Project Status Report for: June 2000

Project Title: Ultra Low NOx Integrated System for Coal-Fired Power Plants

Project Number: 91890460 **Project Manager:** John Marion

Customer Name: U.S. DOE / Performance Projects **Project Leader:** Charles Maney

GOALS AND OBJECTIVES:

Develop low cost, retrofit NO_x control technologies to address current and anticipated, near term emissions control legislation for existing coal fired utility boilers. Specific goals include:

- Achieve < 0.15 lb/MMBtu NO_x for eastern bituminous coals
- Achieve < 0.10 lb/MMBtu NO_x for western sub-bituminous or lignitic coals
- Achieve economics at least 25% less than SCR-only technology
- Validate NOx control technology through large (15 MWt) pilot scale demonstration
- Evaluate the engineering feasibility and economics for representative plant cases
- Provide input to develop commercial guidelines for specified equipment
- Provide input to develop a commercialization plan for the resultant technologies

WORK PLANNED FROM PREVIOUS REPORT:

Task 2.1 – Test Fuels Characterization

- Samples of the candidate low reactivity bituminous coals will be obtained and characterization work will be initiated in June.

Task 2.2 – Low NOx Pyrolysis Burners

- Proposed, draft overfire air elevation locations will be compared with that of typical, existing field units in order to enable a final selection to be made.

Task 2.3 – Global Mixing Process Improvement

- Eight of the 16 parametric runs to evaluate global mixing will be completed in June. In addition, a user-defined function to calculate the degree of mixing for a given SOFA arrangement will be developed. Finally, chemical kinetic modeling to investigate / evaluate the high temperature SNCR process will be begun.

Task 2.4 – Advanced Control System Design

- Complete investigation of secondary approaches to obtain data for neural net model development including identification of candidate (field) source units.
- Continue MatLab / Simulink air and fuel flow balancing controller modeling
- Complete engineering design of fuel and air flow control system for large pilot scale testing and procure additional needed materials. This involves designing cost effective modifications that may improve the usefulness of BSF test data for neural net modeling as well as making balancing tests easier to perform.
- Identify approach(es) to address on-line carbon in ash analysis needs.

Task 3.1 – Test Planning & Facility Preparation

- Pursuant to project Milestone #5, General Test Facility Preparation, check-out of the BSF plumbing / mechanical and electrical systems will be completed by the revised date of June 30. Remaining, planned work associated with this activity includes:

Plumbing / Mechanical	% Completed
- Complete the integrity testing of the "V – Hopper,"	50
- Complete the refurbishment of waterbed compartments,	85
- Inspect the main secondary air flow ducting (FD fan to BSF),	0
- Complete inspection of all air & water utility plumbing systems,	50
- Complete inspection of the coal transport lines	40
Electrical	
- Complete inspection / operate facility fans (FD & ignitor)	50

In addition, the following combustion test facility preparation work will also occur in June:

Plumbing / Mechanical

- Check coal line orifice spools,
- Schedule sootblower maintenance,
- Reinstall superheater tube-banks,
- Continue BSF water-jacket hydro testing,
- Reinstall combustion air dampers,
- Inspect coal feed silo systems operation,
- Order required flexible coal piping,
- Inspect / repair main water control valve.

Electrical

- Service / calibrate pulverized coal feeder,
- Upgrade direct fired air heater burner,
- Refurbish individual windbox compartment flow devices,
- Install remote I/O for new DCS,
- Select flame scanner hardware,
- Determine action with regard to on-line carbon in ash measurement.

Task 4 – Carbon Burnout System Evaluation

- The field unit for CBO™ cost / performance evaluation will be selected. In addition, preliminary CBO™ cost and performance data will be transferred from Progress Materials to U.S. Power Plant Laboratories.

Task 5 – Engineering Systems Analysis & Economics

- Review previous studies on economics of low NOx systems. Set-up the economic model to perform cost comparison between the selected preliminary systems.

ACCOMPLISHMENTS FOR REPORTING PERIOD:

Task 2.1 – Test Fuels Characterization

- *Samples of the candidate low reactivity bituminous coals will be obtained and characterization work will be initiated in June.*

Final agreement was reached both internally and with the respective advisory panel members on the three test fuels for use during the combustion test program (refer to Table 1). As shown, these fuels represent each of three desired categories with respect to coal property requirements for the test work. These include: (1) a low reactivity (med vol) bituminous coal (~25% VM), (2) a subbituminous coal, and (3) a high reactivity (high vol) bituminous coal (~35% VM). The intent of these selections is to bracket the range of likely coals for use with an ultra-low NOx integrated system during the combustion testing, thereby bracketing the range of expected performance benefit for eventual field retrofit.

Table 1 -- Large Pilot Scale Combustion Test Fuels

	High Vol Bit	Sub Bit	Med Vol Bit
Proximate			
VM	35.8%	29.5%	24.3%
FC	43.5%	34.5%	57.9%
FC/VM	1.22	1.17	2.38
VM, DAF	45.1%	46.1%	28.1%
Ultimate			
Moisture	14.1%	31.2%	-
Hydrogen	4.6%	3.1%	4.6%
Carbon	64.0%	48.4%	71.8%
Sulfur	2.3%	0.4%	1.5%
Nitrogen	1.0%	0.6%	1.3%
Oxygen	7.2%	11.4%	7.2%
Ash	6.7%	4.9%	13.7%
Total	100.0%	100.0%	100.0%
HHV, BTU/lb	11,737	8,150	12,689

A sample of the low volatile bituminous coal is being procured for laboratory and bench scale evaluation during the month of July.

Task 2.2 – Low NOx Pyrolysis Burners

- *Proposed, draft overfire air elevation locations will be compared with that of typical, existing field units in order to enable a final selection to be made.*

Figure 1 compares the relative location of two, alternate separated overfire air (SOFA) elevations in the BSF to that of a range of field units retrofit with the TFS 2000™ firing system. As shown, the second of the two selected locations (BSF 2) is most representative of that of a typical field unit, falling within the range of field lower SOFA locations, while extending the range with respect to the upper SOFA, there by bracketing expected field performance on a staged residence time basis.

Further evaluation of possible overfire air locations based on BSF configurations 2 will occur in July, with final selection / installation occurring in August.

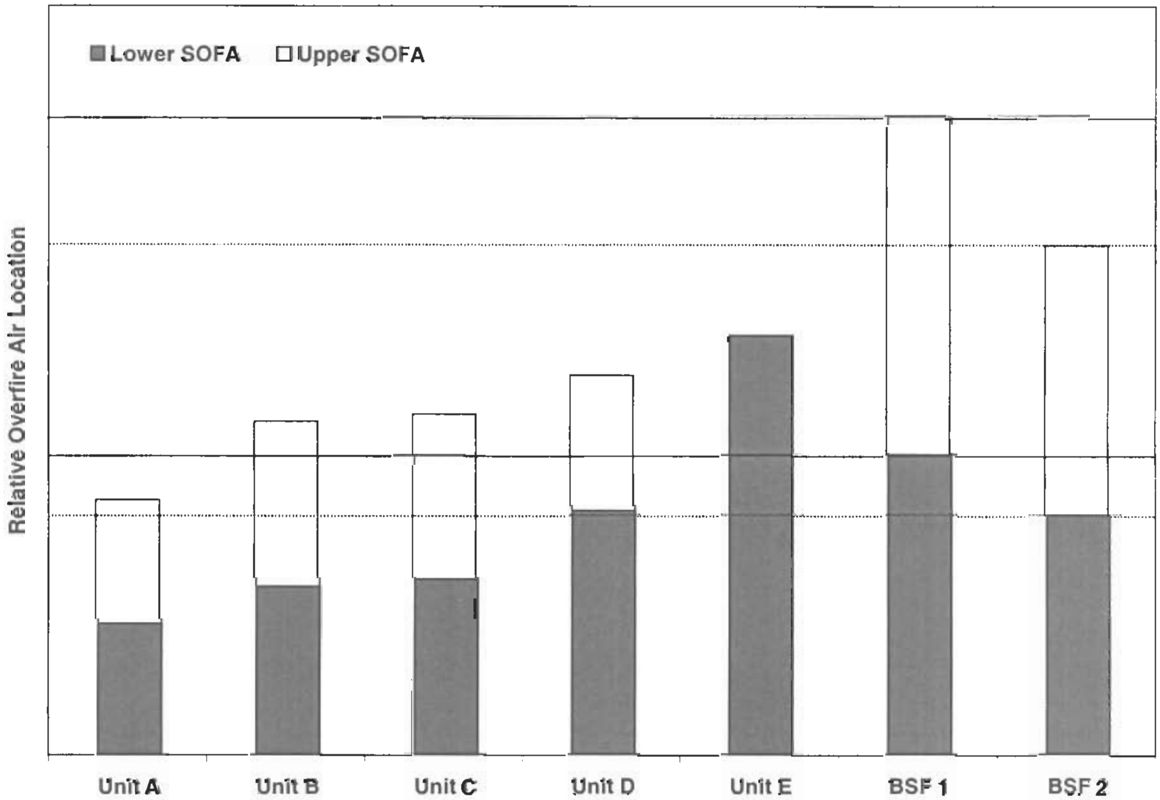

Figure 1 – Relative Overfire Air Locations: BSF vs. Field Units

The first set of the scaled-down version of the LNCFS™-P2 low NOx pyrolysis burners to be tested in the BSF has been received as shown in Figure 2. Two different sets of burners having differing exit areas are being built to maintain a constant outlet velocity as the transport air to fuel ratio is decreased during the test program. The second (high velocity) set is due to arrive in Windsor in July.

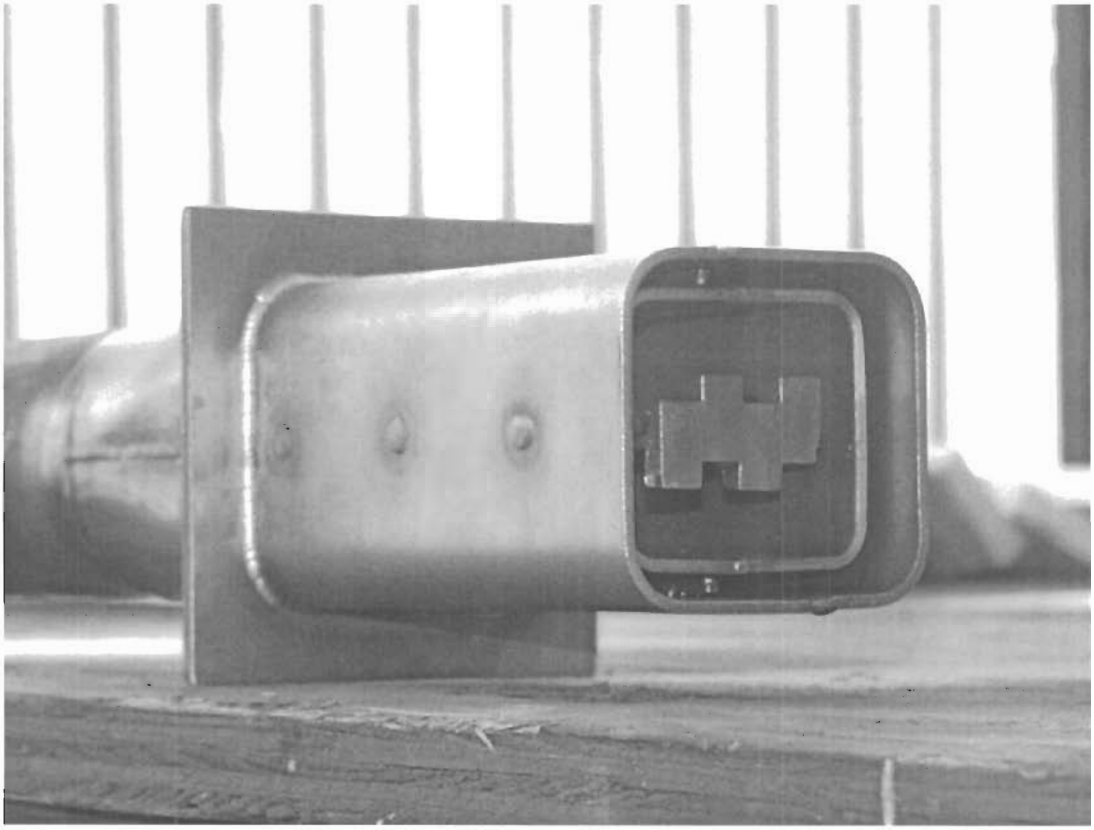

Figure 2 – Photo of the coal nozzle tip to be used in the BSF testing.

In addition to the low NOx burners, the modified separated overfire air (SOFA) assemblies for use during the upcoming BSF testing have been received. A photo of a modified SOFA assembly is shown in Figure 3. In the previous BSF testing, only the upper 2 nozzles of the SOFA assembly were used. For the subject testing, a new, larger air compartment was added to the bottom of the SOFA assembly in order to increase the range of air velocities and mass flow rates / stoichiometries that can be tested in the BSF. This added flexibility increases our ability to study and understand the impact of jet velocity on the penetration and mixing of the overfire air with respect to unburned carbon and CO oxidation.

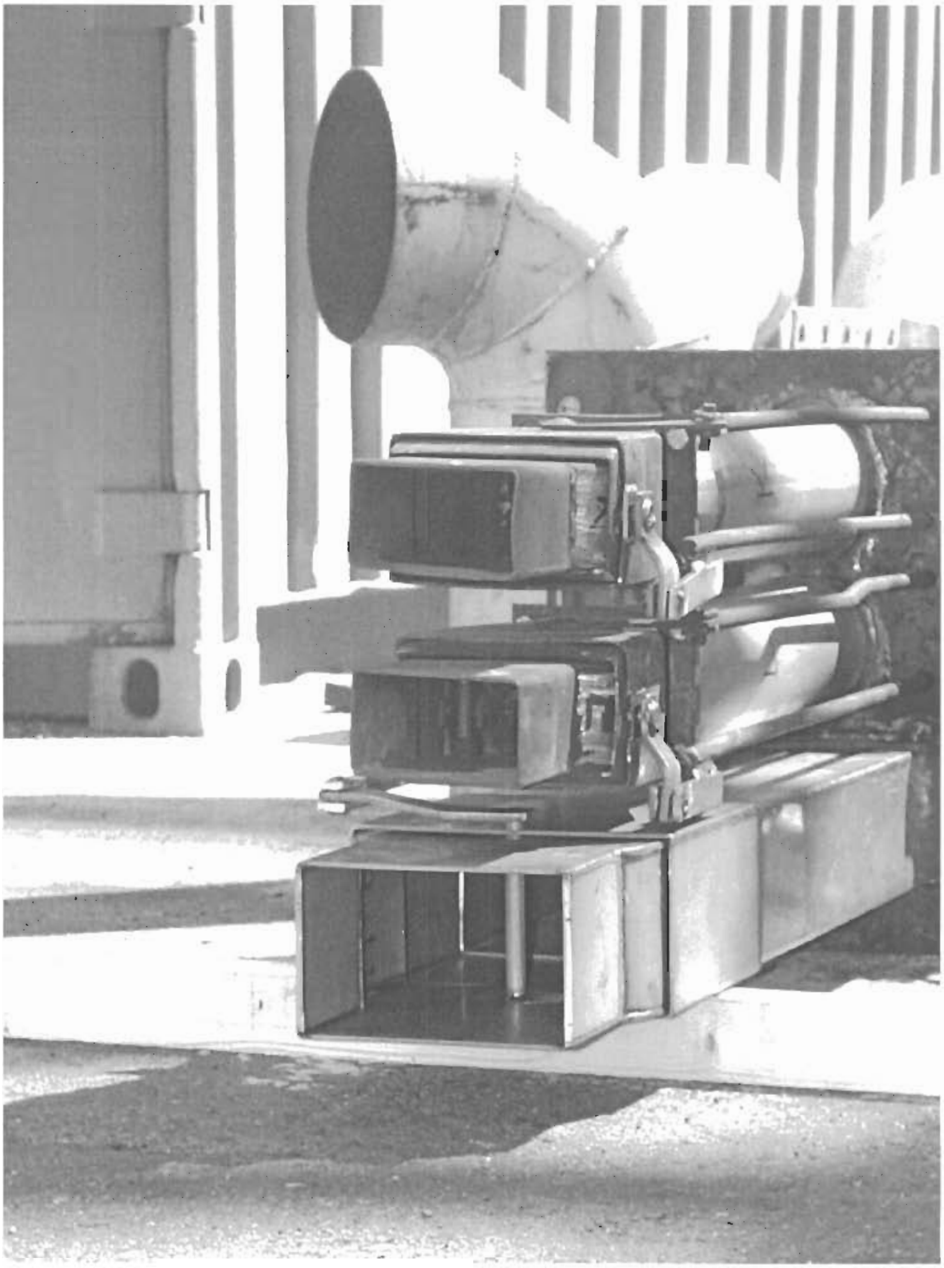

Figure 3 – Photo of the modified SOFA assemblies to be used in the BSF testing.

Task 2.3 – Global Mixing Process Improvement

- *Eight of the 16 parametric runs to evaluate global mixing will be completed in June. In addition, a user-defined function to calculate the degree of mixing for a given SOFA arrangement will be developed. Finally, chemical kinetic modeling to investigate / evaluate the high temperature SNCR process will be begun.*

To date, eleven (11) parametric, computational fluid dynamic (CFD) runs have been completed to examine the impact of velocity and location on the degree of separated overfire air (SOFA) mixing. For this work, the SOFA mixing at a given plane is defined as:

$$Mixedness = \sum_{n=1}^{n_{tot}} M_n \frac{(x_n - x_{final})}{x_{final}}$$

where n is the local grid cell, n_{tot} is the total number of cells on a given horizontal plane, M_n is the normalized mass flux through cell n, X_n is the oxygen mole fraction in cell n, and x_{final} is the average oxygen mole fraction at the furnace outlet, which was 0.027 (2.7% O2 by volume) for these simulations.

Figure 4 shows the predicted improvement in SOFA mixing at the horizontal furnace outlet plane (boiler nose) of the BSF for four modifications to a standard, corner fired overfire air arrangement ("T-Fired Overfire Air"). For this work, the modifications focused on variations in overfire air velocity as compared to present (field) design values. As expected, the degree of SOFA mixing increases with velocity (decreasing nozzle free area) as shown in the figure, suggesting a significant improvement in mixing can be made through the use of higher OFA velocities for current T-fired designs. It should be noted that the mass flow rate and temperature of the overfire air was held constant for each of these cases as was the main windbox configuration.

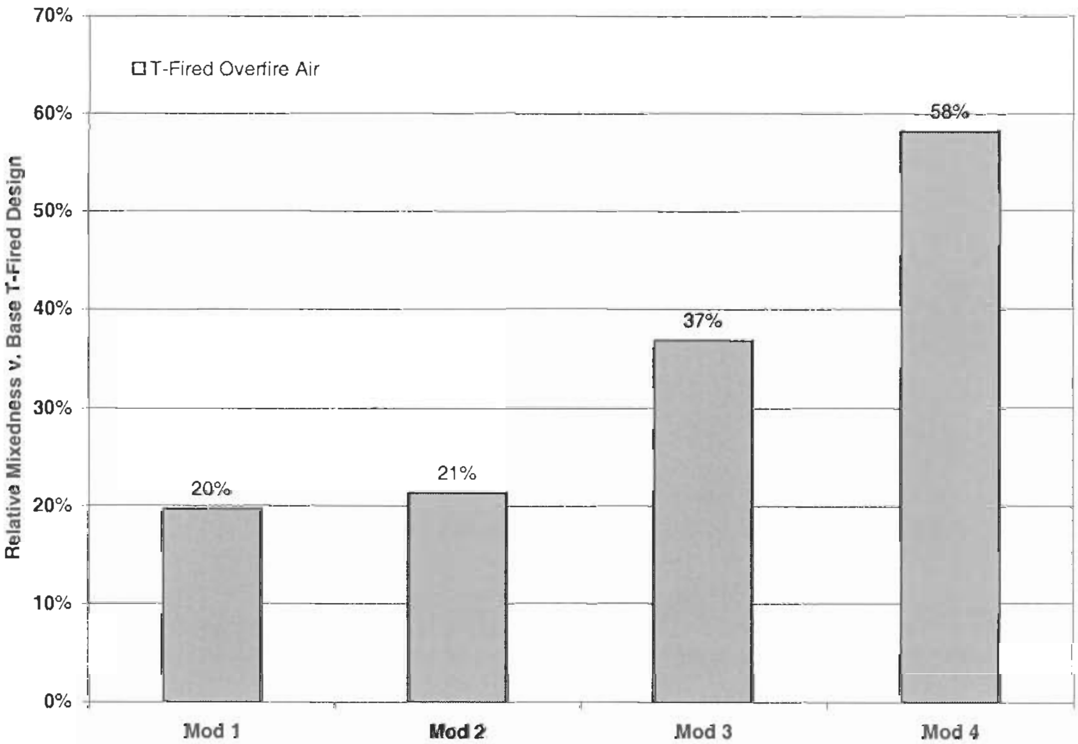

Figure 4 – Relative SOFA Mixedness v. Velocity for T-Fired OFA Systems

In addition to the above mentioned T-fired studies, a series of cases was run injecting the overfire air from various wall-fired locations to examine the overall impact on bulk furnace mixing. The computational grid used for this study was designed with 3, equidistant, SOFA nozzle locations on each wall as shown in Figure 5. The left, mid, and right designations refer to the SOFA nozzle location when viewing the inlets from outside of the boiler.

Each of the wall fired cases was run using one or more of the SOFA nozzles on each wall to maintain total free areas, and thus velocity, consistent with that of the T-fired work.

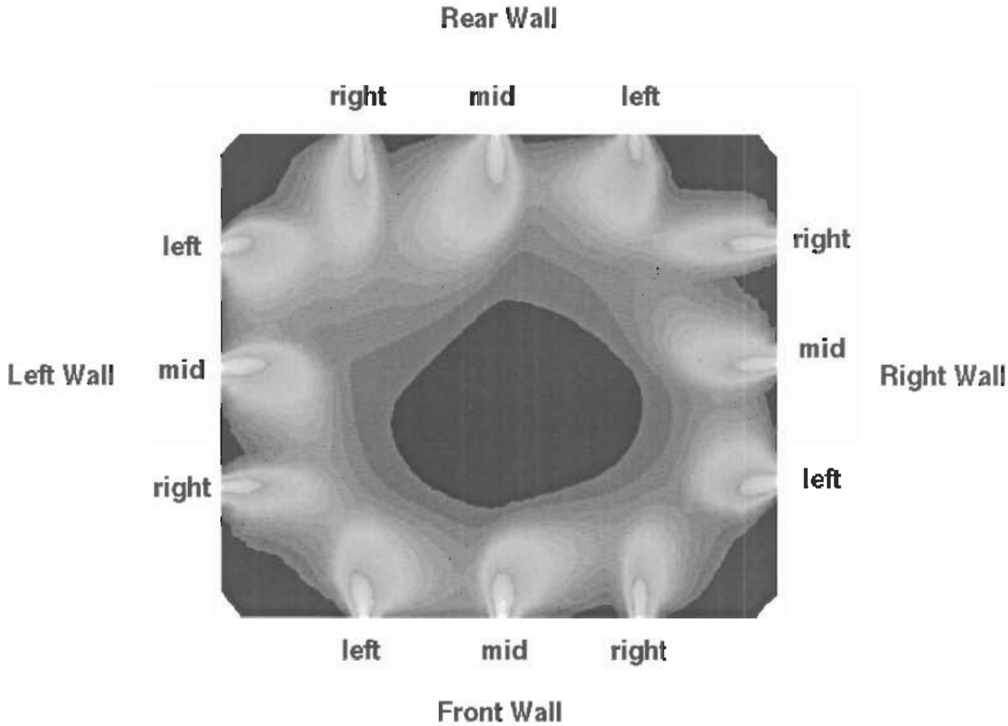

Figure 5 – SOFA Nozzle Locations for Wall-fired Overfire Air Study

Figure 6 shows the predicted SOFA mixing relative to a standard T-fired design for several cases with SOFA nozzles at different locations on the boiler walls ("Wall Fired Overfire Air"). In all but one of the test cases, the mixing for the evaluated wall fired SOFA configuration was worse than that of a T-fired case with an equivalent total free area.

In T-fired SOFA configurations, the air is introduced through the corners which results in high oxygen concentrations near the walls. With sufficient residence time above the SOFA nozzles, the oxygen will mix into the center of the furnace. However, in general the predicted oxygen concentration is higher near the walls and lower in the center of the furnace. In contrast, the wall-fired SOFA configurations were more easily able to penetrate to the center of the furnace, but often left pockets of high CO in the corners and near the furnace walls. To address this issue, additional cases are being run to investigate other SOFA configurations including combinations of T- and wall fired designs as a means to optimize mixing on the cross section of the boiler at a given overfire air velocity.

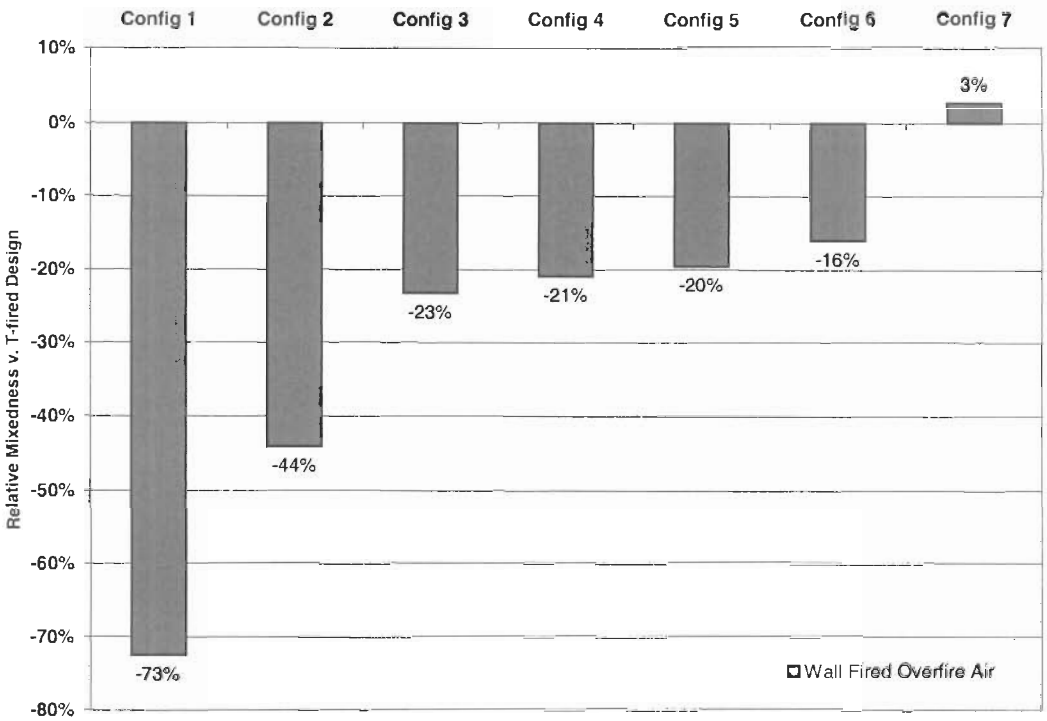

Figure 6 – Predicted SOFA mixing in the BSF as a function of nozzle location.

The chemical kinetic modeling of the SNCR process using Chemkin 3.5 was initiated during the month of June. A methodology is being developed to adequately approximate the gas composition and temperature profile for coal combustion under deeply staged conditions.

Task 2.4 – Advanced Control System Design

- *Complete investigation of secondary approaches to obtain data for neural net model development including identification of candidate (field) source units.*

Secondary approaches to obtain data for neural net model development were investigated in June, including identification of possible field source units. As part of this work, Pavilion Technologies, a commercial neural net based optimization and control company, was invited and has agreed to participate in the project and will supply the following information and support:

1. Assistance with obtaining unit data suitable for NOx – heat rate, carbon in ash modeling from at least one large tangentially fired pulverized coal utility boiler.

2. Engineering consulting to support neural net based NOx – heat rate, carbon in ash modeling of the field data from the large tangentially fired pulverized coal utility boiler above, as well as consulting support for other neural net modeling efforts such as modeling the above parameters with test data from the USPPL Boiler Simulation Facility.

3. Consulting support in the engineering systems analysis and economics task of this project. Specifically, Pavilion will provide experience based cost-benefit information for the application of the Pavilion's Power Perfecter to tangentially fired pulverized coal utility boilers.

- *Continue MatLab / Simulink air and fuel flow balancing controller modeling*

Further MatLab / Simulink air and fuel flow balancing controller modeling has been postponed in lieu of providing support to critical path, facility preparation and controls related efforts.

- *Complete engineering design of fuel and air flow control system for large pilot scale testing and procure additional needed materials. This involves designing cost effective modifications that may improve the usefulness of BSF test data for neural net modeling as well as making balancing tests easier to perform.*

Various concepts for the design of the fuel and air flow control system for large pilot scale testing have been evaluated and preliminary engineering has been completed. A final design for use in the BSF will be completed in July.

- *Identify approach(es) to address on-line carbon in ash analysis needs.*

Based upon short comings of commercially available instrumentation for on-line carbon in ash analysis it was decided to utilize existing USPPL expertise to build a laboratory scale, on-line extractive sampling carbon in ash (CIA) sensor system for use on this project. Engineering design, and materials procurement activities on this work will be performed in July.

Additional Items Completed in June:

Invited project participation from additional international coal flow sensor vendors. In addition to the procured ABB Kent Taylor instrumentation sensors, Acoustica (Norway) and SWR Engineering (Germany) have responded with a desire to participate by supplying on a loan basis, coal flow sensor systems for pilot scale evaluation.

In addition, all major material items have been received for upgrade of the large pilot scale test facility control system. Graphical interface and environment conversion is underway and installation, reconfiguration of DCS Software and switch-over to the new system is planned for July 17 for this project related, internally funded activity.

Task 3.1 – Test Planning & Facility Preparation

- *Pursuant to project Milestone #5, General Test Facility Preparation, check-out of the BSF plumbing / mechanical and electrical systems will be completed by the revised date of June 30.*

Check-out of all, remaining plumbing/mechanical and electrical systems was completed in June in fulfillment of Milestone #5. This included the following work:

Plumbing / Mechanical	% Completed
- Complete the integrity testing of the "V – Hopper,"	100
- Complete the refurbishment of waterbed compartments,	100
- Inspect the main secondary air flow ducting (FD fan to BSF),	100
- Complete inspection of all air & water utility plumbing systems,	100
- Complete inspection of the coal transport lines	100
Electrical	
- Complete inspection / operate facility fans (FD & ignitor)	100

In addition, the following combustion test facility preparation work was initiated and / or completed in June:

Plumbing / Mechanical	% Completed
- Check coal line orifice spools,	100
- Schedule sootblower maintenance,	100
- Reinstall superheater tube-banks,	100[1]
- Continue BSF water-jacket hydro testing,	100
- Reinstall combustion air dampers,	100
- Inspect coal feed silo systems operation,	100
- Order required flexible coal piping,	0[2]
- Inspect / repair main water control valve.	100

[1] *After reinstallation, additional leaks were found in the top of the superheaters in a region not included in the prior repair / reinstallation work. These new leaks will be repaired in July.*

[2] *A supply of flexible coal piping was found to exist in-house and will be consumed in advanced of purchasing additional, new material.*

Electrical	
- Service / calibrate pulverized coal feeder,	100
- Upgrade direct fired air heater burner,	30
- Refurbish individual windbox compartment flow devices,	70
- Install remote I/O for new DCS,	80
- Select flame scanner hardware,	100
- Determine action with regard to on-line carbon in ash measurement.	100

The following additional tasks were also completed in June:

- Cleaned scale from combustion air ducting
- Q-pipe damper operation tested and verified
- Soot blower serviced (mechanical operation is fine, control system will be repaired).
- BSF RTD's removed and sent out for calibration.

Task 4 – Carbon Burnout System Evaluation

- *The field unit for CBO™ cost / performance evaluation will be selected. In addition, preliminary CBO™ cost and performance data will be transferred from Progress Materials to U.S. Power Plant Laboratories.*

No activity occurred on the CBO™ evaluation task in the month of June. The noted work scope will be performed in July and August, 2000.

Task 5 – Engineering Systems Analysis & Economics

- *Review previous studies on economics of low NOx systems. Set-up the economic model to perform cost comparison between the selected preliminary systems.*

Reviewed previous in-house conducted studies on the economics of low NOx emission systems. Continued developing a preliminary cost comparison between various ultra-low NOx control systems. Eight preliminary system designs are being evaluated for cost comparison. These are: 1) Base Case (as is design), 2) TFS 2000™R plus advanced control system, 3) TFS 2000™R plus advanced control system plus coal fines injection (CFI), 4) TFS 2000™R plus advanced control system plus CFI plus SNCR, 5) TFS 2000™R plus advanced control system plus CFI plus SCR, 6) TFS 2000™R plus SCR, 7) Base Case plus SCR and 8) TFS 2000™R. Input data to an in-house developed proprietary economic model is being completed.

In addition to the above, the final case study field units were selected for engineering systems and economic evaluation. Selected units include:

1) A 330 MW PacifiCorp unit burning a Powder River Basin subbituminous coal, and
2) A 550 MW Indianapolis Power and Light Company (IPALCO) unit burning a medium volatile bituminous coal.

As part of the evaluation work, consideration will also be given to the performance and economic impact firing of a low volatile bituminous coal in the 550 MW IPALCO unit in order to assess the cost and performance of proposed system designs across a range of fuel types / reactivities.

WORK PLANNED FOR NEXT REPORTING PERIOD:

Task 2.3 – Global Mixing Process Improvement

- The remaining parametric runs to evaluate SOFA mixing will be completed in July. Additional post processing of the existing cases will be started to investigate the impact of SOFA mixing on the mass flow and temperature distributions entering the convective pass. Chemical kinetic modeling to investigate / evaluate the high temperature SNCR process will be continued.

Task 2.4 – Advanced Control System Design

- Install and configure AC 460 DCS Upgrade (internally funded, project related work)
- Obtain unit data suitable for NOx-heat rate and carbon in ash neural net modeling from at least one large Tangentially Fired Pulverized Coal Utility Boiler and begin modeling effort.
- Receive the first of the PC flow meters; develop detailed plans for August installation.
- Build on-line extractive sampling CIA sensor system
- Build optical combustion sensing system for use during BSF testing.

Task 3.1 – Test Planning & Facility Preparation

- The following work will be completed in July for Task 3.1:

  Plumbing / Mechanical

  - Finish repairing identified leaks in the BSF water-jacket
  - Install corner SOFA assemblies
  - Service CFS air buckets
  - Install coal and air nozzles in windbox
  - Procure materials for installation of coal mass flow meters
  - Install 18" flexible ducting for combustion air system
  - Remove blankoff plate after Maxon (direct fired air preheat / warm-up) burner