TECHNICAL PUBLICATION

Evaluation of Furnace Nose Arch Modifications to Reduce Slag Formation on a 695 MW Utility Boiler Firing PRB Coal

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ABSTRACT

In 2007 Riley Power Inc., a Babcock Power Inc. company, retrofitted a 695 MW opposed-wall fired, dry-bottom, balanced draft boiler with new low NO_x CCV® Dual Air Zone (DAZ) burners and an advanced overfire air (OFA) system. This unit is designed to burn pulverized Powder River Basin (PRB) coal to generate 4,440,000 lbs/hr of steam flow at 2640 psig and 1005 ^oF. The unit is equipped with fifty-six (56) CCV®-DAZ burners and twenty (20) advanced OFA ports. Aside from the low NO_x burner project, Riley Power has been contracted to replace the secondary superheater intermediate pendant and nose arch panel. As part of the contract, CFD modeling was used to evaluate three different furnace nose arch configurations to determine the optimum depth of the nose arch into the furnace.

This paper describes Riley Power Inc.'s (RPI) approach to evaluate and optimize the flue gas flow and temperature distributions at the furnace exit plane, around the nose arch and through the intermediate superheater pendants to determine the optimum depth of the nose arch into the furnace. The proposed design has been evaluated in regard to desired thermal performance of the secondary superheater. CFD modeling was conducted for both burner and furnace. The full furnace modeling utilized results from burner modeling work completed for the low NO_x retrofit project. All burner, OFA settings and operating conditions were adjusted to match post-retrofit operating data from field tests as closely as possible. The different configurations, modeling results and their impact on flue gas temperatures, slagging and erosion are discussed in detail.

INTRODUCTION

In 2006, RPI retrofitted a 695 MW opposed-wall fired, dry-bottom, balanced draft boiler with new low NO_x CCV® Dual Air Zone (DAZ) burners and an advanced overfire air (OFA) system. This unit is designed to burn pulverized Powder River Basin (PRB) coal to generate 4,440,000 lbs/hr of steam flow at 2640 psig and 1005 °F. The unit is equipped with fifty-six (56) CCV®-DAZ burners and twenty (20) advanced OFA ports. Aside from the low NO_x project, RPI has been contracted to replace the secondary superheater intermediate pendant (in-kind) and redesign the furnace nose arch panel. As part of the contract, CFD modeling was used to evaluate three different furnace nose arch configurations to determine the optimum depth of the nose arch into the furnace. This paper describes RPI's approach to help reduce slag build up on the secondary superheater by evaluating the flue gas flow and temperature distributions at the furnace exit plane, around the nose arch and through the intermediate superheater pendants. The results of the evaluation were then used to determine the optimum depth of the nose arch into the furnace.

Reducing NO_x emissions from utility coal fired boilers continues to be a primary goal of environmental authorities. To meet mandated NO_x levels, coal-fired boilers are using a variety of reduction methods: low-NO_x burners, Over Fire Air (OFA) systems, Selective Non-Catalytic reduction (SNCR), Advanced Reburning, Selective Catalytic Reduction (SCR) etc. In many existing units, application of SCR is cost prohibitive and as a result, there is strong interest for 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. However, these advantages have to be balanced against adverse potential impacts of the selected solution such as a possible increase of unburned carbon in fly ash and CO emissions. 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. Solutions have varied anywhere from burner component modifications to complete burner replacement combined with an advanced air staging system or the addition of an SCR. Riley Power Inc 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]. Design requirements for these applications range from burner upgrades and overfire air to 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 during the design of these systems.

Slag formation on superheater tubes is generally a function of the coal ash mineral analysis and the relationship between the tube metal temperature and ash fusion temperatures. PRB coals have a low ash fusion temperature (typically between 2050°F and 2300°F) and a mineral analysis that is conducive to slag formation in superheater pendants. As the slag formation increases, the flue gas flow area becomes smaller, increasing the potential for tube erosion. Large slag falls that shed from the superheater can also result in damage to the furnace hopper. Therefore, prevention of slag build-up is important for reliable boiler operation. The intent of extending the nose arch further into the furnace is to reduce the peak flue gas temperature entering the superheater thereby potentially reducing the sootblowing frequency. Historically this boiler has experienced severe build up of slag on the secondary superheater tubes, which are located at the furnace exit just above the nose arch. The plant currently uses retractable sootblowers located at the front and rear of the superheater to remove slag build up from the tubes. These sootblowers are blown regularly to remove the slag, and frequent plant maintenance is critical to keep the sootblowers operating reliably. By reducing the amount of slag build up in the superheater the plant can reduce the blowing frequency and maintenance requirements of the sootblowers.

RPI's Low-NO_x 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 2200 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

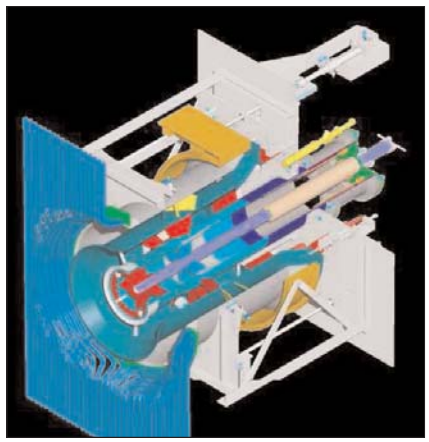

Figure 1. RPI CCV DAZ Low-NO_x Coal Burner

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. 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 and 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.

For the application referenced in this paper, the proper 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 a 695 MW Boiler Firing PRB Coal — LNB, OFA and Nose Arch Modifications

The modeling for this project was done in several separate steps. First, the burner modeling for the RPI CCV-DAZ burner was completed in order to finalize design details and determine the optimum aerodynamic pattern for low-NO_x operation. This was done for the low-NO_x retrofit project. The second step was completed as part of the nose arch modification project and consisted of the full furnace modeling, for which three separate simulations were conducted. The first one includes the Base Case or as-is furnace configuration with settings corresponding to test data. The second and third cases are the modified furnace configurations, representing the two different nose arch depths into the furnace respectively. Case 2 represents the intermediate nose arch depth while Case 3 represents the case where the nose arch was extended all the way to the tip of the radiant superheater.

CFD modeling is conducted for all combustion applications in which the patented low NO_x CCV-DAZ burner (U.S. Patent No. 6,474,250) is used. Several models are usually prepared to evaluate and optimize the near field aerodynamics and parametric optimization is conducted to optimize burner settings. Since RPI completed the retrofit of this unit in 2006, all needed burner data was obtained from the RPI contract for which burner modeling was conducted.

The utility boiler in this application is equipped with fifty-six (56) opposed-fired Riley Power CCV-DAZ burners with 3 rows of 8 burners on the front wall and 4 rows of 8 burners on the rear wall. The low NO_x retrofit also included an overfire air (OFA) system, which consists of 10 ports located on the front wall and 10 ports located on the rear wall. Figures 2 and 3 illustrate the basic features of the Base Case furnace model created for this study. Some of the details of the furnace model, including burner locations, radiant superheater and model outlet are presented with the walls removed for added clarity. The models take advantage of the left-to-right symmetry to reduce model size and conserve computational time. Tables 1 and 2 list some typical furnace operating conditions and chemical properties of the coal fired during Baseline testing.

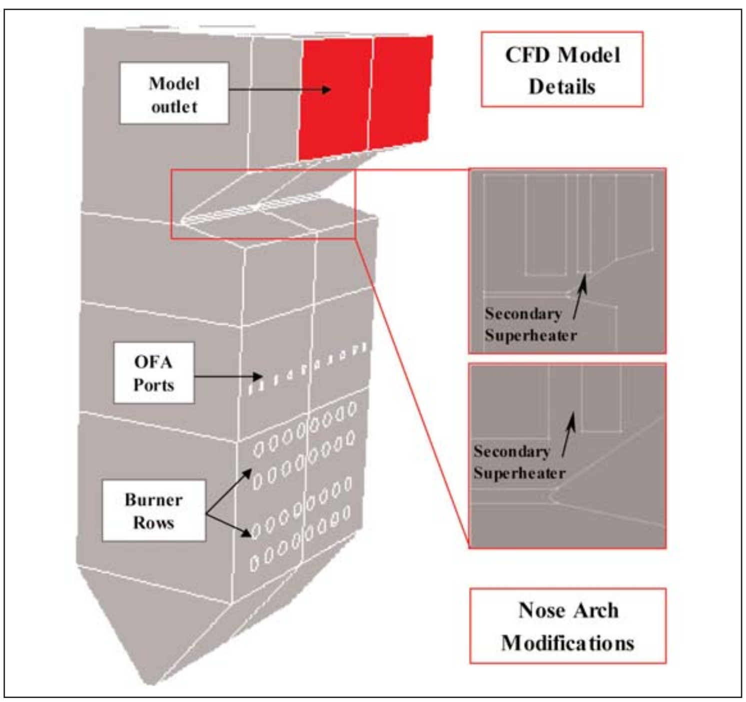

Figure 2. Furnace Model Geometry for the Baseline Case

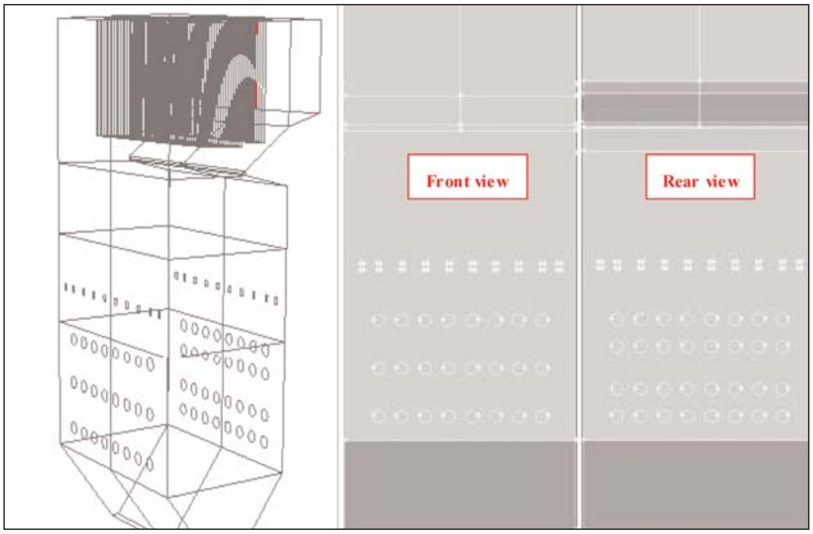

Figure 3. CFD Model Schematic for the 695 MW Utility Boiler Baseline Case

Table 1

Overall Conditions for the 695 MW Utility Boiler Furnace Simulations

Parameters	Baseline Fuel PRB Coal
No. of Burners	56
Total Coal Flow (lb/hr)	821,500
Total Air (lb/hr)	6,050,785
Excess Air @ MCR	18.0
PA Temperature (^oF)	140
SA Temperature (^oF)	700

Table 2

Chemical Properties of the PRB Coal Fired during Baseline Testing

As Received Proximate	PRB Coal	Ultimate	PRB Coal (Wt %)
HHV (Btu/lb)	8,552	C	50.0
Volatiles (Wt %)	31.13	H	3.66
Fixed Carbon (Wt %)	35.3	S	0.22
Coal Type	PRB	N	0.68
		O	11.87
Moisture (Wt %)	29.39	Moisture	29.39
Ash (Wt %)	4.18	Ash	4.18

Modeling Results

Model Overview

As outlined before, CFD modeling of this system involves an iterative procedure in which the conservation equations for mass and momentum are solved over a computational domain, which in this case is the current furnace. Figure 4 presents a schematic of the 3 separate furnace geometries studied for the current project. They include: Base Case which is the current furnace nose arch configuration, Case 2 which is the case where the nose arch is extended at an intermediate depth into the furnace and Case 3 which represents the case where the nose arch is extended all the way to the tip of the superheater.

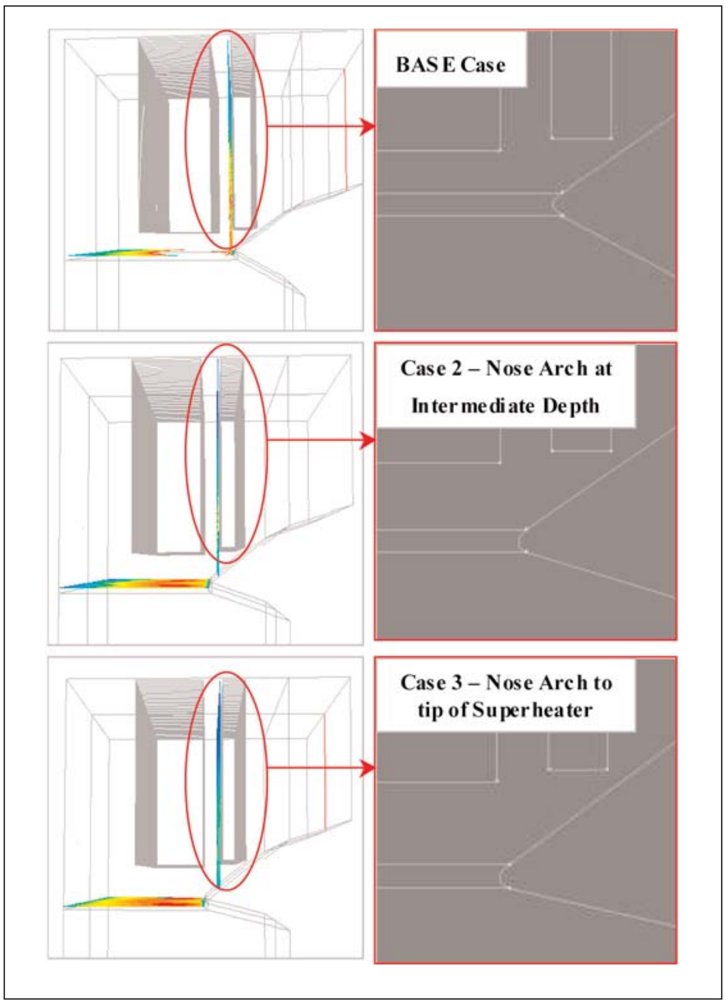

Figure 4. Schematic for the three separate nose arch geometries

It is worth noting that all simulations take advantage of the left-to-right symmetry for the furnace models in order to reduce model size and conserve computational time. However, even with the symmetry simplification, the furnace models contain between 1.7 and 3.4 million cells in order to obtain adequate geometric detail. The furnace models assume there is no front-to-rear windbox bias and that all coal nozzles have equal and stable primary air and coal flows. Operating conditions and chemical properties of the PRB coal fired for this unit are based on data measured and sampled during low-NO_x project acceptance testing. Specific settings were adjusted to match those in the field as closely as possible.

Modeling Results for the Baseline Case

In general, furnace gas velocity is a good starting point for understanding furnace behavior and performance. Figure 5 presents the velocity magnitude contours through vertical and horizontal slices through the furnace for the Baseline case. Distinct jets in the burner zone show good penetration and flow features characteristic of the wall-fired furnaces equipped with CCV-DAZ burners. Figure 6 shows the corresponding temperature distributions through the same planes for the Baseline case. Although only half of the furnace was modeled, all the images show the entire furnace, taking advantage of the left to right symmetry. The flames appear well developed, exhibiting minor non-uniformity as they move upward.

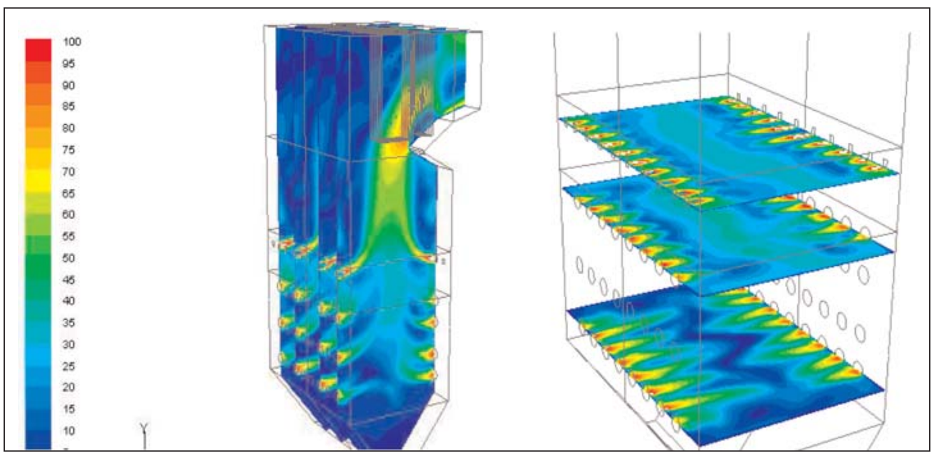

Figure 5. Calculated velocity distributions (ft/s) through vertical and horizontal planes for the Base Case Furnace Model

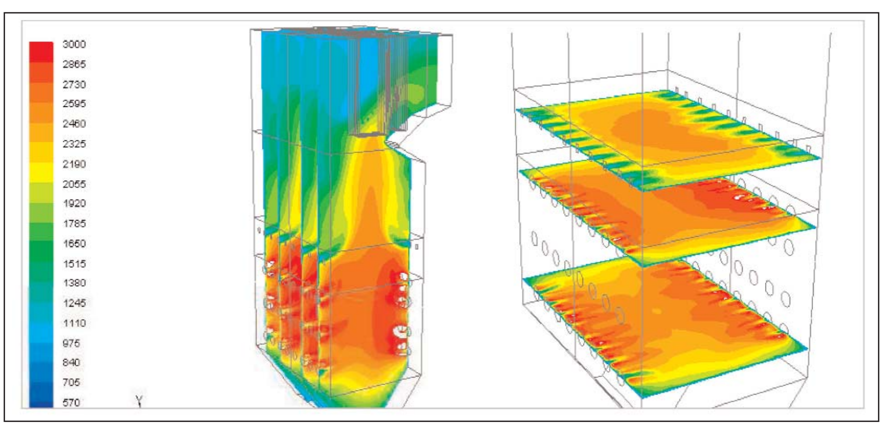

Figure 6. Calculated temperature distributions (°F) through vertical and horizontal planes for the Baseline Case Furnace Model

Figures 7 and 8 display the computed velocity and temperature magnitude distributions in horizontal and vertical nose arch planes for the Baseline case. The results also indicate the maximum velocity and temperatures in the two planes respectively. This maximum value, rather than the area-weighted average value which is usually reported, serves as an indication of the “hot spots” in the areas of interest for the current study.

The results for the Baseline Case, which represents the as-is furnace configuration with the existing nose arch design, illustrate the presence of several hot spots right before the superheater. Typically the slag formation on the tubes would start in the lower section of the superheater, this observation being consistent with the hot spots shown in Figure 8. As the slag would build up and bridge from element to element, the hot spot would move up blocking off more of the flue gas free area and increasing the flue gas velocity, thereby increasing the potential for tube erosion.

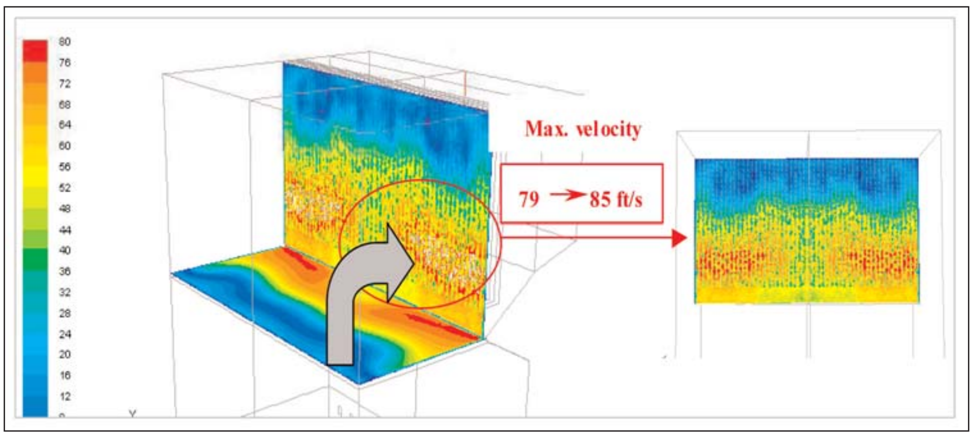

Figure 7. Calculated velocity magnitude (ft/s) in vertical and horizontal nose arch planes for the Baseline Case Furnace Model

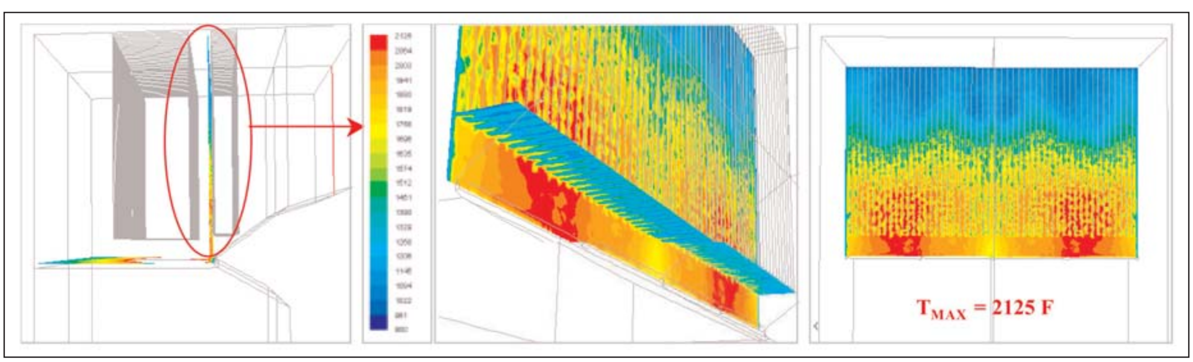

Figure 8. Calculated temperature distribution (°F) in the plane before Superheater for the Baseline Case Furnace Model

As noted before, although the area-weighted average value is usually reported, for the current study this maximum value serves as an indication of the absolute change due to changes in arch nose design only. The Baseline simulation was conducted for the High load (695 MW), 100% MCR Case, corresponding to test conditions in the RPI Acceptance Test report, issued in August 2007. Specific burner and OFA settings were adjusted to match those in the field as closely as possible. For the RPI-solution case, several configurations were considered and simulated, including several different upper furnace modification cases. However, for the current study only the results from the RPI-proposed solution (i.e. case 3) are presented.

Typical Modeling Results for the RPI-Solution Case 3 — Nose Arch at Tip of Superheater

The third full furnace modeling case of this study consists of the nose arch at the tip of the superheater configuration. This case includes all burner, furnace OFA and load parameters similar to the Base Case. The only modification is represented by the nose arch geometry, which in this case is extended all the way to the lower tip of the radiant superheater. The CFD furnace simulation was conducted for the same fuel, operating conditions and under the same model assumptions as the Baseline case.

The velocity magnitude contours through vertical and horizontal slices through the furnace for the Case 3 configuration were similar to the Base Case scenario, which is expected due to the fact that all inputs are the same. Distinct differences develop in the upper furnace area where the flow curves over the nose arch toward the exit, slightly accelerating due to the smaller cross-sectional area available at the furnace nose.

Figures 9 and 10 display the computed velocity and temperature magnitude distributions in horizontal and vertical nose arch planes for the Case 3 configuration. As before, the results also indicate the maximum velocity and temperatures in the two planes respectively. Figure 11 illustrates the predicted coal fly ash concentration for this case and indicates the areas of higher deposition. This information was used as an indicator for evaluating the risk of erosion and slag formation in the upper furnace area.

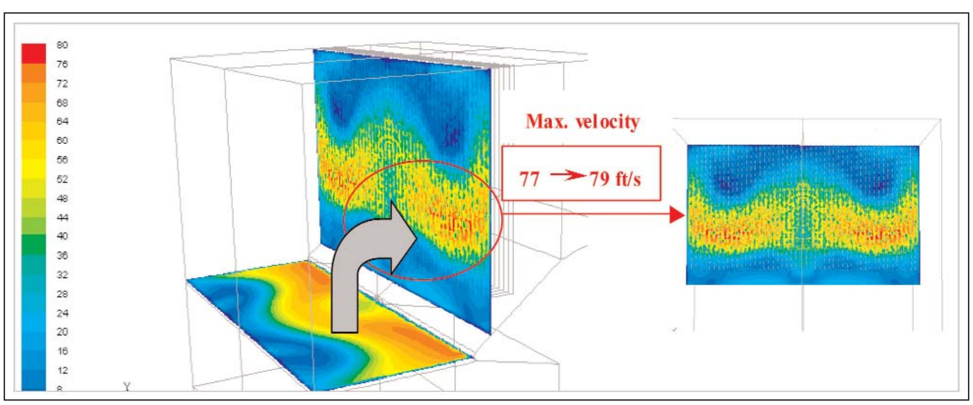

Figure 9. Calculated velocity magnitude (ft/s) in vertical and horizontal nose arch planes for the RPI-Solution Case 3 — Nose Arch to tip of Superheater — Furnace Model

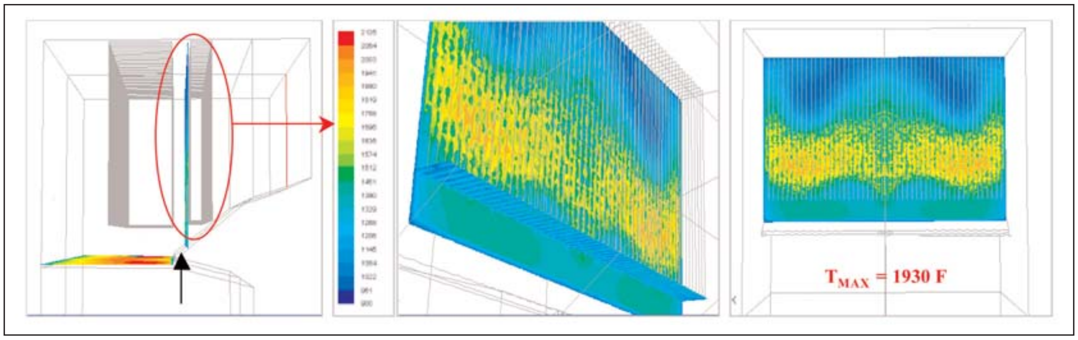

Figure 10. Calculated temperature distribution (^oF) in the plane before Superheater for the RPI-Solution Case 3 — Nose Arch to tip of Superheater — Furnace Model

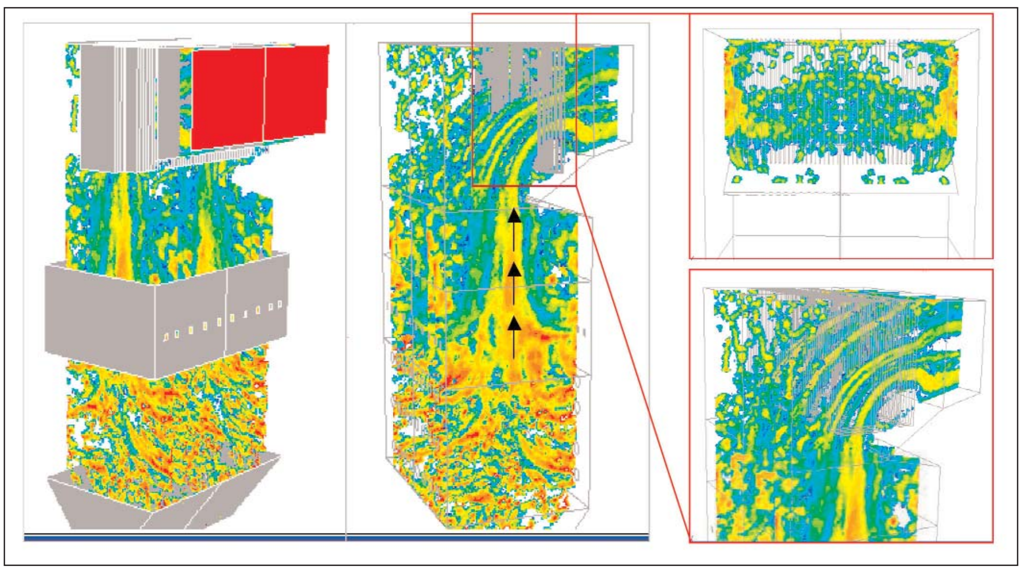

Figure 11. Typical Predicted coal fly ash concentration in the furnace and at the Superheater plane for the RPI — Solution Case 3 — Nose Arch to tip of Superheater — Furnace Model

The results for Case 3 — Nose Arch extended to the lower tip of radiant superheater, show the same location for the hot spots right before the superheater. The magnitude and extent of these hot spots is significantly diminished compared to the Base case. Since all other boundary conditions were kept the same in the three separate furnace models, the results are indicative of the impact due to changes in the nose arch configuration. It can be seen that the as the nose arch is extended to the tip of the radiant superheater, there is a significant drop in the maximum temperature in the plane right before the intermediate superheater. The maximum temperature in the plane before the superheater as well as the extent of the hot spot area are both significantly reduced compared to both the Base Case and Case 2.

SUMMARY

The results from this study indicate that the recommended RPI solution (i.e. Case 3 — Furnace nose arch extended to the tip of superheater) is beneficial in controlling and minimizing the impact on temperature, slagging and erosion in the upper furnace area and at the superheater. Figure 12 displays the CFD model configuration and the temperature profiles in the plane right before the intermediate superheater, also indicating the maximum temperature in that plane for each different case. Since all other boundary conditions were kept the same in the three separate furnace models, the results indicate the impact due to changes in the nose arch configuration. It can be seen that as the nose arch is extended to the tip of the superheater, there is a significant drop in the maximum temperature in the plane immediately before the intermediate superheater. Case 3, which represents the case where the nose arch is extended all the way to the tip of the superheater has the lowest maximum temperature and also lowest peak flue gas velocities and improved flue gas distributions. The improvements made in this case are expected to have a positive impact on reducing slagging and erosion for this particular installation.

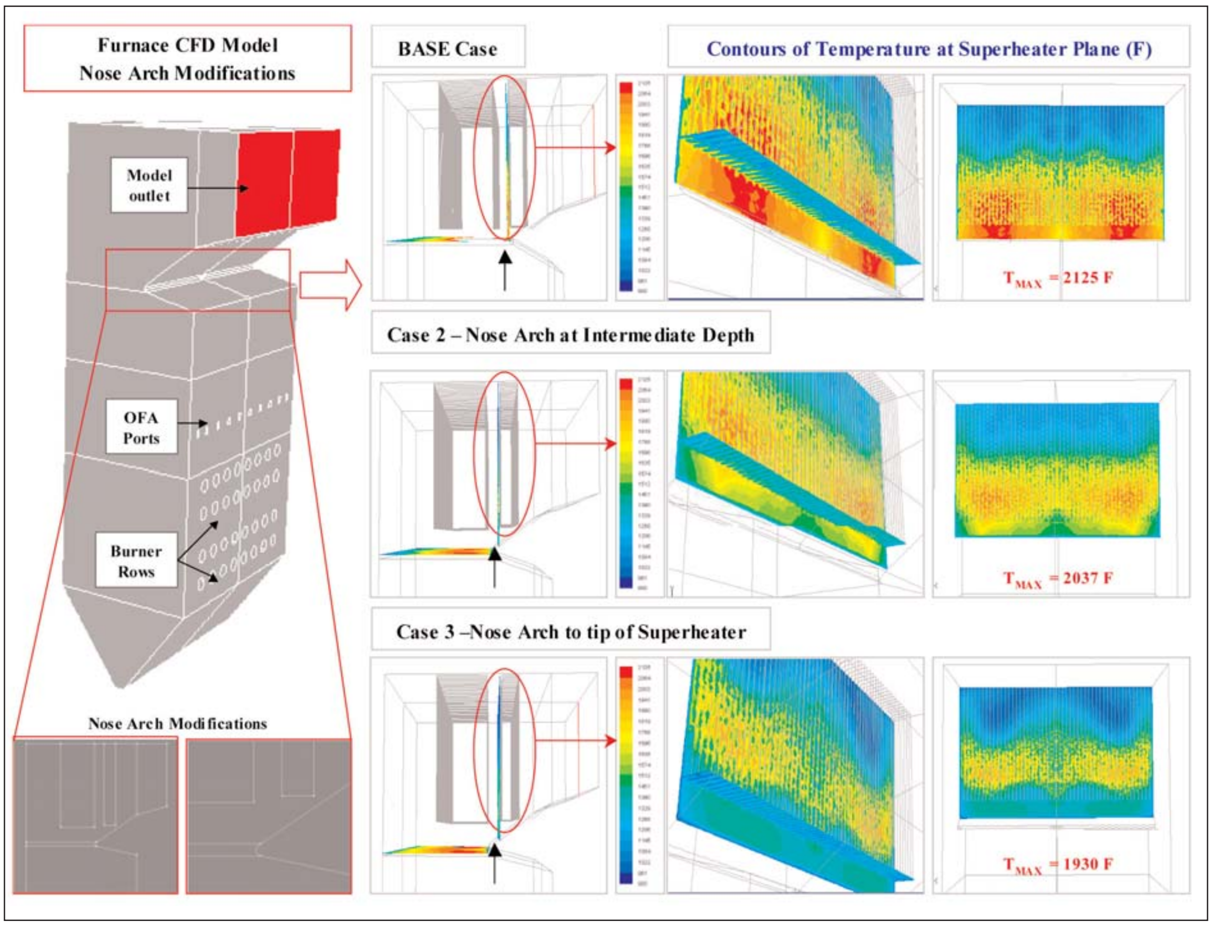

Figure 12. CFD Model Geometry, Temperature Contours (^{O}F), and Maximum Temperature (^{O}F) in the Plane right before the Intermediate Superheater for three separate Nose Arch Configurations

REFERENCES

1. Penterson, C.A., Hules, K.R., “Reducing NO_x Emissions to below 0.15 lb/106 Btu on a 600 MW Utility Boiler with Combustion Control Only.” Presented at DOE/EPRI/EPA/ A&WMA Combined Power Plant Air Pollutant Control “Mega” Symposium, 2003.

2. Hules, K.R., Penterson, C.A., “Computational Fluid Dynamics for Cost-Effective Solutions of Problems in Complex Burner and Combustion Systems,” Presented at Power-Gen International 2005, Las Vegas, NV, 2005.

3. Riley Power Inc. Internal Contract Report, August 27, 2007.

4. Zarnescu, V., Dorman, D., Courtemanche, B., Penterson, C., “NO_x Control Solutions and their Impact on CO Emissions for Coal-fired Utility Boilers.”, Presented at the 32nd Intl. Technical Conf. On Coal Utilization and Fuel Systems, Clearwater, FL, 2007.