Minimize NO_x using only combustion control

You may not have to spend big bucks on an SCR system to reduce your NO_x emissions. The retrofit of a 600-MW opposed-wall-fired utility boiler with low-NO_x, dual air zone burners and overfire air cut the Wyoming PRB coal burner's NO_x output nearly in half. The key to the project's success, from the design stage through final testing and boiler tuning, was CFD modeling.

By Craig A. Penterson and Kenneth R. Hules, ScD, Riley Power Inc., a Babcock Power Inc. Company

Facing tighter fleetwide NO_x limits, a midwestern utility found itself having to decide which emissions-control technologies to install at which plants. As part of the process, the utility did a technical and economic analysis of NO_x-reduction options. The analysis suggested that upgrading the combustion control of one of its plants would avoid having to add an expensive selective catalytic reduction (SCR) or selective noncatalytic reduction(SNCR) system at the plant and be sufficient to meet fleetwide NO_x-reduction goals—but only if doing so reduced the plant's NO_x output by half.

Babcock Power Inc., through its Worcester, Mass.–based subsidiary Riley Power Inc. (RPI), took on the challenge of reducing the plant's NO_x emissions from 0.30 lb/million Btu (mmBtu) to 0.155 lb/mmBtu, while maintaining CO levels below 100 ppm and carbon-in-ash levels below 0.5%.

The boiler in question is opposed-wall-fired, originally burned subbituminous Powder River Basin (PRB) coal exclusively, and came equipped with 56 low-NO_x, dual-register, first-generation Babcock & Wilcox burners at four elevations. However, due to high localized furnace heat release rates and excessive slagging, 16 of the burners (4 per elevation) were removed from service following startup. The boiler was designed to generate 4,550,000 lb/hr of main steam at 2,650 psig and 1,005F, and 4,281,000 lb/hr of reheat steam at 602 psig and 1,005F. At full load, the plant's turbine-generator produces approximately 600 MW.

A clean-burning design

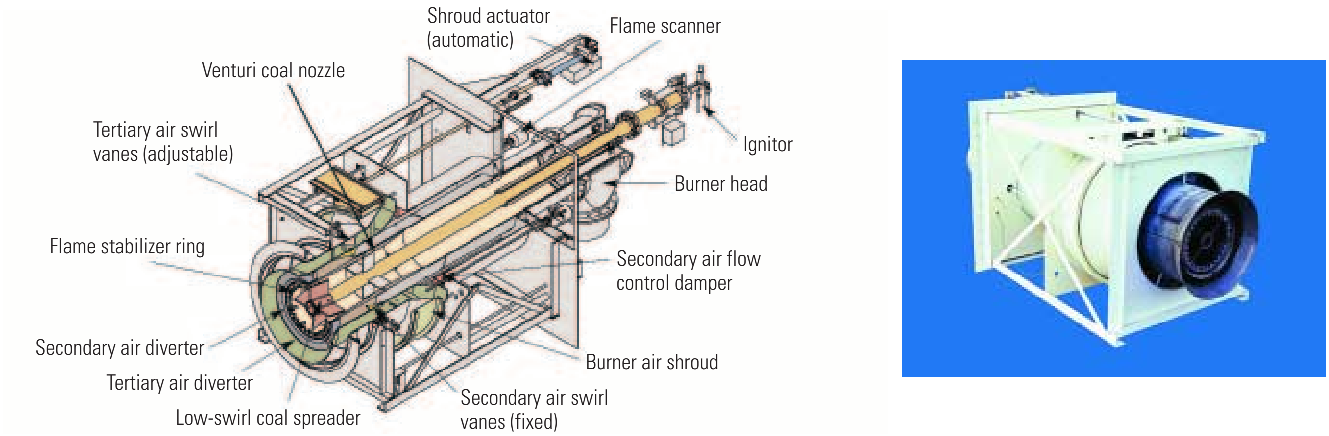
Major modifications to the boiler's existing combustion hardware included installing upgraded burners, new overfire air (OFA), and rearranging the burners to allow those at the upper elevation to take their combustion air from the lower three windbox compartments. The OFA nozzles were installed in the uppermost windbox compartment.

The burner selected for the project uses RPI's latest low-NO_x, dual air zone, controlled-combustion venturi (CCV) burner technology (Figure 1). The venturi coal nozzle, low-swirl coal spreader, and flame stabilizer ring produce a well-attached, fuel-rich flame—the fundamental necessity for minimizing the formation of both fuel and thermal NO_x.

The use of OFA further stages the combustion process and produces additional NO_x reduction. Typically, up to 25% of the combustion air can be diverted from the main burner and introduced above the top elevation of burners. This reduces the stoichiometry at the main burner zone and creates a reducing environment for combustion. Air staging is limited (or not used at all) on boilers burning high-sulfur coals and on boilers designed for supercritical operation due to the possibility of lower furnace waterwall corrosion.

Separate on/off dampers within each OFA section control air flow through each

1. The low-NO_x, dual air zone burner's schematic (L) and hardware (R)



Source: Riley Power Inc.

of the compartments. This results in better control of the penetration and mixing of the overfire air over a range of operating loads—a key factor in optimizing combustion and minimizing CO production throughout the load range.

The NO_x-reducing features of the burner design include dual combustion-air zones, the low-swirl coal spreader, and the flame stabilizer ring. The zoning divides the combustion air into secondary and tertiary air passages, each of which contains swirl vanes for spin control. Using shrouds and dampers to independently control the air flow to each passage improves control of the stoichiometry at the burner discharge and the burner's ability to reduce NO_x emissions as well. The low-swirl coal spreader disperses the pulverized coal into individual streams that enter the furnace in a helical flow pattern. The flames produced are longer than those produced by high-swirl coal spreaders. Finally, the flame stabilizer ring produces a well-attached, tubular-shaped coal flame, which further reduces NO_x emissions.

The modeling simulated the gas flow inside the burners in terms of its velocities, turbulence, temperature, pressure, density, and local chemical composition.

Analyze this

The design of the burners and their target furnace were modeled using computational fluid dynamics (CFD) techniques. The modeling simulated the gas flow inside the burners in terms of its velocities, turbulence, temperature, pressure, density, and local chemical composition.

Two types of steady-state models were needed to achieve the project goals. One modeled the individual burners to fine-tune their design, to obtain data for the furnace model, and to obtain the burner settings needed to produce the desired low-NO_x flow patterns for initial settings during burner and unit shakedown. This reduced recommissioning time.

Burner models were 2-D simulations that used aerodynamics only (no combustion) to represent a single burner in an idealized tunnel furnace that in turn represented the equivalent firing wall region of an outside burner. This approach yielded a tunnel diameter similar in size to the actual firing environment but without the flame-to-flame interactions that dominate the flow behavior several throat diameters from the wall (Figure 2).

The flow pattern in Figure 2 (L) shows a well-attached, broad, bushy flame. However, streamlines within the quarl show that primary air (PA) and secondary air (SA) streams interact strongly with rapid mixing driven by the high SA swirl relative to the axial PA flow. As a result, excess oxygen enters the primary ignition zone, so NO_x production will be high. The flow patterns in Figure 2 (R), which are expected to be enlarged slightly by the high reactivity of the PRB coal, show a longer, more tubular flame strongly attached to the burner tip.

The second steady-state model was of the entire furnace and concentrated on OFA design and performance. The variables on which the model focused were upper furnace oxygen distribution, CO and carbon burnout, the effect of different configurations of mills being out of service on furnace and OFA performance, and possible approaches for boundary air design to reduce or eliminate sidewall corrosion, should it develop.

Because of the left-to-right asymmetry that results from taking burners out of service, the models of the furnace cover its full width. Each model uses more than 860,000 brick-like cells to represent the 82-ft-wide by 51-ft-deep by 184-ft-high furnace volume. More than two-thirds of the cells are concentrated around the burner openings to capture reasonable detail of burner flow patterns, flame structures, and their interactions. Farther away from the burners, the furnace flow patterns are of a larger scale.

To balance calculation time against flow detail, the furnace models separated the pulverized-coal streams to the burners into three different-sized bins of small, medium, and large coal particles. This captured most of the differences in flow behavior among the variously sized coal particles. The devolatilization rate and the composition of volatiles were adjusted for the reactivity of the particular PRB coal. A two-step reaction system (volatiles to CO to CO_2) allowed the realistic simulation of furnace CO levels from furnace bottom to furnace exit. Carbon-in-ash (CIA) values were calculated, and small adjustments in the char burnout reaction rate were made as the base case simulation progressed. This enabled the CIA levels of flyash at the furnace exit to remain close to field data.

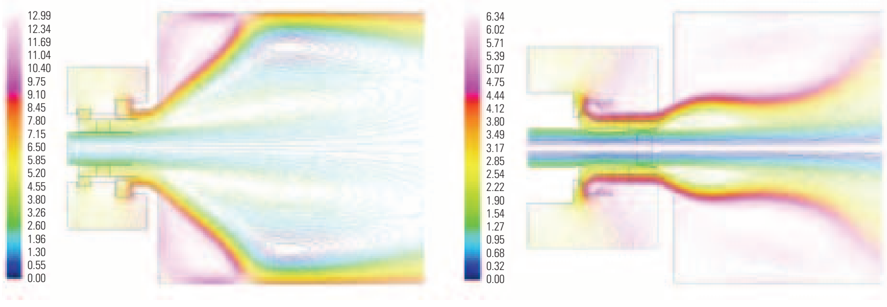
Because field-measured values of furnace exit gas temperature (FEGT) and upper furnace gas temperatures and composition were not available, the base-case results of the furnace model could not be validated directly against actual measurements. But it was possible to indirectly validate the model by comparing it to the model of a pre-retrofit furnace with a burner configuration known to produce high FEGT, as deduced by high steam temperatures and high spray flows.

The FEGT results for the two CFD cases yielded a difference commensurate with the back-end heat transfer calculations for the regular and high-FEGT field setups. No CFD-based NO_x calculations were made. RPI prefers to rely on regression-analysis calculations of NO_x emissions based on field measurements at more than 150 coal-fired utility units.

In-depth analysis

Figures 3 and 4 show the computed FEGT and oxygen distribution fields for the pre- and post-retrofit cases. The plots of Figure 3 indicate that the retrofit did not create any

2. The streamlines of a CFD-modeled single-burner, pre-retrofit (L) and post-retrofit (R)



Source: Riley Power Inc.

unusual temperature disturbances anywhere in the furnace and that the incremental FEGT difference is less than the 50 degrees F needed to maintain control of ash buildup in the upper furnace ash. Meanwhile, the oxygen plots of Figure 4 indicate that, although the post-retrofit OFA system made major redistributions of combustion air and oxygen as part of the NO_x-reduction process, the oxygen distribution in the upper furnace (and particularly at the furnace exit) is more uniform for the post-retrofit case.

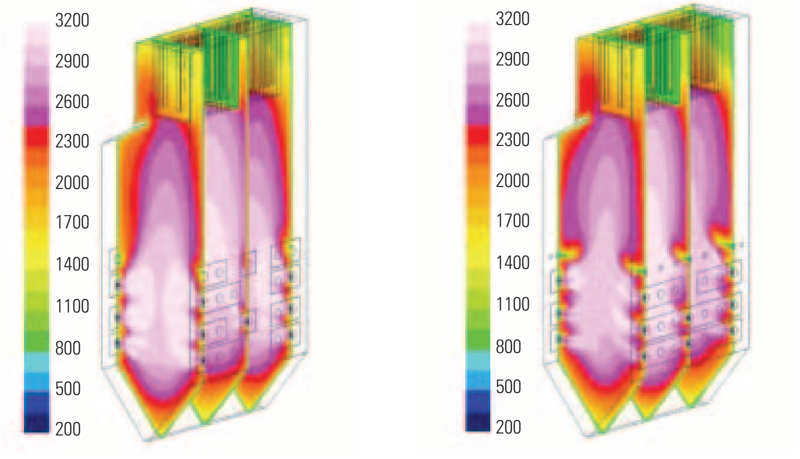
CFD furnace modeling addressed potential problems that might surface from the burner zone air staging that RPI expected would be required to meet the project's NO_x-reduction goal. It is well known that opposed-fired utility furnaces can suffer sidewall corrosion even without air staging (that is, without OFA), primarily in the middle of the sidewalls at upper burner elevations. Although sidewall wastage had not been a problem at this unit, because burner zone air staging is part of the NO_x-reduction strategy, the potential for sidewall corrosion may become more severe in the post-retrofit situation. Accordingly, a plan to minimize this potential should be in place. Figure 5 shows the computed gas oxygen content at the sidewalls. A comparison of Figure 6 (L) to Figure 6 (R) indicates that the post-retrofit firing arrangement decreased the peak sidewall heat flux while increasing the area of elevated heat flux. This was due to the "spreading out" of the combustion process by overfire air.

Last but not least, CFD furnace modeling also helped control project costs. Another post-retrofit furnace model containing additional "wing" OFA ports indicated this alternate OFA layout was not as effective in this unit at upper furnace oxygen mixing and distribution as originally thought. The CFD modeling informed the engineering decision to discard this more complex and costly OFA layout in favor of the design shown in Figure 4.

Passing with flying colors

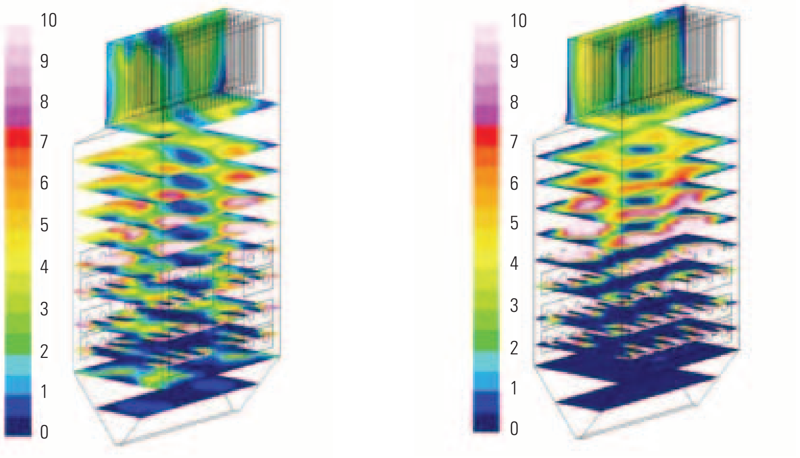
The low-NO_x burners and OFA were installed during a scheduled outage of the plant in the spring of 2002. During the outage, prior to burner installation, the burners were preassembled on the ground and hoisted to the burner deck for installation into the windbox as a "one-piece" design, minimizing the construction effort inside the windbox. They were sized to fit within the existing burner throat openings, avoiding additional modifications to the boiler's pressure parts.

3. Computed gas temperatures (F) for the pre-retrofit (L) and post-retrofit (R) furnace



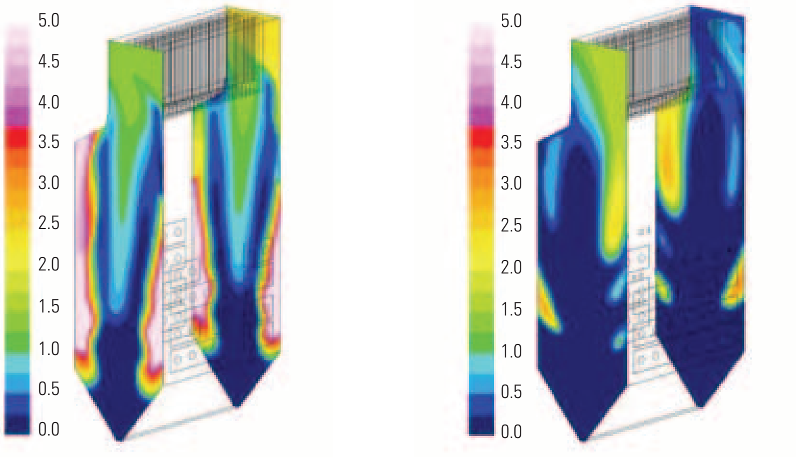
Source: Riley Power Inc.

4. Computed gas oxygen percentage for the pre-retrofit (L) and post-retrofit (R) furnace



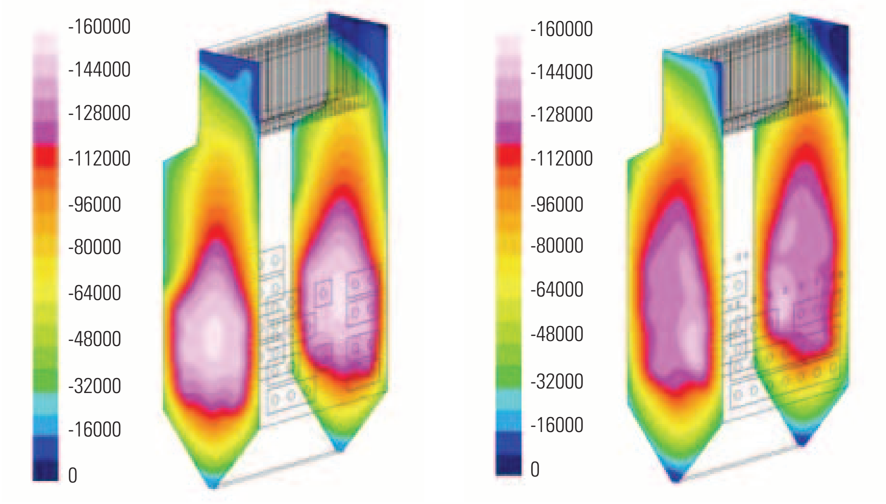
Source: Riley Power Inc.

5. Computed sidewall oxygen percentage for the pre-retrofit (L) and post-retrofit (R) furnace



Source: Riley Power Inc.

6. Post-retrofit sidewall heat flux (Btu/hr-ft^2) for pre-retrofit (L) and post-retrofit furnaces (R)



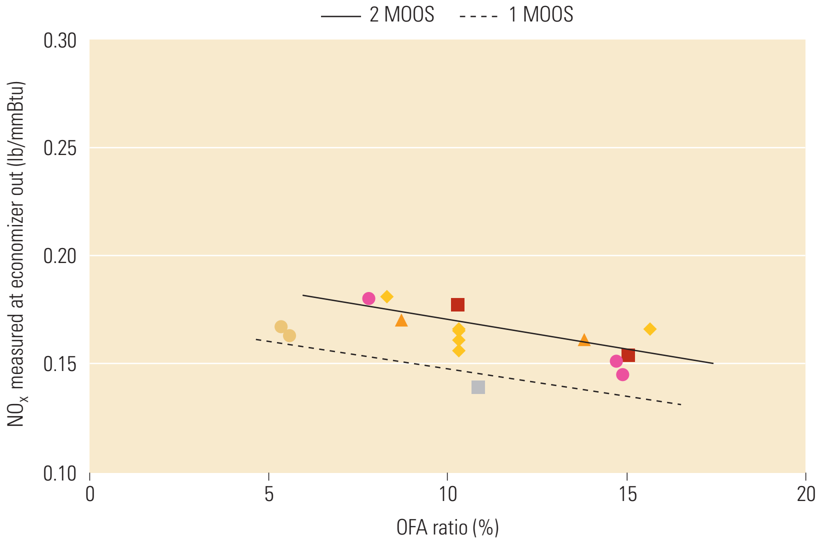
Source: Riley Power Inc.

Table 1. Comparing test results to project performance targets

Operating parameter	Pre-retrofit baseline	Performance target	Performance test
Unit load (MW)	600	600	600
Overfire air (%)	7	20	14
NO_x emissions (lb/million Btu)	0.3	<0.185	0.158
CO emissions (ppm)	10	<100	40
Unburned carbon in flyash (%)	0.06	<2.0	0.09

Source: Riley Power Inc.

7. The impact of OFA flow on NO_x emissions (in ppm), as a function of the number of mills out of service (MOOS)



Source: Riley Power Inc.

Table 2. The results of additional post-project performance testing

Operating parameter	Pre-retrofit	Post-retrofit
Gross generation (MW)	600	600
Feedwater flow (lb/hr)	4,308,500	4,066,000
Main steam temp (F)	1,001	1,012
Main steam spray (lb/hr)	0	162,000
Reheat steam temp (F)	1,003	1,006
Reheat steam spray (lb/hr)	78,000	31,000
Coal flow (lb/hr)	664,000	648,000
Total air flow (lb/hr)	6,145,000	5,983,000
Average FEGT (F)	2,337	2,315
Economizer O_2 (%)	3.1	3.1
NO_x emissions (lb/million Btu)	0.3	0.158
CO emissions (ppmdv)	10	40
Carbon in ash (%)	0.06	0.09
Opacity (%)	4	0.9

Source: Riley Power Inc.

After the unit was returned to service and operating close to full load, coal lines were balanced using variable orifices installed in them during the retrofit. No additional testing for coal fineness was done. Once the coal lines were balanced, the unit underwent optimization testing and tuning for one week. CFD facilitated this process as well, by providing initial starting-point settings for the burners that were close to the settings determined at completion of the burner tuning.

As Table 1 indicates, the new burners met all of the project's performance targets. Table 2 compares the results of additional pre- and post-retrofit performance testing on the boiler at full load. Fossil Energy Research Corp. (Laguna Hills, Calif.) did flue-gas emissions measurements and isokinetic flyash sampling at the outlet ducts of the boiler's economizer. Table 2 confirms that the retrofit reduced NO_x emissions by nearly 50%.

As expected, NO_x emissions decrease as the OFA ratio increases (Figure 7). Average NO_x emissions of around 0.155 lb/mmBtu, and as low as 0.138 lb/mmBtu (with an OFA ratio of 20%), were achieved. The number of coal mills in operation also had an impact on NO_x emissions. Keeping seven mills—rather than six of the eight available—in service produced lower NO_x emissions because the low-NO_x burners were sized for operation with seven mills. Operating with six mills produced higher burner velocities and more turbulent mixing, and higher NO_x as a result. ■