MINIMIZATION OF NO EMISSIONS FROM MULTI-BURNER COAL-FIRED BOILERS

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Program Overview

The focus of this program is to provide insight into the formation and minimization of NOx in multi-burner arrays, such as those that would be found in a typical utility boiler. Most detailed studies are performed in single-burner test facilities, and may not capture significant burner-to-burner interactions that could influence NOx emissions.

Our approach is to investigate such interactions by a combination of single and multiple burner experiments in a pilot-scale coal-fired test facility at the University of Utah, and by the use of computational combustion simulations to provide insight into the experimental results and to evaluate full-scale utility boilers. In addition, fundamental studies on nitrogen release from coal will be performed in support of the modeling effort. Improved submodels describing transformations of both volatile nitrogen species and char nitrogen species will be developed.

The program is broken into four main tasks, and reporting will be divided into these main areas:

1- Fundamental studies on nitrogen release from coal. These studies will be used to enhance the predictive capabilities of the combustion simulations. Studies focusing on secondary coal pyrolysis will be carried out at Brigham Young University, and studies focusing on char nitrogen will be performed at the University of Utah.
2- Comprehensive modeling of burner arrays. This task will be performed by Reaction Engineering International and the Unversity of Utah.
3- Pilot-scale optimization of multi-burner arrays. This task will be carried out by the University of Utah.
4- Technology transfer. This task involves coordination with utility consultants who will provide oversight of the research program.

Pilot-Scale Studies: Initial Measurements of Multiburner Firing

Summary

An initial testing campaign was carried out during the summer of 2000 to evaluate the impact of multiburner firing on NOx emissions. Extensive data had been collected during the Fall of 1999 and Spring of 2000 using a single pulverized-coal (PC) burner, and this data collection was funded by a separate Department of Energy program, the Combustion 2000 Low Emission Boiler System (LEBS) project under the direction of DB Riley. This single-burner data was thus available for comparison with NOx emissions obtained while firing three burners at the same overall load and operating conditions.

A range of operating conditions were explored that were compatible with single-burner data, and thus the emission trends as a function of air staging, burner swirl and other parameters will be described below. In addition, a number of burner-to-burner operational variations were explored that provided interesing insight on their potential impact on NOx emissions. Some of these variations include: running one burner very fuel rich while running the others fuel lean; varying the swirl of a single burner while holding others constant; increasing the firing rate of a single burner while decreasing the others.

In general, the results to date indicated that multiburner firing yielded higher NOx emissions than single burner firing at the same fuel rate and excess air. At very fuel rich burner stoichiometries (SR < 0.75), the difference between multiple and single burners became indistinguishable. This result is consistent with previous single-burner data that showed that at very rich stoichiometries the NOx emissions became independent of burner settings such as air distributions, velocities and burner swirl.

Experimental

The University of Utah pilot-scale combustion test furnace referred to as the “L1500” is a nominal 5 MMBtu/hr pilot-scale pulverized-coal-fired furnace designed to simulate commercial combustion conditions. A major objective of this combustion facility is to study pollutant formation and control, carbon utilization, and ash management in a system which operates similar to commercial boilers. Therefore, the L1500 pilot-scale furnace has the following characteristics:

- Simulates the range of time/temperature histories that are found in commercial units.
- Includes both the ability to fire single or multiple gas burners and/or coal burners.
- Has the provision for evaluating different slag screen designs for improved ash management.
- Has the capability to test different reburning and burnout air injection locations and velocities for emissions control.
- Provides simulated waterwall area (if desired) for deposition studies.
- Has a nominal firing rate of 5 MMBtu/hr with coal.
- Permits multiple locations for coal injection such that coal and/or gas can be used as reburning fuels independent of main firing burner.
- Has adequate sample/observation ports for measuring all inputs and outputs as well as ports to allow detailed species and temperature profiles to be obtained.
- Has a completely instrumented control room adjacent to the facility to control the operation of the furnace and to record and analyze data.

Figure 1 is a schematic diagram of the L1500 combustor. The horizontal-fired combustor is 1.1 m x 1.1 m square and nearly 12.5 meters long. The walls have multiple-layered insulation to reduce the temperature from about 1925 K on the fire-side to below 330 K on the shell-side. The combustor is modular in design with numerous access ports and optional cooling panels in each section. This allows the flue gas temperature profile to be adjusted to better simulate commercial equipment. The access ports are used for visual observations, fuel and/or air injection, and product sampling.

The overall combustion facility includes the air supply system, water supply and cooling system, L1500 combustor, fuel supply systems (either gas or coal or both), a flue-gas cooling chamber, scrubber, and induced-draft fan and a stack. The facility meets all environmental regulations.

Figure 2 shows a comparison between the two different firing configurations. The single 5 million BTU/hr burner is shown on the left, and the three 1.5 million BTU/hr burners are shown on the right. All burners are based on the same low NOx burner design, and the scaling to the smaller, multiple burners was performed by matching velocities. The burners are dual-air-register burners, and the innermost air annulus is termed the secondary air stream while the outermost air annulus is termed the tertiary air stream. For most conditions in these tests, 33% of the combustion air was introduced in the secondary and 67% was introduced in the tertiary. An additional amount of air (15% of stoichiometric requirement) was utilized in the primary air stream to convey the pulverized coal.

The coal pipe runs down the center of the burner and has a bluff body along its centerline, resulting in the coal being introduced in an annular region. A small annulus for natural gas injection is located on the periphery of the coal pipe, and unless otherwise indicated a small amount of natural gas (~5% of thermal input) was introduced at this location to assist with flame attachment. The burner swirl is generated by the use of IFRF-type swirl blocks, and there is separate swirl control for the secondary and tertiary air streams. Unless otherwise specified, all tests were performed at a firing rate of 4.5 million BTU/hr with exhaust conditions of 15% excess air. Tests involving burner staging used staging air introduced into section 3 of the L1500, providing a staged residence time of approximately 1 second.

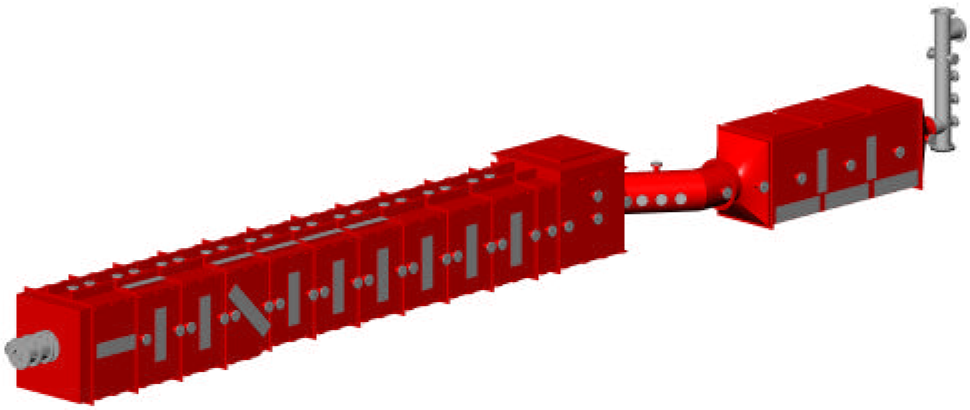

Figure 1. The 5 MMBtu/hr multi-fuel combustion test facility at the University of Utah referred to as the L1500 Furnace.

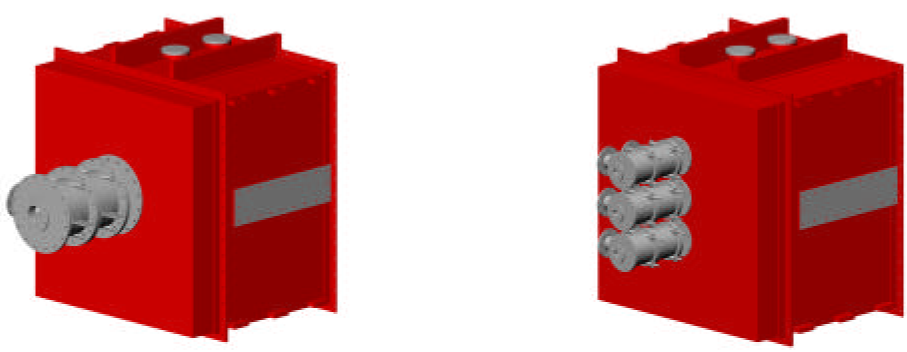

Figure 2. Two different firing configurations for the L1500. A single 5 MMBtu/hr burner is shown on the left, and three 1.5 MMBtu/hr burners are shown on the right.

Results & Discussion

Effect of Burner Swirl

An initial comparison was made between the two firing conditions under unstaged conditions, and the major firing parameter varied was burner swirl. The results, shown in Figure 3, indicate higher NOx emissions for the multiburner scenario. The swirl setting axis refers to a percentage of maximum swirl achievable with the IFRF-type swirl blocks used with these burners. The 100% swirl setting corresponds to a theoretical swirl number of 2. Note that under the condition of totally axial flow (swirl setting of 0%), that both firing configurations yield similar NOx emissions; however, this condition represents optimized burner operation (reflected by the high NOx levels) and does not represent how these burners would be utilized in practice. No combustion air preheat was used for these swirl comparisons; therefore, all flame attachment (and thus NO reduction) was due to the interaction of the swirl setting and the burner quarl geometry.

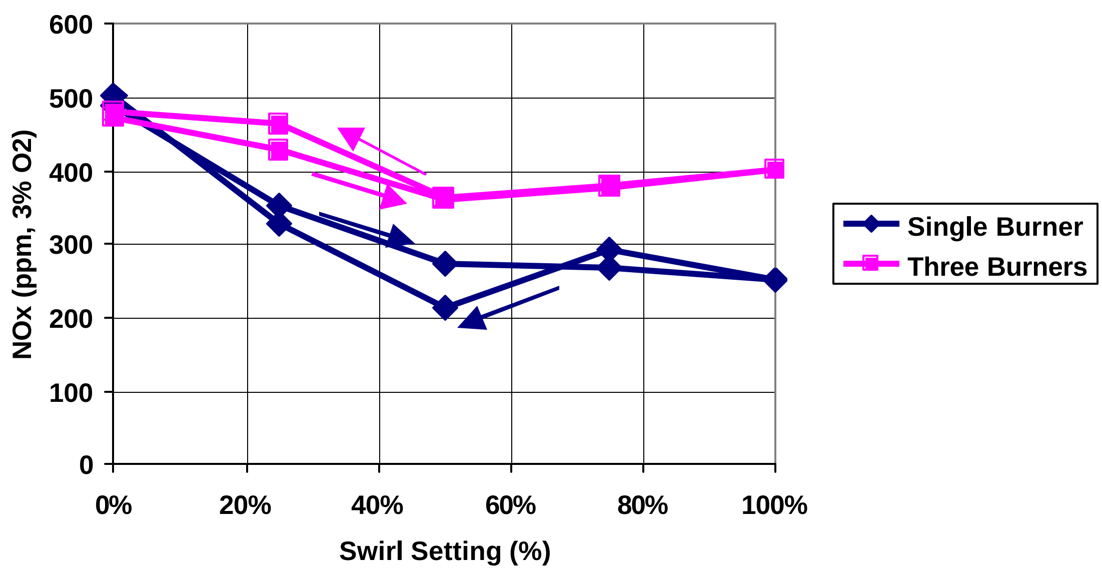

Figure 3. Comparison of the effect of burner swirl on single and multiburner firing scenarios under unstaged conditions.

Effect of Air Staging

Both firing configurations were tested under staged conditions to see how the two conditions compared as increasing lower burner zone stoichiometries. The results are shown in Figure 4, where it is clear that again the multiburner firing condition yielded higher NOx except at very low burner stoichiometries.

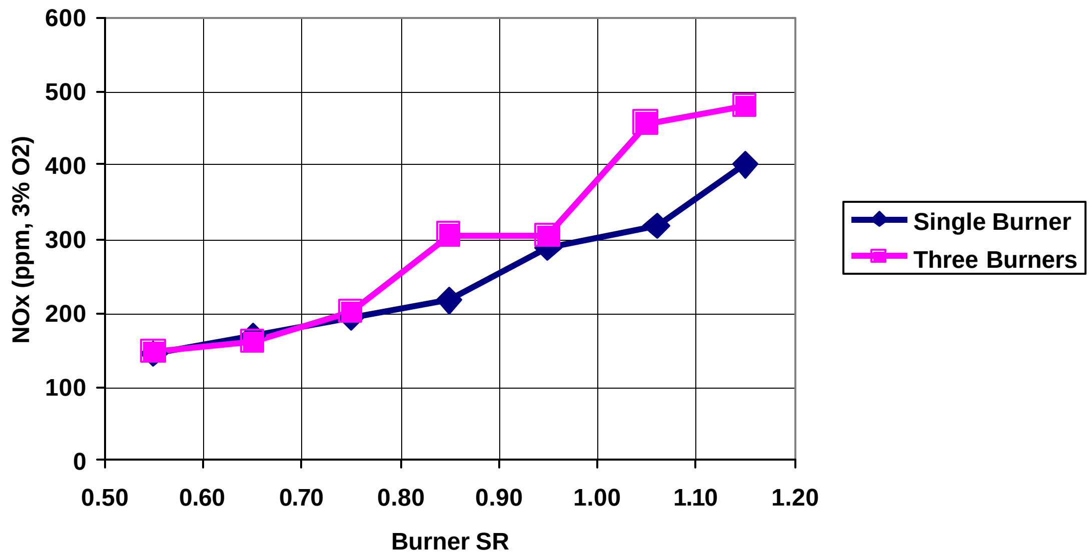

Figure 4. Comparison of the effect of air staging on single and multiburner firing scenarios. Burner swirl was set at 25%.

At very fuel rich burner stoichiometries (SR < 0.75), the difference between multiple and single burners became indistinguishable. This result is consistent with previous single-burner data [Eddings et al, 2000] that showed that at very rich stoichiometries the NOx emissions became independent of burner settings such as air distributions, velocities and burner swirl. The explanation of this independence is the removal of large quantities of air from the burner zone to be later introduced downstream for air staging. Once the air flow rates have been reduced substantially, the burner aerodynamics become less significant with respect to NOx formation behavior. The oxidation of fuel nitrogen species such as HCN and NH3 in the burner zone, will be controlled by the level of oxygen entrained into the fuel rich core created by this burner design. An unattached flame or significant shear layer mixing between the primary and secondary streams can both increase the amount of oxygen in the fuel rich core early in the flame. Typically, low NOx pulverized-coal burners are designed to minimize the possibility of these two phenomena, thereby providing the greatest opportunity for fuel nitrogen decay to N2 in the hot, rich regions of the coal flame. As more and more air is removed from the burner, the probability for flame detachment or significant secondary/primary shear layer mixing is minimized.

Effect of Mismatched Firing Rates

To identify whether a burner mismatch has advantageous or deleterious effects on NOx emissions, a staging curve was run for widely varied firing rates as shown in Figure 5. For the mismatched firing rate data, the center burner was operated at 3X the firing rate of the other two, yielding firing rates of (from top to bottom burner) 0.9MM BTU/hr, 2.7 MM BTU/hr and 0.9 MM Btu/hr. The increases and decreases in firing rate were accomplished by increasing both fuel and air flow rates; therefore, the burner stoichiometries were held constant relative to each other. As shown in the figure, the burner mismatch provided slightly lower NOx levels for all burner stoichiometries except for unstaged conditions. As noted with the single versus multiburner comparison, the differences at very low stoichiometries are very minimal due to the large amount of air that has been removed from the burners.

For the unstaged condition (SR=1.15), it appeared that NOx emissions were higher with a burner mismatch. Additional data were taken to further explore this behavior using both a 2X and a 3X increase in middle burner firing rate, as shown in Figure 6. Each condition was run under a range of swirl settings to try and obtain optimal burner conditions for stability and low NOx. Also, the overall firing rate was held constant at 4.5 MM BTU/hr for all three data sets. As shown, a factor of 2 mismatch in burner firing rates did not provide a significant increase in NOx emissions under unstaged conditions; however, a factor of 3 mismatch resulted in a very notable increase in NOx emissions.

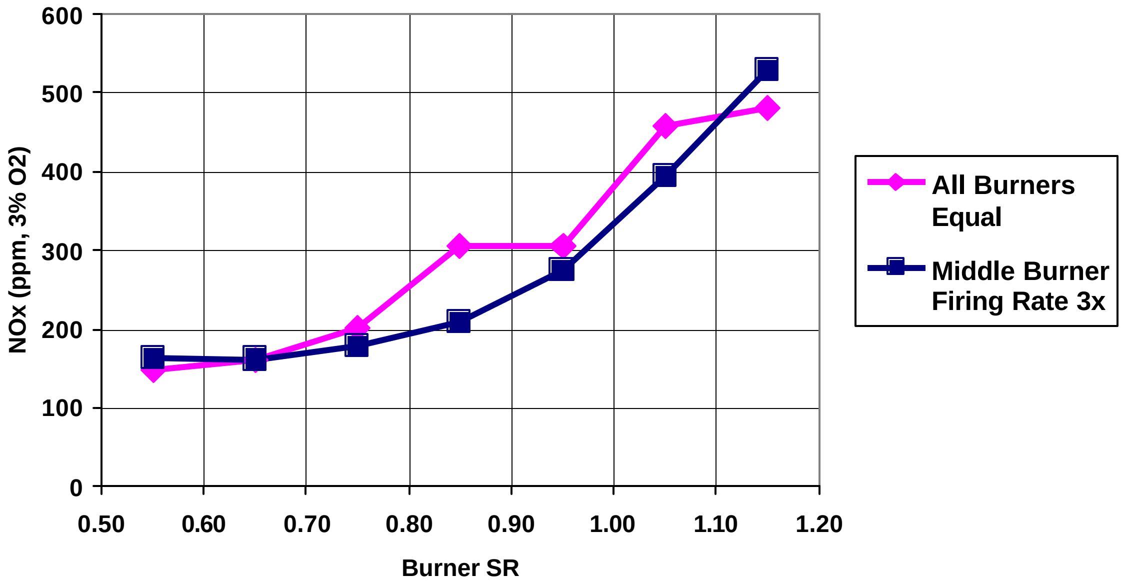

Figure 5. Effect of mismatched firing rates on NOx emissions under staged conditions.

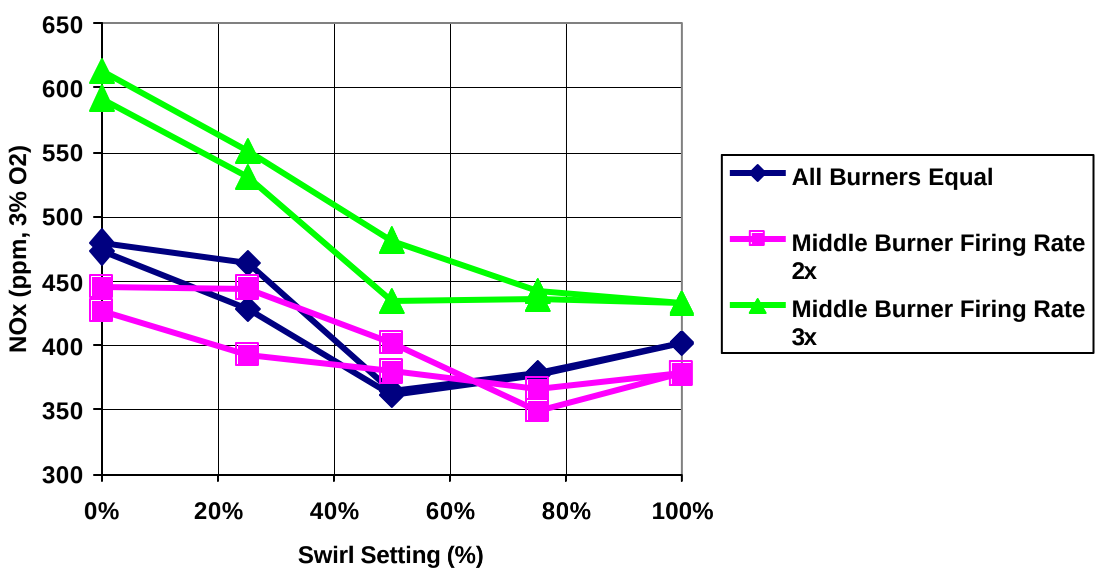

Figure 6. Effect of mismatched firing rates on NOx emissions under unstaged conditions.

Effect of Burner Biasing

The use of burner biasing, where some burners are operated fuel rich and others are operated fuel lean, represents a condition that could have potential for NOx reductions. To explore this possibility, tests were performed using two different biasing scenarios. In these tests, the firing rate (coal mass flow) to each burner was held constant and the air input was varied to provide different levels of biasing. The overall burner zone stoichiometry was held constant at 1.15, with the center burner being operated fuel rich and the upper and lower burners being operated fuel lean. The first scenario represented mild biasing, with the middle burner operating at SR=0.95 and the outer burners operating at SR=1.25. The second scenario represented very severe biasing, with the middle burner operating at SR=0.65 and the outer burners operating at SR=1.40. The results, shown in Figure 7, indicate a minimal impact using the mild biasing scenario (middle burner SR=0.95). The severe biasing scenario, however, shows some promise for NOx reductions. There is a significant amount of spread in the data at low levels of swirl, indicating the highly unstable flames produced with the biasing. However, at high levels of swirl the spread in the data is minimal and the severe biasing configuration provides consistently lower NOx.

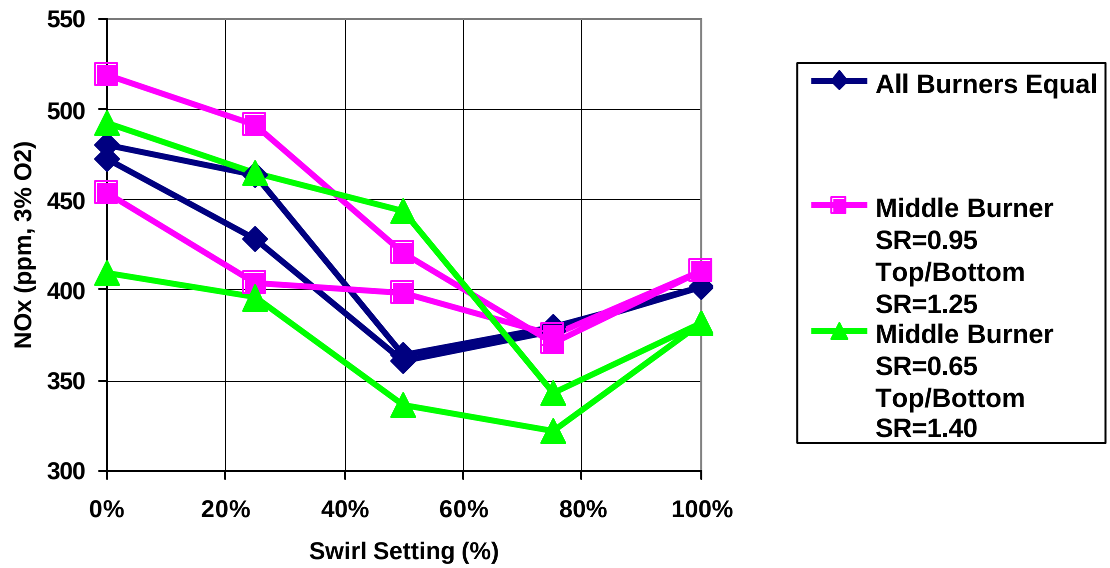

Figure 7. Effect of burner biasing on NOx emissions. Burner firing rates were held constant (same coal mass flow) while air flow rates were varied.

Conclusions & Recommendations

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In general, the results to date indicated that multiburner firing yielded higher NOx emissions than single burner firing at the same fuel rate and excess air. At very fuel rich burner stoichiometries

(SR < 0.75), the difference between multiple and single burners became indistinguishable. This result is consistent with previous single-burner data that showed that at very rich stoichiometries the NOx emissions became independent of burner settings such as air distributions, velocities and burner swirl.

A mismatch in firing rates to different burners yielded mixed results. Under staged conditions, NOx emissions were generally lower when the middle burner had a firing rate that was 3X that of the outer burners. For unstaged conditions, however, the reverse was true. A 3X increase in firing rate in the center burner resulted in a notable increase in NOx emissions. The firing rate increase was effected by increasing both fuel and air flow rates, such that burner stoichiometry remained constant. Note that a 2X increase in firing rate in the center burner resulted in minimal differences from uniform operation.

Some conditions were identified where NOx emissions could be reduced in a multiburner firing scenario; specifically, through the use of burner biasing under unstaged conditions. If the middle burner was operated fuel rich, with the outer burners operated at excess air levels to compensate , the overall NOx emissions were lower than when all burners were operated with equal air/fuel flow rates. Burner parameters such as swirl had to be optimized, however, to achieve stable operation. This approach yielded NOx emissions that were slightly lower than the single burner data under unstaged conditions; however, the application of such severe biasing should be evaluated in the context of corrosion, deposition, or other potential adverse affects in the near burner region.

Future work

A second test series is planned for the Spring of 2001 to explore in more detail some of the effects noted in the first test series. One issue will be to repeat the baseline data comparison between single and multiple burners. There was an odd data point at SR=0.95 for the multiburner case that appeared to be inconsistent, and additional data will verify whether expected trend holds.

Also, the test series on firing rate mismatch should be rerun in a different manner. In a typical PC boiler, each elevation of burners is fed by a different pulverizer; therefore, it is possible that different elevations can have somewhat different fuel flow rates. The air to each burner, however, is fed from a common windbox. Thus, unless dampers have been specifically set to bias air flow from one burner or level to another, the amount of air flow to each burner is most likely to be similar. The previous tests on burner mismatch were run with both coal and air flowrates varying to yield increases/decreases, thereby maintaining consistent stoichiometry among the three burners. The tests will be rerun to reflect a more likely scenario of equal air flow between the three burners but varying coal flow rates.

In addition, detailed profile data including NO, CO, temperature and carbon in ash will be obtained for a select set of conditions to be used for comparison with CFD modeling of the L1500.

References

Eddings, E.G. et al, “Combustion 2000 Low Emission Boiler System (LEBS),” Interim Technical Report to D.B. Riley, Inc., Project Number DE-AC22-92PC92158, *Department of Chemical and Fuels Engineering*, *University of Utah*, June, 2000.