Which is easier: Reducing NO_x from PRB or bituminous coal?

Georgia Power's Plant Scherer learned the answer during a project that aimed to halve the NO_x emissions from three units, only one of which fires PRB coal. Test results confirmed that overfire air can reduce formation of the pollutant while keeping increases in CO and unburned carbon to a minimum. And a comparison of the test results at Scherer with those from another plant in the Southern Company fleet confirms that coal composition has a significant impact on NO_x emissions, and NO_x emissions from boilers burning PRB coal are independent of boiler size.

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Utilities with coal-fired capacity are under tremendous pressure to do two things simultaneously: make their plants less polluting and take advantage of the revenue opportunities that deregulation offers to low-cost producers. Accordingly, Southern Company has been working with Babcock & Wilcox Co. (B&W) of Barberton, Ohio, to increase both companies' understanding of the technical fundamentals, emissions behavior, and economics of tangentially fired, coal-burning boilers.

For example, the two firms recently and successfully retrofitted Units 2, 3, and 4 of Georgia Power Co.'s Plant R.W. Scherer in Juliette with separated overfire air (SOFA) ports. Georgia Power is a Southern Company subsidiary; both companies are based in Atlanta. The low-NO_x systems were installed during scheduled outages in the fall of 2001, the spring of 2002, and the fall of 2002 for Units 3, 2, and 4, respectively. Optimization and guarantee testing has shown that the systems reliably and cost-effectively deliver requisite NO_x reductions with minimal impact on unit operating efficiency and practices and boiler performance.

Efforts to minimize the SOFA project's capital costs included minimizing new ductwork, maintaining existing access around the boilers, minimizing unit structural changes, and maximizing constructability. For the longer term, these changes are compatible with the addition of post-combustion NO_x control, should additional NO_x reductions be required in the future. In addition, because the low-NO_x systems of all three units are nearly identical, the design is compatible with Plant Scherer's plans to switch Unit 2 from bituminous coal to PRB coal in the near future with minimal additional changes.

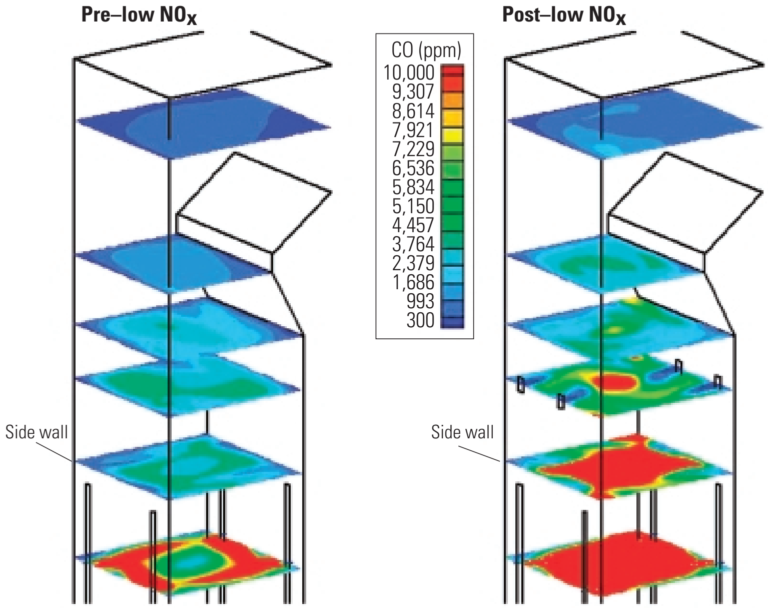
NO_x basics

Most NO_x-reduction technologies either (1) address the combustion process, the fuel stream, or both or (2) use post-combustion flue gas treatment using chemical reagents. For coal-fired applications, combustion system changes are generally less costly and are usually the first step in any integrated NO_x-reduction plan. Such is the case for the three units at Plant Scherer.

NO_x is formed during combustion of fossil fuels in one of two ways—by the oxidation of nitrogen (thermal NO_x) at high temperatures or by oxidizing organically bound nitrogen in the fuel itself (fuel NO_x). Fuel NO_x is responsible for 80% of the NO_x produced by burning pulverized coal. High levels of NO_x are produced when the concentration of oxygen is high during the early stages of combustion. The phenomenon is insensitive to temperature.

Several methods are available to effectively limit the formation of thermal NO_x during combustion. The design or redesign of a combustion system optimized for thermal NO_x reduction may incorporate several methods, depending on the unit's capacity, the fuels it fires, and the level of reduction

1. CFD modeling. During the design stage of the retrofit project, the low-NO_x system was modeled using computational fluid dynamic techniques. The objective was to optimize the quantity and location of SOFA ports and the mixing of overfire air with combustion gases in order to minimize emissions and the impact on steam temperatures and spray flows. *Courtesy: Babcock & Wilcox*



needed. For example, reducing the thermal loading on the combustion zone can inhibit the production of thermal NO_x either by (1) increasing the size of the combustion zone for a given thermal input, (2) reducing the rate of combustion and peak flame temperatures with specially designed burners, or (3) adding recirculated flue gas to the combustion air to depress flame temperature.

Separately, the formation of fuel NO_x can be reduced by switching to—or co-firing with—fuel with a lower nitrogen content and/or by limiting oxygen availability during the early stages of combustion. Oxygen-reduction mechanisms include reducing excess air; reducing burner stoichiometry by removing a portion of the combustion air from the burner zone and introducing this air later through NO_x or overfire air (OFA) ports in a process called air staging; and limiting the rate at which air is introduced to the fuel during the early stages of combustion with specially designed burners.

Off on a tangent

In tangentially fired boilers, fuel and combustion air are introduced at corners of the boiler on a tangent to an imaginary circle in the middle of the furnace. The combination of the firing angles and momentum of the fuel and air streams creates a rotating or cyclonic fireball that fills the plan area of the furnace as combustion proceeds up inside it. In this firing system, the furnace acts like a large burner; each corner provides the ignition energy to the corner downstream and the swirling action of the fireball stabilizes the flames.

The firing system design is characterized by injecting coal and primary (transport) air at distinct elevations. Each unit has nine elevations of coal nozzles per corner for a total of 72 coal nozzles, and each elevation of coal nozzles receives coal from one pulverizer. A small portion of the secondary combustion air (fuel air) is introduced through the coal compartments co-annular to the pulverized coal and primary air stream. The majority of secondary air (auxiliary air) is introduced through air compartments located above and below each fuel-admission assembly. This method of layered air and fuel introduction results in lower NO_x emissions than other methods of fuel firing, because the air is initially more separated (staged) from the fuel and mixes at a slower rate. Because this creates hydrocarbon fragments that contain nitrogen in a reducing atmosphere, NO_x formation is inhibited.

B&W's approach to redesigning a combustion system to minimize NO_x emissions is to use an interlaced SOFA system located some distance above the top coal elevation. As part of the retrofit, the auxiliary air compartments, nozzles, and dampers are downsized to increase air and fuel separation during the initial stages of combustion and to maintain existing injection velocities, pressure drop, and damper controllability, despite the reduced flow of air through the windboxes under staged conditions.

Back at the plant

Units 2, 3, and 4 at Plant Scherer are subcritical, controlled-circulation, radiant-reheat, corner-fired, balanced-draft units manufactured by Combustion Engineering in the mid-'70s. The furnaces are 100 feet wide by 47.3 feet deep and were originally designed to fire pulverized Midwestern bituminous or subbituminous coal.

Unit 2, rated at 900 MW, currently burns nothing but Eastern bituminous coal. Its boiler generates 6,330 klb/hr of steam at 1,000F and 2,625 psig. The unit has a furnace division wall and uses one of two flue gas recirculation fans and periodic injection of a slagging agent to maximize steam temperatures. The furnaces of 910-MW Unit 3 and 925-MW Unit 4 are open designs with no division wall and burn Powder River Basin (PRB) coal exclusively. Their steam conditions are identical: 6,215 klb/hr at 1,000F and 2,625 psig. Each of these two units also has four water cannons to control furnace wall slagging and optimize steam temperature control.

Change in the air

For all three units at Plant Scherer, the changes made to their combustion systems to reduce NO_x emissions entailed adding SOFA ports and openings to provide deeper staging capability and separation distance above the combustion zone. As mentioned, auxiliary air compartments, nozzles, and dampers were downsized as well. Most coal nozzles and adjustable tips were reused.

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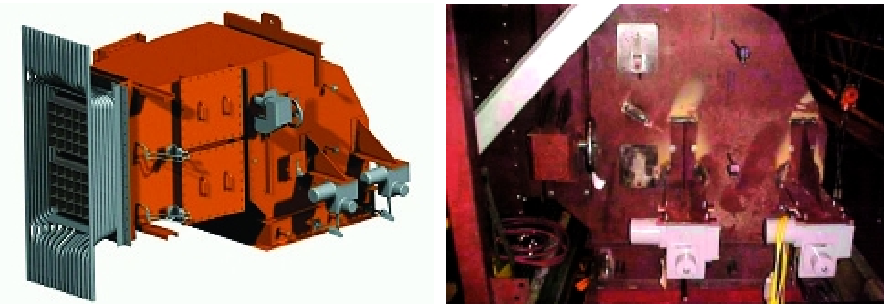
Figure 1 illustrates partial results of the CFD modeling and compares predicted CO levels for the original and low-NO_x combustion systems. CO levels were used to indicate the effectiveness of mixing in the overfire air. In addition, NO_x levels, gas temperature profiles, and speeds were compared. Minimizing structural modifications and maximizing access around the units were also important considerations in locating the SOFA ports.

Based on the modeling, one level of SOFA was added to each unit approximately 28 feet above the top coal elevation. For Unit 2, a total of 10 ports were added: four on the front furnace wall, four on the rear wall, and one on each side wall. For Units 3 and 4, a total of eight ports were added: four on the front wall and four on the rear wall. The port openings are designed to introduce overfire air into the furnace perpendicular to the waterwall. The ports are interlaced, front to rear, to increase coverage of the furnace plan area. As part of the interlaced design, the ports are also offset in the direction of fireball rotation to increase corner coverage for CO control. New air ducts with integral turning vanes were added to supply air to each port from the existing secondary air ducts.

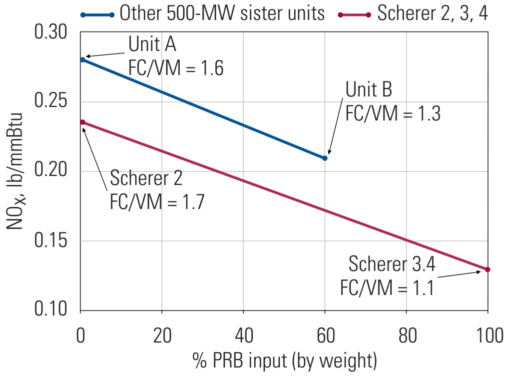
Figure 2 is an isometric view of the typical SOFA port/windbox assembly installed on Units 2, 3, and 4. The wall openings were manufactured as panel inserts to simplify field installation. Each opening features a membrane bent tube, gas-tight construction, and a deep water-cooled throat to cool the air nozzles from the intense radiant heat in the overfire air zone. Each assembly has an upper and lower air compartment; airflows are controlled independently via opposed



2. Isometric view. SOFA ports and the windbox assembly as installed on Units 2, 3, and 4 of Plant Scherer (left). The side of the assembly is shown on the right. *Courtesy: Babcock & Wilcox*

3. Close-up of a typical SOFA port assembly before (left) and after (right) installation. Adding overfire air to a tangentially fired coal-burning unit typically reduces its NO_x emissions by 20% to 60%. *Courtesy: Babcock & Wilcox*

4. Comparison test. The results of tests of coal blending at Plant Scherer and at other plants in the Southern Company fleet indicate two things: Coal composition has a significant impact on NO_x emissions, and NO_x emissions from tangentially fired boilers burning PRB coal are independent of boiler size. The data represented by the blue line is for a pair of 500-MW, eight-corner sister units burning different blends of PRB and Eastern bituminous coal. *Source: Babcock & Wilcox*



blade dampers. This feature provides operational flexibility; one of the compartments can be partially closed to maintain high air velocities and penetration for CO control and good carbon burnout over the load range.

The SOFA ports also are equipped with integral turning vanes, devices for manually tilting and yawing them to reduce NO_x and CO emissions, thermocouples to monitor nozzle temperatures, and pitot tubes to indicate relative flow and balance. Figure 3 is a photograph of a typical SOFA port assembly before and after installation.

Test results, from a narrow and broad perspective

Pre-retrofit (baseline) testing—before installation of the low-NO_x system—was completed on Unit 2 in the spring of 2000 and on Units 3 and 4 in the fall of 2000. Post-installation optimization and guarantee testing of Units 2 and 3 took place in the spring of 2002 and in the spring of 2003 for Unit 4. The results are summarized in the table and explained in the caption.

Although these results are illuminating on their own, the low-NO_x project at Plant Scherer also provides another lesson. The PRB coal burned by Plant Scherer's Units 3 and 4 is characterized by its high reactivity, high moisture content, and low sulfur content. This type of coal has been shown in the past to burn readily and produce lower levels of NO_x and unburned carbon emissions than Eastern bituminous coal. PRB coal's high reactivity can be attributed to its high levels of volatile matter. Indications of that content include PRB coal's low (1.0 to 1.2) ratio of fixed carbon to volatile matter (FC/VM), the high percentage of oxygen present, and the presence of alkalis that are thought to catalyze combustion.

With this technical discussion in mind, consider Figure 4, which plots NO_x emissions versus the PRB content of fuel burned by the three Plant Scherer units and by two smaller units at another plant in the Southern Company fleet. The parallel lines confirm that NO_x emissions from a tangentially fired boiler unit burning PRB coal are generally independent of boiler size. For example, a 500-MW unit reduced its NO_x emissions by 25% by switching from a bituminous coal with a FC/VM ratio of 1.6 to a 60/40 blend of PRB/bituminous coal with a ratio of 1.3. The percentage reduction is similar to that achieved at Plant Scherer. ■

Comparing NO_x reductions at Plant Scherer. For Unit 2, which fires Eastern bituminous coal exclusively, the addition of the SOFA system resulted in NO_x levels of 0.23 lb/mmBtu with less than 60 ppm CO and less than 9.5% unburned carbon (UBC). This was better than expected performance, considering the poor quality and less-than-optimum fineness of the coal fired, in addition to fuel imbalances. Post-retrofit emissions results for Units 3 and 4, which only fire PRB coal, were very similar; NO_x levels were generally less than 0.13 lb/mmBtu with less than 125 ppm CO and less than 0.5% UBC. Both units had similar fuel imbalances; Unit 3 also was saddled with coal of less-than-optimum fineness. For all three units, the test results suggest that if fuel imbalances can be reduced or eliminated, even lower levels of NO_x and CO—as well as higher boiler efficiency—could be possible, because excess air could be reduced. *Source: Babcock & Wilcox*

	Unit 2		Unit 3		Unit 4	
Number of mills in service	5		7		7	
Coal type	Eastern bituminous		PRB		PRB	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Gross MW	865	870	883	884	881	873
SH steam flow, klb/hr	6,205	6,012	5,791	5,985	5,859	5,721
RH steam flow, klbs/hr	5,726	5,531	5,332	5,396	5,273	5,149
SH steam temp, F	981	995	1,002	1,000	1,001	1,000
RH steam temp, F	1,002	1,005	1,000	1,001	1,006	1,000
Burner tilt, deg A/B	+6/+4	–5/–2	–4/–4	–5/–5	–5/–5	–3/–3
Excess O_2 @ economizer exit, %	2.8	3.7	3.4	3.3	2.8	3.1
NO_x, lb/mmBtu	0.33	0.23	0.29	0.13	0.33	0.13
CO, ppm @ 3% O	118	32	12	114	32	121
UBC, % C by weight	9.1	8.3	no test	0.2	0.07	0.1
Opacity, %	8	7	7	6	8	5

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