TECHNICAL PUBLICATION

Computational Fluid Dynamics for Cost-Effective Solutions of Problems in Complex Burner and Combustion Systems

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ABSTRACT

In recent years, Riley Power Inc. (RPI), a Babcock Power Inc company, has used Computational Fluid Dynamics (CFD) modeling extensively to analyze and resolve performance issues experienced in complex combustion systems. The ability of CFD analysis to predict and understand the flow dynamics and combustion behavior of complex low NO_x furnace systems has become important to the industry to allow cost-effective and technically sound solutions to be offered for reducing emissions in new or existing electric power plant systems.

This paper presents several examples of how RPI has used CFD modeling to develop design upgrades and modifications for reducing emissions in a wide range of applications. These include a coal-fired turbo-furnace, a front wall-fired design with a unique firing pattern, a down-fired red liquor recovery furnace firing oil, natural gas, and waste streams from a paper pulping process, an oil/gas fired unit with extremely short furnace retention time, and component modifications to B&W coal-fired XCL burners. Results of the modeling will be discussed and compared to actual field performance achieved. The benefits of using CFD modeling to minimize start up and commissioning time by up to 50% will also be presented.

INTRODUCTION

CFD analysis is an important element in the design of low NO_x combustion systems for utility boilers. RPI has been using CFD modeling for over 20 years to assist in the design process. RPI performs both burner and furnace modeling using Fluent®, a commercially available, general purpose CFD code, to study mixing patterns and velocity profiles in burners as well as gas composition, temperature, and heat flux distributions throughout a furnace of a power boiler.

In the past four years RPI completed several low NO_x retrofit projects designed to reduce NO_x emissions or solve other combustion problems in a wide range of unique designs, firing configurations, and fuels burned. Table 1 gives a brief description of the projects discussed in this paper.

Table 1

Summary of Recent RPI Low NO_x Retrofit Projects Using CFD Modeling

Furnace Type	Fuel Type	Steam Flow KPPH	Description
Turbo®	PRB Coal	4,700	Install LNB & overfire air (OFA)
Wall-Fired	Bit Coal/Pet Coke	2 x 750	Reduce high CO & opacity
Down-Fired	NG, Oil, Waste Fuels	258	Install LNB & OFA
Wall-Fired	Oil, NG	870	Install OFA & upgraded burners
Wall-Fired	Bit Coal	1,800	Modify B&W XCL burner & install OFA

The unique and challenging design requirements for these low NO_x applications could be analyzed and addressed properly only using CFD modeling. Once the modeling demonstrated a solution, the actual implementation in the field was straightforward and efficient, greatly reducing commissioning time for the restarts.

Low NO_x Upgrades and Combustion Enhancement of a Large Coal-Fired Turbo-Furnace

The Riley Turbo® furnace is a unique utility furnace design as shown in Figure 1. The Turbo® furnace is very wide but relatively shallow in depth. There is a single row of closely spaced, typically non-swirl planar-type burners, opposed-fired on front and rear walls. The burners fire slightly downward due to their location on the underside of a pinched waist wall. Often there are OFA ports above each burner and possibly wing OFA ports between outside burners and the sidewalls as well as underfire air ports in the furnace hopper. This configuration exaggerates the differences between the lower furnace below the burner row and the upper furnace. The Turbo® design was developed in the 1960's to burn low volatile fuels and tends to be a high heat release unit with higher NO_x output than newer, lower heat release furnaces such as wall-fired units.

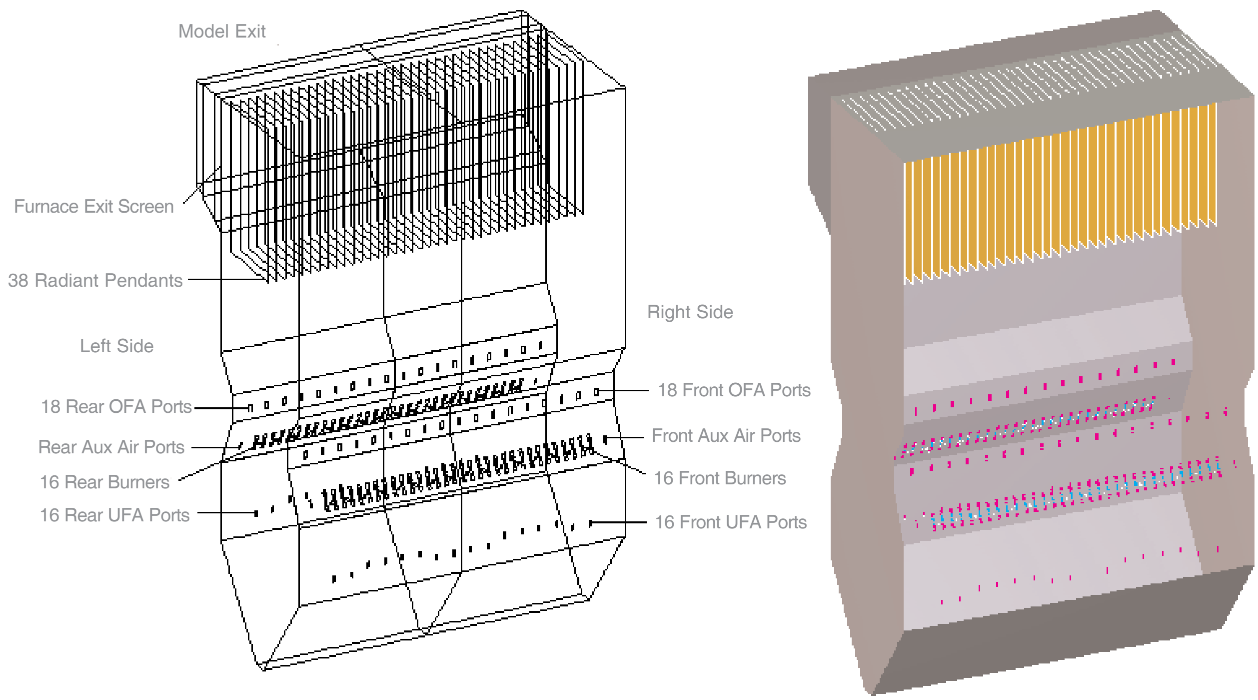

Figure 1. 600 MW Riley Turbo® Furnace Geometry.

The two 600 MW units in Figure 1 initially operated with NO_x emissions of 0.35 lb/MBtu while firing PRB coal with a hot upper furnace limiting load to keep radiant pendant tube metal temperatures under control. Recently RPI completed a combustion upgrade project to reduce the NO_x from 0.35 to 0.20 lb/MBtu. Although the shakedown trials after restart resulted in NO_x emissions slightly above the target of 0.20 lb/MBtu, unit CO emissions were unacceptable, OFA could not be increased any more to reduce NO_x, and radiant pendant tube metal temperatures remained troublesome.

Flow modeling isolated an internal constriction at the OFA takeoffs from the windbox caused by structural steel. Perforations in the non-stressed webs of the H-columns relieved this problem.

RPI used CFD furnace modeling to help solve most of the other issues. Figure 2 compares Base Case CFD model results and in-furnace measurements of CO emissions. The results demonstrated that furnace CFD models were realistic representations of actual furnace behavior. They also suggested an approach to controlling CO emissions with a slot-type boundary air system above the OFA elevation. This approach takes advantage of the membrane construction of the furnace water walls in these units.

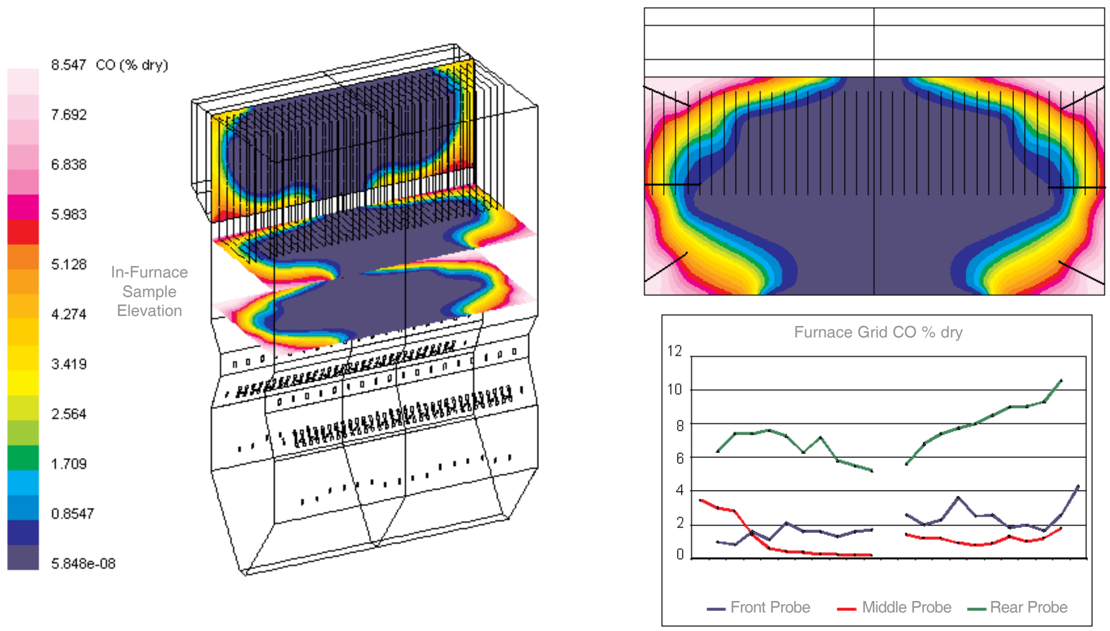

Figure 2. Comparison of In-Furnace CO Measurements and CFD Model Results.

Additional CFD furnace combustion modeling investigated the effects of slot boundary air configurations and amounts, a new coal nozzle design, burner setup, and OFA and underfire air (UFA) amounts on furnace thermal performance and CO emissions. The burners are complex with four online adjustments for each of the 32 burners plus online OFA and UFA adjustments. All of these factors affect furnace performance noticeably. Field testing and furnace tuning can be quite difficult, lengthy and expensive. Figure 3 shows several types of burner nozzle tilt patterns that were potentially useful for controlling the NO_x, CO, and thermal behavior of the units. Furnace simulations of these burner nozzle tilt patterns used the model with a slot boundary air system shown in Figure 4. As noted above, the CO pattern from the in-furnace field testing and Base Case model results shown in Figure 2 indicated this low massflow boundary air design approach could be quite good at controlling CO emissions, relatively easy and quick to install, require no controls, and very cost-effective.

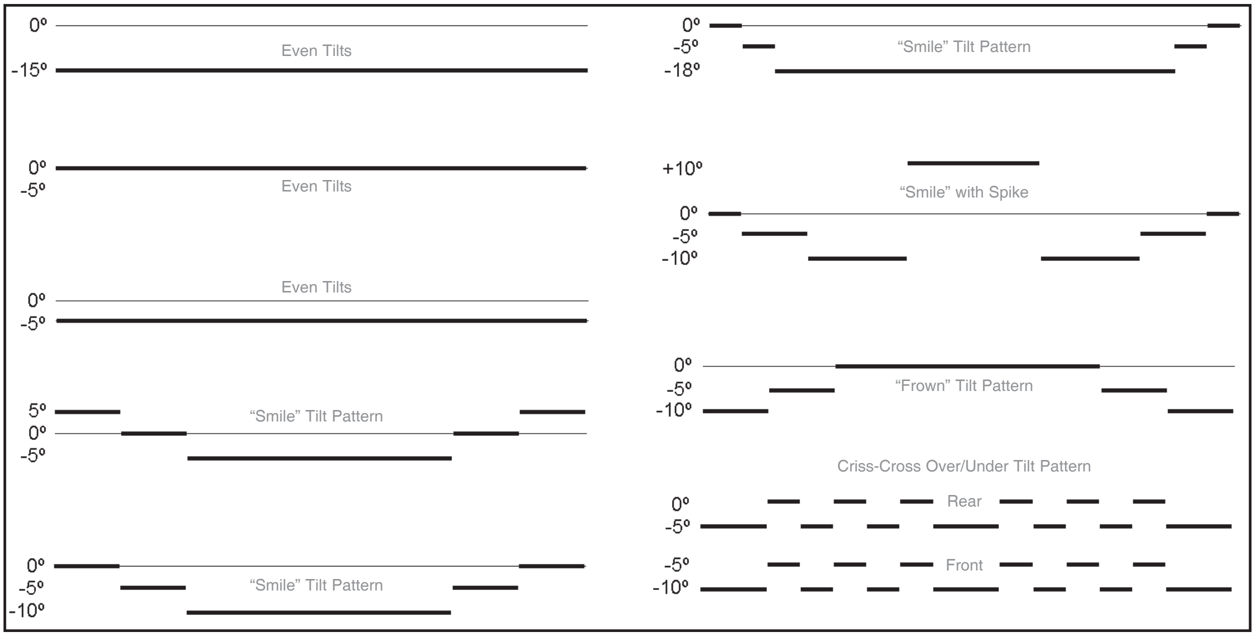

Figure 3. Burner Nozzle Tilt Patterns Studied with CFD Modeling.

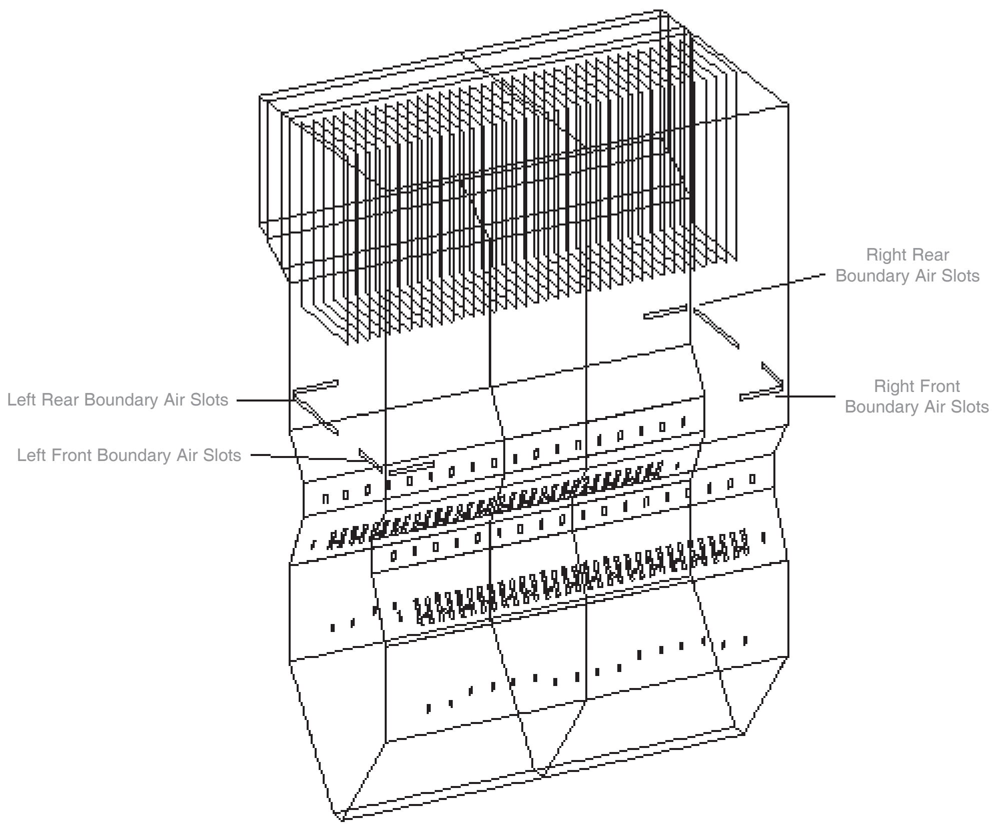

Figure 4. Modified 600 MW Furnace CFD Model Showing Slot-Fed Boundary Air System.

Figures 5 and 6 show CFD model results of furnace CO distributions and a surface of 2,700 °F, respectively, for the Base Case and one of the two final nozzle tilt patterns selected from the modeling. Thus the figures show "before" (left) and "after" (right) patterns of furnace behavior.

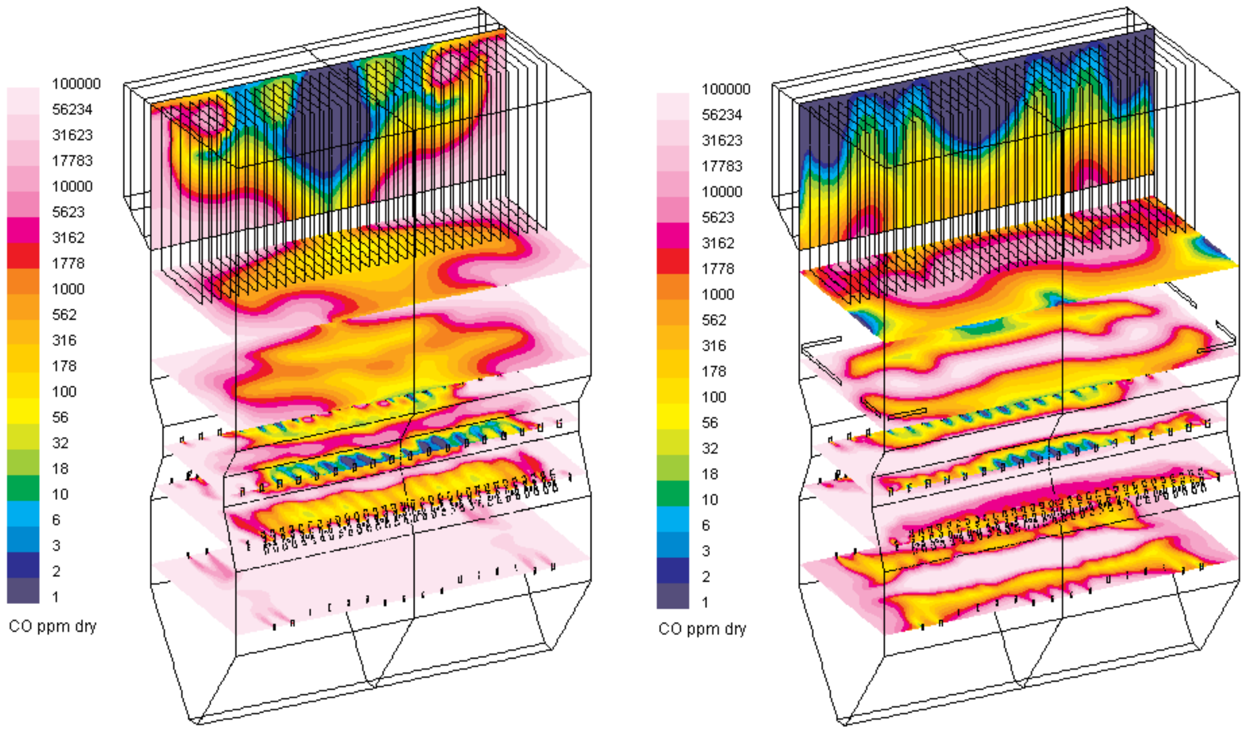

Figure 5. Furnace CO Distributions (% Dry, Log Scale) for the Base Case (Left) and a Selected Final Modified Furnace Configuration (Right).

Figure 5 uses a log scale to show distribution details at both the ppm range and the percent range. The "before" image shows very high CO levels (several percent dry) in the Base Case throughout the upper and lower furnace, and especially in the corners and along the sidewalls. The "after" image shows how the slot boundary air burns out almost all of the corner and sidewall CO, while OFA turbulence burns out the CO in the center of the upper furnace. The figure also indicates the new nozzle design delivers more O2 to the lower furnace resulting in reduced CO in the hopper region as well.

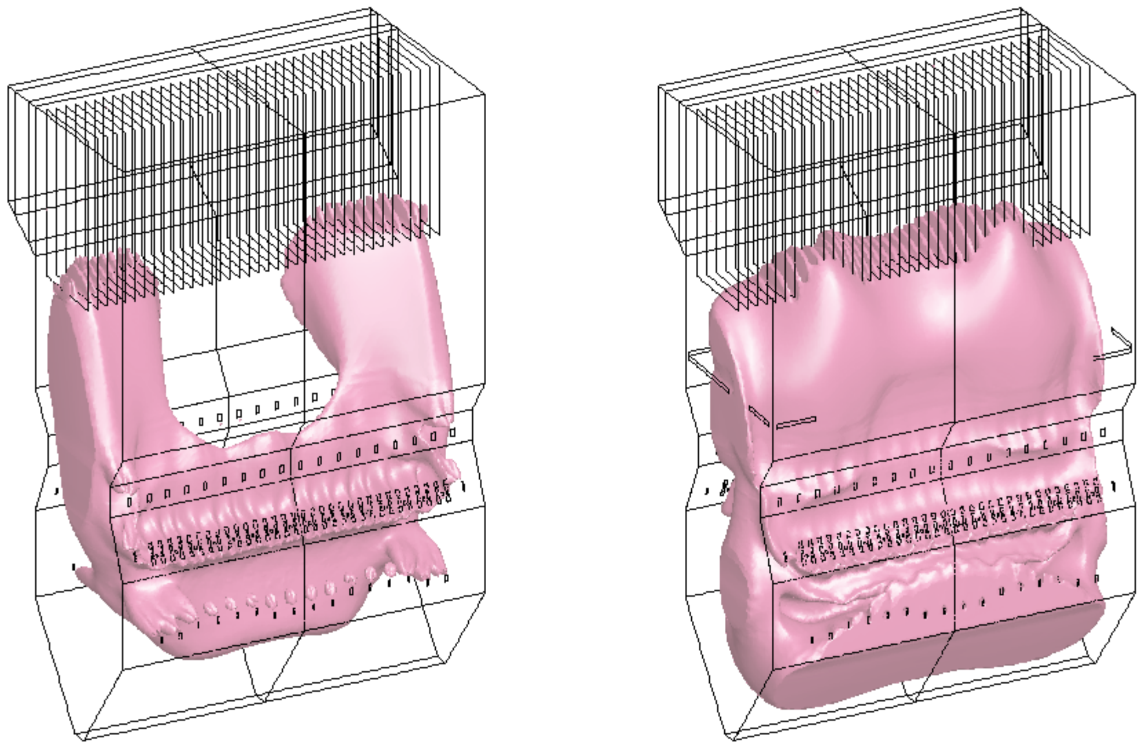

Figure 6. Surface of Constant 2,700 °F Temperature for the Base Case (Left) and a Selected Final Modified Configuration (Right).

The surfaces of constant temperature in Figure 6 enclose gas temperatures above 2,700 °F, while outside the surfaces the gas temperature is less than 2,700 °F. Although 2,700 °F is an arbitrary choice, the images highlight how the new nozzles with an advantageous tilt pattern, coupled with modulation of the flows from each OFA and UFA port, changes lower and upper furnace temperature fields. In particular, the modifications increase lower furnace temperatures and heat pickup to compensate partially for the larger OFA amount, and therefore delayed upper furnace combustion, needed in the "after" case to reach the required NO_x emissions level. Gas temperatures in the upper furnace were significantly more uniform with the final equipment modifications.

Using results of and recommendations from all the flow modeling and testing, RPI achieved the following significant results:

- Reduced NO_x emissions 43% from 0.35 to 0.20 lb/MBtu.
- Reduced CO emissions from >2,000 to < 300 ppm.
- Reduced upper furnace tube metal temperatures.
- Recovered 5% boiler derate produced by excessive emissions and high tube metal temperature problems.
- Eliminated heavy slag buildup previously experienced in the upper furnace.
- Improved overall unit handling and operation.

Low NO_x Upgrades and Combustion Improvement of a Front Wall-Fired Design

Even the more familiar front wall-fired utility furnaces can display problems as low NO_x upgrades are installed. For example, two 150 MW furnaces depicted in Figure 7 have eight swirl-stabilized burners in an unusual placement pattern, namely a 3-row by 3-column layout with the bottom middle burner missing. A recent RPI burner upgrade project reduced NO_x significantly without an increase in loss on ignition (LOI) values. However, the units remained derated 10% to comply with opacity and CO limits.

A follow-on CFD furnace-modeling project determined the source of combustion imbalances in the furnaces that were thought to give rise to the opacity and CO problems, and high radiant metal temperatures on the unit left sides, a problem for operations for many years. CFD furnace model results showed the effects of imbalances of secondary air (SA) supply left/right, coal flow left/right, coal ropes within the burners, higher/lower coal nozzle exit velocity, and burner air and coal swirl direction patterns on furnace exit temperature, O_2, and CO distributions as well as radiant pendant absorption distributions.

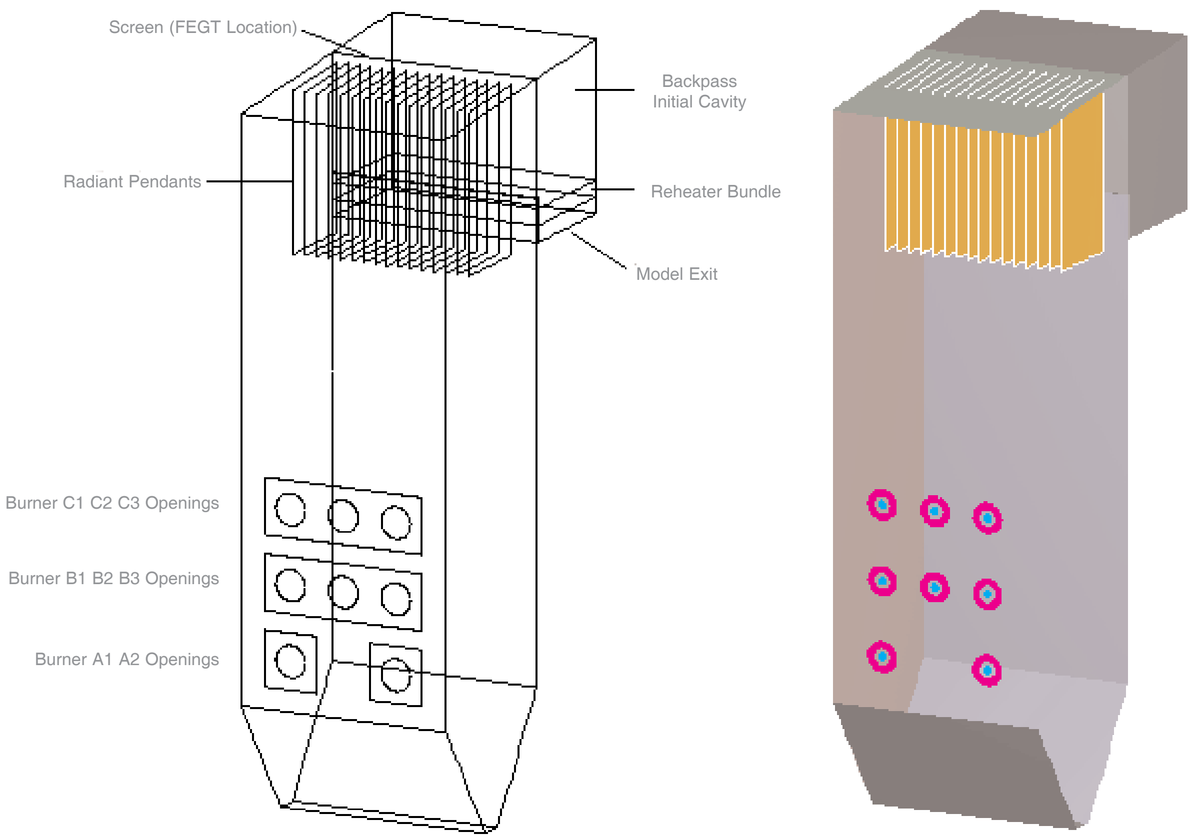

Figure 7. 150 MW Front Wall-Fired Utility Furnace Geometry.

Figures 8a and 8b display summary results of CO and temperature distribution, respectively, for these inlet imbalance conditions. The figures divide the distributions into left, center, and right furnace zones consistent with the burner columns and field observations. Figure 9 displays the computed effects of the imbalances on heat absorption for each radiant pendant from left to right across the unit. These figures indicate almost no effect from large left-right imbalances of SA or coal flow (+/- 20%) and not much effect from nozzle velocity except in the pendant absorption, becoming less even with nozzle velocity reductions. The figures indicate the most important parameter affecting overall left-right furnace balance is burner swirl direction in the left burner column, specifically burners A1 and B1 in this installation.

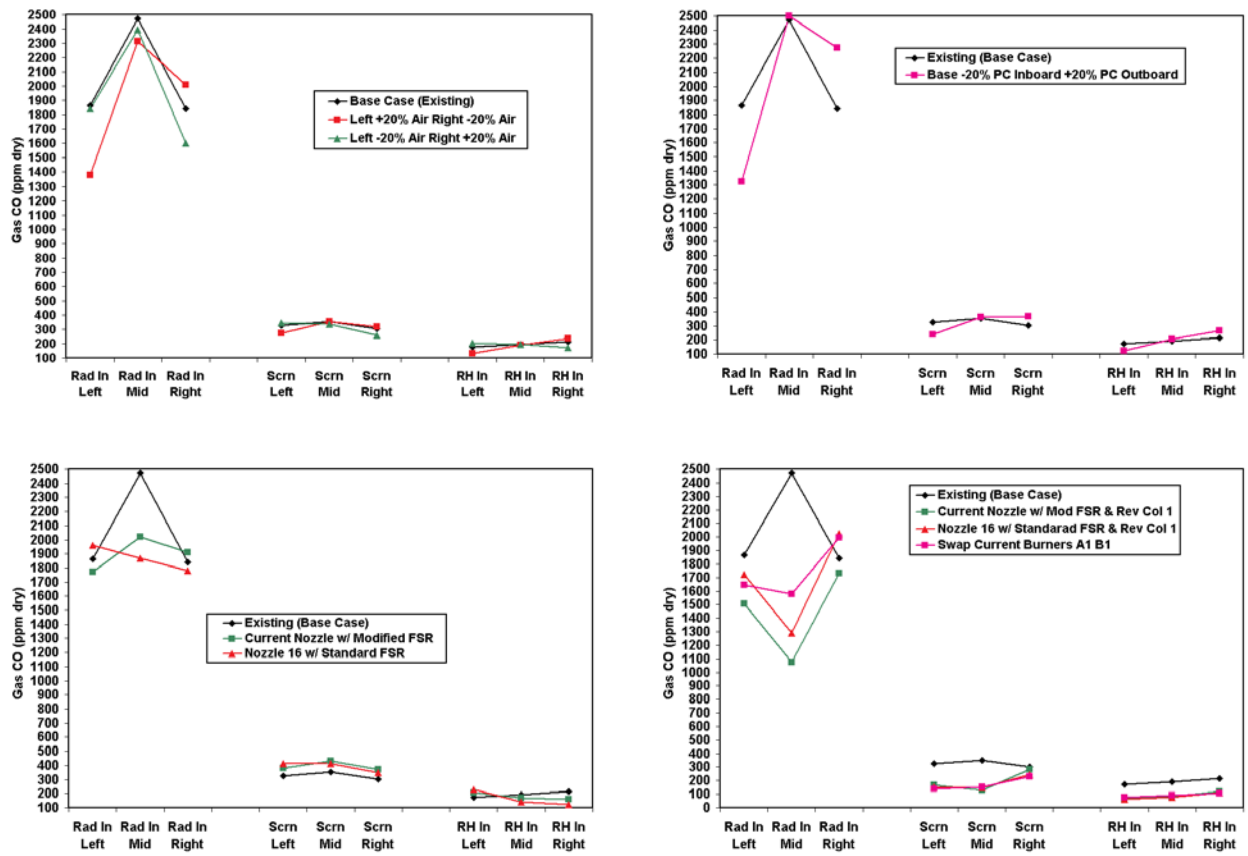

Figure 8a. Effects of Airflow and Fuel Flow Imbalances, Nozzle Velocity, and Burner Swirl Rotation on Furnace Left-to-Right CO Imbalance.

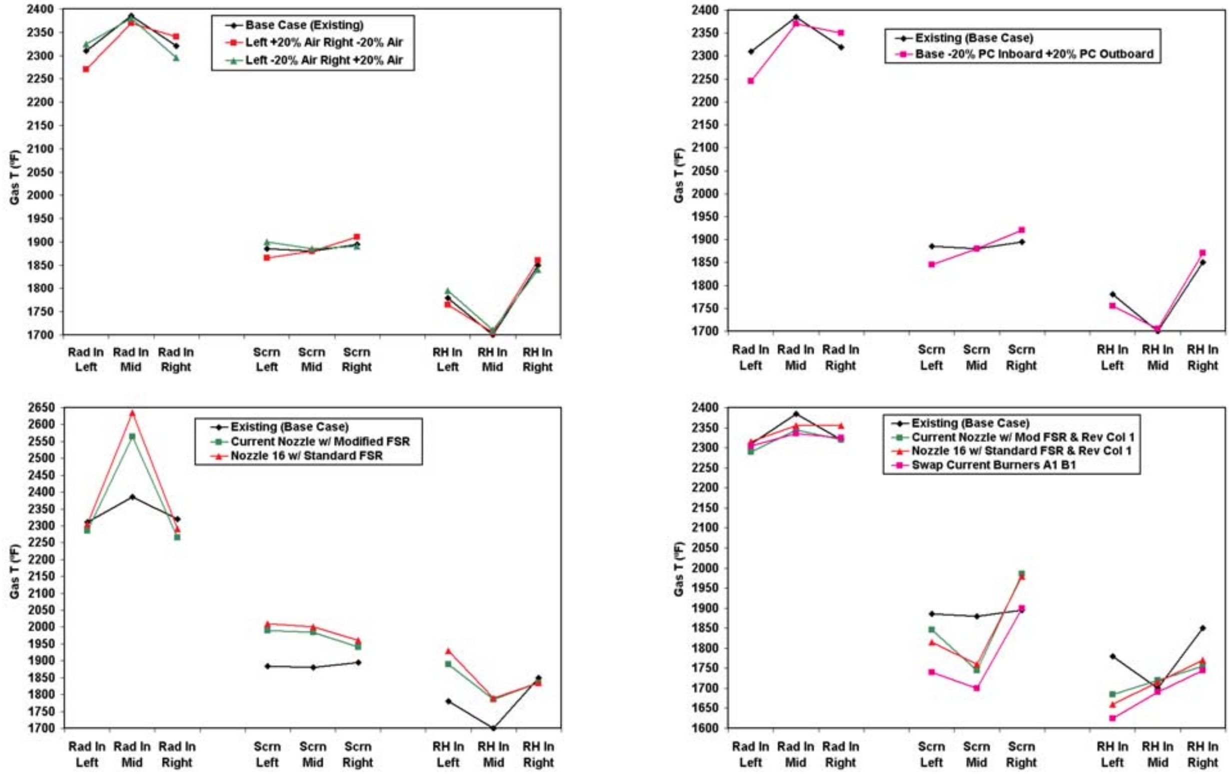

Figure 8b. Effects of Airflow and Fuel Flow Imbalances, Nozzle Velocity, and Burner Swirl Rotation on Furnace Left-to-Right Gas Temperature Imbalance.

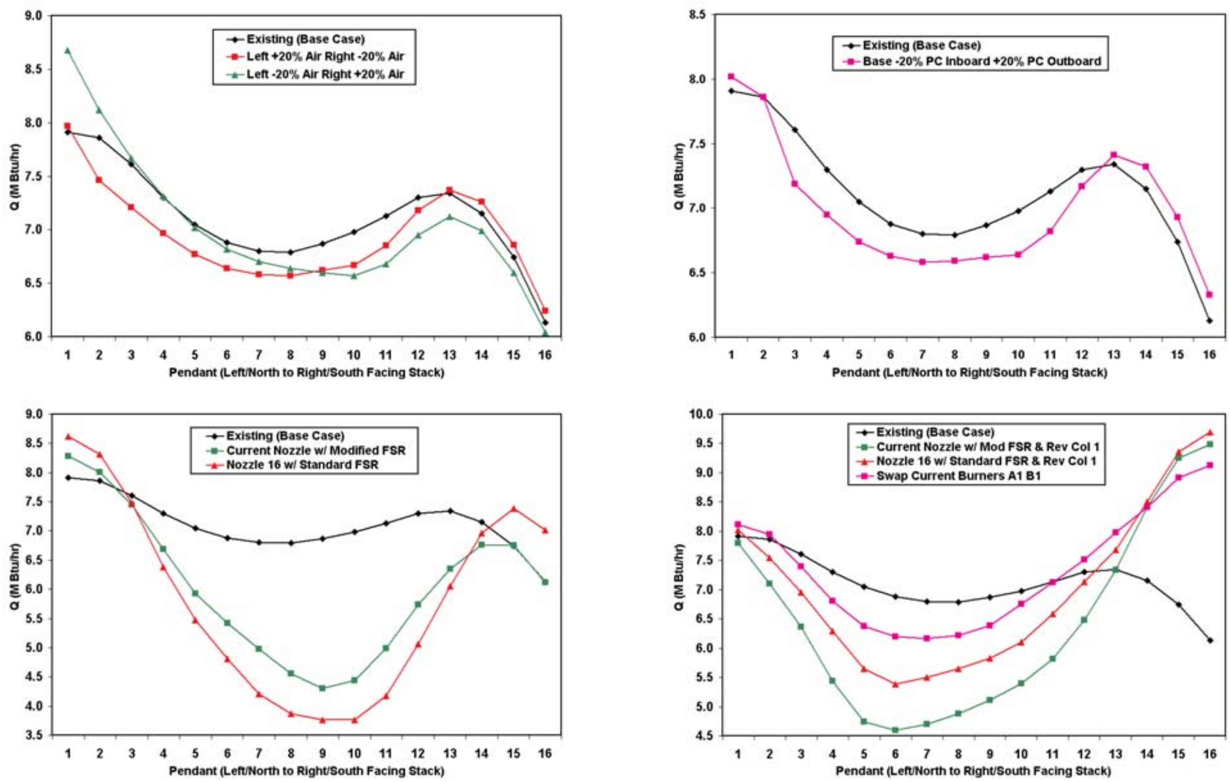

Figure 9. Effects of Airflow and Fuel Flow Imbalances, Nozzle Velocity, and Burner Swirl Rotation on Radiant Pendant Left-to-Right Heat Absorption.

Figures 10 and 11 display coal particle traces (colored by burner of origin) for the existing furnace and the recommended burner swirl rotation pattern. These figures show the traces as if looking through all four walls of the unit in succession. Figure 10 indicates that in the original configuration, there is significant pulverized coal transfer from the lower right burner through the hopper to the unit left side, as shown by the light blue traces dominating the hopper in all four views. This transfer agrees exactly with field observations of gas and particulate motion in the hopper. Figure 11 shows that in the recommended burner swirl configuration there is a complete separation of the hopper into left burner and right burner zones with essentially no transfer from one to the other. Additionally, the figures show a dramatic change in the upper furnace left side flow pattern by the interchange of the red and green burner traces. Upper furnace coal particle traces appear to mix more thoroughly with the revised burner swirl pattern.

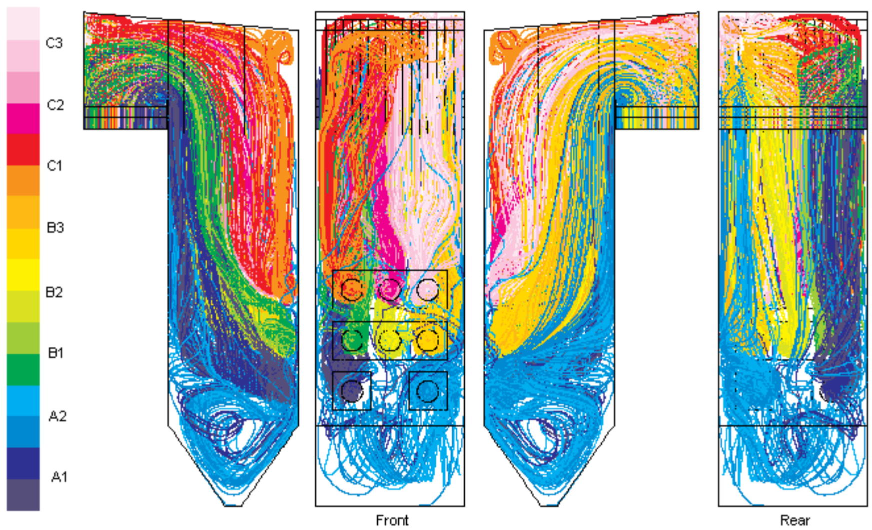

Figure 10. Fine Coal Particle Traces for Original Burner Swirl Configuration.

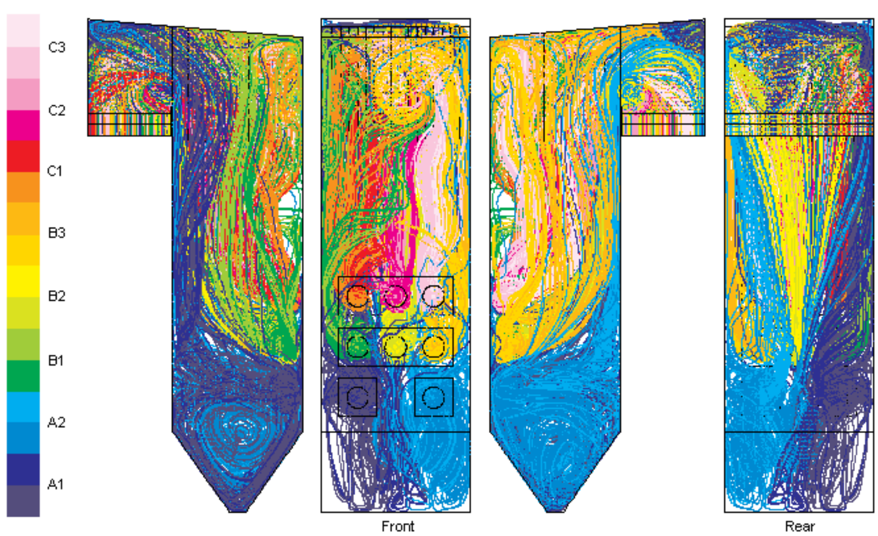

Figure 11. Fine Coal Particle Traces for Recommended Burner Swirl Configuration.

For these units, CFD furnace modeling demonstrated a solution via a simple swap of two burners (A1 and B1), to change the overall swirl pattern with the following field post-retrofit results:

* Reduced opacity and CO emissions to acceptable levels.

* Recovered the 10% derate.

* No new or additional burner hardware was needed.

* Outage time was very short, and labor costs were minimal.

Low NO_x Reconfiguration of a Down-Fired Red Liquor Recovery Furnace

More unusual furnace types firing exotic and dangerous fuels often come with demanding performance requirements. The down-fired red liquor recovery boiler shown in Figure 12 was converted to a power boiler but still fires different process waste off-gas streams: a large, fixed amount of low-Btu dilute non-condensable gas (DNCG) containing significant excess O_2, and an explosive medium-Btu stripper off gas (SOG). From a heat input perspective the main fuels are oil and natural gas. Pre-project NO_x emissions at 80% load were 0.60 lb/MBtu firing Number 6 oil and 0.44 lb/MBtu firing gas. Guarantee NO_x limits at 100% load were 0.25 lb/MBtu firing oil and 0.22 lb/MBtu firing gas. At 45.5% load the guarantee limits rose to 0.39 lb/MBtu and 0.34 lb/MBtu respectively. At all loads the guarantee limits for CO and VOC (methane equivalent) were 0.15 lb/MBtu and 0.0064 lb/MBtu respectively.

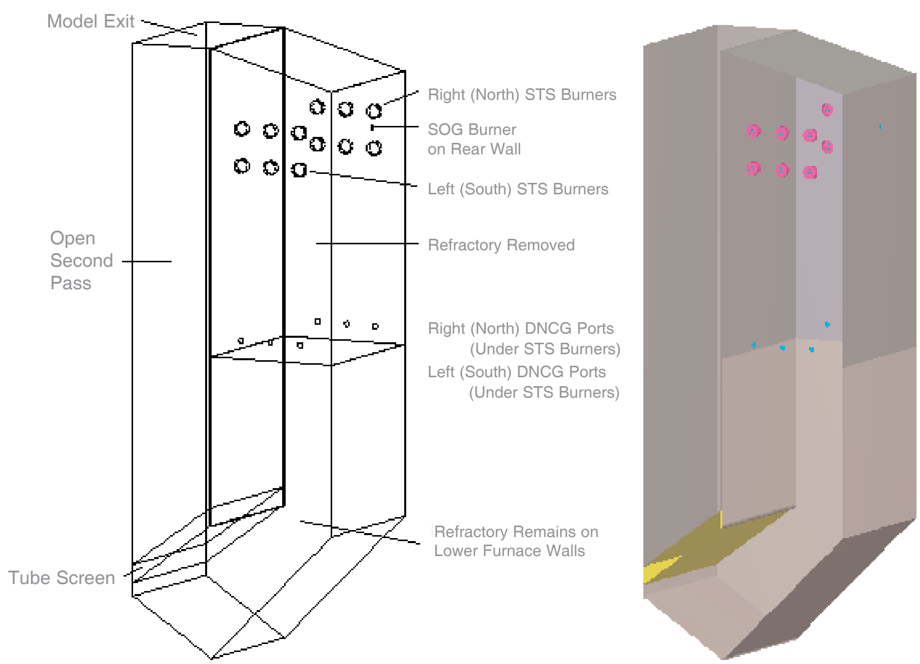

Figure 12. Reconfigured Recovery Furnace Geometry.

In order to achieve the large reductions in NO_x emissions while producing very low CO output, RPI proposed an innovative approach. The original 16 small gas and oil burners (6 on each sidewall and 4 on the rear wall) would be replaced with 12 new, larger RPI low NO_x STS gas and oil burners on the sidewalls only. The DNCG was relocated down 22.5 feet, and the SOG burner was moved up 9 feet between the two STS burner rows. The new locations followed a design approach of firing the gas and oil burners (the main furnace heat input source) in the form of two blanket layers to trap and burn out the dangerous SOG feed stream. Furnace turndown to 29% load required the lower burner row to maintain an adequate high temperature zone through which the SOG must mix and burn out. The DNCG, with its large mass flow and high excess O_2 content, became the OFA to reduce burner zone stoichiometry significantly. In the down-fired geometry, the DNCG OFA ports are conceptually over the burner zone, i.e. downstream, but are physically below the burners. The design furnace residence time from lower STS burners to the

DNCG ports was 0.7 seconds (i.e. longer than typical burner-to-OFA separations) to burn out the SOG at elevated temperature before addition of the very cool OFA (DNCG entered at room temperatures). Residence time from OFA to furnace exit was almost 2 seconds to ensure burnout of the main gas/oil fuel and DNCG in this low heat release unit.

In this project CFD furnace modeling had several important objectives. The most important goal was to determine whether an opposed or interleaved DNCG OFA port layout produced better mixing and burnout of the oil/gas main fuel and DNCG from 100% load to as low as 29% load. Both CO and VOC (methane equivalent) emissions were important here. The modeling also had to demonstrate the proposed system would provide adequate time and temperature for treating the explosive SOG even with only the lower burner row in service.

These CFD models were computationally large and slow because it was necessary to track separately the CO production and destruction from the gas or oil, DNCG, and SOG fuels. In other words, the models calculated three types of CO rather than one. VOC emissions did not require this detail, simply the overall amounts.

Ultimately, the furnace models indicated the opposed DNCG port layout was more advantageous than the interleaved layout, especially at lower loads. The final design features the opposed lay-out. Figures 13 through 16 show CFD model results for the opposed DNCG configuration at 100% load and 45% load as left and right images in each group. In the 45% load cases all 12 STS burners were turned down and in service.

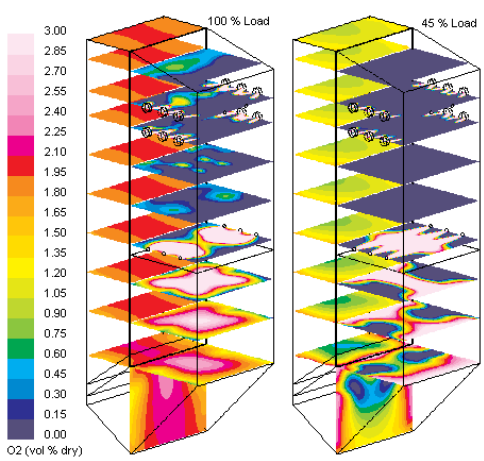

Figure 13. Full and Low Load Furnace Model O_2 Distributions.

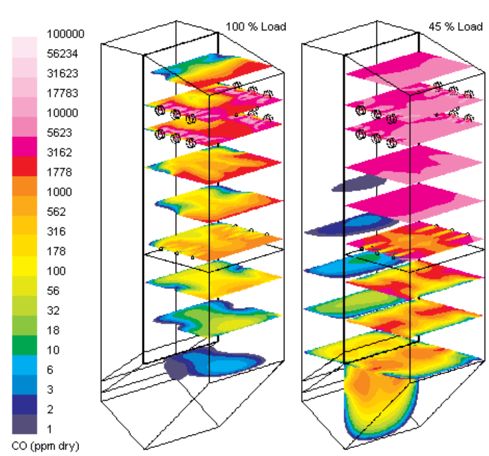

Figure 14. Full and Low Load Furnace Model CO Distributions.

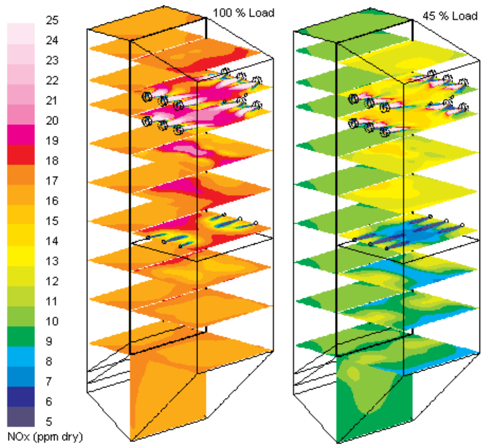

Figure 15. Full and Low Load Furnace Model NO_x Distributions.

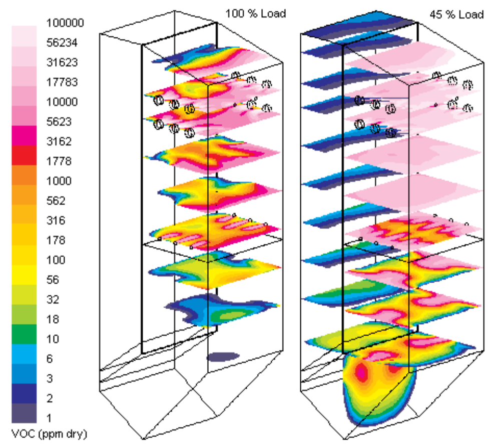

Figure 16. Full and Low Load Furnace Model VOC Distributions.

Figure 13 highlights the excellent DNCG OFA penetration and mixing at high and low load. Part of the selection of opposed rather than interleaved DNCG port layout also addressed the fact that the DNCG flow remained essentially constant over the load range, so that good mixing with the STS burner gases was essential for DNCG burnout. The figure also highlights the very low burner zone stoichiometry created by the large O_2 content in the DNCG flow.

Figure 14 shows the composite, or total, CO distributions. About 95% of the CO in Figure 14 for either load originated with the STS burners. The figure indicates final CO burnout to be less than 1 ppm dry for both loads, which the authors believed was too good to be true. However, acceptance testing recorded negligible CO from 100% to 45% load for both oil and gas firing.

Figure 15 displays CFD-computed NO_x distributions for the two loads using maximum NO_x formation rate parameters. The model exit values are less than the acceptance test results.

Figure 16 shows the computed VOC (methane equivalent) distributions for the two loads. Once again, the authors believed the results were too good, but acceptance testing recorded negligible VOC emissions over the load range for both oil and gas firing.

This innovative combustion system design produced the following notable results based on actual post-retrofit testing:

* Installed system reduced NO_x emissions at 100% load by 63% firing oil and 55% firing gas, and up to 75% at low loads. At full load final NO_x emissions were 0.22 / 0.20 lb/MBtu for oil/gas firing compared to guarantees of 0.25 / 0.22 lb/MBtu respectively. At 45% load NOx emissions were 0.28 lb/MBtu firing oil and an extremely low 0.07 lb/MBtu firing gas.

* Negligible CO emissions recorded at all loads compared to guarantee requirements of 0.15 lb/MBtu.

* Negligible VOC emissions recorded at all loads compared to guarantee requirements of 0.0064 lb/MBtu.

Low NO_x Upgrade of an Oil/Gas-Fired Unit with Extremely Short Furnace Retention Time

Often, older utility furnace designs are not at all conducive to meeting current goals for NO_x and CO emissions. For example, the Number 2 oil/gas fired furnace shown in Figure 17 is a high heat release unit (350 kBtu/hr ft2) with a relatively high burner placement. There is only a small distance above the burners for an OFA system installation to reduce NO_x emissions from a pre-retrofit value of 0.40 lb/MBtu to a guarantee value of 0.10 lb/MBtu. Furnace residence time from the upper burners to the exit was 0.56 seconds and pre-retrofit CO emissions were 114 ppm at 23% excess air with a guarantee requirement of less than 400 ppm after the retrofit.

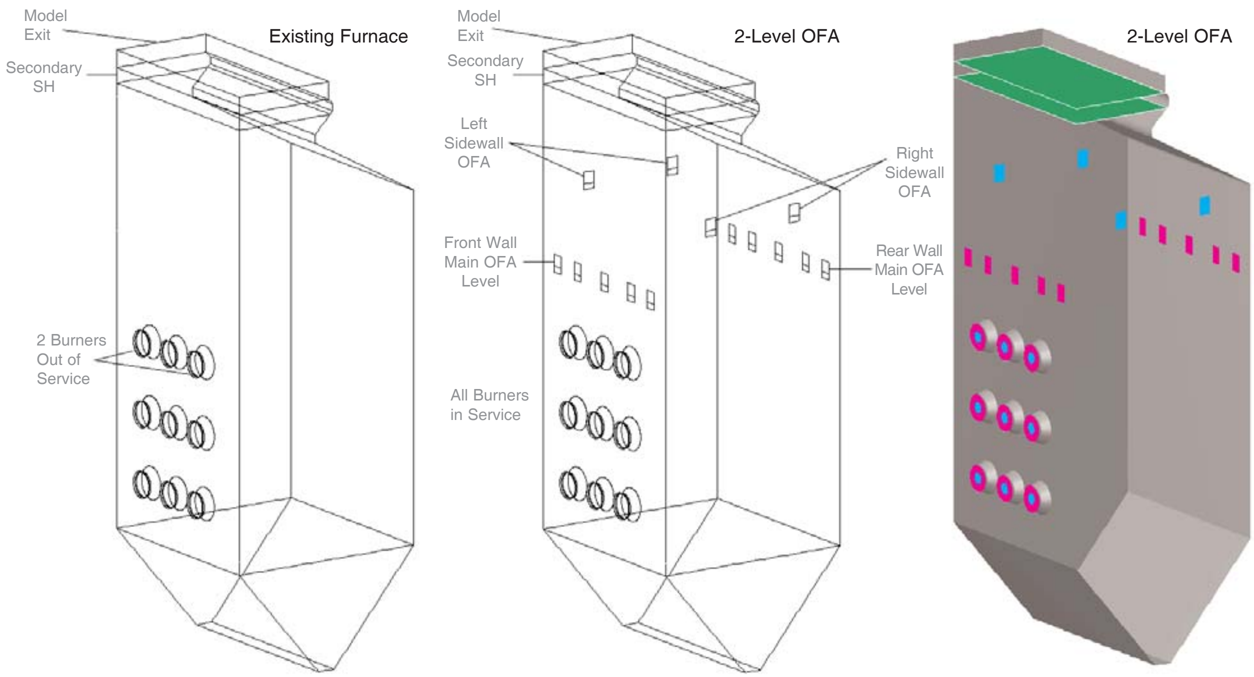

Figure 17. 117 MW Oil/Gas Fired Utility Furnace Geometry, Pre-Retrofit and Post-Retrofit.

To reach these low required NO_x emissions levels, RPI implemented an innovative approach. This included replacing the existing hopper flue gas recirculation (FGR) system, used for steam temperature control, with a windbox FGR system including fan sized for maximum 25% FGR at full load. Additionally the RPI combustion system design upgraded the existing unused OFA system of three ports on the rear wall to an aggressive two-level, four-wall, 14 port OFA system designed for 37% OFA with a burner zone stoichiometry of 0.7 to 0.75. The RPI approach also reused the existing B&W circular burners with gas canes to reduce project costs, i.e. no pressure part modifications. Figure 17 shows the finalized RPI furnace design to obtain the desired NO_x reduction and also control CO emissions to very low levels, even with a furnace residence time from the OFA to the exit of only 0.28 seconds.

A CFD furnace modeling task was crucial for RPI to design properly the two-level, four-wall OFA system to determine the number and placement of OFA ports, especially for reduced load and the benefit of Wing OFA ports outboard of the main OFA above the burners. The CFD task included two furnace models: a pre-retrofit "Existing" case, representative of existing operations, shown on the left side of Figure 17, and a post-retrofit "2-Level OFA" case shown on the right in the finalized configuration. The post-retrofit model also contained several other alternate OFA port locations, not shown, which ultimately were not beneficial for the required furnace NO_x and CO control. Figure 17 also shows that the finalized 2-Level OFA geometry includes Wing OFA ports on the front and rear wall in order to provide the required CO control.

Figures 18 to 21 show computed distributions of temperature, O_2, NO_x, and CO respectively for the pre-retrofit furnace on the left and the post-retrofit furnace on the right in each figure for comparison of the changes brought about by the retrofit process.

Figure 18 clearly shows how the FGR and OFA staging contribute to greatly reduced furnace temperatures from the hopper to the nose arch. Flame temperature reduction, such as indicated in Figure 18, is the chemical basis for NO_x reduction in gas flames in particular. The figure also indicates that steam temperature control will not be compromised by the FGR system relocation or the addition of OFA in this combustion system modification.

Figure 19 shows that the modifications do not alter the low O_2 environment in the lower furnace, which results from low excess air operation (6% to 10%). The figure also clearly shows how the sidewall OFA assists the Wing OFA to improve the upper furnace O_2 distribution as well as increase upper furnace mixing to improve final burnout. Although the O_2 distribution above the arch in the post-retrofit model is not even, it is significantly better than in the pre-retrofit case.

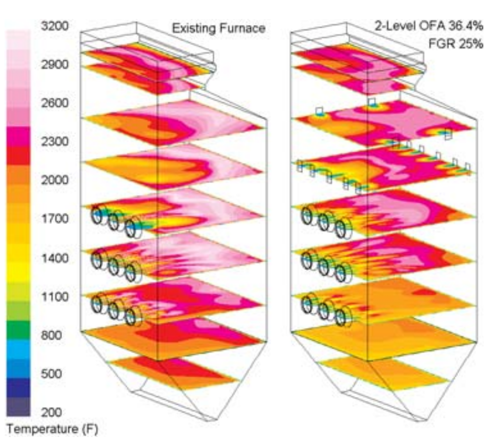

Figure 18. Pre-Retrofit and Post-Retrofit Furnace Model Temperature Distributions.

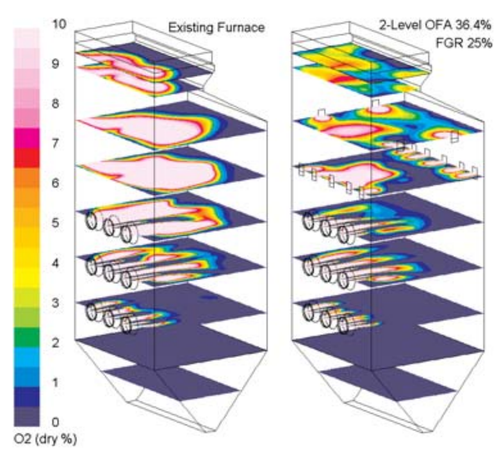

Figure 19. Pre-Retrofit and Post-Retrofit Furnace Model O_2 Distributions.

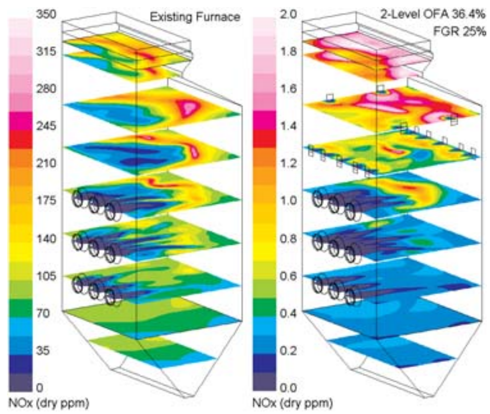

Figure 20. Pre-Retrofit and Post-Retrofit Furnace Model NO_x Distributions.

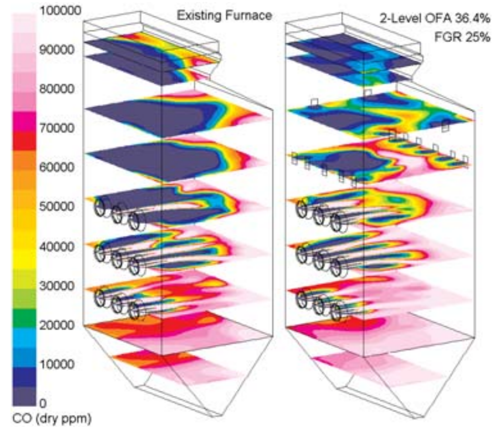

Figure 21. Pre-Retrofit and Post-Retrofit Furnace Model CO Distributions.

Figure 20 displays the computed NO_x distributions in the two cases, but employs two different scales because the results are dramatically different. The furnace exit NO_x results in Figure 20 for the pre-retrofit model agree closely with the pre-retrofit field value of 0.40 lb/MBtu, but in the post-retrofit case the results in the figure are lower than the acceptance test results.

Figure 21 highlights several important features about furnace CO emissions. In both cases the lower furnace has elevated CO as the lower burner flows move around through the hoppers. In the pre-retrofit case in the left image, most of the furnace exit contains almost no CO. All the unit's CO emissions leave the furnace at the rear corners. Many furnaces demonstrate this same behavior of excess CO moving out through the corners. The figure also shows clearly that the 2-level OFA system with Wing ports controls the rear corners and burns out the CO quite well.

This aggressive combustion system design achieved several significant results during post-retrofit testing:

* NO_x reduction of 81% from 0.40 lb/MBtu to 0.075 lb/MBtu at full load using existing burners, FGR, and an advanced OFA system in a furnace with minimal residence time. This result compares favorably to a guarantee requirement of 0.10 lb/MBtu.

* CO reduction at full load of 64% from 114 ppm at 23% excess air to 41 ppm at 14% excess air using FGR, existing burners, and an advanced OFA system in a furnace with minimal residence time. This result compares well to a guarantee requirement of less than 400 ppm.

* Reused existing burners, no resizing of burner throats to account for staged firing, and there-fore no expensive pressure part modifications.

* OFA system installation proceeded without difficulty.

* Restart was very quick, and the unit reached full load operation in full compliance without any burner adjustments.

Low NO_x Upgrade Via Component Modifications to B&W Coal-Fired XCL Burners

Sometimes a partial burner upgrade and OFA system installation is the most cost-effective approach for NO_x reduction in a utility furnace. In 2003 RPI executed a low NO_x B&W XCL burner upgrade using RPI low NO_x CCV® components and installed a new OFA system in a 270 MW wall-fired furnace burning an eastern bituminous coal. Pre-retrofit furnace NO_x emissions with the unstaged XCL burners were a little less than 0.45 lb/MBtu, but CO emissions were higher than desired, flame attachment was poor, and superheat and reheat spray flows were excessive during full load operation. The goals for the 2003 upgrade were NO_x emissions less than 0.32 lb/MBtu over the load range and CO emissions less than 150 ppm.

RPI offered four technically sound approaches for reducing emissions of this unit. 1) A separated OFA system. 2) New CCV® dual air zone (DAZ) burners. 3) New CCV® DAZ burners plus the OFA system. 4) An innovative approach coupling the OFA system with RPI low NO_x CCV® components upgrade of the existing XCL burners. The customer recognized the burner component upgrade plus OFA system approach as beneficial from performance, cost, hardware installation, and outage time perspectives and selected this method.

RPI uses CFD single burner modeling as part of its burner replacement or upgrade activities to customize the burner hardware and initial settings to the unit requirements. In particular, RPI uses CFD single burner modeling to determine CCV® type modifications to B&W XCL burners to improve the near field flow patterns to achieve low NO_x emissions. Over 10 years of RPI experience coupling CFD modeling into burner design has shown that, when CFD modeling of CCV® type burners produces the desired near-field flow behavior, then burner behavior in the field correlates well with the CFD results.

Figure 22 shows burner model close-ups, with the original B&W XCL burner on the left and the CCV® components upgrade on the right. As the figure indicates, the modification affects only a few pieces in the burner: coal nozzle with coal spreader and FSR, and SA and TA diverters.

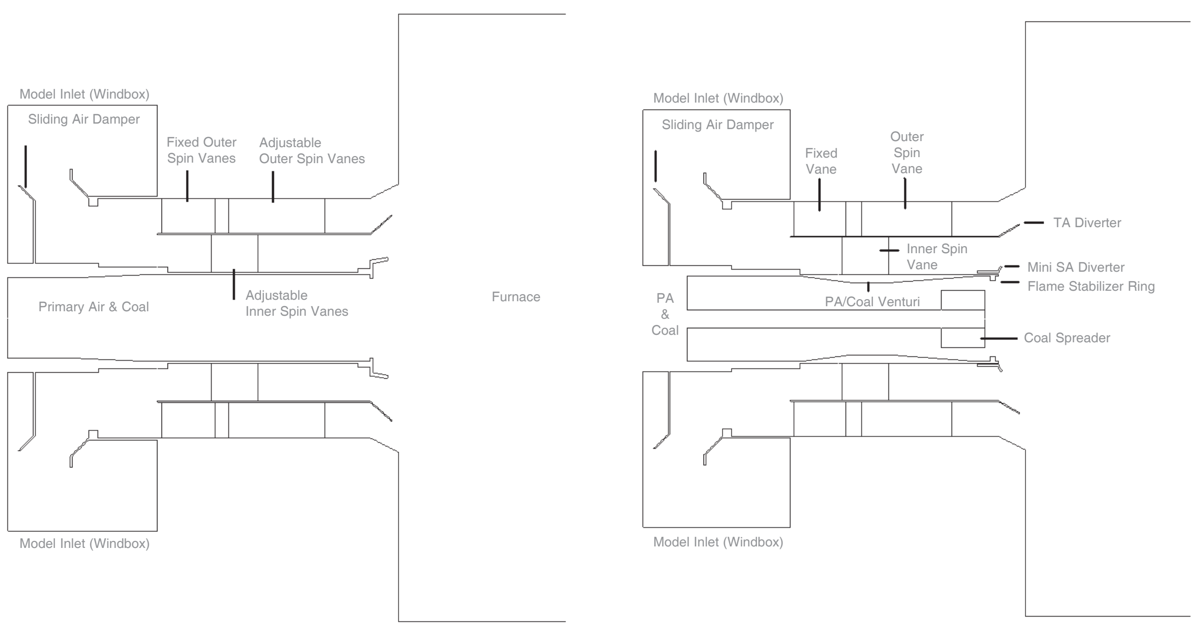

Figure 22. CFD 2-D Single Burner Models For Original B&W XCL Burner and RPI CCV® Components Upgrade Burner.

Figure 23 compares the computed velocity fields for the pre- and post-modified burner respectively. Figure 24 displays the streamlines for the two burner configurations. Streamlines are useful since they show flow direction and highlight internal recirculation zones necessary for good flame attachment at the burner tip. Internal recirculation zones also determine if the burner near-field flow will be good or poor for NO_x reduction. The figures indicated that the proposed CCV® components modification would produce satisfactory internal recirculation behavior in the burner near-field region. The CFD modeling results also produced suggested initial burner settings for sliding air damper, SA swirl vanes, and TA swirl vanes to create the desired flow pattern while controlling burner pressure drop to fit unit operation requirements, as well as a range of burner settings for good operability. RPI experience has been that such suggestions from CFD modeling can be very close to the final burner adjustments for acceptance testing and therefore save considerable burner tuning time after unit restart.

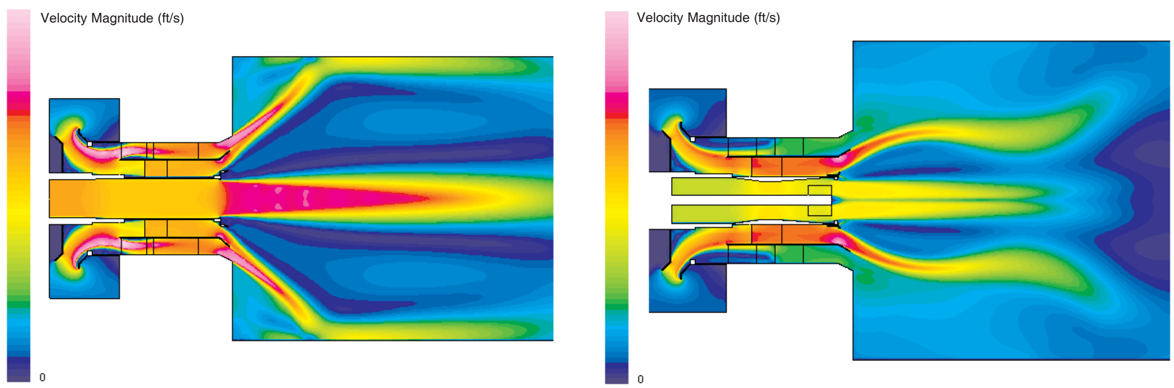

Figure 23. Computed Velocity Field For
Original B&W XCL Burner and RPI CCV® Components Upgrade Burner.

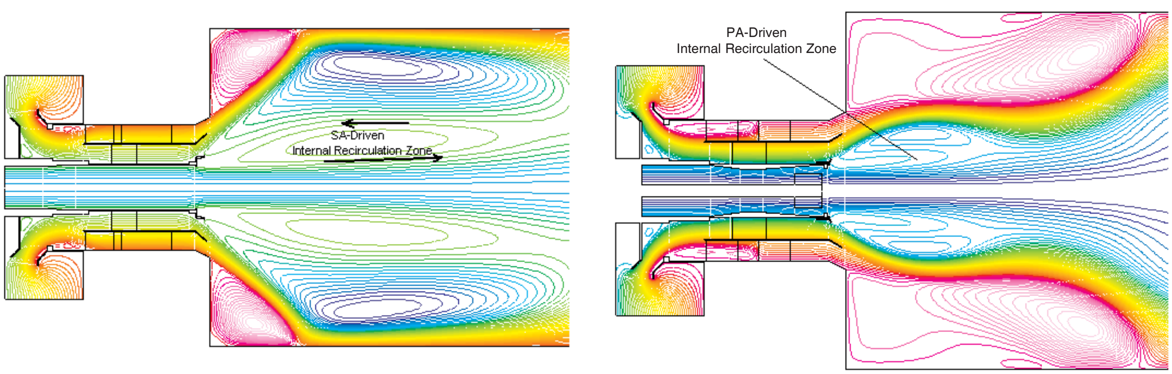

Figure 24. Computed Streamlines For
Original B&W XCL Burner and RPI CCV® Components Upgrade Burner.

Notable project accomplishments from post-retrofit testing include:

* RPI low NO_x CCV® DAZ component modifications, designed for staged operation but applied to unstaged B&W XCL burner, resulted in 12% NO_x emissions reduction with the OFA system shut off. This was accomplished without optimizing for this type of operation.
* With OFA system in operation, NO_x emissions reduction was 30%.
* Final NO_x emissions value of 0.288 lb/MBtu at full load compared to the guarantee of 0.320 lb/MBtu. NO_x emissions remained below 0.320 lb/MBtu over the unit load range.
* CO emissions of 112 ppm at full load and less than 10 ppm at reduced loads were 25% and 93% less than the guarantee of 150 ppm.
* Unburned carbon results were 50% to 70% of guarantee over complete load range.
* The burner components upgrade and new OFA system approach had a significantly lower total cost than new burner replacements alone.
* Burner modifications did not require burner removal or windbox alteration. All modifications were made from the furnace or burner deck.
* Installation of the burner components and OFA system took significantly less time than available in the 4-week scheduled outage.
* Initial burner settings (swirl amounts and damper openings) from the CFD task decreased restart and shakedown/tuning time to only 5 days and 9 tests (including tests at full, intermediate, and low loads) before acceptance testing of the modified burners and OFA system.
* Superheat spray reduced by 90%, reheat spray reduced by 2% at full load.

SUMMARY

Although CFD cannot solve every problem, there is an ever-increasing need to apply CFD to utility and industrial power plant projects geared toward lowering emissions and improving capacity and reliability. This paper has reviewed several upgrade projects completed successfully by RPI in the last four years. The projects included constraints on the upgrade approach, hardware, costs, and installation times. RPI integrated innovative low NO_x systems into furnaces with unique designs and fuel streams. This process created several challenges to overcome in the design process. An important component in these successful projects for RPI has been the use of CFD to assist the design process of the upgrade hardware, demonstrate project results from the upgrades, and to assist the field engineers in minimizing shakedown and unit restart time.