level considerably before the economizer plane, where CO measurements are typically collected. Furnace exit flyash UBC was predicted using proprietary empirical methods to be relatively low at 7.5 % for this eastern bituminous coal.

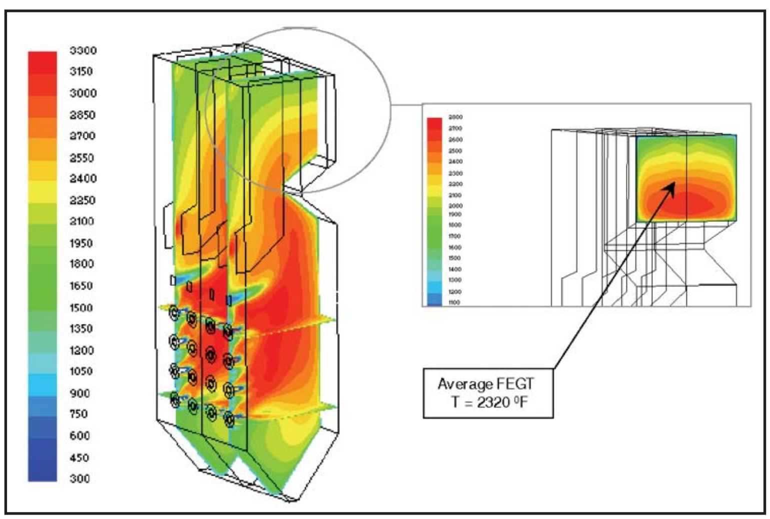


Figure 3. Calculated Temperature Distributions in the Furnace (ºF).

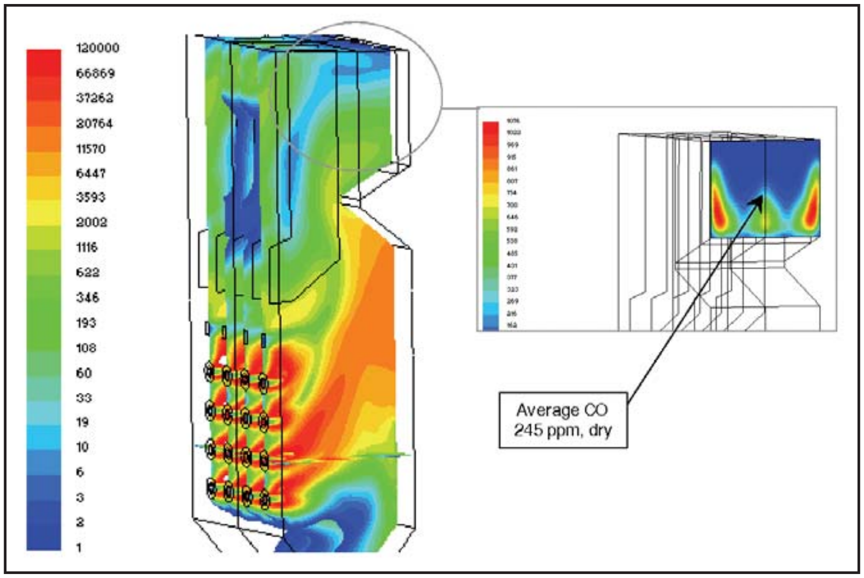


Figure 4. Calculated CO Distribution in the Furnace (ppm, dry).

The final performance for this unit demonstrated a NO_x reduction of 45 % from > 0.60 to 0.34 lb/mmBtu, which subsequently was reduced further to <0.30 lb/mmBtu at 40% boiler load. At the same time CO emissions and unburned carbon levels remained low at 128 ppm and 5.9%, respectively. This compared well with the baseline values of 150 ppm and with the post-retrofit guarantee value of < 300 ppm. Figure 5 presents the pre- and post-retrofit NO_x performance for this application.

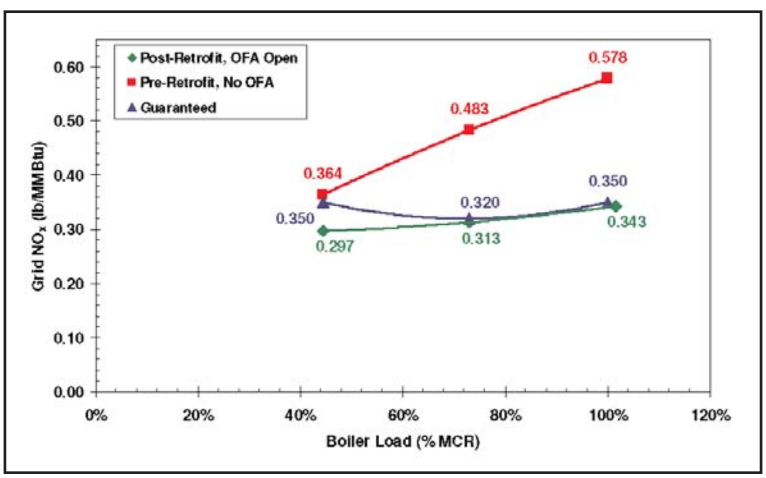


Figure 5. Pre & Post Retrofit NO_x Performance — 320 MWg Boiler.

Application to Opposed Wall Fired Boiler — LNB and OFA

Another recent application, for an opposed wall-fired boiler, was the LNB and OFA retrofit of a 365 MWg boiler with 32 opposed fired burners, burning Powder River Basin (PRB) coal. Similar to the previous application, the retrofit involved replacement of the OEM's first generation LNB's with RPI's CCV®-DAZ type low-NO_x burners and addition of an RPI-designed OFA system. The goal of the CFD modeling was two-fold: 1) finalize details of the burner design and settings to minimize burner and unit optimization test periods, and 2) optimize the OFA system design to maximize the reduction of furnace NO_x emissions, while minimizing adverse effects such as increased FEGT and increased CO emissions. OFA system design considerations included OFA port placement elevation, port geometry and jet velocity. Several options were considered, most notably the placement of OFA ports at different elevations, including one replacing the OEM's NO_x ports. Figure 6 presents a schematic of the baseline geometry and one of RPI's design options. An initial baseline simulation was performed to model the current operating conditions and to verify the accuracy and validity of the model. The baseline simulation predicted an average FEGT of 2213 oF and a model exit CO of 618 ppm, dry. The FEGT predictions were very close to the field-measured values (< 5% difference). The CO levels can be expected to further decrease between the model exit and economizer outlet. The results for the 365 MWg Boiler Base Case are shown in Figures 7 and 8 respectively. The RPI design configurations included the CCV®-DAZ low-NO_x burners and various OFA configurations, based on residence time and construction limitations. The OFA port elevation and placement of the ports were variables used to bias the air injection and effectively target the pockets of high CO especially in the corners of the furnace above the burners.

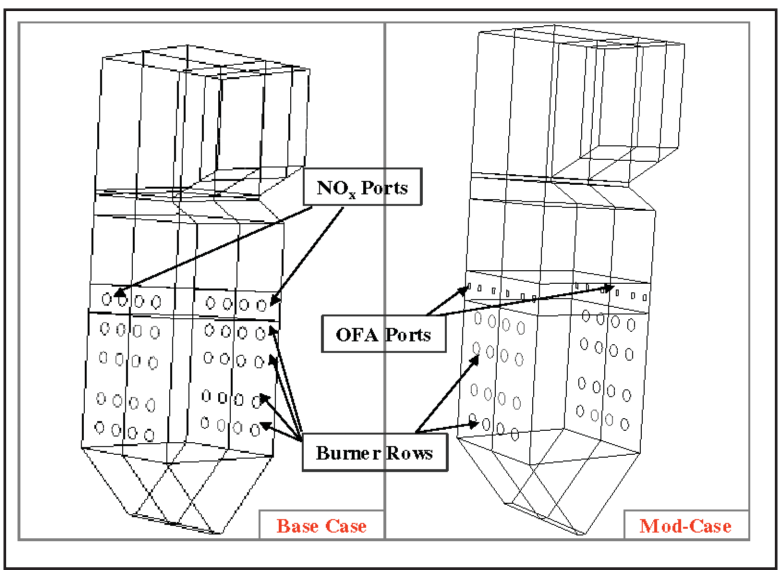


Figure 6. Schematic of the CFD Base Case and one of the RPI-modified cases.

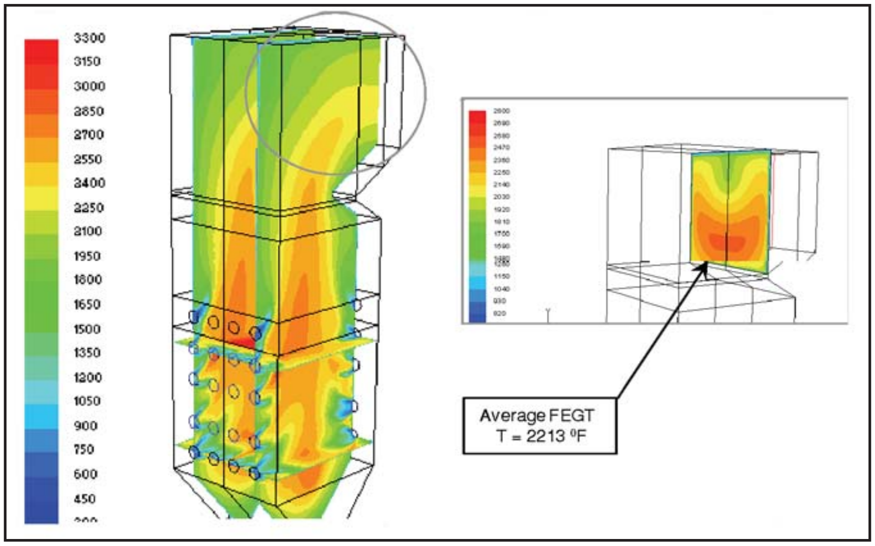


Figure 7. Calculated Temperature Distributions in the Furnace for the Base Case (ºF).

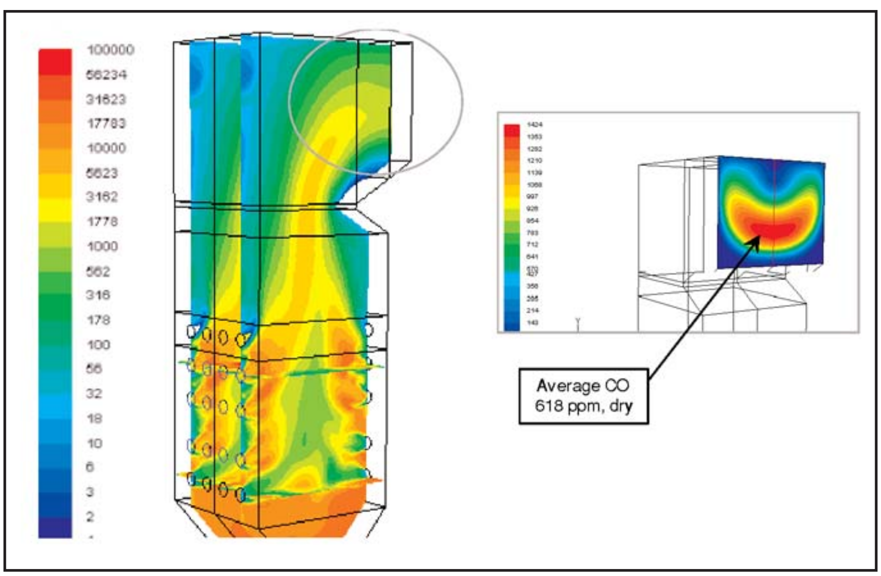


Figure 8. Calculated CO Distribution in the Furnace for the Base Case (ppm, dry).

Figures 9 and 10 present the results for one of RPI's configurations in which the existing NO_x ports immediately above the burners were replaced with RPI's OFA system. The average temperature in the FEGT plane increased less than 5 % but was still within the acceptable limits while the CO emissions at the model exit were reduced by 50% from the Base Case model.

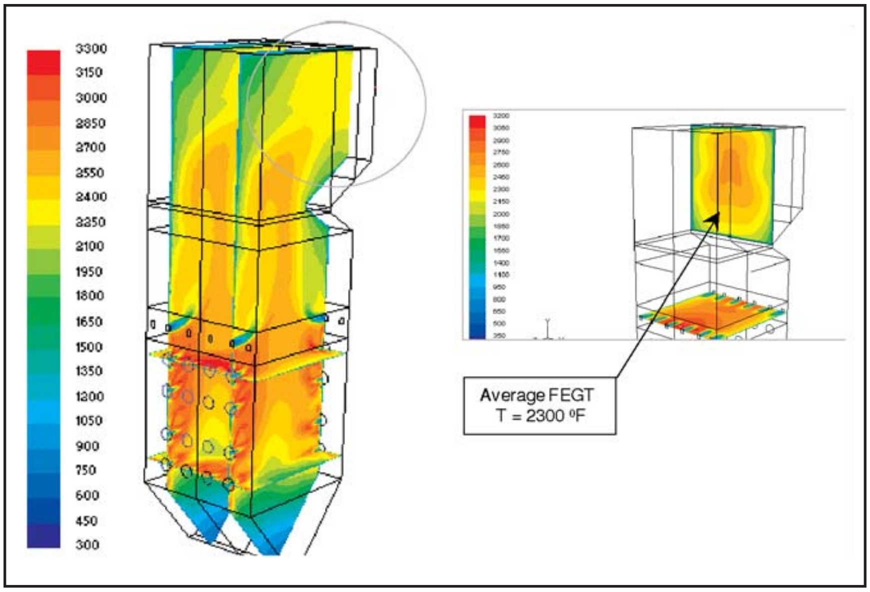


Figure 9. Calculated Temperature Distributions in the Furnace for the RPI Mod Case (°F).

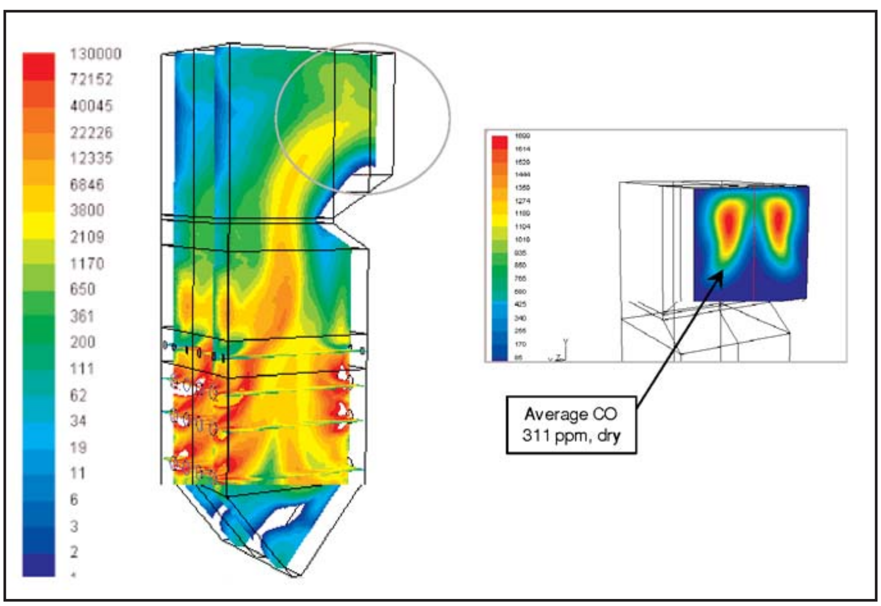


Figure 10. Calculated CO Distribution in the Furnace for the RPI Mod Case (ppm, dry).

Good penetration and mixing from the OFA jets smoothes out considerably the CO levels in the upper furnace through the exit. Additionally, the use of wing OFA ports close to the furnace side waterwalls provides OFA to regions of otherwise high CO concentration, resulting in a lower average CO at the model outlet. Since this is an ongoing RPI project, the full results of this retrofit are not yet available, however it is expected that NO_x emissions of 0.15 lb/MMBtu or less will be demonstrated, while minimizing any adverse effects on increased FEGT and CO emissions.

Application to Turbo® Fired Boilers — LNB and 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 due to their location on the underside of a waist wall. The original Riley axial flow "Directional Flame (DF) Burners" feature 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. Approximately twenty (20) Turbo® Furnaces are in operation today ranging from 85-600 MWg in capacity firing various fuels from low volatile petroleum coke to high volatile sub-bituminous coal. 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 reduced NO_x emissions focus on better flame attachment, better airflow recirculation patterns and earlier ignition and pyrolysis of the coal in the primary combustion zone. The modifications also provide 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 a 500 MWg Turbo® Furnace burning pulverized bituminous coal through twenty-four (24) opposed-fired Riley Directional Flame (DF) burners, fed from three (3) ball tube mill systems. The utility needed to reduce NO_x emissions on this boiler and also to improve combustion and OFA system performance, while at the same time minimizing CO emissions and lower-furnace waterwall corrosion and flame impingement. CFD analysis was extensively used to analyze and develop the modification details for the DF burners as well as for the firing configurations used in the full furnace modeling. RPI modifications included new coal nozzles and OFA system design. Furnace modeling demonstrated the benefits of the combined RPI nozzle technologies and OFA system improvements on furnace performance. The addition of a boundary air system in combination with RPI tilting nozzle technology proved beneficial in controlling the CO emissions in the upper furnace. Further burner setting optimization and field-testing was used to balance O_2 distribution in the lower part of the furnace and hence minimize the potential for corrosion.

Basic features of the model are shown in Figure 11. Included in the figure are a typical schematic and a CFD pattern of the DF burner. Figure 12 displays plots of furnace CO distributions for the Base Case (non-optimized) and the Modified Case (which includes RPI tilting nozzles with optimized settings and the addition of a boundary air system).

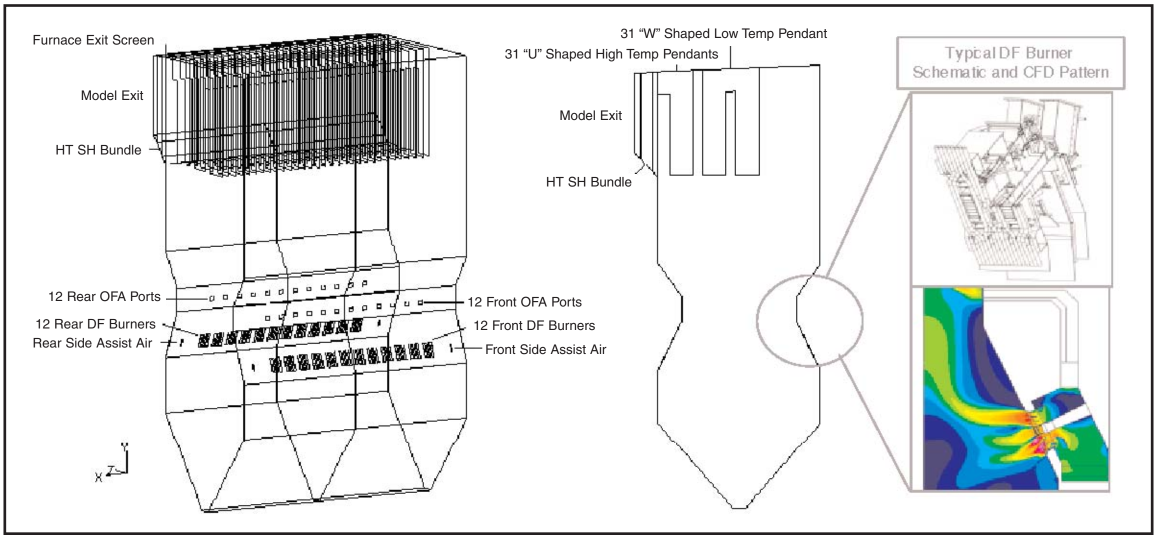


Figure 11. Basic Features of the Riley 500 MWg Turbo® Furnace CFD Model.

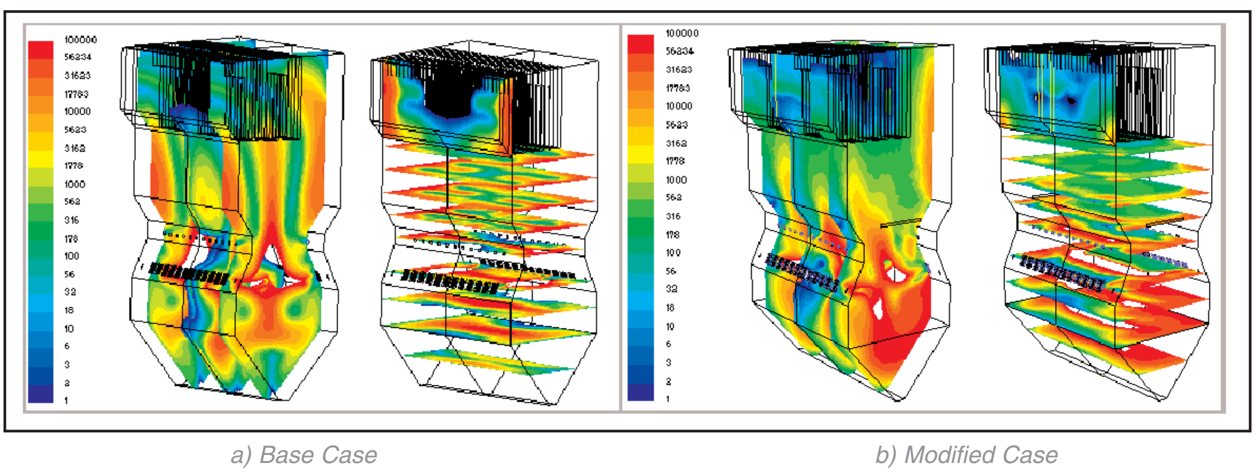
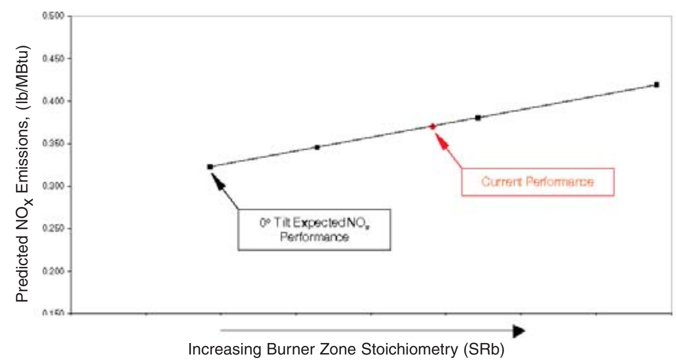


Figure 12. Contours of CO distribution (ppm, wet) for: a) Base Case and b) Modified Case.

The Base Case model results compared well with available test data and observations about the unit's behavior and performance. The coal flames were shorter and more attached and the CO concentration increased along the sidewalls, which was in agreement with CFD predictions. The Modified Case, which included boundary air introduced through sidewalls in the upper furnace showed that there is significantly less CO in the upper furnace region. This was a dramatic change from the Base case, where excessive CO content in the flue gas could be observed leaving the furnace at the exit plane and along the sidewalls and in contrast was reduced significantly in the Modified Case.

From the baseline test conducted by RPI it was determined that the unit was staged only about 10% versus the original design value of 20%. Using RPI's NO_x regression analysis system of a database of measured performance (pre- and post- low-NO_x retrofit) covering several boilers with low-NO_x enhancements it was determined that further NO_x reduction is possible if the unit staging is increased from current levels to 20%. Figure 13 presents the current and predicted performance of the Riley 500 MWg Turbo® Furnace from the regression analysis output. It is also worth mentioning that additional NO_x reduction can be accomplished by changing the nozzle tilt angle. Additional Post-retrofit testing with the latest modifications incorporated has yet to be conducted on this unit.



Predicted Performance of the Riley 500 MWg Turbo Furnace

Staging	%	20
Excess Air	%	19
NO_x	Lb/MBtu	0.35
CO	ppmvd	<300
UBC	% wt.	<1.5* Baseline

Figure 13. Predicted Riley 500 MWg Turbo® Furnace Unit Performance.

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. Three (3) examples have been presented to illustrate Riley Power Inc's approach to NO_x control and its use of CFD modeling as an integral tool in the design and implementation of NO_x reduction technologies in utility boiler applications. All cited examples have primarily involved upgrades to or replacement of existing first and second-generation low NO_x burners with overfire air. CFD simulations were effectively used to identify designs that maximize in-furnace NO_x emission reduction, while minimizing adverse effects such as increased CO emissions and increased carbon in fly ash. Actual field performance demonstrated NO_x reductions of 15-45% from pre-retrofit first generation burner design NO_x levels. RPI's experience presented in this paper covers a range of boiler types including wall fired and Turbo fired furnace designs. The low-NO_x burner technology includes 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

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