Computer Model Evaluation of Overfire Air on a Tangential PC Fired Boiler

Technical Report

Computer Model Evaluation of Overfire Air on a Tangential PC Fired Boiler

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REPORT SUMMARY

This report describes results of a combustion modeling effort and its predicted impacts on NOx emissions. Detailed descriptions of the Computational Fluid Dynamics (CFD) model, assumptions made, and recommendations are presented.

Background

In response to increasingly stringent emission reductions mandated by the Clean Air Act Amendments of 1990, Oglethorpe Power Corporation (OPC) and the Municipal Electricity Authority of Georgia (MEAG) are actively investigating options to meet those future compliance mandates. As part of their compliance strategy, the Robert W. Scherer Power Plant, one of the largest electricity generating fossil-fired plants in the United States, located in Juliette, Georgia, is considering the evaluation of an improved overfire air system. OPC, MEAG, and EPRI established a Tailored Collaboration (TC) agreement to conduct a numerical modeling study of a conceptual staged combustion system while firing an alternate coal type.

Objectives

- To evaluate the potential for NOx emissions reduction on a tangential pulverized coal (PC) fired boiler through use of separated overfire air (SOFA) ports.
- To evaluate the impact of firing a Powder River Basin (PRB) coal on NOx emissions under SOFA conditions.

Approach

The evaluation was carried out by compiling necessary instrumental data from Plant Robert W. Scherer Unit 2 and constructing a three-dimensional (3D) computer model. With data supplied by the plant, the model was then entered into the CFD commercial code FLUENT. The initial simulation consisted of computing the model under full load operating conditions to serve as a baseline case. Further parametric case runs were then conducted and compared to these baseline predictions.

Results

CFD analysis provided insightful trends in combustion behavior for the major parameters of interest. Modeling predictions from this study indicate that SOFA is a viable option for this plant as a technique to reduce its baseline NOx emissions. Under simulated firing of a low-rank PRB coal, NOx predictions were lower than those under its baseline eastern bituminous coal. The results indicate an increasing trend in unburned carbon in the ash and carbon monoxide as a function of staging.

EPRI Perspective

This study continues EPRI's investigations in the area of cost-effective combustion options for mitigating NOx emissions from pulverized coal-fired boilers. Previous numerical simulation studies in this area include *Gas Cofiring Evaluation of a Tangential PC-Fired Boiler* (1000449), *Modeling of CSW's Pirkey Station OFA Ports and Potential Corrosion Conditions* (1001135), and *Modifications to pf Burners to Reduce NOx Emissions—Stanwell Power Station* (1004049). Other related EPRI reports include *Application of WIR Technology at CP&L's Weatherspoon Unit 3* (TE-113166), *Combustion Modifications to Reduce LOI* (TE-113769), *Computer Modeling of an Opposed Wall-Fired Boiler to Identify the Cause of Excessive Waterwall Corrosion* (TE-114643), and *Computer Modeling of TVA's Widows Creek Boiler to Assess Waterwall Corrosion Potential* (TE-114644).

Keywords

NOx reduction
Numerical simulation
Pulverized coal
Overfire air

ABSTRACT

A project was undertaken to evaluate the potential for NOx emissions reduction on a tangential pulverized coal fired boiler through use of separated overfire air ports (SOFA). This was undertaken on the Robert E. Scherer Power Plant Unit 2 owned by Oglethorpe Power Corporation and the Municipal Electricity Authority of Georgia. The impact of firing a Powder River Basin coal on NOx emission was determined. Modeling predictions from this study indicate that SOFA is a viable option for this plant as a technique to reduce its baseline NOx emission. Under simulated firing of a low-rank PRB coal, NOx predictions were lower than those under its baseline eastern bituminous coal, and it appears the desired goal of 0.15 lbs/Mbtu can be met. Project results also indicate an increasing trend in unburned carbon in the ash and carbon monoxide as a result of staging.

ACKNOWLEDGMENTS

The investigators wish to address the invaluable cooperation of members of the Robert W. Scherer Plant engineering staff who provided vital information necessary to conduct this study. The following individuals are recognized for their cooperation and support:

Mr. Russell Briggs, Municipal Electricity Authority of Georgia

Mr. David Williams, Oglethorpe Power Corporation

Mr. Kerry Faulker, Oglethorpe Power Corporation

Mr. W. Scott Ramsay, Oglethorpe Power Corporation

EXECUTIVE SUMMARY

The objective of this study was to evaluate the mitigation of NOx emissions at Plant Scherer Unit 2 when firing PRB coal by using a numerical model. The scope of the investigation also included evaluating potential NOx reductions under its existing Closed Coupled Overfire Air (CCOFA) burner configuration and with a conceptual Separated Overfire Air (SOFA) design system.

The numerical model inputs were derived from a set of baseline performance data for operating conditions of Unit 2 while firing bituminous coal. Because the unit does not have firing experience with PRB coal, operating performance data from its sister Unit 3 was used to estimate a pseudo baseline condition for Unit 2. As such, the first two simulations were geared towards establishing a Baseline and PRB Pseudo-Baseline conditions.

Subsequently, eight parametric runs were conducted each firing PRB coal under either CCOFA or SOFA configurations. Each simulation ran under fuel rich or fuel lean conditions based on the available oxygen in the region upstream of the overfire air injection point. This parameter is referred to in this report as the burner zone stoichiometric ratio (BZSR). The BZSR range of operability for T-fired units is typically from 0.85 to 0.95 of overall furnace stoichiometry.

Predicted parameters from CFD studies present excellent qualitative insights into the operations and performance of combustion systems. Predictions of temperature, CO, NOx and Carbon-in-Ash (CIA) were generated from all simulations. Based on these results, the following observations can be deduced from this effort,

- All staged combustion simulations resulted in NOx emission reductions when compared to the baseline condition (bituminous coal under CCOFA configuration with a BZSR of 0.95 and overall SR of 1.16).
- One simulation addressed the performance of the conceptual SOFA design simulation while firing bituminous coal. The NOx reduction was marginal at -3% when compared to the CCOFA base condition. Other parameters such as temperature, carbon monoxide (CO) and CIA were minimally affected.
- Predicted Furnace Exit Gas Temperatures (FEGT), at the horizontal plane of the nose, were in close agreement with field pyrometric data reported from earlier performance tests. FEGT predictions varied to a maximum of 12% and a minimum of 6% as a function of BZSR from the baseline prediction of 2297°F (1258°C).

Investigation of the effect of firing PRB coal in Unit 2 yielded favorable results for NOx reductions. Figure ES-1 presents a graphical summary of the differential values of CO, NOx and

CIA for the PRB simulations as compared to the bituminous coal baseline predictions. From this plots, the following observations can be made:

- The conceptual SOFA design mitigates CO emissions more than the CCOFA design as the furnace staging increases. As shown in Figure ES-1a, the maximum CO predicted for the SOFA simulation at BZSR of 0.85 was relatively less than the CO level for the CCOFA configuration at 0.90. It should be noted that these numbers represent CO at the furnace exit. Stack CO levels will be significantly less due to CO oxidation through the convective passes.
- NOx emissions were reduced in all staged simulations with the greatest reduction achieved with the SOFA configuration at BZSR of 0.85. As seen in Figure ES-1b, the predicted relative NOx reduction was of the same magnitude for staging conditions above 0.85 for either SOFA or CCOFA. Simulations operated at or above stoichiometric air, however, predict a large increase in NOx for the conceptual SOFA design.
- Predictions for the PRB simulations suggest that SOFA is more prone to increases in CIA than with the existing CCOFA, although both simulations predict lower levels than the bituminous baseline. This is more likely due to the reduced burnout residence time with the SOFA ports.

Similarly, Figure ES-2 plots present the effect of staging as compared to the PRB pseudo-baseline case (BZSR = 0.95 with CCOFA). These plots allow a direct comparison of the performance of the CCOFA and SOFA configurations under PRB firing conditions.

Conditions simulated on this numerical modeling effort were based on the best available data supplied by the plant and complimented by operating experience documented in the open literature. Validation of these predictions is a challenging task for large scale furnaces as procuring detailed information is difficult due to time, availability and cost constraints. At the time of this writing, Plant Scherer has implemented the SOFA system in its Unit 2 boiler. Testing of the system will be completed during the Spring and Summer of 2002. Such tests are expected to provide validation data for the results of this effort.

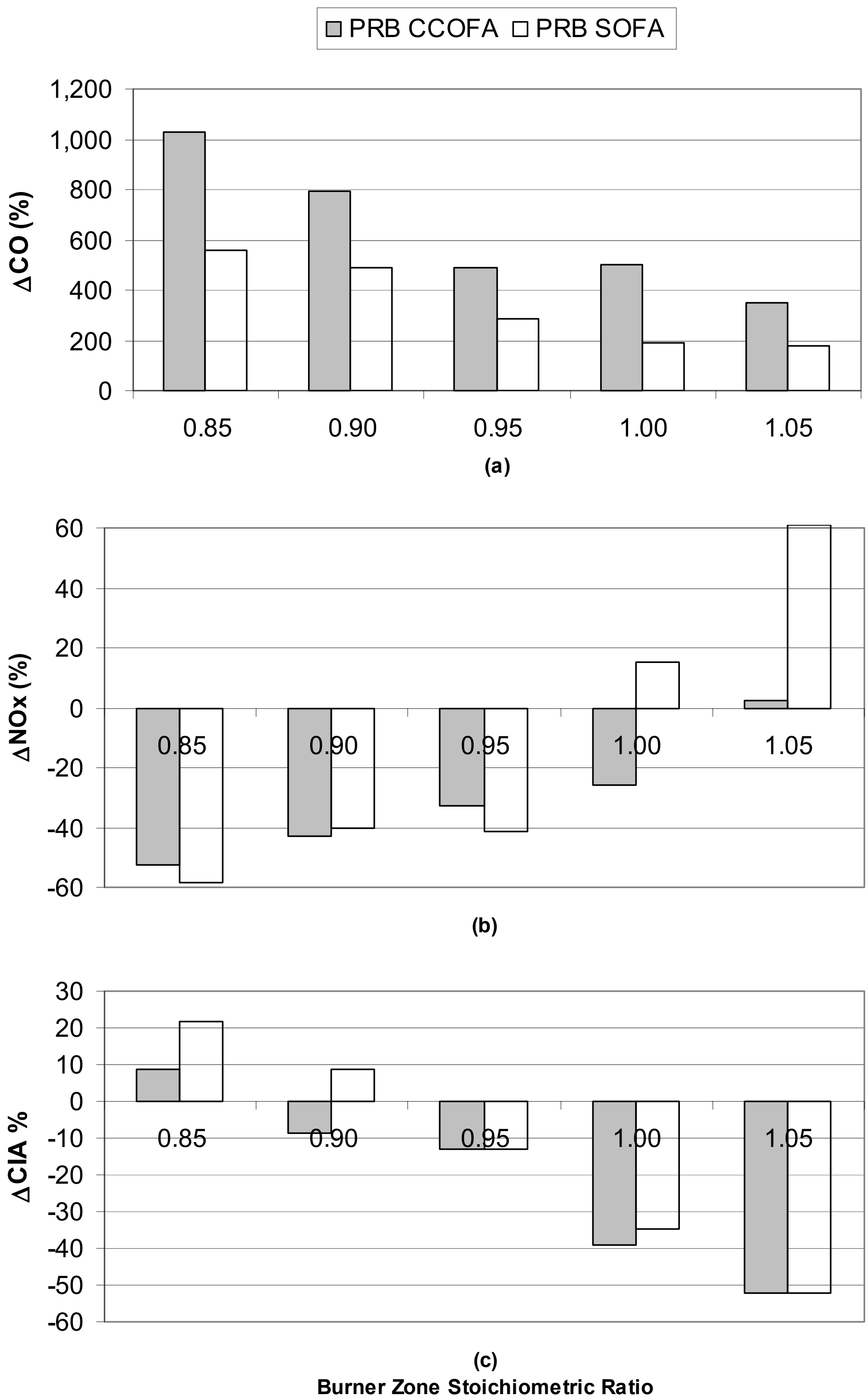

Figure ES-1
Differential Values for Predictions from PRB Simulations as compared to Bituminous Baseline

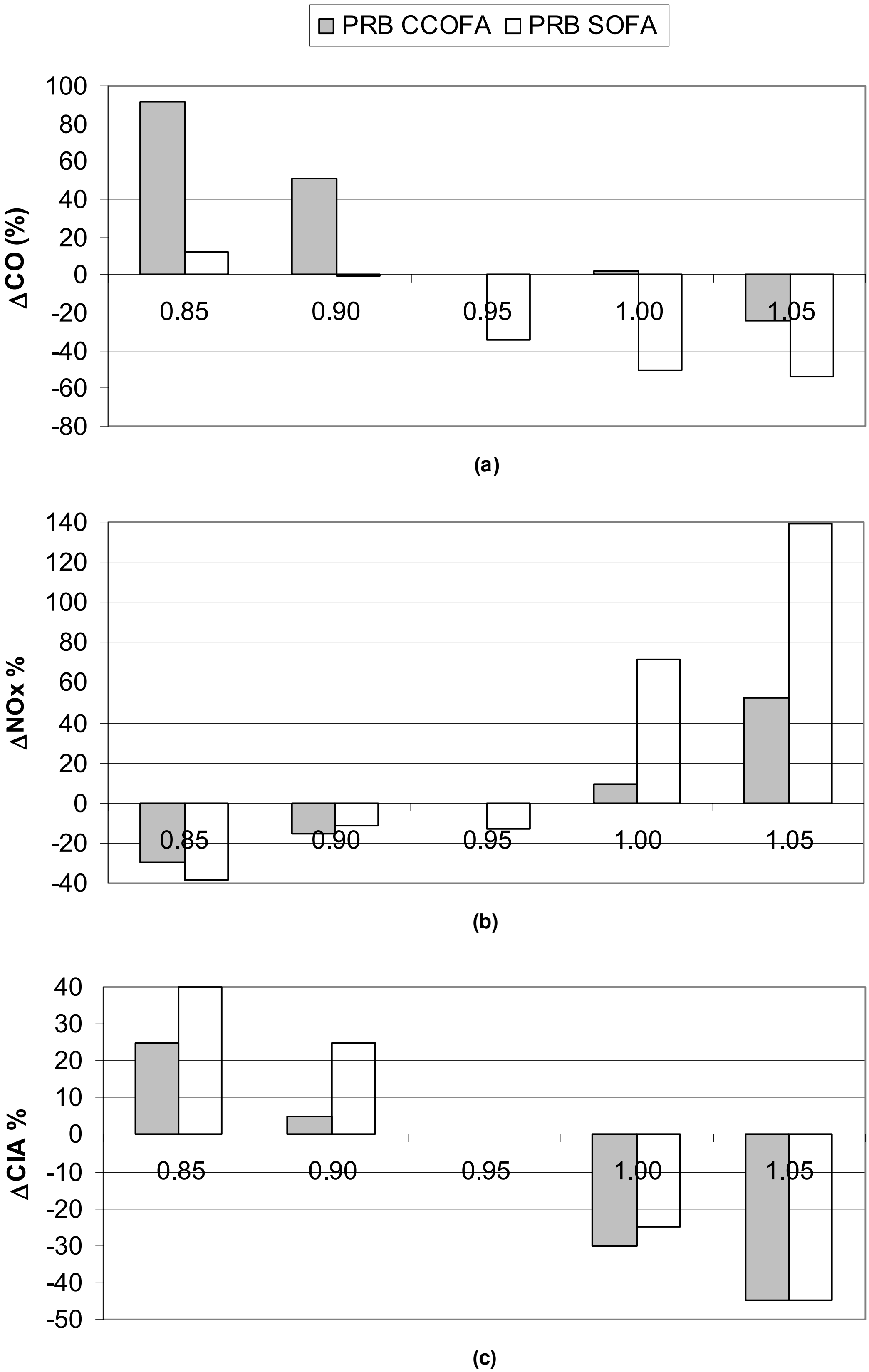

Figure ES-2
Differential Values for Predictions from PRB Simulations as compared to PRB Pseudo-Baseline

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INTRODUCTION

In response to increasingly stringent emission reductions mandated by the Clean Air Act Amendments of 1990, Oglethorpe Power Corporation (OPC) and the Municipal Electricity Authority of Georgia (MEAG) are actively investigating options to meet those future compliance mandates. As part of their compliance strategy, the Robert W. Scherer Power Plant, one of the largest electricity generating fossil fired plants in the United States, located in Juliette, GA, is considering the evaluation of an improved overfire air system.

EPRI, OPC and MEAG entered into a tailored collaboration agreement to conduct a study oriented at examining the effectiveness of current and future Overfire Air (OFA) technologies in combination with fuel switching for the reduction of NOx emissions. More specifically, the objectives of this study were to investigate the effectiveness of a conceptual design Separated Overfire Air (SOFA) system while firing a Wyoming PRB coal for NOx mitigation without jeopardizing unit operability and reliability.

Plant Robert W. Scherer has three 870 MW T-fired boilers, two of which currently fire a compliance eastern bituminous coal and a third which fires a PRB (Unit 3). The boilers are nearly identical although Units 1 and 2 have a membrane wall that divides the twin fireboxes while Unit 3 does not. Unit 1 and 2 currently has close coupled overfire air (CCOFA) ports and Unit 2 will soon be installing B&W SOFA ports. Current emission levels on bituminous coal without overfire air are around 0.50 lb/Mbtu and 0.35 lb/Mbtu with CCOFA. PRB currently fired with CCOFA achieves around 0. 22 lbs/Mbtu on Unit 3.

Unit Description

Unit 2 was designed to provide 5,789,914 Lb/hr (729.52 kg/s) of steam at 2,400 psig (1,723.66 kPa) with a 1,000°F (538°C) superheat and reheat temperatures. The Furnace cross section area measures nominally 47 feet (14.4 m) wide, 100 feet (30.4 m) deep. It is equipped with seven RP1103 bowl mills and two ABB RP 843 bowl mills, but only five ABB RP1103 mills are used at full load. All three units have nine burner elevations with the top two elevations utilizing smaller coal nozzles with approximately half the capacity of a normal nozzle. Only cooling air is supplied to the top two lower capacity burner elevations. When firing bituminous coal, the top two coal elevation, A and B, and the bottom two elevations, H and J, are normally out of service. When firing PRB, six elevations are used, C through H.

Unit 2 is equipped with flue gas re-circulation (FGR) to provide better steam temperatures for reheat and it is also equipped with a hot side precipitator. Two FGR fans introduce flue gas into the hopper area through two of three ports in each furnace. The third port has been blocked in order to push the FGR further into furnace.

The existing tangential firing system includes two levels of CCOFA approximately 2 feet above the uppermost coal elevation. A conceptual design SOFA system will be installed on Unit 2 in the next outage. The proposed location for these SOFA ports is 25 feet downstream from the existing CCOFA ports thereby increasing the rich gas mixture residence time. In addition, the conceptual SOFA design incorporates ports on the front and rear and walls with ports on the sidewalls whereas the existing CCOFA design are located above the traditional tangential burner column.

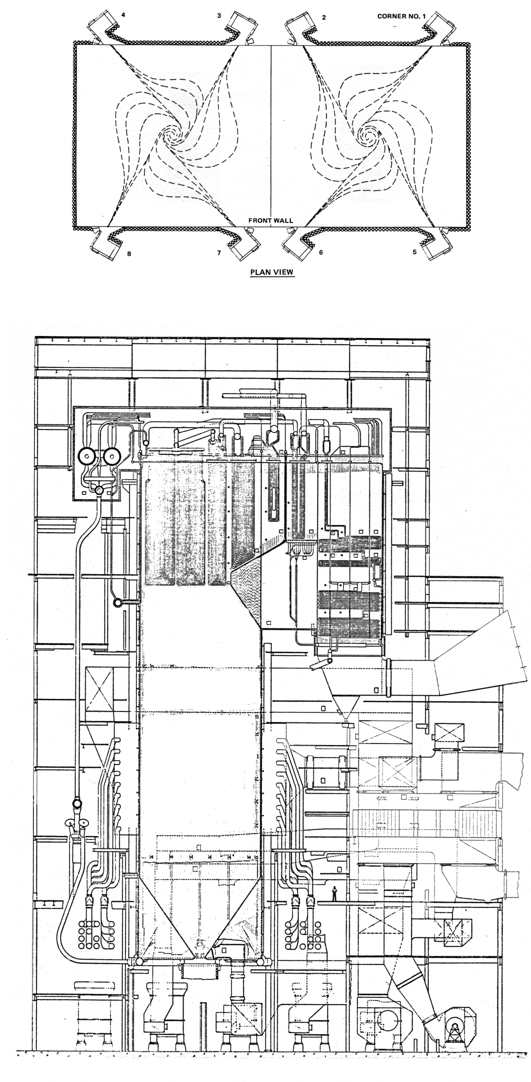


Figure 1-1
Side Elevation and Plan View of Unit 2 Furnace

2
BACKGROUND

NOx Formation

A basic knowledge of NOx formation is beneficial to understanding how NOx control technologies affect emissions. NOx is collectively comprised of two compounds: nitric oxide (NO) and nitrogen dioxide (NO_2). NO is the predominant compound found in NOx at the stack and typically accounts for 95% to 98% of the total NOx emitted from fossil fuel-fired boilers. The combustion process involves three main sources of NOx:

1. Fuel NOx, which refers to the conversion of chemically bound nitrogen in the fuel

2. Thermal NOx, which refers to the high temperature reaction of nitrogen and oxygen in the combustion air

3. Prompt NOx, which refers to the rapid formation of NOx in the flame front due to reactions between hydrocarbons and atmospheric nitrogen.

Because most of the baseline NOx is formed via fuel and thermal related reactions, control techniques typically concentrate on reducing these forms of NOx.

Fuel NOx generally arises from the oxidation of organically bound nitrogen compounds associated with coal. Only a fraction of the fuel nitrogen is converted to NOx, with the conversion rate decreasing as the nitrogen content increases. Bituminous and sub-bituminous coals within the continental United States exhibit a relatively narrow range of fuel nitrogen levels, typically between 1.0% to 1.7%. Relatively insensitive to flame temperature, the most significant property affecting fuel nitrogen conversion is the availability of oxygen to react with the fuel nitrogen compounds in their gaseous state. Thus, the principal control measure for fuel nitrogen conversion is staged combustion, either within a burner or more globally within the furnace, in which a fuel rich zone is initially created to limit fuel nitrogen oxidation to nitric oxide. After reduction of the fuel nitrogen species to molecular nitrogen, the balance of the combustion air can then be added.

Thermal NOx is dependent upon the reaction temperature, local fuel and oxygen stoichiometry, and residence time at the peak reaction temperature. During combustion, high temperatures dissociate nitrogen and oxygen in the air, leading to the formation of NOx according to a set of reactions referred to as the extended Zeldovich mechanism. NOx formation increases exponentially with temperature, becoming significant above 2800°F (1538°C). Thus, formation of thermal NOx is best controlled by reducing the temperature, and less importantly, reducing the concentration of available oxygen, and/or the residence time at the peak temperature.

CFD Code Description

The FLUENT™ commercial CFD code utilizes a cell-volume based technique to transform the governing equations, of mass, energy and momentum, to algebraic equations that can be solved numerically. The solution to the system of equations is carried out by integrating the governing equations at each cell volume. This iterative scheme is repeated until the system yields a converged solution based on the user defined boundary conditions.

Gas Phase Combustion Model

In general, the code uses a Reynolds-Averaged Navier-Stokes (RANS) scheme for resolving the turbulent velocity field. In this study, a standard κ–ε turbulence model along with a Semi-Implicit Method for Pressure-Linked Equations (SIMPLE) velocity coupling algorithm were used. Heat transfer mechanisms include convection, conduction and most importantly radiation. The radiation heat transfer was simulated through a model based on the expansion of the radiation intensity into an orthogonal series of spherical harmonics.

Numerical simulation of combustion processes require precise modeling of the most controlling physical mechanisms. The combustion approach used in these simulations assumed the rate at which primary combustion reactions occur is limited by the rate of mixing. That is, for turbulent diffusion flames such as those in utility boilers, the rate of chemical reactions is faster than the mixing rate and full chemical equilibrium is assumed.

The effect of turbulence on the mean chemical composition is determined through the turbulence model under a parameter called the mixture fraction (*f*):

$$f = \frac{Z_{\kappa} - Z_{\kappa,O}}{Z_{\kappa,F} - Z_{\kappa,O}}$$

where Z_{κ} is the element mass fraction for some element κ. The subscript *O* refers to the value at the oxidizing stream inlets and subscript *F* refers to the value at the fuel stream inlets. The basis for the mixture fraction approach is that under a certain set of simplifying assumptions the instantaneous thermochemical state of the fluid at each cell is related to this parameter. Transport equations for individual species are not solved or defined from specified kinetic data but derived from the predicted mixture fraction distribution. The reacting system is treated using chemical equilibrium calculations and physical properties defined in the FLUENT™ database. Turbulence-chemistry interaction is accounted for by using a fast-equilibrium probability density function approximation (PDF).

Coal Particle Model

Solid fuel trajectories are calculated through a discrete phase model based on a Lagrangian frame of reference. The effect of turbulence fluctuations is accounted for by a Monte Carlo random walk approach. Integration of a force balance between the gas and solid phases, at each cell volume, determines the effect that each other exhort on the flow field. The code tracks the fate of each particle from its injection point at the coal nozzle until its consumption or departure from the computational domain.

The heat and mass transfer for the particles is occurs in four stages: 1) inert heating, 2) devolatilization, 3) char combustion, and 4) inert heating of remaining ash. In Stage 1, the coal particle undergoes heating until a temperature at which devolatilization starts. In Stage 2, the particle volatiles are consumed via a two competing Arrhenious rate scheme based on the model by Kobayashi. In Stage 3, char oxidation is simulated through a combined oxygen diffusion/kinetic rate model. Once all the carbon is consumed, the remaining ash particle is tracked while undergoing inert heating.

NOx Models

Because NOx concentrations generated in combustion systems are relatively small, it is commonly assumed that NOx chemistry has a negligible influence on the predicted temperature and flow fields of the combustion process. As a result, NOx concentrations are derived from a converged combustion solution through a post-processing step.

Sub-models used in this study included thermal NOx, fuel NOx and NOx destruction through reactions with hydrocarbons or reburn. Thermal NOx is modeled through an extended Zeldovich mechanism. The model uses an equilibrium assumption for oxygen radical concentration to calculate the NOx formation rate. The fuel NOx model utilizes a user specified distribution for nitrogen release between the volatile and char coal components. The mechanism for the fuel NOx assumes that volatile N converts to HCN then to NO whereas all char N converts directly to NO. The reburn model reactions are applicable for the temperature range of 2420°F $< T <$ 3320°F (1327°C $< T <$ 1826°C).

3 STUDY APPROACH

The combustion simulation for Unit 2 was carried out using the following approach:

1. Create a three-dimensional (3D) furnace model based on plant drawings. Dimensional parameters not available in the drawings, but vital to simulate the burner geometries, were measured by plant engineers from spare parts in storage. For the SOFA configuration, geometry dimensions were based on a conceptual design drawing provided by the plant.

2. Prior to initiation of the simulation, EPRI conducted an estimate of air and fuel inputs based on performance data from earlier tests conducted by a third party on Unit 2. The same procedure was used to establish a baseline operating condition while firing PRB coal except that the performance data originated from similar tests performed on Unit 3.

3. Once initial operating conditions were established for each fuel type, four runs were conducted based on the estimated BZSR of 0.95. The first two cases simulated CCOFA and SOFA baseline conditions while firing Eastern Bituminous coal. Similarly, the third and fourth cases, investigated the use of PRB coal also with a BZSR of 0.95.

4. For all simulations, predictions of furnace exit gas temperature (FEGT), major species concentrations of interest, such as CO and O_2, as well as CIA estimates, generated by performing a mass weighed integration at horizontal exit plane of the furnace. Upon convergence of the mass and energy balances, the NOx sub-model post-processor was run for each simulation.

Furnace Model Description

Figure 3-1 describes the furnace model dimensions and the extent of its boundaries. As shown, the computational domain begins at the ash hopper and ends at a horizontal plane near the furnace nose. This domain was subdivided into 450,000 independent cell volumes; 70% of which captured the main burner zone. Given the symmetrical nature of the twin furnace, only the north side furnace that incorporates burners 3, 4, 7, and 8, and it is bounded by the front and rear walls, the center division wall, and the left wall, were used to develop the model.

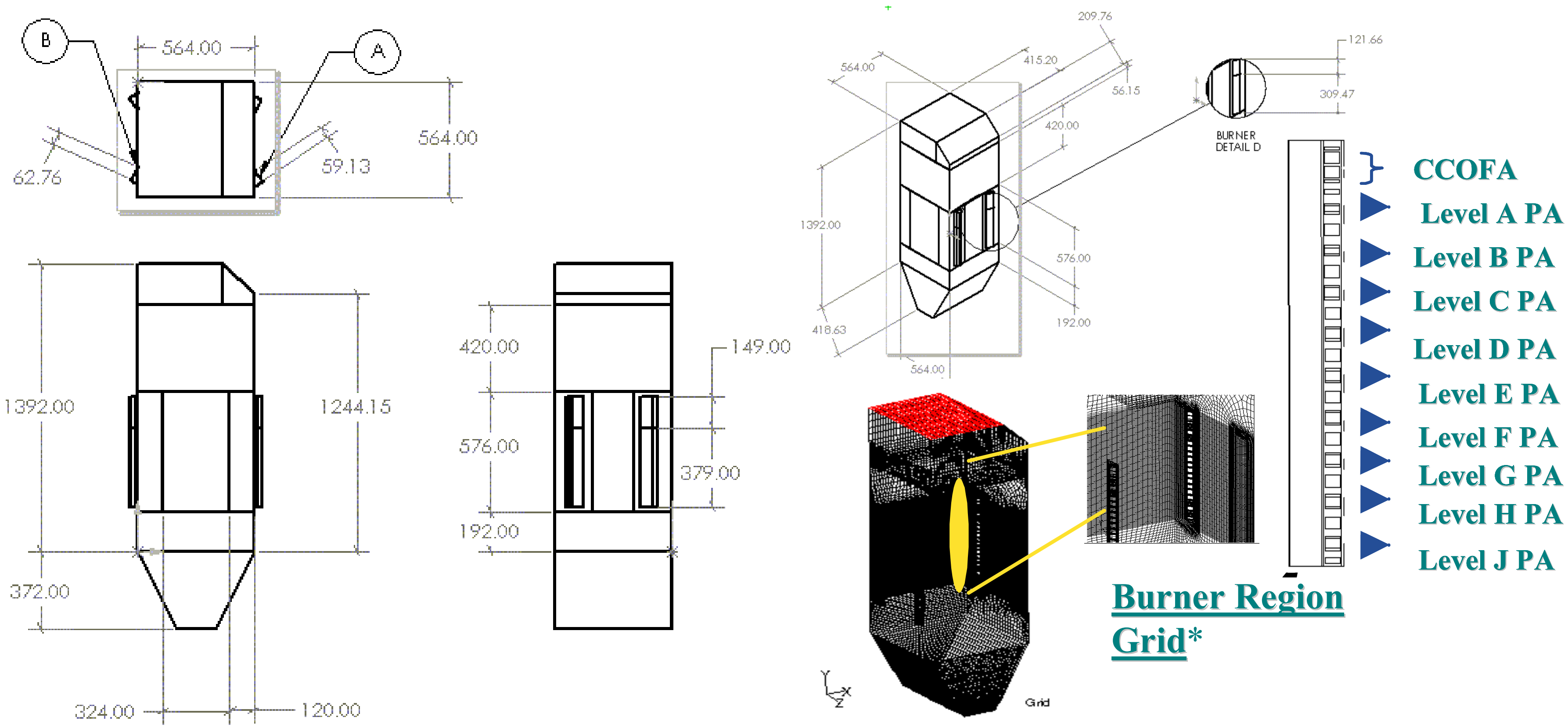


Figure 3-1
Furnace Model Dimensions with Isometric View of Numerical Grid

Baseline Operating Conditions

The objective of the first simulation focused on establishing the baseline full load operation of the unit under CCOFA staged operation (BZSR=0.95, total SR = 1.16). The operating data derived from a combination of Plant Information Network (PIN) data and field measurements from Test 10 of the April 21, 2000 Baseline Performance Testing. The second case investigated the effectiveness of the conceptual design SOFA ports under the same operating conditions of the baseline Case 1. The objective here was to have a direct comparison of the CCOFA performance as compared to the five SOFA port system.

Cases 3 and 4 simulated normal operating conditions as derived from Unit 3 but applied to Unit 2 for PRB coal (BZSR=095, total SR=1.11). Differences in furnace operation between PRB coal and bituminous coal included additional burner levels in service (C-J), lower primary air temperature, and lower overall exit stoichiometry. A summary of the relevant flows is presented in Table 3-1.

Table 3-1
Performance Test Operating Data Used for Numerical Simulations

Operating Factor	Baseline with Bituminous (Test#10, 4/2000)	Pseudo-Baseline with PRB (Test#1, 10/2000)
Gross Load (MW)	868	883
Coal Flow, lbs/hr (kg/s)	636,000 (80.1)	970,100 (122.3)
Primary Air, lbs/hr (kg/s)	1,351,585 (170.3)	1,622,747 (204.5)
Secondary Air, lbs/hr (kg/s)	5,979,766 (753.4)	6,380,788 (803.9)
Excess O_2, % dry	3.3	2.4
Primary Air Temp., °F, (°K)	167 (348)	120 (322)
Secondary air Temp., °F, (°K)	630 (605)	630 (605)
Furnace Stoichiometry	1.16	1.11

Due to lack of detailed secondary air flow distribution data, estimates were made based on a combination of visual position of the windbox dampers and PIN data from the field tests. The airflow rate at each secondary air nozzle elevation, including SOFA nozzles, was estimated based on nozzle flow area, windbox compartment flow area, damper position and windbox to furnace pressure differential pressure. Detailed tables with calculated values are presented in Appendix B.

Coal Analysis

The coals used for all simulations derived from averaged values documented in the performance test reports. A summary of key parameters for each coal is presented in Table 3-2. Ultimate and Proximate Analyses of the averaged values were used to conduct mass and energy balances. Detailed calculations are presented in Appendix B.

Table 3-2
Average Coal Analyses for As-Received Coals Used for CFD Simulations.

Parameter	Eastern Bituminous	PRB
Heating Value (Btu/lb)	13,065	8,379
Total Moisture	6.35%	29.06%
Total Ash	8.6%	6.23%
Volatile Matter	30.36%	30.43%
Fixed Carbon	54.69%	34.28%
Sulfur	0.66%	0.40%
Nitrogen	1.36%	0.80%
Stoichiometric Air/Fuel Ratio	9.71	7.00
% Passing 50 Mesh	99.2	99.4
% Passing 200 Mesh	70.0	77.6

Parametric Simulations with PRB Coal

Cases 5-12 concentrated on investigating the effect of varying the degree of staging for both the CCOFA and SOFA furnace firing schemes while firing PRB coal. These simulations proved less computationally expensive than the first four cases because the latter provided a starting point solution on which to base the parametric runs for the combustion aspect of the simulation. After each simulation was converged, NOx predictions were carried out using the post-processor described in Section 2. Table 3-3 summarizes all simulations conducted in this effort.

Table 3-3
Summary of Baseline and Parametric CFD Simulations.

Case #	Configuration	Fuel	BZSR
1	CCOFA (Baseline)	Bituminous	0.95
2	SOFA	Bituminous	0.95
3	CCOFA (pseudo Baseline)	PRB	0.95
4	SOFA	PRB	0.95
5	CCOFA	PRB	0.90
6	SOFA	PRB	0.90
7	CCOFA	PRB	0.85
8	SOFA	PRB	0.85
9	CCOFA	PRB	1.00
10	SOFA	PRB	1.00
11	CCOFA	PRB	1.05
12	SOFA	PRB	1.05

Other Model Assumptions

In addition to the comments in the previous section, other assumptions and generalizations were made to facilitate convergence to a steady-state solution. These assumptions, although partially supported by the available field data, are typical for CFD furnace modeling:

1. Furnace wall temperature was assumed constant at the saturation temperature and operating pressure of the steam. (Nominally ~ 700°F [377°C]).
2. For Eastern Bituminous cases, primary air temperature was set to 165°F (74°C) (at the nozzle tip) whereas for PRB cases a temperature of 120°F (49°C) as reported by DCS data.
3. For all simulations, secondary air temperature was set to its indicated value of 630°F (332°C).
4. All simulations assumed a primary air/coal ratio of nominally 2.2 pounds air per pound fuel. This assumption was necessary to maintain an appropriate coal transport velocity of 76-86 ft/s.

5. As noted in previous sections, Unit 2 was originally designed to burn PRB coal, therefore only coal elevations C-G are used for normal full load operation while firing bituminous coal. The uppermost two coal elevations (A, B) and the lowermost two elevations (H, J) are typically kept out of service. Elevations C-H are used on Unit 3 while firing PRB.

6. Fuel supply to each burner elevation was based on a relative distribution as determined from PIN data for total fuel flow of each mill. The fuel at each burner level was assumed equally distributed between the four corners of the model.

7. Burner tilt elevation angles were assumed horizontal, or 0° with respect to the normal.

8. The conceptual design SOFA ports were located at Elevation 619 feet or approximately 25 feet downstream from the centerline of the existing CCOFA ports.

9. Literature values were used for specific data not readily available including, thermodynamic parameters of the coal, kinetic rate data for devolatilization, char oxidation, nitrogen release, and particle rebound data.

4
RESULTS AND DISCUSSION

Baseline and Pseudo Baseline Predictions

A summary of predicted results, for Cases 1 and 3 (bituminous baseline and PRB pseudo-baseline, respectively), obtained by integrating the horizontal nose plane is provided in Table 4-1. These predictions are not directly comparable to field measurements because field measurements were obtained at sampling locations farther downstream from the nose plane where the predicted values were computed. For instance, most pyrometric readings were taken 8 feet above the nose plane and species concentrations were measured downstream of the convection pass at the economizer outlet. The field data, however, provided a relative indication of the operational range of the furnace conditions for both the baseline and pseudo baseline simulation predictions. Although NOx and O_2 levels (depending on in-leakage) may be similar, CO and CIA levels could be considerably different.

Table 4-1
Reported Field Data and CFD Model Predictions

Parameter	Performance Test 10 Unit 2	Baseline[1] Bituminous SR 0.95	Performance Test 1 Unit 3	Pseudo-Baseline[1] PRB SR 0.95
Temperature °F (°C)	2353[2] (1289)	2297 (1258)	2403[2] (1317)	2542 (1394)
O_2%	2.9[3]	3.7	2.4[3]	4.6
CO ppmd[4]	118	733	28	4325
NOx lb/ppmd[4]	0.33	0.32	0.22	0.22
CIA %	9	23	<1	20

1. Integrated mass weighted averages at the horizontal nose exit plane.
2. Average of IR Pyrometer reading 10 feet above nose plane.
3. Measured at economizer outlet.
4. Concentrations normalized to 3% O_2; CO levels at the stack will be substantially lower.

Flue gas temperature predictions differed by 4% from pyrometric data readings for the bituminous baseline. Predicted parameters for oxygen and CO concentrations and CIA were higher than those reported in the performance tests. Several parameters were investigated to gain insights as to the nature of the differences of the model predictions. Uncertainties in some model inputs such as kinetic rate data and chemical equilibrium assumptions may partially influence predicted species concentrations. NOx sub-model predictions were tuned for the baseline and pseudo-baseline cases. To accomplish this task, the fuel NOx parameters that manage the distribution of nitrogen release during devolatilization and char combustion were estimated from literature drop tube experimental data. These values suggested that bituminous coal released less fuel nitrogen during devolatilization than PRB coal. This nitrogen distribution approach yielded the close agreement of predicted NOx values as shown in Table 4-1 and was not changed for all other parametric simulations.

Due to the lack of PRB operating data on Unit 2, validation of model predictions is not directly feasible. However, the pseudo baseline conditions derived from Unit 3 data yielded informative insights into the potential behavior of PRB combustion on Unit 2. A summary of all the simulations performed along with predicted values and relative differentials is also presented in Table 4-1.

Baseline Bituminous vs. Pseudo Baseline PRB

An estimate of the impact of PRB on Unit 2 was determined by comparing the baseline bituminous case with the PRB pseudo-baseline. The PRB run indicated NOx emission levels 33% lower than the baseline along with improved CIA levels and reasonable temperature ranges. Carbon monoxide predictions, in contrast, were suspect, as industry experience with PRB combustion has not indicated levels of CO emissions such as those predicted by the model. Note again that model predictions were estimated at the furnace exit and not downstream of the convective pass. Field testing at a location close to the furnace nose would provide more insightful data to compare with model predictions.

Other Parametric Studies

A number of parametric runs were conducted to investigate the effects of operating both OFA configurations under various levels of BZSR under the same operating load. The following sections discuss the results from those simulations.

Case 2 - Bituminous SOFA Simulation

The simulation investigated the effect of SOFA under identical firing conditions of the baseline. Air originally entering the furnace from the CCOFA ports was re-routed to the five SOFA ports located 25 feet downstream. Predictions indicate a 9% increase in FEGT relative to the baseline. As shown in Figure 2, a broader region of high temperature is evident with the SOFA configuration which is more likely due to the delayed combustion. O_2 predictions were slightly higher than those observed in the baseline simulation but, in a reverse trend, CO concentrations were reduced by 68%. This CO change may indicate an enhancement to air and flue gas mixing caused by the sidewall SOFA port not present in the existing CCOFA configuration. Despite the increase in residence time of the fuel rich zone, NOx emissions were reduced only by 3% from baseline levels. CIA predictions also remained unchanged from those observed in the CCOFA case.

Table 4-2
Summary of CFD Predictions and relative differentials as compared to bituminous baseline predictions and to the PRB Pseudo-Baseline

Fuel Type	Bituminous		PRB					PRB				
OFA Type	CCOFA	SOFA	CCOFA					SOFA				
BZSR	0.95	0.95	0.85	0.90	0.95	1.00	1.05	0.85	0.90	0.95	1.00	1.05
O_2%	3.7	3.7	5.0	4.8	4.6	4.5	4.4	5.0	4.8	4.6	4.4	4.3
FEGT °F (°C)	2297 (1258)	2509 (1376)	2476 (1358)	2504 (1373)	2542 (1394)	2570 (1410)	2657 (1458)	2431 (1332)	2459 (1349)	2498 (1370)	2545 (1396)	2622 (1439)
CO ppm @ 3% O_2	733	236	8,290	6,542	4,325	4,409	3,295	4,832	4,316	2,843	2,146	2,013
NOx ppm @ 3% O_2	237	229	112	135	160	175	243	99	141	139	274	382
CIA %	23	23	25	21	20	14	11	28	25	20	15	11
Differentials Relative to Bituminous Baseline Predictions												
•NOx (%)	BASE	-3	-53	-43	-33	-26	3	-58	-40	-42	15	61
•CO (%)	BASE	-68	1,031	793	490	502	350	559	489	288	193	175
•T (%)	BASE	9	8	9	11	12	16	6	7	9	11	14
•CIA (%)	BASE	0	9	-9	-13	-39	-52	22	9	-13	-35	-52
Differentials Relative to PRB Pseudo-baseline Predictions												
•NOx (%)			-30	-16	BASE	10	52	-38	-12	-13	71	139
•CO (%)			92	51	BASE	2	-24	12	0	-34	-50	-53
•T (%)			-3	-2	BASE	1	5	-4	-3	-2	0	3
•CIA (%)			25	5	BASE	-30	-45	40	25	0	-25	-45

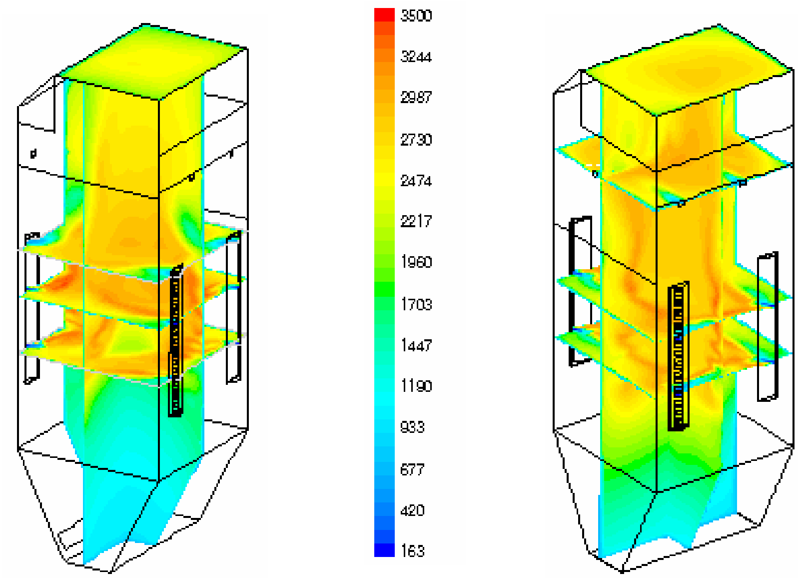


Figure 4-1
Predicted Furnace Temperature Profiles from the Baseline (left) and SOFA Simulations Firing Bituminous Coal

PRB Simulations Prediction - Cases 3 through 12

Several PRB coal furnace simulations were conducted to investigate the sensitivity of varying oxygen availability in the lower furnace for both CCOFA and SOFA designs. This was accomplished by decreasing the BZSR to levels as low as 0.85 and as high as 1.05. Recall that the pseudo-baseline condition assumed a BZSR of 0.95. Figure 4-2 presents a summary of the predicted values for all PRB simulations as a function of BZSR.

Predicted NOx concentrations suggest that the SOFA firing configuration is more sensitive to changes in BZSR than the current CCOFA design, although the lowest NOx predictions differ by only 8%. This is apparent because SOFA NOx predictions increased by 71% under stoichiometric conditions (BZSR=1.0) whereas the CCOFA NOx only increased by 10%. At the least staged condition of 1.05, CCOFA NOx levels also increased albeit at a slower rate than those predicted with SOFA.

One possible explanation for this difference is the tempering effect caused by the introduction of cooler secondary air in the upper furnace. The curves of Figure 4-3 depict average flue gas temperatures as a function of furnace height for all simulations. It can be seen in Figure 4-3 that, the average gas temperature of the CCOFA configuration, at a BZSR of 1.0, is about 200°F (93°C) cooler than the SOFA case for the same level of BZSR. The stoichiometric gas mixture remains hotter than the CCOFA flue gases until the SOFA is injected 25 feet downstream from the burner zone. At that point, the SOFA flue gas temperature drops about 180°F (82°C). This hotter temperature window combined with more O_2 available in the lower furnace may explain the formation of more thermal NOx in the SOFA configuration at the BZSR of 1.0. In addition, because the combustion process is delayed farther upstream with SOFA, the upper furnace is exposed to increased heat release in a smaller volume thereby increasing the furnace exit temperature.

CIA values, predicted at the furnace nose, exhibited similar trends for both CCOFA and SOFA simulations. As noted in Table 4-1, the decreasing CIA trends of the relative differences emphasize the impact of oxygen availability for char combustion in the lower furnace. In the case of CO, predictions at the exit of the computational domain, which is farther upstream from the field measurements sampling point (taken at the economizer), were higher than expected but the relative differences serve to give an indication of the impact of the OFA effectiveness. CO predictions of the magnitude predicted by the model are not expected to be experienced in the field. Figure 4-2b presents absolute CO predictions for all PRB simulations. These trends indicate that the SOFA design is more effective at mixing the burnout air and flue gases than the CCOFA system.

Since all PRB simulations were based on an exit stoichiometry of 1.11, the oxygen level at the furnace exit was expected to be nearly the same, which was not the case. The increase in oxygen at the nose exit plane and the increase in CO and CIA indicates that as the BZSR was reduced, less fuel was burned in the lower furnace.

In general, FEGT predictions agreed well with measured values from similar sister units. The maximum temperatures were predicted for both OFA designs at a BZSR of 1.0. Despite the difference of air injection point, the largest difference temperature variations remained within 4% of the pseudo baseline value of 2542°F (1394°C).

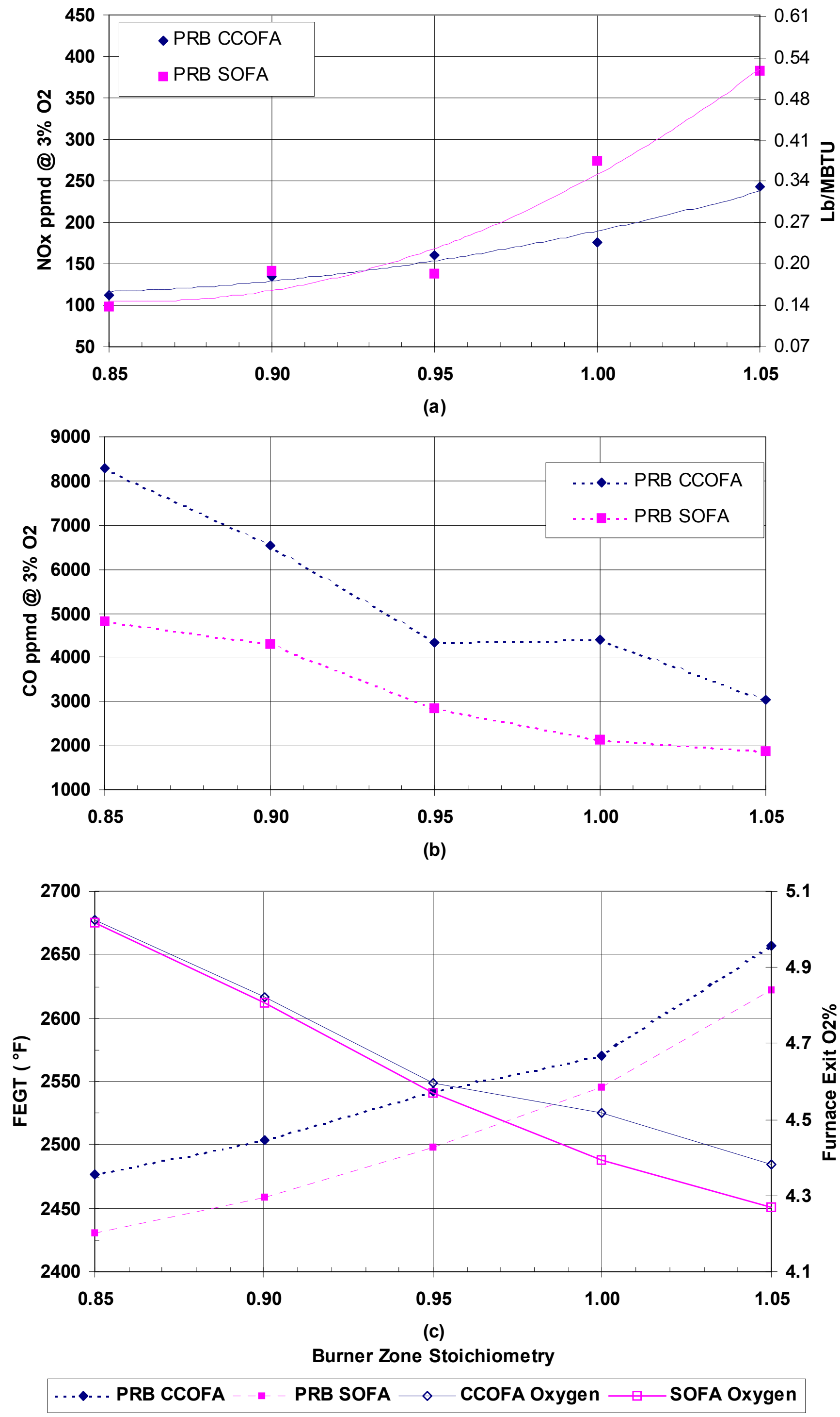


Figure 4-2
Predicted Parameters for PRB Simulations as a Function of Burner Zone Stoichiometric Ratio at Horizontal Plane of Furnace Exit

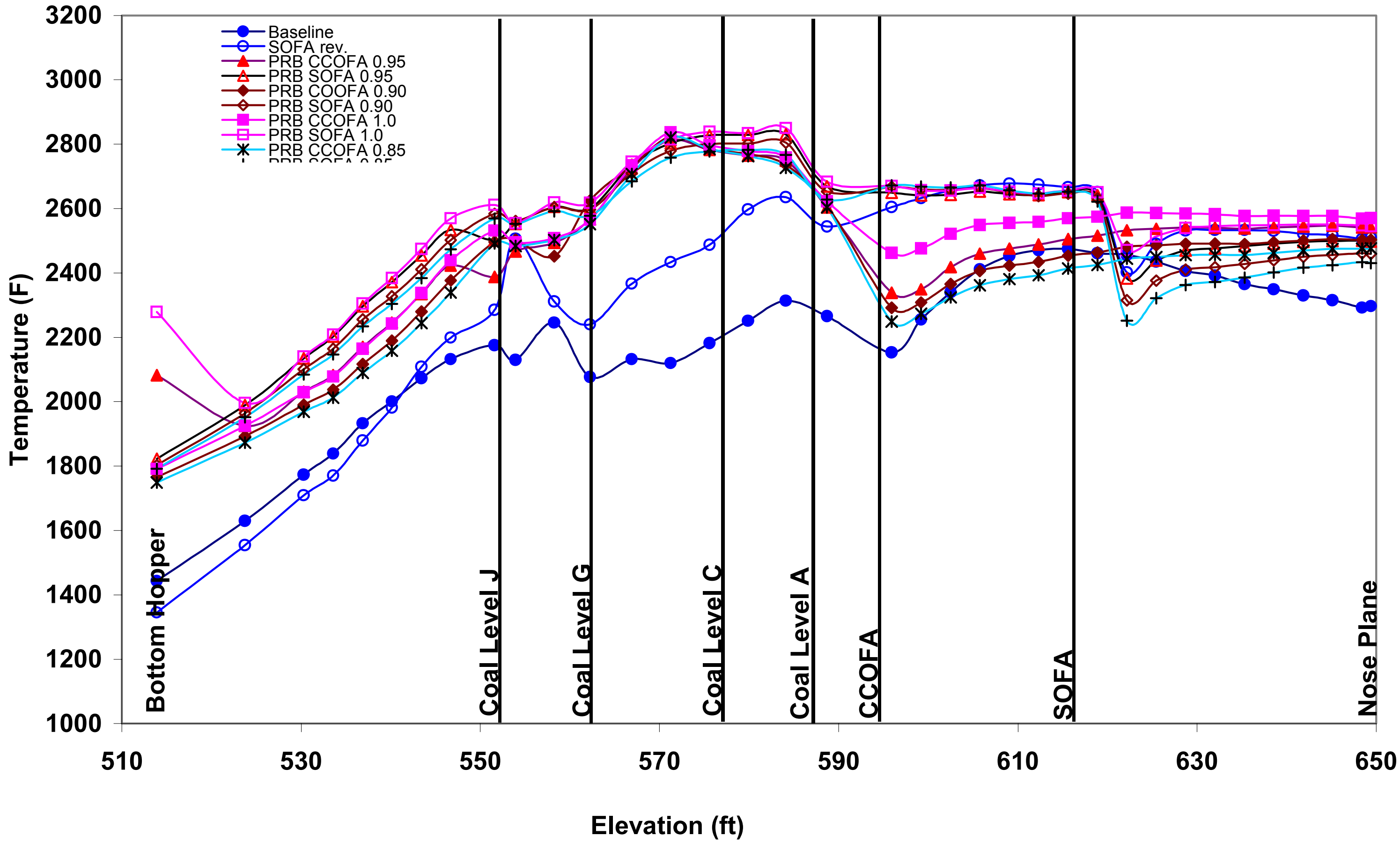


Figure 4-3
Average Flue Gas Temperatures at Various Furnace Heights for all Simulations

5 CONCLUSIONS AND RECOMMENDATIONS

Based on the underlying assumptions of the CFD model, the results of this study suggest that firing PRB coal under CCOFA or SOFA configurations will achieve the desired NOx reductions when compared to the current baseline operating condition (i.e., firing bituminous coal under CCOFA). These reductions reached a maximum of 58% under deep substoichiometric conditions in the burner zone while using the SOFA configuration.

Although the models also suggest that the use of PRB may increase levels of CO while achieving maximum NOx reductions, predicted CO concentrations do not reflect industry experience. The CO over prediction is potentially an artifact of various modeling parameters including the combustion model equilibrium chemistry assumption, the location of the CO prediction (furnace nose) and of other uncertainties in the model inputs such as kinetic data for char and volatiles. However, these CO trends indicate that the SOFA configuration is more effective than the current CCOFA configuration at mitigating CO. This may be due to the ten port SOFA inlet locations and their mixing effectiveness as compared to the eight tangential CCOFA ports.

CIA predictions, in general, decreased from the predicted baseline levels when firing PRB. The only predicted increases of CIA (> +9% Delta) occurred when firing under deep substoichiometric conditions of 0.85 for the CCOFA configuration and 0.90 for the SOFA configuration. Industry experience also has not indicated high levels of CIA when firing PRB.

Temperature predictions at the furnace nose increased by up to 12% as compared to levels predicted under baseline simulation conditions. These predictions are considered to be within reasonable range for CFD predictions.

The following recommendations are made based on the insights from this CFD study:

- Establish a field test program, to validate the model predictions and to assess the absolute impacts on CO, CIA and FEGT.
- Similarly, because the differential in NOx reduction is somewhat marginal between the SOFA and CCOFA configurations, it is suggested that SOFA port size, and injection direction be further investigated. This study simulated only one SOFA port size and assumed an injection direction normal to each furnace wall, both of which were based on the available information for the proposed SOFA design. The performance of this proposed system may be improved by conducting further simulations with varying incident injection directions.

The assumptions for this model were based on the best available data present at the time. Further improvements in the collection of plant operating data, such as secondary and primary air flows, total fuel flow, particle size distribution and flue gas analysis, will reduce uncertainty in the predicted results.

A
FURNACE PROFILES FOR VARIOUS PARAMETERS

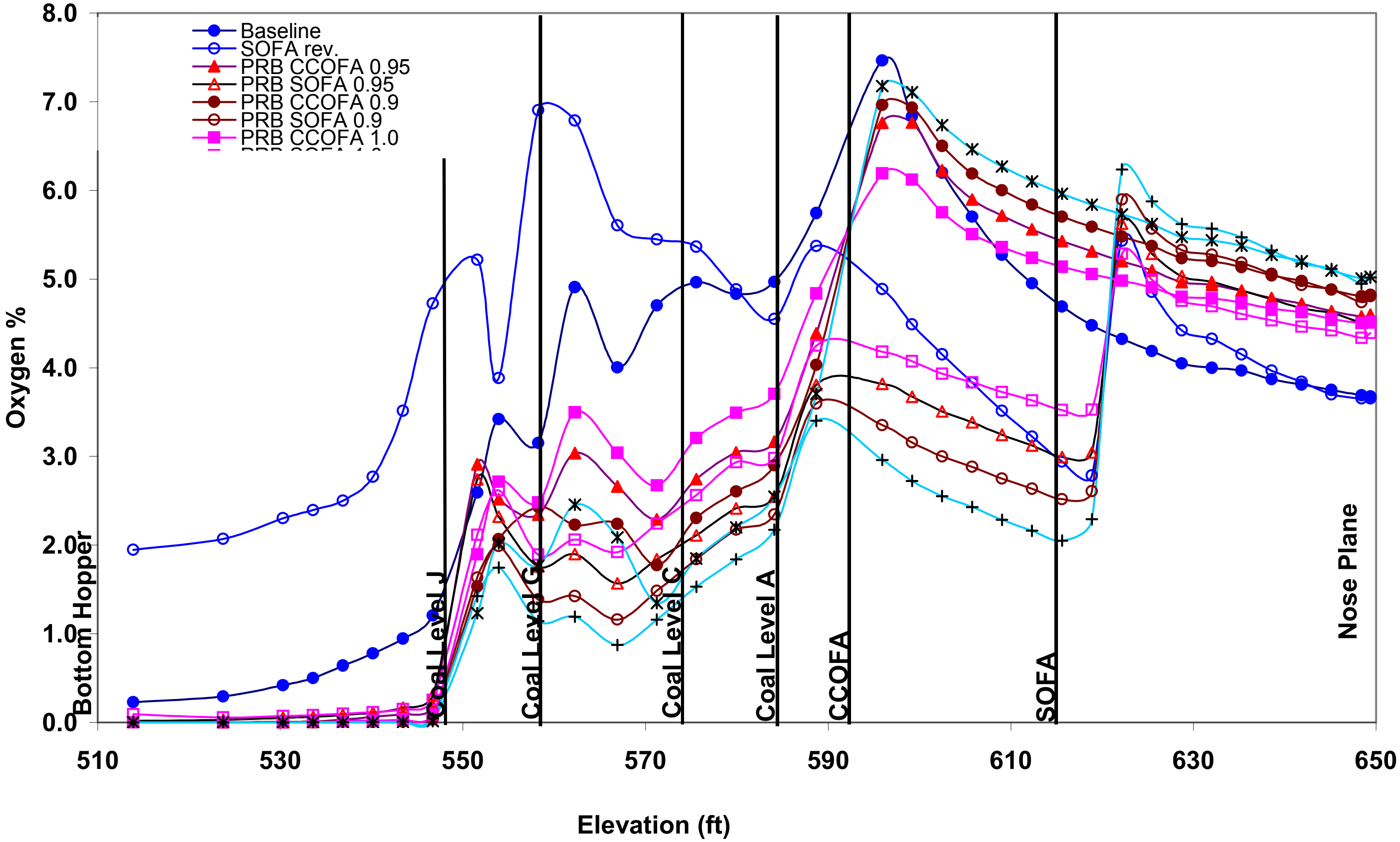


Figure A-1
Average Oxygen Concentrations in Horizontal Planes as a Function of Furnace Height

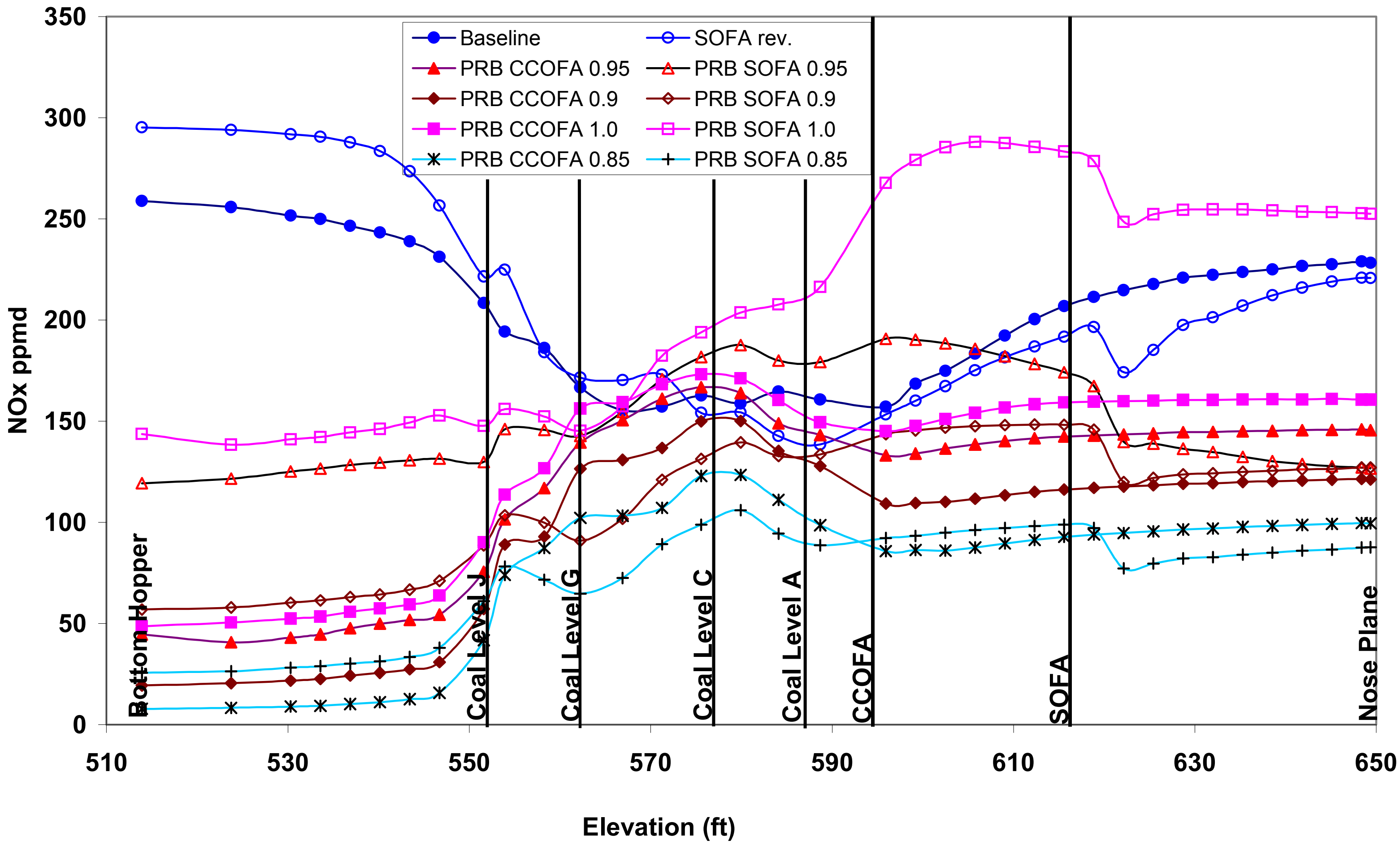


Figure A-2
Average NOx Concentration in Horizontal Planes as a Function of Furnace Height

B

AIR/FUEL DISTRIBUTION ESTIMATES, COAL ANALYSIS AND MASS BALANCES

Table B-1
Bituminous Simulations Air and Fuel Summary

ESTIMATION OF FUEL AND AIRFLOW DISTRIBUTION

SOURCE	Mills	Fuel Flow (lb/hr)	Fuel Flow (kg/s)	Total Fuel Flow (%)	Mill Outlet Temp (°F)	Total Airflow (lb/hr)	% of Primary Air	Total Airflow (lb/hr)	Primary Air to Fuel Ratio
								0	
PIN DATA	A	0	0.000	0.0%	0	0	0.0%	0	0.00
PIN DATA	B	0	0.000	0.0%	0	0	0.0%	0	0.00
PIN DATA	C	115,340	14.533	18.9%	165	255,016	18.9%	255,016	2.20
PIN DATA	D	126,874	15.986	20.8%	165	280,518	20.8%	280,518	2.20
PIN DATA	E	126,874	15.986	20.8%	173	280,518	20.8%	280,518	2.20
PIN DATA	F	115,340	14.533	18.9%	165	255,016	18.9%	255,016	2.20
PIN DATA	G	126,874	15.986	20.8%	165	280,518	20.8%	280,518	2.20
PIN DATA	H	0	0.000	0.0%	0	0	0.0%	0	2.20
PIN DATA	J	0	0.000	0.0%	0	0	0.0%	0	2.20
	Totals	611,300	77.023	100%	166.60	1,351,585	100.00%	1,351,585	

Calculated	**Total Fuel Dry Basis**	**611,300**	**lb/hr**
Calculated	**Total Dry Air Flow**	**7,331,351**	**lb/hr**
	Stoichiometric A/F Ratio	**9.71**	**lb dry air/lb fuel**
Calculated	**Stoichiometric A/F Ratio**	**10.37**	**lb dry air/lb dry fuel**
PIN DATA	**Total Fuel Recorded**	636,000	**lb/hr**
	Fuel Adjustment Factor	3.9%	

Airflow Distribution Summary

			% of Flow	T (°F)	Density (lb/ft3)	Viscosity (lb/ft-hr)
Estimated	**Total Primary Air**	**1,351,585**	18.4%	165	0.06351	5.00E-02
Estimated	**Total Secondary Air**	**4,525,391**	61.7%	630	0.03791	7.37E-02
Estimated	**Total SOFA**	**1,454,375**	19.8%	630	0.03791	7.37E-02
Estimated	**Total IFGR**	-				

Table B-2
Bituminous Simulation Air Distribution per Elevation, BZSR = 0.95, Overall Exit SR = 1.16

Calculation of Secondary/OFA Airflow Distribution

(Based on open flow area at nozzles, damper position and Windbox to Furnace Differential Pressure)

Source	Elevation	Nozzle Area (sq ft)	Nozzle Flow Area (%)	Damper Position % open	Velocity at Nozzle (ft/s)	Pressure Based Cummulative Stoichiometry	Pressure Based Mass Flow (lb/hr)	Pressure Based Mass Flow/Corner (kg/s)	Fraction of Total Air to Boiler
Field Data	Upper CCOFA	2.78	8.14%	60%	**216**	1.16	654,073	**10.3016**	8.92%
Field Data	Lower CCOFA	2.78	8.14%	60%	**216**	1.05	654,073	**10.3016**	8.92%
	Subtotal	5.56							0.00%
Field Data	AA Aux Air	0.84	2.46%	20%	**84**	0.95	77,301	**1.2175**	1.05%
Field Data	A SA	0.92	2.69%	31%	**193**	0.94	192,863	**3.0376**	2.63%
Field Data	A PA	1.08	**No Fuel**		**0**		0	**0.0000**	0.00%
Field Data	AB	2.30	6.74%	40%	**139**	0.91	347,657	**5.4756**	4.74%
Field Data	B SA	0.92	2.69%	31%	**193**	0.85	192,863	**3.0376**	2.63%
Field Data	B PA	1.08	**No Fuel**		**0**	0.82	0	**0.0000**	0.00%
Field Data	BC	2.30	6.74%	40%	**139**	0.82	347,657	**5.4756**	4.74%
Field Data	C SA	0.92	2.69%	31%	**193**	0.77	192,863	**3.0376**	2.63%
Field Data	C PA	1.83	**FUEL INPUT**		**76**	0.74	255,016	**4.0165**	3.48%
Field Data	CD	2.30	6.74%	40%	**139**	0.86	347,657	**5.4756**	4.74%
Field Data	D SA	0.92	2.69%	31%	**193**	0.79	192,863	**3.0376**	2.63%
Field Data	D PA	1.83	**FUEL INPUT**		**84**	0.75	280,518	**4.4181**	3.83%
Field Data	DE	2.30	6.74%	40%	**139**	0.94	347,657	**5.4756**	4.74%
Field Data	E SA	0.92	2.69%	31%	**193**	0.85	192,863	**3.0376**	2.63%
Field Data	E PA	1.83	**FUEL INPUT**		**84**	0.80	280,518	**4.4181**	3.83%
Field Data	EF	2.30	6.74%	40%	**139**	1.10	347,657	**5.4756**	4.74%
Field Data	F SA	0.92	2.69%	31%	**193**	0.97	192,863	**3.0376**	2.63%
Field Data	F PA	1.83	**FUEL INPUT**		**76**	0.89	255,016	**4.0165**	3.48%
Field Data	FG	2.30	6.74%	40%	**139**	1.50	347,657	**5.4756**	4.74%
Field Data	G SA	0.92	2.69%	31%	**193**	1.24	192,863	**3.0376**	2.63%
Field Data	G PA	1.83	**FUEL INPUT**		**84**		280,518	**4.4181**	3.83%
Field Data	GH	2.30	6.74%	40%	**139**		347,657	**5.4756**	4.74%
Field Data	H SA	0.92	2.69%	31%	**193**		192,863	**3.0376**	2.63%
Field Data	H PA	1.83	**FUEL INPUT**		**0**		0	**0.0000**	0.00%
Field Data	HJ	2.30	6.74%	40%	**139**		347,657	**5.4756**	4.74%
Field Data	J SA	0.92	2.69%	31%	**193**		192,863	**3.0376**	2.63%
Field Data	J PA	1.83	**FUEL INPUT**		**0**		0	**0.0000**	0.00%
Field Data	JJ Aux Air	1.09	3.20%	20%	**65**		77,301	**1.2175**	1.05%
TOTAL SA ONLY		28.57					**4,671,620**	**73.58**	
TOTAL SA + OFA		34.13	100.00%				**5,979,766**	**94.18**	
TOTAL PA ONLY		15.00					**1,351,585**	**21.29**	

Table B-3
Coal Analysis and Mass Balance for Bituminous Coal Simulations

UTILITY:	**OPC**	**PLANT:**	**Sherer Unit 2**
COAL NAME:		**TYPE:**	**Eastern Bit**
ANALYSIS DATE:	**10/5/2001**	**SOURCE:**	

Proximate Analysis	**As Received**	**Dry**	**Dry Ash-Free**
MOISTURE:	6.35%	-	-
ASH:	8.60%	9.18%	-
VOLATILE:	30.36%	32.42%	35.70%
FIXED CARBON:	54.69%	58.40%	64.30%
	100.00%	100.00%	100.00%
HHV (BTU/LB) :	13,065	13,951	

Ultimate Analysis	**As Received**	**Dry**	**Dry Ash-Free**
MOISTURE:	6.35%	-	-
CARBON:	72.53%	77.45%	85.28%
HYDROGEN:	4.63%	4.94%	5.44%
NITROGEN:	1.36%	1.45%	1.5991%
CHLORINE:		0.00%	0.00%
SULFUR:	0.66%	0.70%	0.78%
ASH:	8.60%	9.18%	-
OXYGEN (by diff):	5.87%	6.27%	6.90%
	100.00%	100.00%	100.00%

OPERATING CONDITIONS

COAL INPUT FROM EDR for TEST 10	8,528,180,000			
GROSS HEAT RATE (Btu/kWh):	9,825	0		
HEAT INPUT (Btu/hr):	8,528,180,000		2,497,690,718	Watts
LOAD (MWg):	868.0		868	
EXCESS OXYGEN (%,dry):	3.28%			
(%,wet):	3.04%			
HUMIDITY RATIO:	0.0050			
STOICH A/F:	9.71	From Mole Balance		
THEORETICAL A/F:	11.23	From Mole Balance		
STOICHIOMETRIC RATIO:	1.156			
MOLECULAR WEIGHT (lb/lbmole):	29.75	0.00		
AIR FLOW (lb/hr):	7,331,351	7,331,351	924	kg/s
FUEL FLOW (lb/hr):	652,750		82	kg/s
(tph):	326.4			

Combustion Mass Balance Stack Calculations	**Wet Basis**	**Dry Basis**	**Mass Flow (lb/hr)**	**Molar Basis (lbmole/hr)**	**Mass/Heat Input ($lb/10^6$ Btu)**
O2	3.04%	3.28%	259,160	8,099	30.39
CO2	14.53%	15.66%	1,703,924	38,726	199.80
H2O	7.21%	-	345,931	19,218	40.56
N2	75.15%	80.99%	5,607,585	200,271	657.54
SO_2 (PPM @ 99% CONV):	491	529	8,373	131	0.98
SO_3 (PPM @ 1% CONV):	5	6	111	1	0.01
HCl (ppmv):	0	0	0	0	0.00
Measured NO (ppmv):	235	252	2,881	63	0.34
		100.00%	7,927,965	266,508	929.62

ASH	3.80	gr/scf		
ASH	56,137	lb/hr	7.07	kg/s
FLUE GAS	7,927,965	lb/hr	998.92	kg/s
FLUE GAS	29.75	lb/lbmole		
FLUE GAS	12.15	lb/lb fuel		
FLUE GAS DENSITY @ 300 F	0.0536	lb/ft^3	0.8590	kg/m^3
FLUE GAS DENSITY @ 2400 F	0.0170	lb/ft^3	0.2720	kg/m^3

Table B-4
PRB Simulations Fuel Distribution

ESTIMATION OF FUEL AND AIRFLOW DISTRIBUTION

SOURCE	Mills	Fuel Flow (lb/hr)	Fuel Flow (kg/s)	Total Fuel Flow (%)	Mill Outlet Temp (°F)	Total Airflow (lb/hr)	% of Primary Air	Total Airflow (lb/hr)	Primary Air to Fuel Ratio
								0	
PIN DATA	A	0	0.000	0.0%	98	0	0.0%	0	0.00
PIN DATA	B	0	0.000	0.0%	100	0	0.0%	0	0.00
PIN DATA	C	105,983	13.354	14.6%	120	236,194	14.6%	236,194	2.20
PIN DATA	D	105,308	13.269	14.5%	119	234,689	14.5%	234,689	2.20
PIN DATA	E	100,429	12.654	13.8%	120	223,816	13.8%	223,816	2.20
PIN DATA	F	105,983	13.354	14.6%	116	236,194	14.6%	236,194	2.20
PIN DATA	G	104,632	13.184	14.4%	123	233,183	14.4%	233,183	2.20
PIN DATA	H	99,078	12.484	13.6%	119	220,805	13.6%	220,805	2.20
PIN DATA	J	106,734	13.448	14.7%	121	237,867	14.7%	237,867	2.20
	Totals	728,146	91.746	100%	119.60	1,622,747	100.00%	1,622,747	

Calculated	Total Fuel Dry Basis	728,146	lb/hr
Calculated	Total Dry Air Flow	8,003,536	lb/hr
	Stoichiometric A/F Ratio	7.00	lb dry air/lb fuel
Calculated	Stoichiometric A/F Ratio	9.87	lb dry air/lb dry fuel
PIN DATA	Total Fuel Recorded	970,100	lb/hr
	Fuel Adjustment Factor	24.9%	

Airflow Distribution Summary

			% of Flow	T (°F)	Density (lb/ft3)	Viscosity (lb/ft-hr)
Estimated	Total Primary Air	1,622,747	20.3%	120	0.06843	4.72E-02
Estimated	Total Secondary Air	4,976,846	62.2%	630	0.03791	7.37E-02
Estimated	Total SOFA	1,403,942	17.5%	630	0.03791	7.37E-02

Table B-5
PRB Simulations Air Distribution per Elevation, BZSR =0.95, Overall Exit SR =1.11

Calculation of Secondary/OFA Airflow Distribution

(Based on open flow area at nozzles, damper position and Windbox to Furnace Differential Pressure)

Source	Elevation	Nozzle Area (sq ft)	Nozzle Flow Area (%)	Damper Position % open	Velocity at Nozzle (ft/s)	Pressure Based Cummulative Stoichiometry	Pressure Based Mass Flow (lb/hr)	Pressure Based Mass Flow/Corner (kg/s)	Fraction of Total Air to Boiler
Field Data	Upper CCOFA	2.78	8.14%	57%	**194**	1.11	589,378	**9.2826**	7.36%
Field Data	Lower CCOFA	2.78	8.14%	57%	**194**	1.03	589,378	**9.2826**	7.36%
	Subtotal	5.56							0.00%
Field Data	AA Aux Air	0.84	2.46%	22%	**92**	0.95	84,351	**1.3285**	1.05%
Field Data	A SA	0.92	2.69%	34%	**213**	0.94	212,864	**3.3526**	2.66%
Field Data	A PA	1.08	**No Fuel**		**0**		0	**0.0000**	0.00%
Field Data	AB	2.30	6.74%	44%	**155**	0.91	389,694	**6.1376**	4.87%
Field Data	B SA	0.92	2.69%	34%	**213**	0.85	212,864	**3.3526**	2.66%
Field Data	B PA	1.08	**No Fuel**		**0**	0.82	0	**0.0000**	0.00%
Field Data	BC	2.30	6.74%	44%	**155**	0.82	389,694	**6.1376**	4.87%
Field Data	C SA	0.92	2.69%	34%	**213**	0.77	212,864	**3.3526**	2.66%
Field Data	C PA	1.83	**FUEL INPUT**		**65**	0.74	236,194	**3.7200**	2.95%
Field Data	CD	2.30	6.74%	44%	**155**	0.83	389,694	**6.1376**	4.87%
Field Data	D SA	0.92	2.69%	34%	**213**	0.77	212,864	**3.3526**	2.66%
Field Data	D PA	1.83	**FUEL INPUT**		**65**	0.73	234,689	**3.6963**	2.93%
Field Data	DE	2.30	6.74%	44%	**155**	0.83	389,694	**6.1376**	4.87%
Field Data	E SA	0.92	2.69%	34%	**213**	0.76	212,864	**3.3526**	2.66%
Field Data	E PA	1.83	**FUEL INPUT**		**62**	0.72	223,816	**3.5251**	2.80%
Field Data	EF	2.30	6.74%	44%	**155**	0.83	389,694	**6.1376**	4.87%
Field Data	F SA	0.92	2.69%	34%	**213**	0.74	212,864	**3.3526**	2.66%
Field Data	F PA	1.83	**FUEL INPUT**		**65**	0.69	236,194	**3.7200**	2.95%
Field Data	FG	2.30	6.74%	44%	**155**	0.84	389,694	**6.1376**	4.87%
Field Data	G SA	0.92	2.69%	34%	**213**	0.72	212,864	**3.3526**	2.66%
Field Data	G PA	1.83	**FUEL INPUT**		**65**		233,183	**3.6726**	2.91%
Field Data	GH	2.30	6.74%	44%	**155**	0.86	389,694	**6.1376**	4.87%
Field Data	H SA	0.92	2.69%	34%	**213**	0.67	212,864	**3.3526**	2.66%
Field Data	H PA	1.83	**FUEL INPUT**		**61**		220,805	**3.4777**	2.76%
Field Data	HJ	2.30	6.74%	44%	**155**	0.88	389,694	**6.1376**	4.87%
Field Data	J SA	0.92	2.69%	34%	**213**	0.51	212,864	**3.3526**	2.66%
Field Data	J PA	1.83	**FUEL INPUT**		**66**		237,867	**3.7464**	2.97%
Field Data	JJ Aux Air	1.09	3.20%	22%	**71**	0.08	84,351	**1.3285**	1.05%
TOTAL SA ONLY		28.57					**5,202,033**	**81.93**	
TOTAL SA + OFA		34.13	100.00%				**6,380,789**	**100.50**	
TOTAL PA ONLY		15.00					**1,622,747**	**25.56**	

Table B-6
PRB Air Distribution per Elevation, BZSR = 0.90, Overall Exit SR = 1.11

Calculation of Secondary/OFA Airflow Distribution

(Based on open flow area at nozzles, damper position and Windbox to Furnace Differential Pressure)

Source	Elevation	Nozzle Area (sq ft)	Nozzle Flow Area (%)	Damper Position % open	Velocity at Nozzle (ft/s)	P Pressure Based Cummulative Stoichiometry	P Pressure Based Mass Flow (lb/hr)	P Pressure Based Mass Flow/Corner (kg/s)	P Fraction of Total Air to Boiler
Field Data	Upper CCOFA	2.78	8.14%	65%	**254**	1.11	768,977	**12.1113**	9.61%
Field Data	Lower CCOFA	2.78	8.14%	65%	**254**	1.01	768,977	**12.1113**	9.61%
	Subtotal	5.56							0.00%
Field Data	AA Aux Air	0.84	2.46%	21%	**87**	0.90	79,620	**1.2540**	0.99%
Field Data	A SA	0.92	2.69%	32%	**199**	0.89	199,372	**3.1401**	2.49%
Field Data	A PA	1.08	**No Fuel**		**0**		0	**0.0000**	0.00%
Field Data	AB	2.30	6.74%	42%	**144**	0.86	361,156	**5.6882**	4.51%
Field Data	B SA	0.92	2.69%	32%	**199**	0.81	199,372	**3.1401**	2.49%
Field Data	B PA	1.08	**No Fuel**		**0**	0.78	0	**0.0000**	0.00%
Field Data	BC	2.30	6.74%	42%	**144**	0.78	361,156	**5.6882**	4.51%
Field Data	C SA	0.92	2.69%	32%	**199**	0.73	199,372	**3.1401**	2.49%
Field Data	C PA	1.83	**FUEL INPUT**		**65**	0.71	236,194	**3.7200**	2.95%
Field Data	CD	2.30	6.74%	42%	**144**	0.79	361,156	**5.6882**	4.51%
Field Data	D SA	0.92	2.69%	32%	**199**	0.73	199,372	**3.1401**	2.49%
Field Data	D PA	1.83	**FUEL INPUT**		**65**	0.70	234,689	**3.6963**	2.93%
Field Data	DE	2.30	6.74%	42%	**144**	0.79	361,156	**5.6882**	4.51%
Field Data	E SA	0.92	2.69%	32%	**199**	0.72	199,372	**3.1401**	2.49%
Field Data	E PA	1.83	**FUEL INPUT**		**62**	0.68	223,816	**3.5251**	2.80%
Field Data	EF	2.30	6.74%	42%	**144**	0.79	361,156	**5.6882**	4.51%
Field Data	F SA	0.92	2.69%	32%	**199**	0.70	199,372	**3.1401**	2.49%
Field Data	F PA	1.83	**FUEL INPUT**		**65**	0.65	236,194	**3.7200**	2.95%
Field Data	FG	2.30	6.74%	42%	**144**	0.80	361,156	**5.6882**	4.51%
Field Data	G SA	0.92	2.69%	32%	**199**	0.68	199,372	**3.1401**	2.49%
Field Data	G PA	1.83	**FUEL INPUT**		**65**		233,183	**3.6726**	2.91%
Field Data	GH	2.30	6.74%	42%	**144**	0.82	361,156	**5.6882**	4.51%
Field Data	H SA	0.92	2.69%	32%	**199**	0.64	199,372	**3.1401**	2.49%
Field Data	H PA	1.83	**FUEL INPUT**		**61**		220,805	**3.4777**	2.76%
Field Data	HJ	2.30	6.74%	42%	**144**	0.83	361,156	**5.6882**	4.51%
Field Data	J SA	0.92	2.69%	32%	**199**	0.49	199,372	**3.1401**	2.49%
Field Data	J PA	1.83	**FUEL INPUT**		**66**		237,867	**3.7464**	2.97%
Field Data	JJ Aux Air	1.09	3.20%	21%	**67**	0.08	79,620	**1.2540**	0.99%
TOTAL SA ONLY		28.57					**4,842,834**	**76.27**	
TOTAL SA + OFA		34.13	100.00%				**6,380,789**	**100.50**	
TOTAL PA ONLY		15.00					**1,622,747**	**25.56**	

Table B-7
PRB Simulation Air Distribution per Elevation, BZSR = 0.85, Overall Exit SR = 1.11

Calculation of Secondary/OFA Airflow Distribution

(Based on open flow area at nozzles, damper position and Windbox to Furnace Differential Pressure)

Source	Elevation	Nozzle Area (sq ft)	Nozzle Flow Area (%)	Damper Position % open	Velocity at Nozzle (ft/s)	P Pressure Based Cummulative Stoichiometry	P Pressure Based Mass Flow (lb/hr)	P Pressure Based Mass Flow/Corner (kg/s)	P Fraction of Total Air to Boiler
Field Data	Upper CCOFA	2.78	8.14%	70%	**313**	1.11	948,577	**14.9400**	11.85%
Field Data	Lower CCOFA	2.78	8.14%	70%	**313**	0.98	948,577	**14.9400**	11.85%
	Subtotal	5.56							0.00%
Field Data	AA Aux Air	0.84	2.46%	20%	**81**	0.85	74,708	**1.1766**	0.93%
Field Data	A SA	0.92	2.69%	30%	**186**	0.84	185,658	**2.9241**	2.32%
Field Data	A PA	1.08	**No Fuel**		**0**		0	**0.0000**	0.00%
Field Data	AB	2.30	6.74%	39%	**133**	0.81	332,912	**5.2433**	4.16%
Field Data	B SA	0.92	2.69%	30%	**186**	0.77	185,658	**2.9241**	2.32%
Field Data	B PA	1.08	**No Fuel**		**0**	0.74	0	**0.0000**	0.00%
Field Data	BC	2.30	6.74%	39%	**133**	0.74	332,912	**5.2433**	4.16%
Field Data	C SA	0.92	2.69%	30%	**186**	0.70	185,658	**2.9241**	2.32%
Field Data	C PA	1.83	**FUEL INPUT**		**65**	0.67	236,194	**3.7200**	2.95%
Field Data	CD	2.30	6.74%	39%	**133**	0.74	332,912	**5.2433**	4.16%
Field Data	D SA	0.92	2.69%	30%	**186**	0.69	185,658	**2.9241**	2.32%
Field Data	D PA	1.83	**FUEL INPUT**		**65**	0.66	234,689	**3.6963**	2.93%
Field Data	DE	2.30	6.74%	39%	**133**	0.75	332,912	**5.2433**	4.16%
Field Data	E SA	0.92	2.69%	30%	**186**	0.68	185,658	**2.9241**	2.32%
Field Data	E PA	1.83	**FUEL INPUT**		**62**	0.65	223,816	**3.5251**	2.80%
Field Data	EF	2.30	6.74%	39%	**133**	0.75	332,912	**5.2433**	4.16%
Field Data	F SA	0.92	2.69%	30%	**186**	0.67	185,658	**2.9241**	2.32%
Field Data	F PA	1.83	**FUEL INPUT**		**65**	0.62	236,194	**3.7200**	2.95%
Field Data	FG	2.30	6.74%	39%	**133**	0.76	332,912	**5.2433**	4.16%
Field Data	G SA	0.92	2.69%	30%	**186**	0.65	185,658	**2.9241**	2.32%
Field Data	G PA	1.83	**FUEL INPUT**		**65**		233,183	**3.6726**	2.91%
Field Data	GH	2.30	6.74%	39%	**133**	0.77	332,912	**5.2433**	4.16%
Field Data	H SA	0.92	2.69%	30%	**186**	0.61	185,658	**2.9241**	2.32%
Field Data	H PA	1.83	**FUEL INPUT**		**61**		220,805	**3.4777**	2.76%
Field Data	HJ	2.30	6.74%	39%	**133**	0.79	332,912	**5.2433**	4.16%
Field Data	J SA	0.92	2.69%	30%	**186**	0.47	185,658	**2.9241**	2.32%
Field Data	J PA	1.83	**FUEL INPUT**		**66**		237,867	**3.7464**	2.97%
Field Data	JJ Aux Air	1.09	3.20%	20%	**63**	0.07	74,708	**1.1766**	0.93%
TOTAL SA ONLY		28.57					**4,483,635**	**70.62**	
TOTAL SA + OFA		34.13	100.00%				**6,380,789**	**100.50**	
TOTAL PA ONLY		15.00					**1,622,747**	**25.56**	

Table B-8
PRB Simulation Air Distribution per Elevation, BZSR = 1.0, Overall Exit SR = 1.11

Calculation of Secondary/OFA Airflow Distribution

(Based on open flow area at nozzles, damper position and Windbox to Furnace Differential Pressure)

Source	Elevation	Nozzle Area (sq ft)	Nozzle Flow Area (%)	Damper Position % open	Velocity at Nozzle (ft/s)	Pressure Based Cummulative Stoichiometry	Pressure Based Mass Flow (lb/hr)	Pressure Based Mass Flow/Corner (kg/s)	Fraction of Total Air to Boiler
Field Data	Upper CCOFA	2.78	8.14%	46%	**133**	1.11	403,295	**6.3519**	5.04%
Field Data	Lower CCOFA	2.78	8.14%	46%	**133**	1.06	403,295	**6.3519**	5.04%
	Subtotal	5.56							0.00%
Field Data	AA Aux Air	0.84	2.46%	23%	**97**	1.00	89,066	**1.4028**	1.11%
Field Data	A SA	0.92	2.69%	36%	**226**	0.99	226,604	**3.5690**	2.83%
Field Data	A PA	1.08	**No Fuel**		**0**		0	**0.0000**	0.00%
Field Data	AB	2.30	6.74%	46%	**167**	0.96	419,578	**6.6083**	5.24%
Field Data	B SA	0.92	2.69%	36%	**226**	0.90	226,604	**3.5690**	2.83%
Field Data	B PA	1.08	**No Fuel**		**0**	0.87	0	**0.0000**	0.00%
Field Data	BC	2.30	6.74%	46%	**167**	0.87	419,578	**6.6083**	5.24%
Field Data	C SA	0.92	2.69%	36%	**226**	0.81	226,604	**3.5690**	2.83%
Field Data	C PA	1.83	**FUEL INPUT**		**65**	0.78	236,194	**3.7200**	2.95%
Field Data	CD	2.30	6.74%	46%	**167**	0.87	419,578	**6.6083**	5.24%
Field Data	D SA	0.92	2.69%	36%	**226**	0.80	226,604	**3.5690**	2.83%
Field Data	D PA	1.83	**FUEL INPUT**		**65**	0.77	234,689	**3.6963**	2.93%
Field Data	DE	2.30	6.74%	46%	**167**	0.88	419,578	**6.6083**	5.24%
Field Data	E SA	0.92	2.69%	36%	**226**	0.79	226,604	**3.5690**	2.83%
Field Data	E PA	1.83	**FUEL INPUT**		**62**	0.75	223,816	**3.5251**	2.80%
Field Data	EF	2.30	6.74%	46%	**167**	0.88	419,578	**6.6083**	5.24%
Field Data	F SA	0.92	2.69%	36%	**226**	0.77	226,604	**3.5690**	2.83%
Field Data	F PA	1.83	**FUEL INPUT**		**65**	0.72	236,194	**3.7200**	2.95%
Field Data	FG	2.30	6.74%	46%	**167**	0.89	419,578	**6.6083**	5.24%
Field Data	G SA	0.92	2.69%	36%	**226**	0.75	226,604	**3.5690**	2.83%
Field Data	G PA	1.83	**FUEL INPUT**		**65**		233,183	**3.6726**	2.91%
Field Data	GH	2.30	6.74%	46%	**167**	0.91	419,578	**6.6083**	5.24%
Field Data	H SA	0.92	2.69%	36%	**226**	0.70	226,604	**3.5690**	2.83%
Field Data	H PA	1.83	**FUEL INPUT**		**61**		220,805	**3.4777**	2.76%
Field Data	HJ	2.30	6.74%	46%	**167**	0.92	419,578	**6.6083**	5.24%
Field Data	J SA	0.92	2.69%	36%	**226**	0.53	226,604	**3.5690**	2.83%
Field Data	J PA	1.83	**FUEL INPUT**		**66**		237,867	**3.7464**	2.97%
Field Data	JJ Aux Air	1.09	3.20%	23%	**75**	0.08	89,066	**1.4028**	1.11%
TOTAL SA ONLY		28.57					**5,574,198**	**87.79**	
TOTAL SA + OFA		34.13	100.00%				**6,380,789**	**100.50**	
TOTAL PA ONLY		15.00					**1,622,747**	**25.56**	

Table B-9
Coal Analysis and Mass Balance for PRB Simulations

UTILITY:	**OPC**	**PLANT:**	**Sherer Unit 2**
COAL NAME:		**TYPE:**	**PRB**
ANALYSIS DATE:	**10/5/2001**	**SOURCE:**	

Proximate Analysis	**As Received**	**Dry**	**Dry Ash-Free**
MOISTURE:	29.06%	-	-
ASH:	6.23%	8.78%	-
VOLATILE:	30.43%	42.90%	47.03%
FIXED CARBON:	34.28%	48.32%	52.97%
	100.00%	100.00%	100.00%
HHV (BTU/LB) :	8,379	11,811	

Ultimate Analysis	**As Received**	**Dry**	**Dry Ash-Free**
MOISTURE:	29.06%	-	-
CARBON:	52.06%	73.39%	80.45%
HYDROGEN:	3.84%	5.41%	5.93%
NITROGEN:	0.80%	1.13%	1.2363%
CHLORINE:		0.00%	0.00%
SULFUR:	0.40%	0.56%	0.62%
ASH:	6.23%	8.78%	-
OXYGEN (by diff):	7.61%	10.73%	11.76%
	100.00%	100.00%	100.00%

OPERATING CONDITIONS

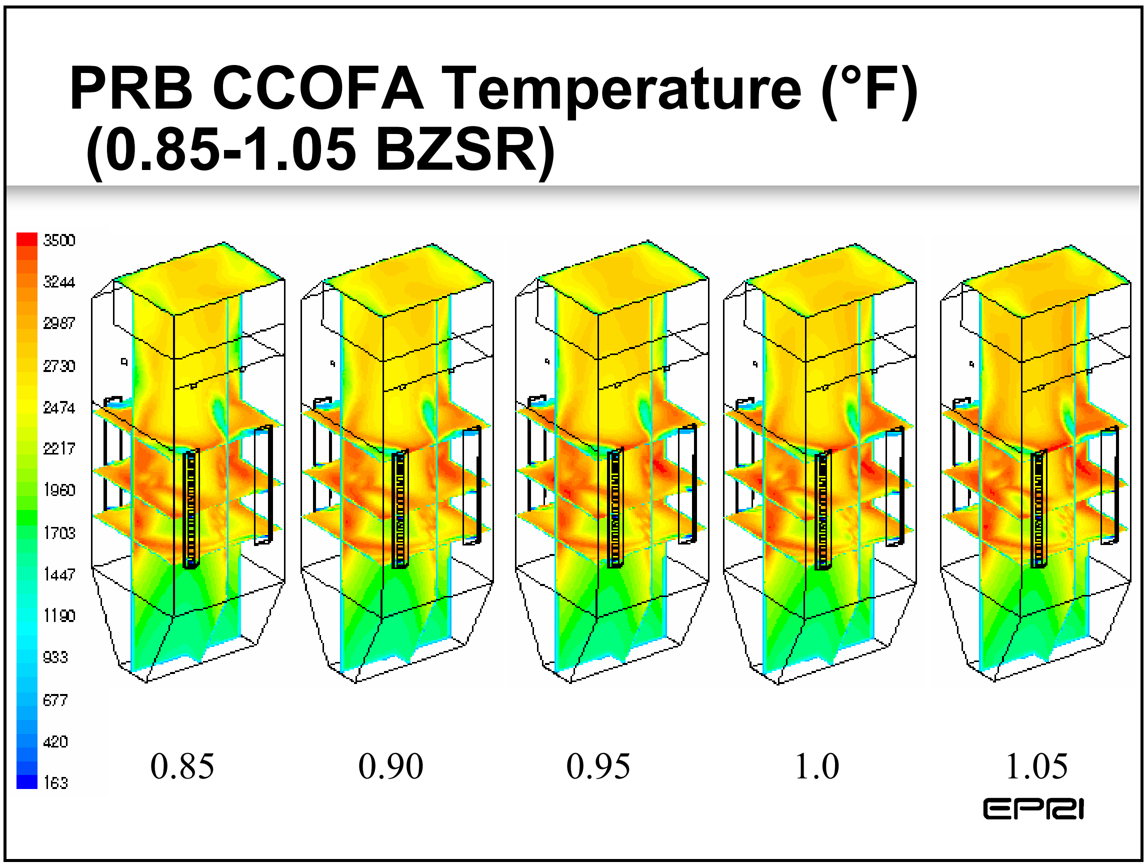
COAL INPUT FROM EDR for TEST 10	8,601,200,000			
GROSS HEAT RATE (Btu/kWh):	9,740	780,000		
HEAT INPUT (Btu/hr):	8,600,420,000			
LOAD (MWg):	883.0			
EXCESS OXYGEN (%,dry):	2.39%			
(%,wet):	2.07%			
HUMIDITY RATIO:	0.0130			
STOICH A/F:	7.00			
THEORETICAL A/F:	7.80			
STOICHIOMETRIC RATIO:	1.114			
MOLECULAR WEIGHT (lb/lbmole):	29.03			
AIR FLOW (lb/hr):	8,003,536		1,008	kg/s
FUEL FLOW (lb/hr):	1,026,426		129	kg/s
(tph):	513.2			

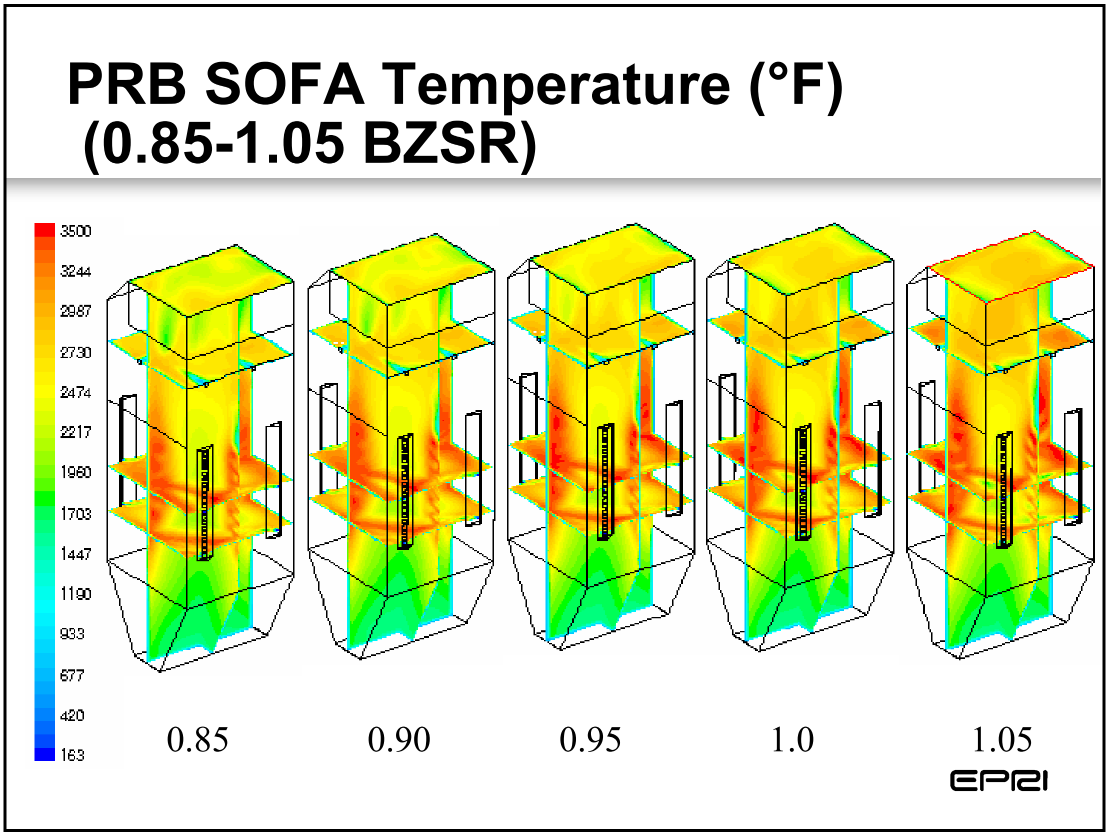
Combustion Mass Balance Stack Calculations	**Wet Basis**	**Dry Basis**	**Mass Flow (lb/hr)**	**Molar Basis (lbmole/hr)**	**Mass/Heat Input ($lb/10^6$ Btu)**
O2	2.07%	2.39%	204,362	6,386	23.76
CO2	14.18%	16.39%	1,927,351	43,803	224.10
H2O	13.49%	-	750,117	41,673	87.22
N2	70.20%	81.15%	6,071,780	216,849	705.99
SO_2 (PPM @ 99% CONV):	405	468	7,997	125	0.93
SO_3 (PPM @ 1% CONV):	4	5	106	1	0.01
HCl (ppmv):	0	0	0	0	0.00
Measured NO (ppmv):	146	166	2,074	45	0.24
		100.00%	8,963,787	308,884	1042.25

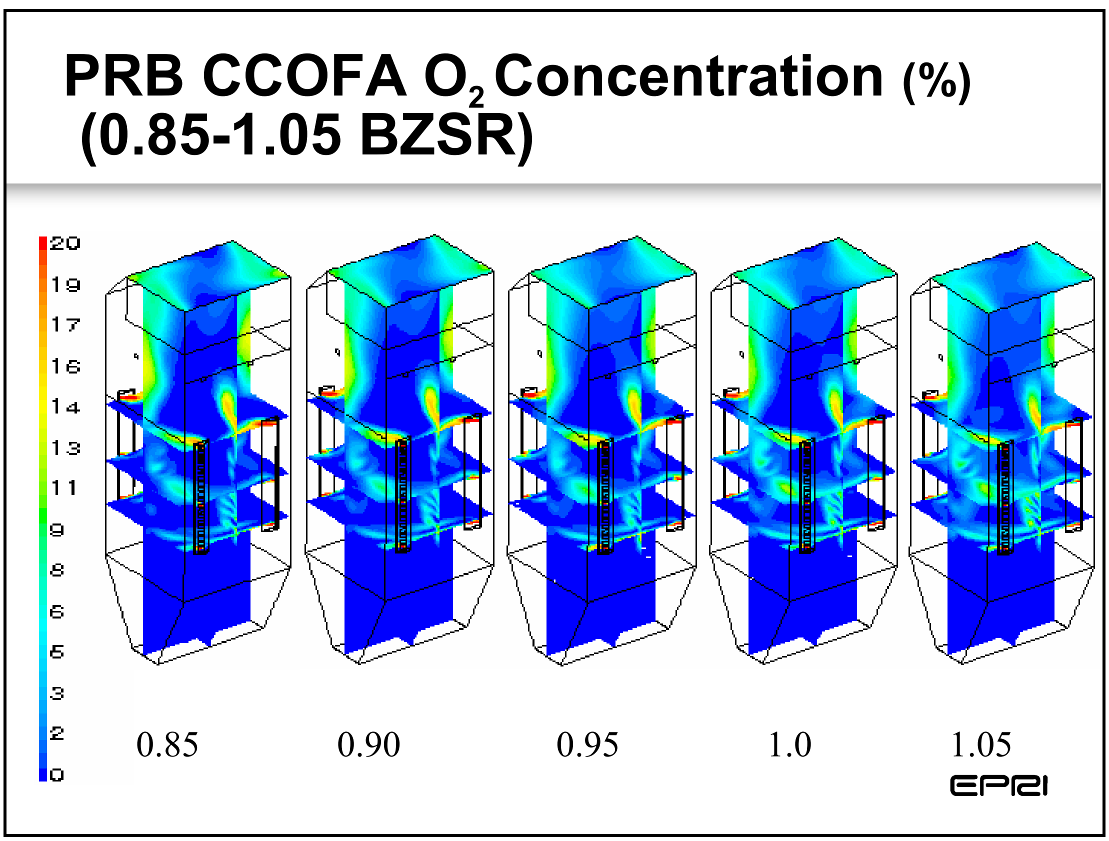
ASH	3.82	gr/scf		
ASH	63,946	lb/hr	8.06	kg/s
FLUE GAS	8,966,015	lb/hr	1,129.71	kg/s
FLUE GAS	29.03	lb/lbmole		
FLUE GAS	8.74	lb/lb fuel		
FLUE GAS DENSITY @ 300 F	0.0523	lb/ft^3	0.8382	kg/m^3
FLUE GAS DENSITY @ 2400 F	0.0139	lb/ft^3	0.2227	kg/m^3

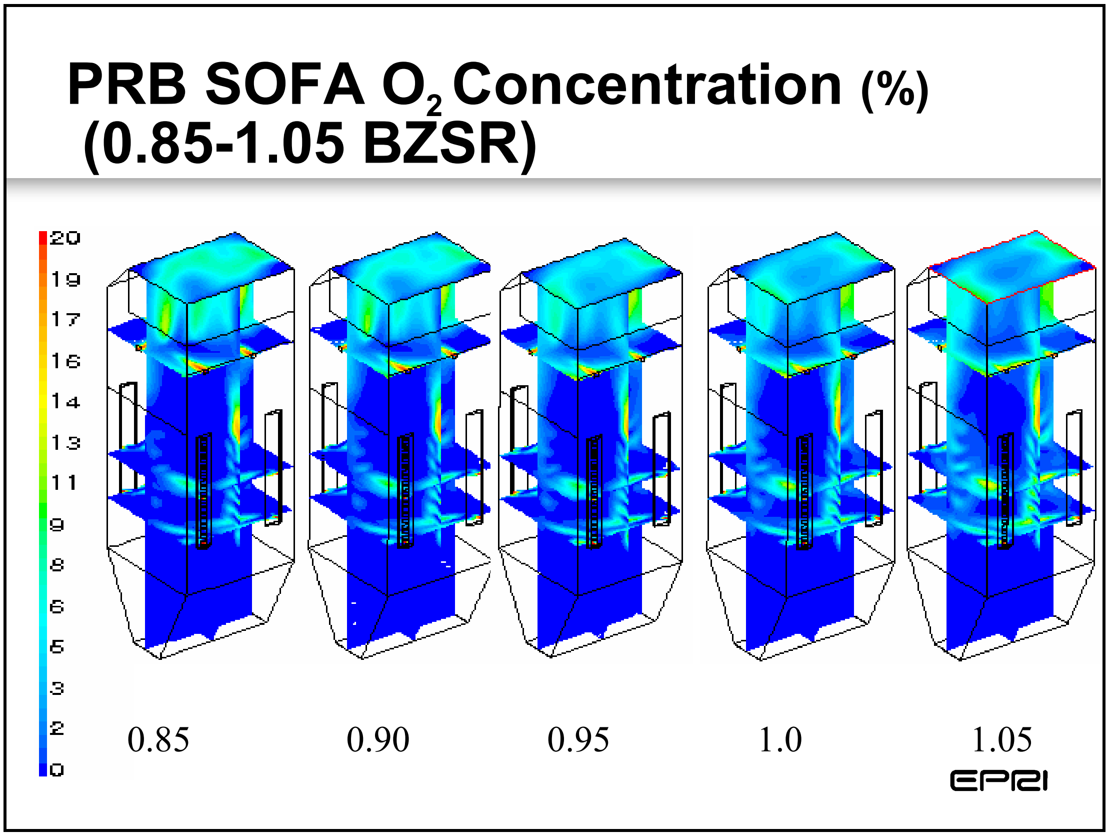
C

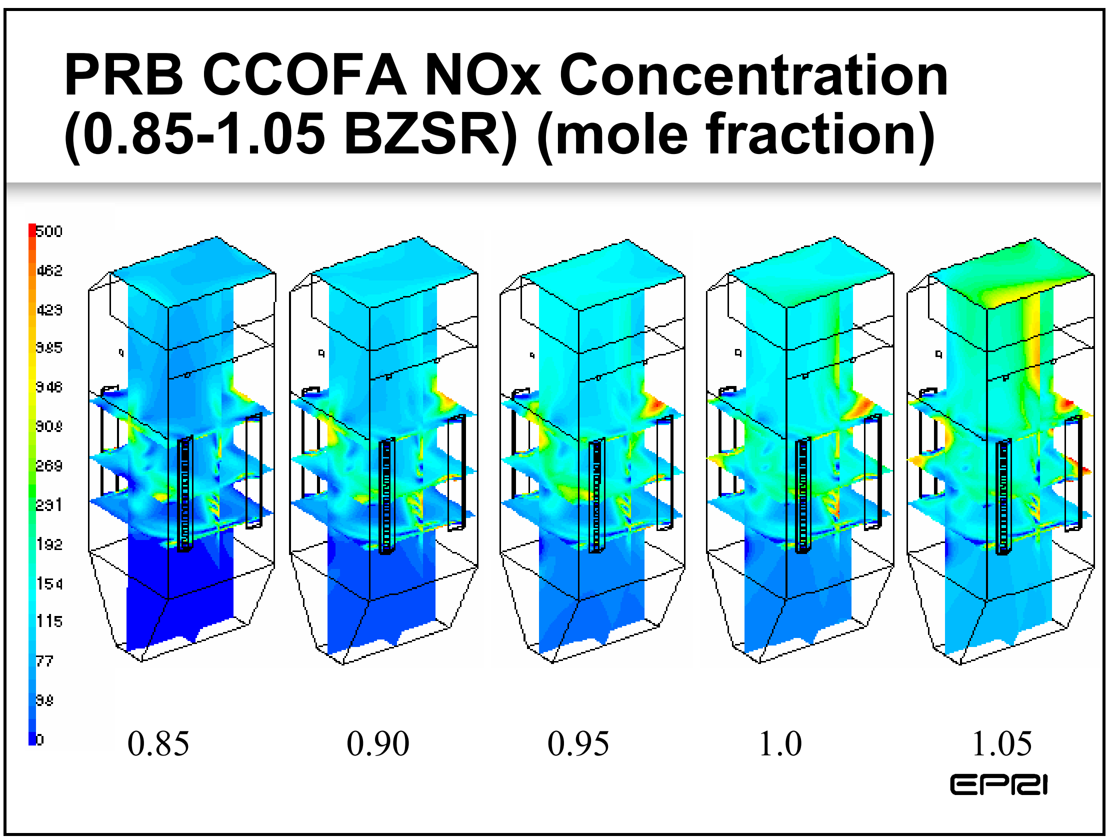
SELECTED SIMULATION CONTOURS



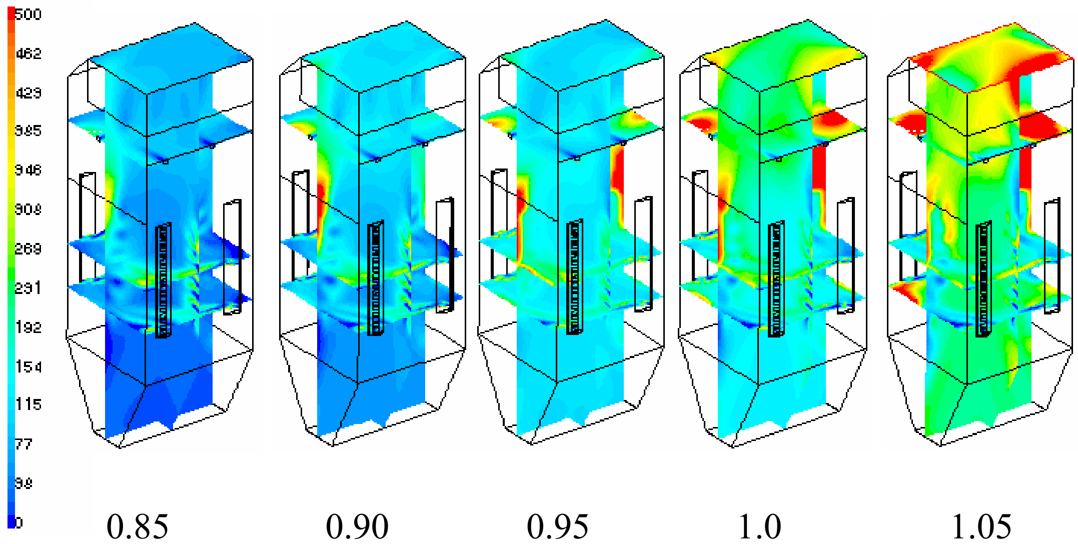

PRB SOFA Temperature (°F)
(0.85-1.05 BZSR)
3500
3244
2987
2730
2474
2217
1960
1703
1447
1190
933
677
420
163
0.85
0.90
0.95
1.0
1.05
EPRI


PRB CCOFA O_2 Concentration (%)
(0.85-1.05 BZSR)
20
19
17
16
14
13
11
9
8
6
5
3
2
0
0.85
0.90
0.95
1.0
1.05
EPRI

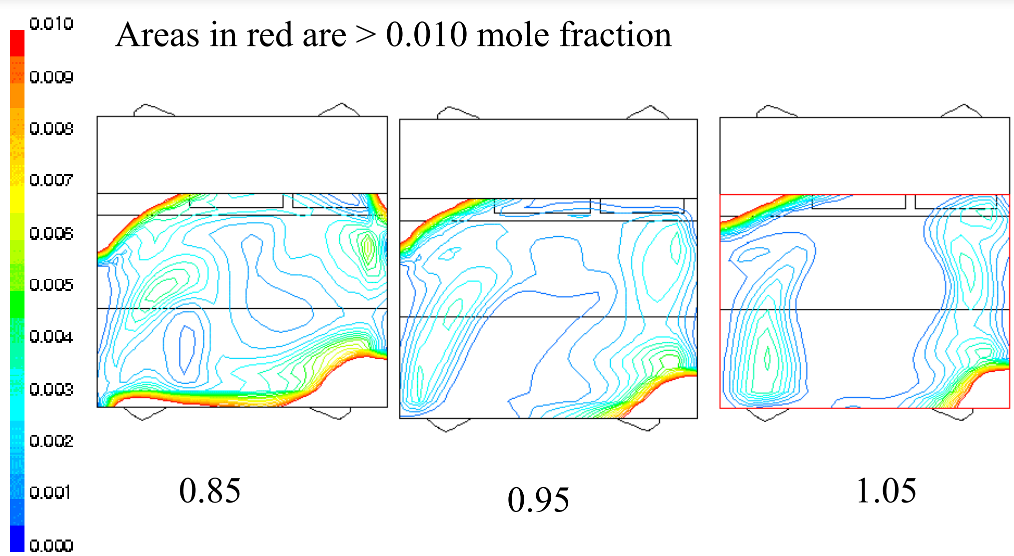

PRB SOFA O_2 Concentration (%)
(0.85-1.05 BZSR)
20
19
17
16
14
13
11
9
8
6
5
3
2
0
0.85
0.90
0.95
1.0
1.05
EPRI


PRB CCOFA NOx Concentration
(0.85-1.05 BZSR) (mole fraction)
500
462
423
385
346
308
269
231
192
154
115
77
38
0
0.85
0.90
0.95
1.0
1.05
EPRI

PRB SOFA NOx Concentration (0.85-1.05) (ppm dry)

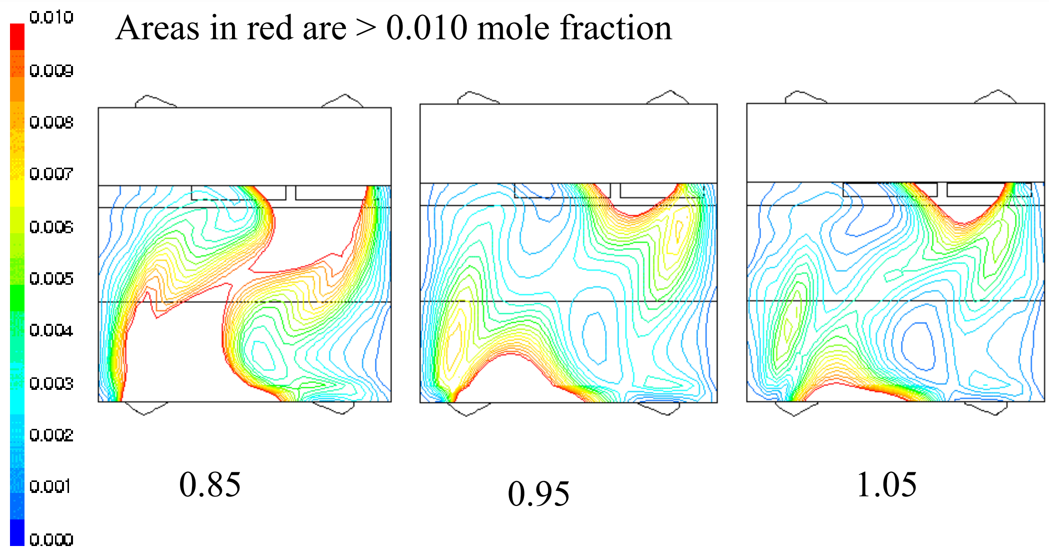


CO Contours @ Furnace Exit Plane – SOFA BZSR = 0.85, 0.95, 1.05



CO Contours @ Furnace Exit Plane – CCOFA BZSR = 0.85, 0.95, 1.05

Areas in red are > 0.010 mole fraction



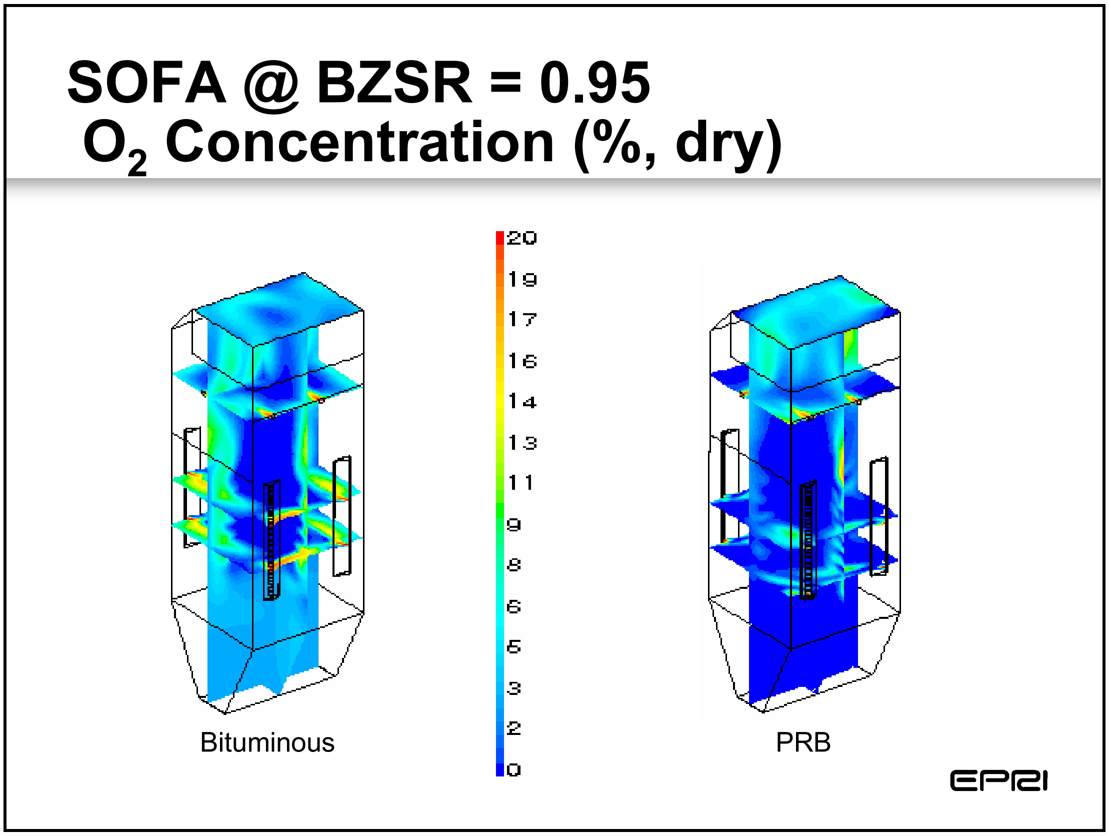
EPRI

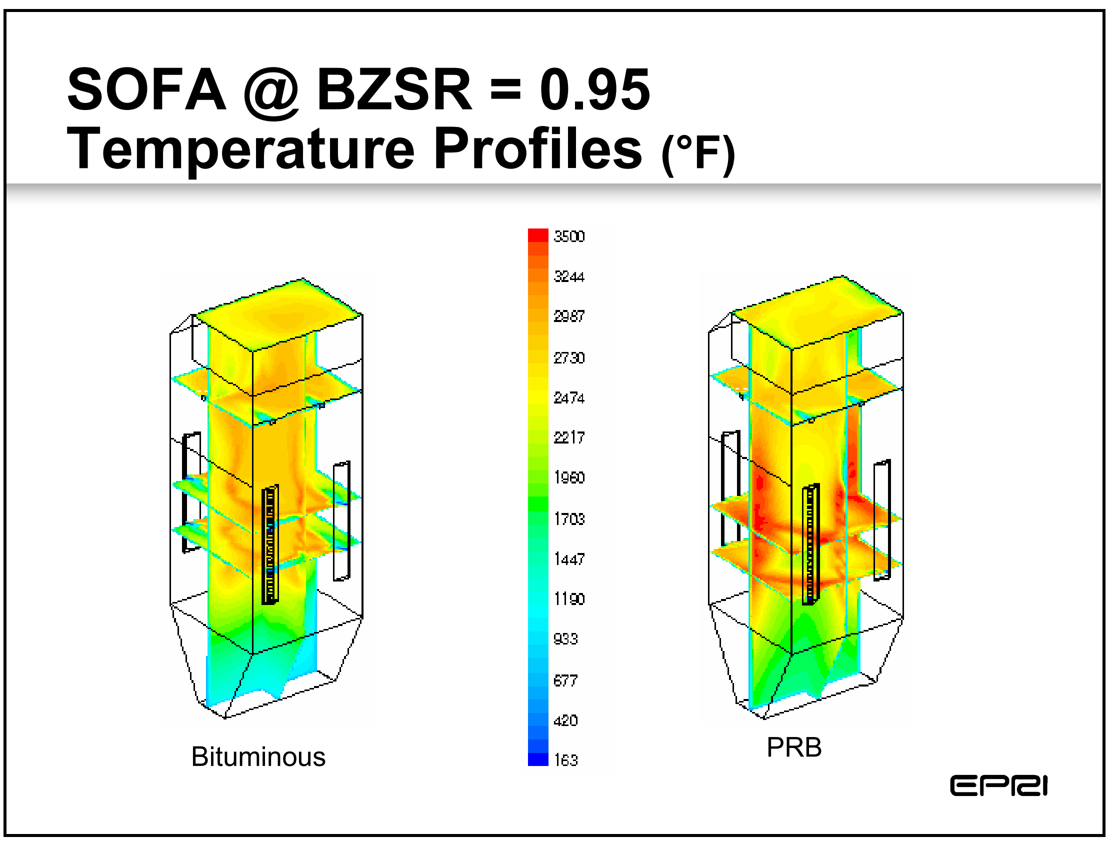
SOFA Bituminous vs. PRB

Simulation Differences

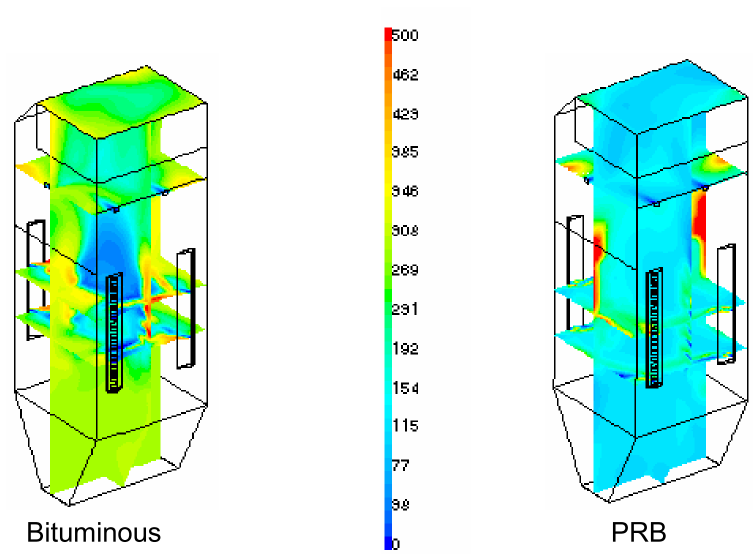
Fuel	Bituminous	PRB
Elevations in Service	5 coal elevations C – H	7 coal elevations C - J
Furnace Exit Stoichiometry	1.16	1.11
Primary Air Temperature, °F	165	120

EPRI


SOFA @ BZSR = 0.95
O_2 Concentration (%, dry)
20
19
17
16
14
13
11
9
8
6
5
3
2
0
Bituminous
PRB
EPRI


SOFA @ BZSR = 0.95
Temperature Profiles (°F)
3500
3244
2987
2730
2474
2217
1960
1703
1447
1190
933
677
420
163
Bituminous
PRB
EPRI

SOFA @ BZSR = 0.95
NOx Concentration (ppm dry)



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Simulations with Bituminous Coal

Baseline conditions:
- BZSR = 0.95
- Furnace Exit Stoichiometry = 1.16

Five Coal Elevations in Service only (C – G)

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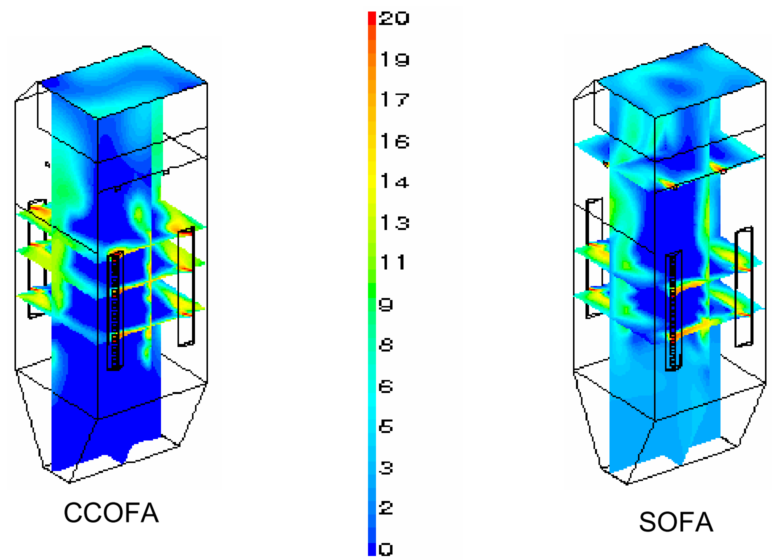
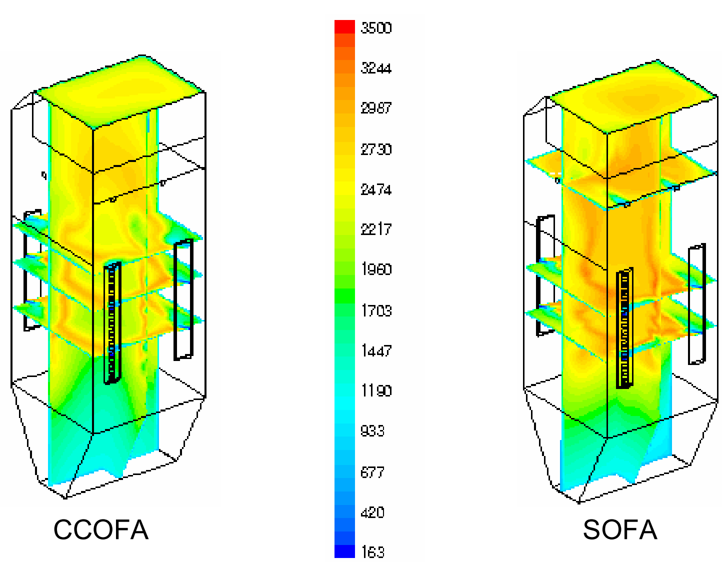
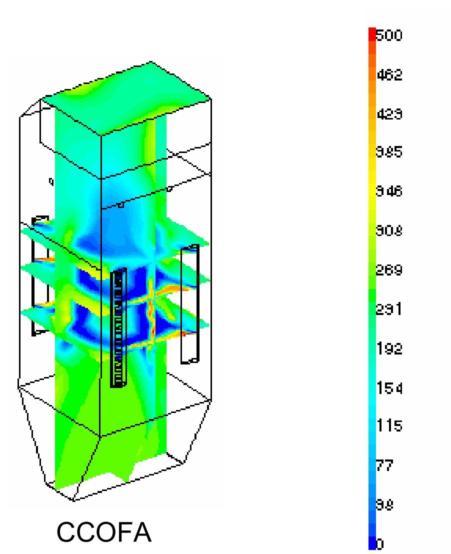
Bituminous O_2 Concentration (%) CCOFA vs. SOFA



Bituminous Temperatures (°F) CCOFA vs. SOFA



Bituminous NOx Concentration (ppm dry) CCOFA vs. SOFA



Target:

Coal Boiler Performance Optimization and Combustion NO_x Control

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