ACHIEVING NEW SOURCE PERFORMANCE STANDARDS (NSPS) EMISSION STANDARDS THROUGH INTEGRATION OF LOW-NOx BURNERS WITH AN OPTIMIZATION PLAN FOR BOILER COMBUSTION

Quarterly Technical Progress Report

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Disclaimer

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Abstract

The objective of this project is to demonstrate the use of an Integrated Combustion Optimization System to achieve NO_X emissions levels in the range of 0.15 to 0.22 lb/MMBtu while simultaneously enabling increased power output. The project consists of the integration of low-NO_X burners and advanced overfire air technology with various process measurement and control devices on the Holcomb Station Unit 1 boiler. The project includes the use of sophisticated neural networks or other artificial intelligence technologies and complex software that can optimize several operating parameters, including NO_X emissions, boiler efficiency, and CO emissions.

The program is being performed in three phases. In Phase I, the boiler is being equipped with sensors that can be used to monitor furnace conditions and coal flow to permit improvements in boiler operation. In Phase II, the boiler will be equipped with burner modifications designed to reduce NO_X emissions and automated coal flow dampers to permit on-line fuel balancing. In Phase III, the boiler will be equipped with an overfire air system to permit deep reductions in NO_X emissions to be achieved. Integration of the overfire air system with the improvements made in Phases I and II will permit optimization of the boiler performance, output, and emissions.

During this reporting period, efforts were focused on completion of Phase I and Phase II activities. The low-NO_X burner modifications, the coal flow dampers, and the coal flow monitoring system were procured and installed during a boiler outage in March 2003. During this reporting period, optimization tests were performed to evaluate system performance and identify optimum operating conditions for the installed equipment. The overfire air system process design activities and preliminary engineering design were completed.

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1.0   Introduction

The objective of this project is to demonstrate the use of an Integrated Combustion Optimization System to achieve NO_X emissions levels in the range of 0.15 to 0.22 lb/MMBtu while simultaneously enabling increased power output. The project consists of the integration of low-NO_X burners and advanced overfire air technology with various process measurement and control devices on the Holcomb Station Unit 1 boiler. The project includes the use of sophisticated neural networks or other artificial intelligence technologies and complex software that can optimize several operating parameters, including NO_X emissions, boiler efficiency, and CO emissions.

The Integrated Combustion Optimization System will be installed in three phases to demonstrate the synergistic effect of layering NO_X control technologies. The three phases are:

- Phase I – Advanced Sensors Upgrade
- Phase II – Low-NO_X Burner Modifications
- Phase III – Advanced Overfire Air System

Phase I – Advanced Sensors Upgrade will demonstrate the effectiveness of novel measuring sensors with respect to the control of factors leading to reduced NO_X emissions and improved thermal efficiency with minimal physical modifications to the boiler.

Phase II – Low-NO_X Burner Modifications will demonstrate the effectiveness of low-cost modifications to the existing, first generation low-NO_X burners to reduce NO_X emissions. The modifications will consist of new burner tips and other parts designed to lower NO_X emissions. This phase will also include modifications to the existing pulverized coal (PC) piping to permit automated fuel balancing among all burners.

Phase III – Advanced Separated Overfire Air (SOFA) will demonstrate deeper NO_X control competitive to SCR installation with the addition of an overfire air system coupled with the existing Phase I and II modifications to optimize overall system performance. The integration of

all three phases of these improvements will provide the opportunity to reduce NO_X emissions and permit improvements in power plant performance and output.

This report summarizes the technical progress during the referenced reporting period.

2.0   Technical Progress

During this reporting period, work continued on Phase I and Phase II of the project. The low-NO_X burner modifications, coal flow dampers, and coal flow measurement system were installed during the plant outage in March 2003. Following installation, optimization tests were performed to characterize the system performance. In addition, preliminary process and engineering design activities for the overfire air system to be installed in spring of 2004 were completed. The schedule for the project is shown in Appendix A – Gantt Chart. The technical progress made during this reporting period is summarized in the following.

2.1   Task 1.0 – Phase I – Advanced Sensors Upgrade

The objective of Phase I is to demonstrate the effectiveness of novel measuring sensors with respect to the control of factors leading to reduced NO_X emissions and improved thermal efficiency with minimal physical modifications to the boiler. The scope of work for the Advanced Sensors Upgrade Phase is being performed in the following six tasks.

2.1.1   Task 1.1 – Process Design and Performance Analysis

In this task, analytical tools and methods were used to evaluate existing process engineering systems and to prepare material/energy balances for the low-NO_X burner modifications and overfire air system.

The demonstration for the project will be performed at Holcomb Station located in Holcomb, Kansas. Unit 1 at the station has a gross generating capacity of approximately 380 MW. A sectional sideview of the boiler is shown in Figure 2-1. The boiler was manufactured by Babcock and Wilcox and uses an opposed wall fired design. The burner configuration features three rows on the front wall and two rows on the rear wall. Each row is equipped with five burners, for a total of twenty-five burners on the unit. Flue gas from the burners flows into the upper furnace and across the platen superheater, secondary superheater, and reheater, and then into the backpass. The unit is equipped with a split backpass where the flue gas flow rate across the

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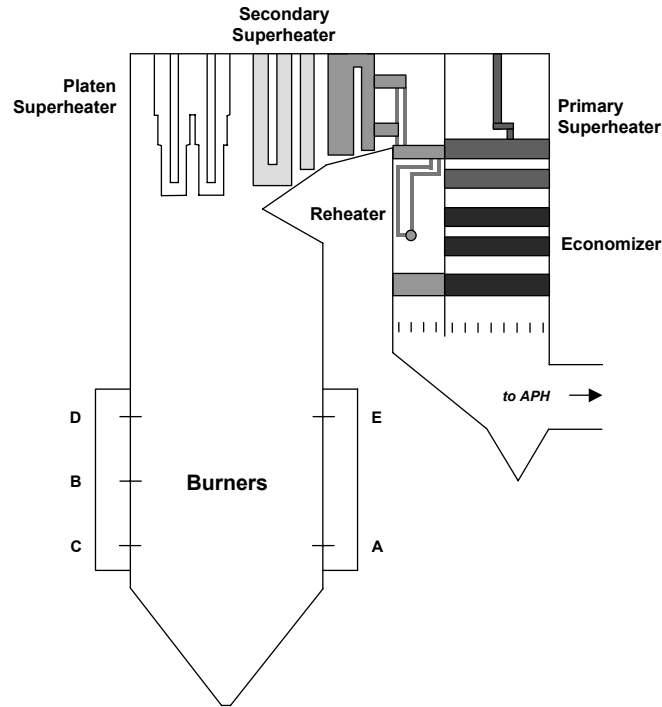
Figure 2-1. Sectional sideview of Holcomb Unit 1.

reheater and primary superheater tube banks is regulated to control reheat steam temperature.
The flue gas streams exiting the split backpass are combined and then diverted to the air
preheater. Following the air preheater, the flue gas flows through a dry scrubber to remove sulfur
dioxide and a baghouse to remove particulate.

The boiler fires Power River Basin (PRB) coal that is supplied from several mines. A summary
of coal analyses prior to and during the program is shown in Table 2-1. There was a change in
coal supply near the end of 2002, which had a minor impact on the coal fired in 2003. Coal is
supplied to the plant by railcars. The coal is fed into bunkers and then to five coal mills where
the coal is pulverized. The unit can generate full load on either four or five mills. One mill feeds
each row of burners. Figure 2-1 shows the mill and burner configuration (A through E).

Due to spinning reserve requirements, the normal day-to-day full load on the unit is currently
373 MWg, which corresponds to an average heat input of $3,607 \times 10^6$ Btu/hr. The goal of this
project is to permit an increase in unit capacity while reducing NO_X emissions and maintaining

TABLE 2-1. COAL ANALYSIS

Coal Analysis		6/14/00 As Fired	10/27/99 As Fired	5/27/99 As Fired	Feb-03 As Fired	May-03 As Fired
Ultimate Analysis						
C	wt. %	49.40	49.33	49.17	52.15	53.68
H	wt. %	3.70	3.61	3.41	3.62	2.05
N	wt. %	0.78	0.77	0.79	0.72	0.85
S	wt. %	0.35	0.39	0.35	0.31	0.48
O	wt. %	11.93	12.59	12.65	12.04	10.63
Ash	wt. %	5.57	5.84	5.51	4.77	5.77
Moisture	wt. %	28.17	27.47	28.12	26.39	26.54
Total		99.90	100.00	100.00	100.00	100.00
Proximate Analysis						
Fixed Carbon	wt. %	34.05	34.15	35.05	36.90	25.83
Volatile Matter	wt. %	32.21	32.54	31.32	31.94	41.86
Moisture	wt. %	28.17	27.47	28.12	26.39	26.54
Ash	wt. %	5.57	5.84	5.51	4.77	5.77
Total		100.00	100.00	100.00	100.00	100.00
HHV	Btu/lb	8,492	8,635	8,505	9,086	9,372

or improving unit performance. It is projected that the normal day-to-day full load will increase to 380 MWg in 2004 once the Phase III equipment is installed on the unit and other factors constraining the unit load are corrected. This load corresponds to a nominal heat input of 3,676 x 10^6 Btu/hr. The nominal full load excess air level is approximately 18 percent. These operating conditions were used as the design basis for the low-NO_X burner modifications and overfire air system.

A physical model of the Unit 1 boiler was fabricated and used to characterize the furnace flow field. The physical model was constructed primarily of acrylic sheet to a 1:20 geometric scale. A photograph of the model is shown in Figure 2-2. The model was designed to be an exact geometric replica of the full-scale boiler and simulates the flow path from the burners in the furnace through the first few banks of the convective pass. The convective tube banks on the model were designed to match the pressure loss coefficients of the tube banks on the full-scale system. The burners were scaled to properly account for the effects of heat release in the furnace on the expansion of the burner flames. Studies performed with the physical model included
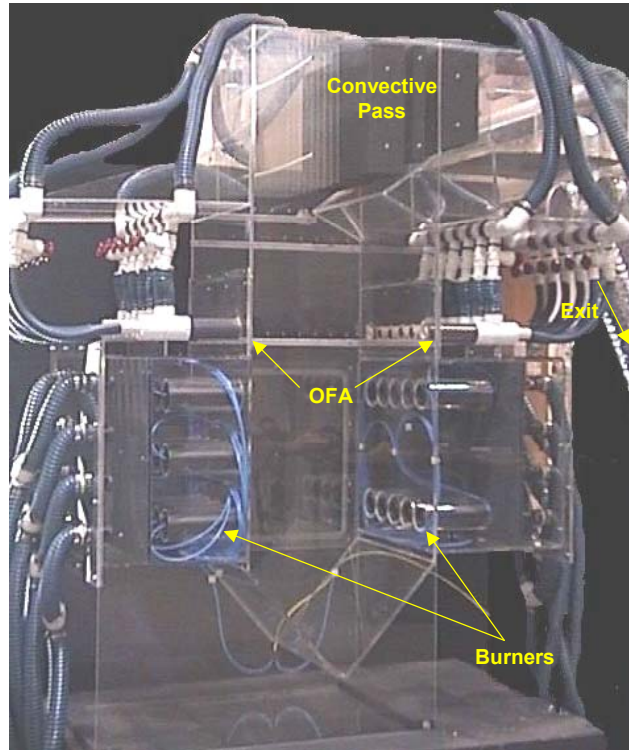
Figure 2-2. Photograph of physical model of boiler.

smoke and bubble tracer visualization and velocity measurements at selected planes within the furnace.

Overall, the predominant features of the furnace flow field are typical of opposed wall-fired boilers and are characterized by: (1) high velocity flow at the center of the boiler and near the sidewalls in the lower furnace leading to high velocities near the furnace arch as the flow enters the upper furnace, and (2) formation of recirculation zones in the hopper and above the upper row of burners on the front and rear walls. Velocity measurements were performed at horizontal planes in the furnace and at the arch to quantify the extent of non-uniformities in the furnace flow profile. The results are shown in Figure 2-3, which show plots of the normalized upward component of the measured velocity. The furnace plane shows that the majority of the flue gas flows up the center of the boiler and along the corners at the front wall, with lower velocities near the rear wall and along the center of the front wall. As the flow moves into the upper furnace, the distribution changes with higher velocities near the rear wall and lower velocities
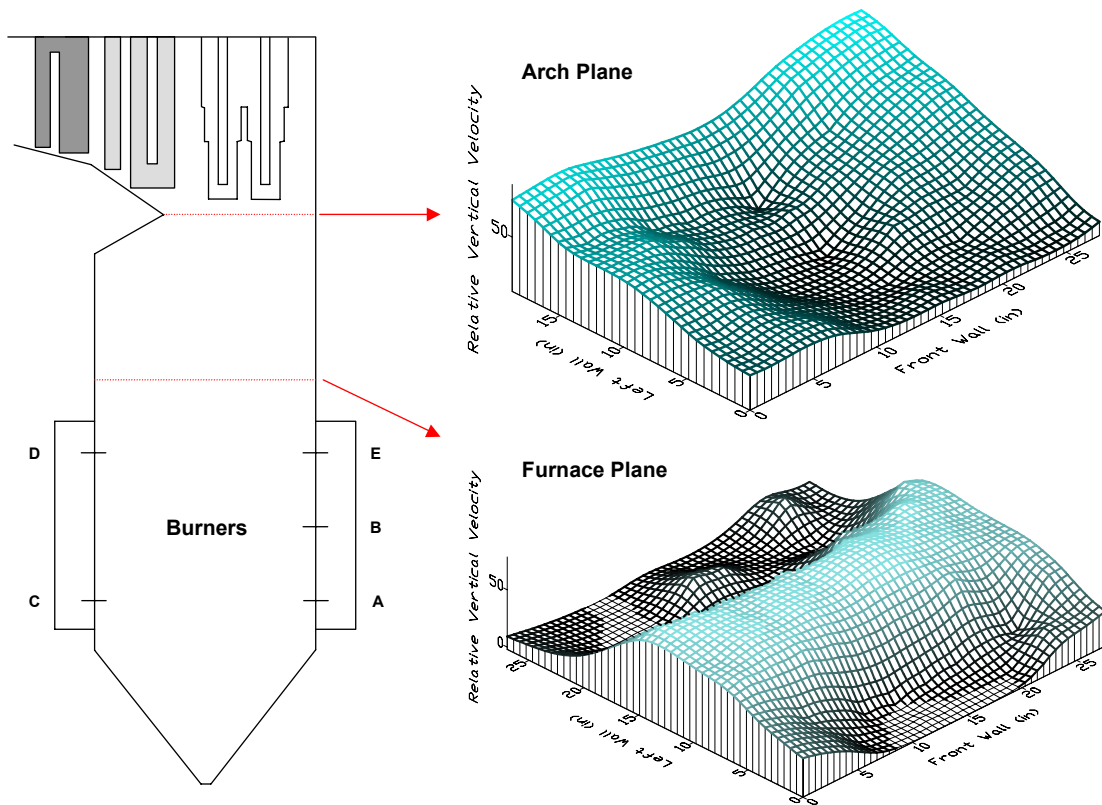
Figure 2-3. Velocity profiles in the furnace and at the arch.

near the front wall. These changes are due to the acceleration of flow near the arch and the decreased furnace cross-sectional area at that plane. The furnace flow field has implications for the design of an overfire air system where the overfire air port design and configuration must take into account the non-uniform velocity field and for furnace slagging and fouling where the high velocity areas of the furnace are typically associated with higher temperatures and lower stoichiometric ratios.

The physical model was also used to provide a dataset for use with the boiler combustion optimization sensors. As discussed in Section 2.1.3, combustion quality sensors were installed in the upper furnace (one sensor above each burner column) and a grid of in-situ CO sensors was installed in the backpass between two sections of the primary superheater tube banks. To support

the use of these sensors in optimizing boiler emissions and performance, tracer dispersion measurements were performed with the physical model in which a tracer gas was added to an individual burner or to rows or columns of burners and tracer concentration measurements were made at the location of the sensors. For the upper furnace sensors, the results of the measurements confirmed that the burner columns below the sensor contributed significantly to the flue gas that the sensor would view, with the front wall upper burner rows burners having the most influence. For the CO sensors, the results of the tracer dispersion measurements were used to develop a model of the influence of each burner on an individual sensor. This model was used to support system tuning and optimization.

To support the design of the low-NO_X burner modifications, a physical model of the current first-generation low-NO_X burner was designed and fabricated. The model was constructed of primarily of sheet metal and acrylic tube to a 1:3 geometric scale and was placed in an acrylic plenum. A photograph of the burner model is shown in Figure 2-4. The model included details of the modifications and the existing swirl registers and dampers. This model was used to evaluate the proposed burner modifications and to determine optimum settings for start up of the modified burners. Photographs of smoke visualization tests performed with the burner are shown in Figure 2-5. This figure compares the impacts of the modifications on the flow from the coal pipe at equivalent air register settings. Compared to the baseline case, the modifications are shown to generate more turbulence and mixing near the coal pipe exit. The results of the flow visualization studies and more quantitative tracer measurements demonstrate that the modifications will help to stabilize the coal flame near the nozzle. This stabilization will be important to maintain good flame stability, combustion performance, and low-NO_X emissions when the overfire air system is installed. In addition to evaluating the impacts of the modifications on flame stability, the burner model was also used to develop transfer functions to enable estimates of the air flow split and flow rates based upon damper settings and windbox pressure. These transfer functions were incorporated into the model developed to relate sensor output to a particular set of burners.
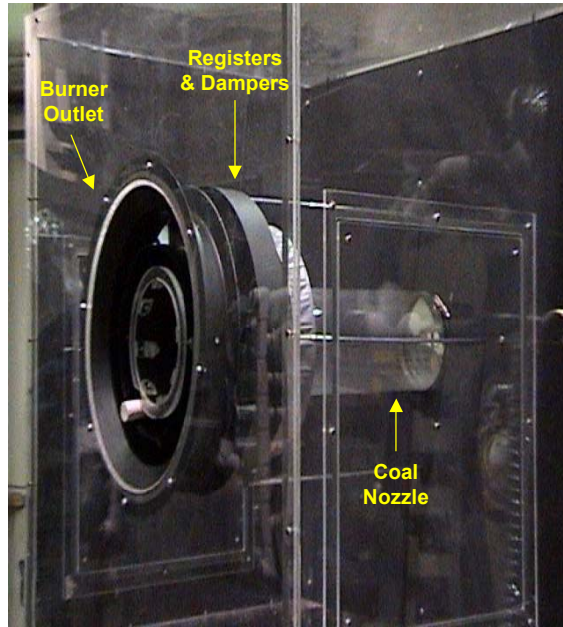
Figure 2-4. Photograph of physical model of burner.
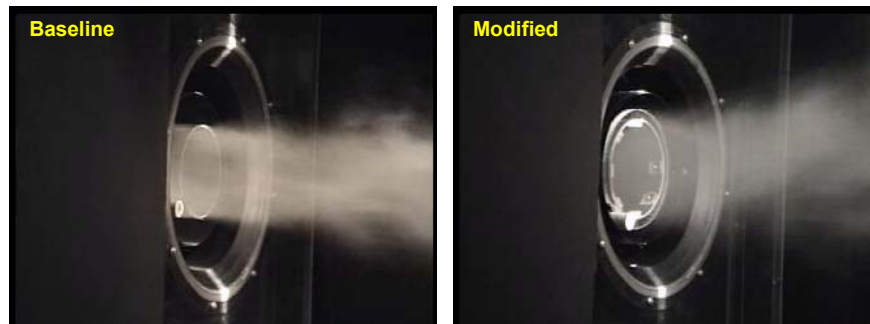
Figure 2-5. Flow visualization of baseline and modified burner.

2.1.2   Task 1.2 – Design and Fabrication/Construction Documents

In this task, design and fabrication drawings for new equipment and other similar detailed information were developed to enable the receipt of contractor proposals for equipment supply and installation.

During the previous reporting period, this task supported the design and installation of the automated coal balancing dampers, coal flow measurement system, and the low-NO$_X$ burner modifications.

2.1.3   Task 1.3 – Boiler Combustion Optimization Sensors

In this task, the boiler was equipped with furnace sensors to monitor the balance among burner columns and between the front and rear firing walls, and with sensors to monitor coal flow in each coal pipe.

A sensors package was procured and installed on the boiler during the previous reporting period and prior to the unit outage in March 2003. The sensors package consists of burner flame scanner sensors (Burner Profiler), LOI/FEGT Sensors, and in-situ CO sensors. An overview of the sensor locations is shown in Figure 2-6. The five LOI/FEGT or combustion sensors are located on the front wall at Elevation 3074′-2″. One sensor is located above each burner column. Fifteen CO
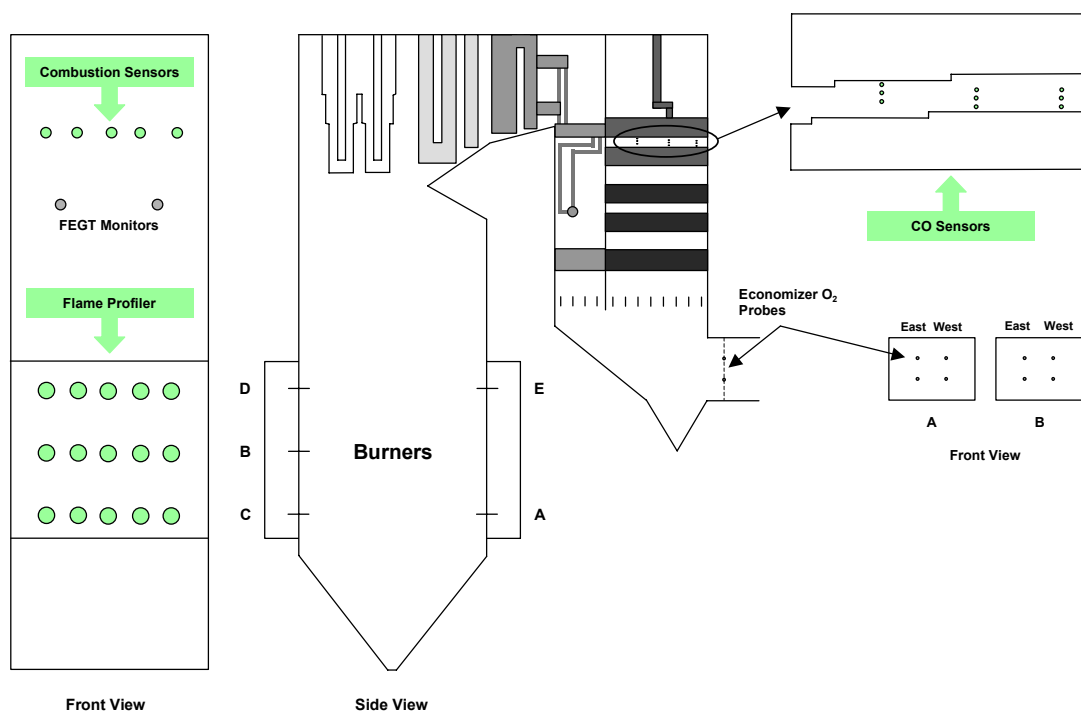
Figure 2-6. Overview of sensor locations on unit.

sensors are located in the backpass between two sections of the primary superheater. The sensors are inserted into the gas path at various depths from both of the boiler sidewalls in order to provide a measurement grid that covers the gas path cross section in that area of the boiler. A burner flame scanner sensor was installed on each burner. Figure 2-6 also shows the location of the optical furnace exit gas temperature (FEGT) monitors that were installed on the unit prior to the current project and the location of the plant oxygen probes. These probes are used for control of the boiler. The oxygen grid consists of a vertical array of eight sensors located in the two ducts exiting the boiler and leading towards the air preheater.

A coal flow measurement system was procured and installed on the unit. The selected system uses microwave signals to detect the bulk density of the solids flowing in the coal pipes. The system is also configured to measure the coal particle velocity. The coal flow monitoring system was procured and installed on the boiler during the March 2003 outage. A set of sensors was installed on each of the coal pipes between the mill outlet and the burners. Figure 2-7 shows a
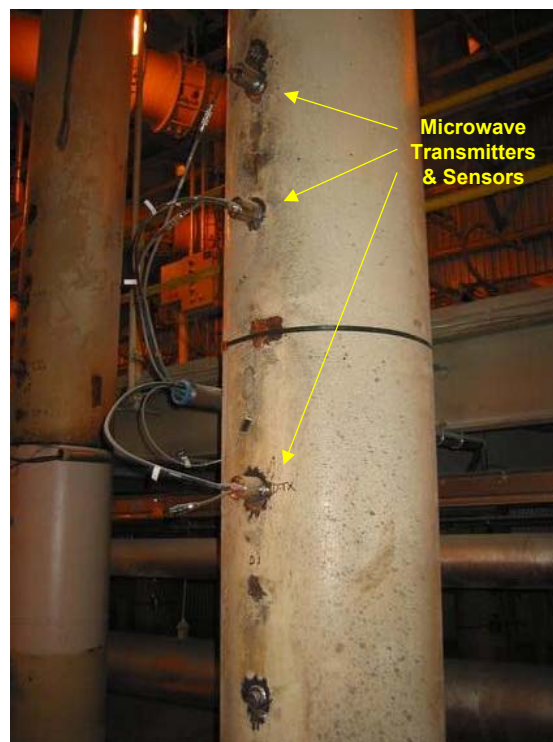
Figure 2-7. Photograph of coal flow sensors installed on coal pipe.

photograph of a typical installation of the sensors on one of the coal pipes. The coal measurement system was commissioned following the outage. Following commissioning, tests were performed to validate the results of the measurements. The first check consisted of monitoring the sensor output relative to the feeder speed. The results of this validation for Mill B are shown in Figures 2-8 and 2-9. Figure 2-8 compares the coal pipe measurements and the mill feeder measurements from April 16th through 28th. This comparison shows that the coal pipe sensors consistently tracked the mill feeder and normal variations in mill coal flow rates as operating load and conditions changed over this time interval. Figure 2-9 compares the sum of the coal pipe measurements over this same interval with the indicated mill feeder flow rate. This comparison shows again that the sensors tracked the mill loading over its normal operating range. Comparison of the indicated coal particle velocities over this time interval also showed that the velocity measurements tracked the variations in mill output. Similar comparisons were performed for the other four mills and showed good results. A second check consisted of performing manual measurements of the air flow exiting the mills using a dirty-air pitot probe and comparing the velocities and flow rate to those implied by the coal particle velocity measurements. This comparison showed a good correspondence between the manual measurements and the coal flow sensor measurements.
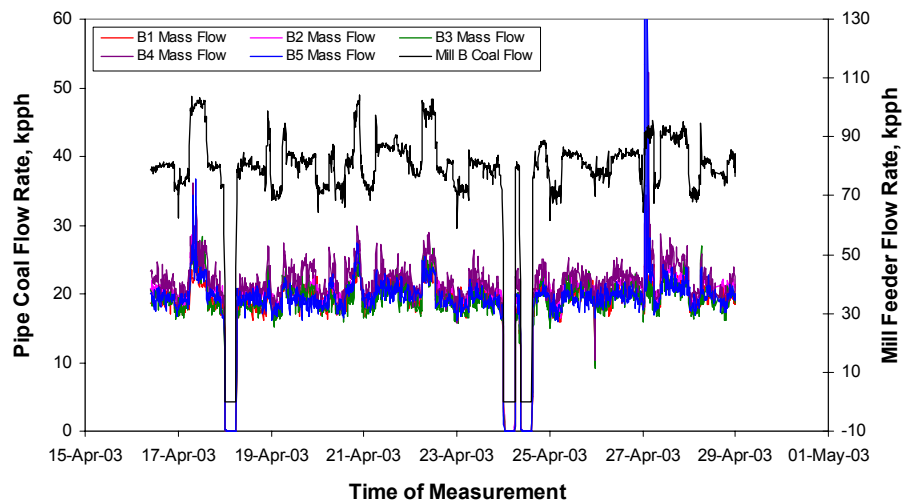
Figure 2-8. Comparison of feeder output and individual coal pipe measurements for Mill B.
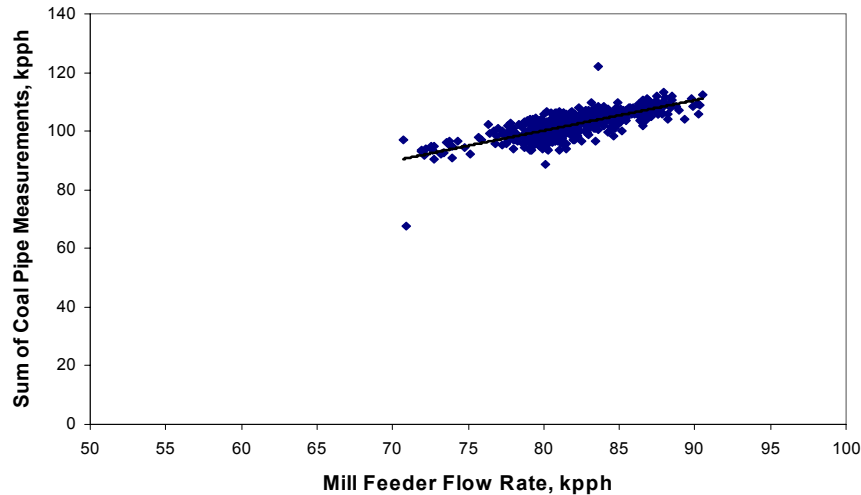
Figure 2-9. Comparison of total individual pipe measurements to mill feeder.

One issue still under investigation is the coal flow sensors on Mill A. The output from the sensors on Mill A show a wide degree of fluctuations in the coal flow rate and coal particle velocity. To diagnose this issue, Mill A was taken off line and inspected. However, no abnormal conditions were noted. In addition, tests were performed in which the primary air was increased to see if slugging in the coal lines was an issue. Increasing the primary air did not help to reduce the fluctuations. Finally, the sensors were recalibrated and checked. No sensor abnormalities were noted and the fluctuations remained following recalibration. At this time, it is still not clear what factors are leading to the high degree of fluctuations in the measurement. A plan is being developed to resolve this issue.

The output from the furnace sensors and the output from the coal flow monitoring system were interfaced into the plant data historian to permit capture of data from the new systems along with other plant performance data.

2.1.4 Task 1.4 – Sensor Integration/Testing

In this task, tests were performed to evaluate the information obtained from the sensors. Data were collected from the furnace sensors during the baseline tests and following start up of the boiler. These data will be presented and discussed in Sections 2.1.5 and 2.2.2.

2.1.5 Task 1.5 – Baseline Testing

In this task, tests were performed on Holcomb Station Unit 1 to gather baseline performance and emissions data prior to retrofit of the emissions control equipment. This data set will serve as a comparison for the results of Phase II and Phase III tests performed on the unit.

In October 2002, tests were performed to characterize the baseline coal and primary air balance and to collect data needed to support the design of the low-NO_X burner modifications. In February 2003, baseline tests were performed on the unit. The primary information collected during the baseline tests consisted of:

- Boiler operating and performance data
- Economizer outlet gaseous emissions data
- Coal and flyash samples

The baseline tests characterized boiler operation and performance under normal operating conditions at full and low loads and at various operating conditions at full load. The various conditions evaluated included variations in the boiler excess air setting and coal flow distribution. Mill biasing tests were also conducted to evaluate the impact of mill operation on spatial combustion performance as well as to provide a relative indication of the burner balance within a mill.

The results of the coal and primary air flow measurements performed in October 2002 are presented in Figure 2-10. The measurements were performed using a dirty-air pitot probe and a RotorProbe instrument. Figure 2-10 shows the burner and mill arrangement and presents two tables summarizing the results. The two tables show the coal flow and air flow measured in each coal pipe expressed as percent of deviation from the average for that particular mill group. As

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Back Wall

Mill		% Deviation From Average				
		5	4	3	2	1
E	Air	4.4	3.6	-21.9	1.9	12.0
	Coal	14.2	30.8	-20.1	-10.4	-14.6
A	Air	9.6	-1.9	-16.4	10.6	-1.9
	Coal	11.6	-1.3	-23.2	10.0	2.9

Mill		% Deviation From Average				
		1	2	3	4	5
D	Air	-17.5	2.8	-4.2	12.5	6.4
	Coal	-8.6	17.5	-2.5	-20.0	13.6
B	Air	-0.4	4.0	-2.3	-5.3	4.1
	Coal	-20.3	20.5	3.6	-1.2	-2.5
C	Air	-3.7	-1.8	-2.2	6.0	1.8
	Coal	-5.2	7.2	8.2	14.7	-24.9

Front Wall
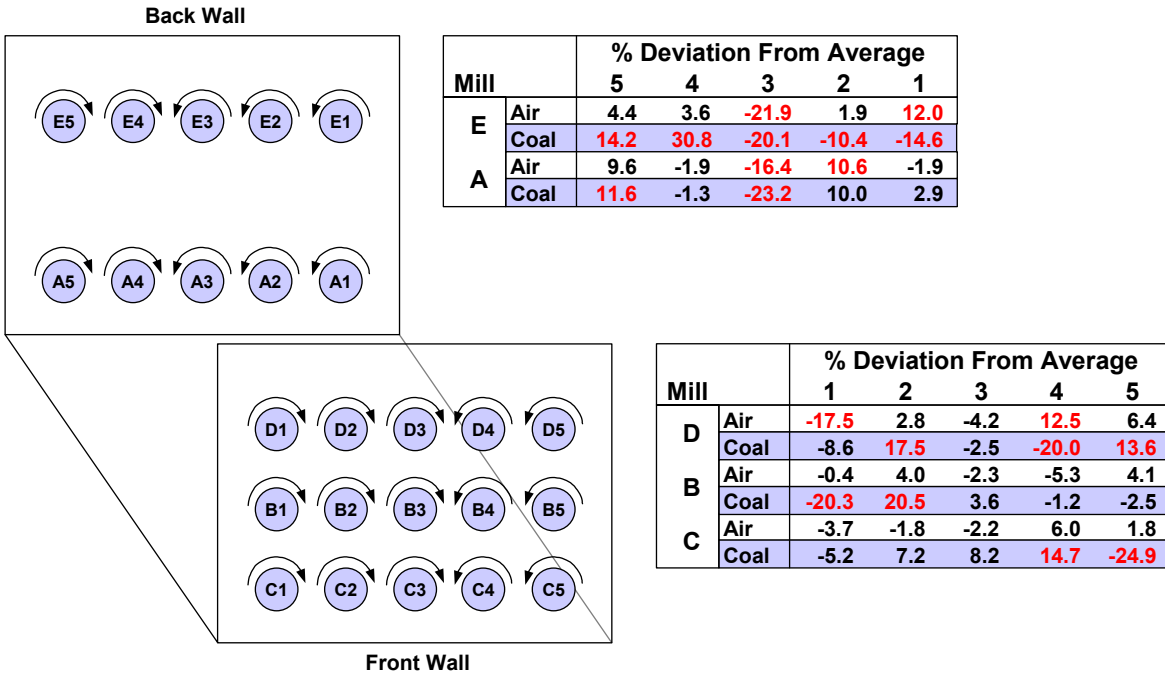
Figure 2-10. Burner arrangement and baseline coal and primary air balance.

shown in this table, the primary air flow was relatively well balanced, but several pipes showed imbalance greater than ± 10% of the average. The RotorProbe measurements showed that fourteen of the twenty-five coal pipes had coal flows greater than ± 10% of the average. The highest variation was observed for the coal pipes from Mill C where the coal flow varied from -14.6% to +30.8% of the average.

A primary objective of the baseline tests was to establish an emissions and performance baseline for comparison to the results achieved following the equipment retrofits in Phases II and Phases III of the project. Figure 2-11 shows the impacts of the boiler excess oxygen level (as measured by the plant oxygen probes) on NO_X and CO emissions measured at the stack. As shown in this figure, NO_X emissions were 0.31 lb/MMBtu and CO emissions were 0.075 lb/MMBtu at the normal operating excess oxygen level of 2.7%. Raising the excess oxygen level results in a reduction in CO emissions, but increases NO_X emissions. NO_X emissions can be reduced by operating at lower excess oxygen levels; however, operation at lower excess oxygen levels
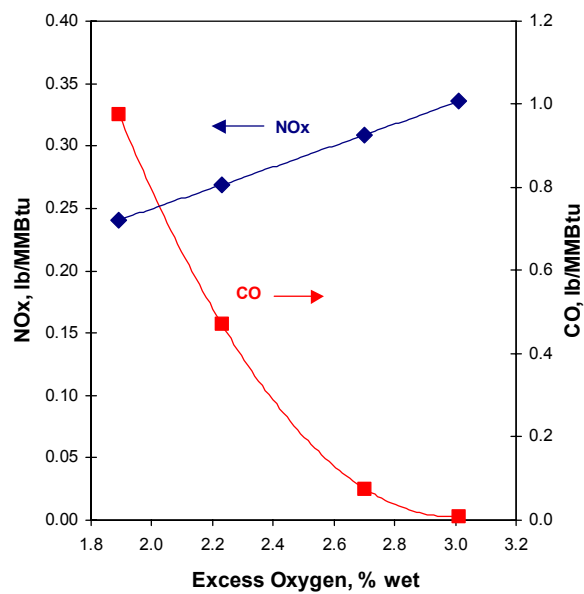
Figure 2-11. Baseline NO_X and CO emissions verses boiler excess oxygen.

results in a substantial increase in CO emissions due to non-uniform distribution of fuel and air to the burners and imbalanced combustion.

The impacts of the boiler excess oxygen level on the distribution of CO as measured by the in-furnace sensors and on the oxygen level measured by the plant oxygen probes are shown in Figures 2-12. This figure shows contour plots of the CO grid measurements as the plant oxygen is reduced. The data are plotted looking from the front of the boiler downward into the primary superheater plane. As oxygen levels are decreased, the contour plots show that there is a significant increase in CO levels. This increase is not uniform, but occurs in several locations or peaks due to non-uniform combustion conditions. The peaks in CO concentration continue to increase as the oxygen level is decreased and lead to the high stack CO emissions shown in Figure 2-11 at the lowest oxygen levels. The peaks in local CO levels can nominally be associated with stratification in the oxygen available for oxidation of CO.

Figure 2-13 shows the variation in oxygen levels measured by the plant oxygen probes as the overall excess oxygen level is decreased. The two boxes in each figure represent a vertical plane in the two ducts exiting the boiler. The data are shown looking from the front of the boiler into

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Figure 2-12. Impact of excess oxygen on stratification at CO sensor grid.

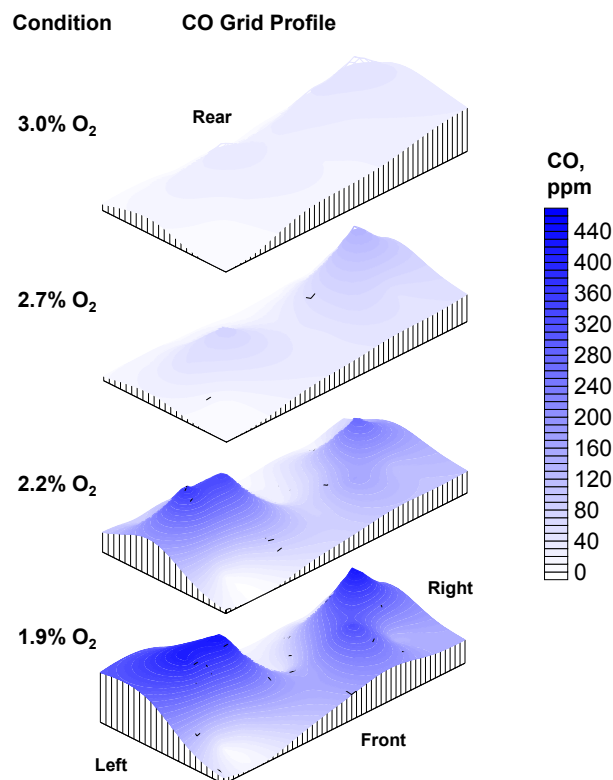**Plant O₂ Grid Measurements**

Condition	Left Duct Top		Right Duct Top	
3.0% O₂	2.86	3.71	3.57	3.10
	1.53	2.26	2.17	N/A
2.7% O₂	2.30	3.29	3.55	3.00
	1.01	2.05	1.85	N/A
2.2% O₂	1.57	2.54	3.06	2.55
	0.50	1.43	1.77	N/A
1.9% O₂	1.15	2.08	2.69	2.23
	0.36	1.46	1.48	N/A
	Left Duct Bottom		**Right Duct Bottom**	

Figure 2-13. Impact of excess oxygen on stratification at plant oxygen probes.

the measurement plane. There are four probes in each duct. One probe in the duct on the right side was not working during the test (value shown as N/A for not available). The data in Figure 2-13 show that a side-to-side bias exists between the two ducts, with the average oxygen concentration on the right-hand side being higher, and that there is significant stratification in oxygen within each duct. This stratification qualitatively maps to the CO profiles shown in Figure 2-12 and is caused by non-uniform distribution of fuel and air to the burners and non-uniform combustion within the furnace.

Figure 2-14 shows the impacts of boiler excess oxygen level on FEGT as measured by the plant's optical sensors. The plant monitors the FEGT as high temperatures have a tendency to lead to an increase in slagging and fouling. As shown in this figure, lowering the excess oxygen level can help to lower the FEGT. Figure 2-12 also shows that there is a side-to-side imbalance
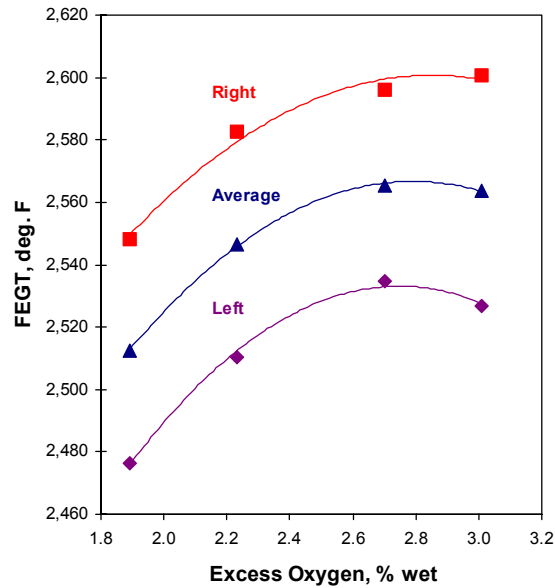
Figure 2-14. Measured FEGT verses boiler excess oxygen.

in the measured FEGT with the right side of the boiler an average of 70ºF higher than the left side. The higher temperatures measured on the right-hand side of the furnace have implications for slagging on that section of the superheater. During the tests, it was noted that the higher temperatures on the right-hand side of the furnace appear to follow the bias in the side-to-side oxygen levels as measured by the plant oxygen probes.

The impacts of the boiler excess oxygen level on the output of the in-furnace optical combustion sensors is shown in Figure 2-15. The two charts in the figure show the output from the five combustion sensors as the boiler excess oxygen level was varied. The chart on the left shows the "Relative LOI" parameter and the chart on the right shows the "Relative Temperature" parameter output as a result of processing the sensor output. Relative LOI is a complex parameter representing the degree of turbulence or combustion quality in the viewing zone of a particular sensor, which non-linearly correlates with products of incomplete combustion, for example, unburned carbon in ash (UBC) or flyash loss-on-ignition (LOI). Relative Temperature represents the average heat flux in the viewing zone of a particular MPV sensor, which is non-linearly correlated with flue gas temperature. Each chart in Figure 2-15 shows how the in-furnace sensor output varied as the boiler excess oxygen level was changed. It is interesting to note that both the

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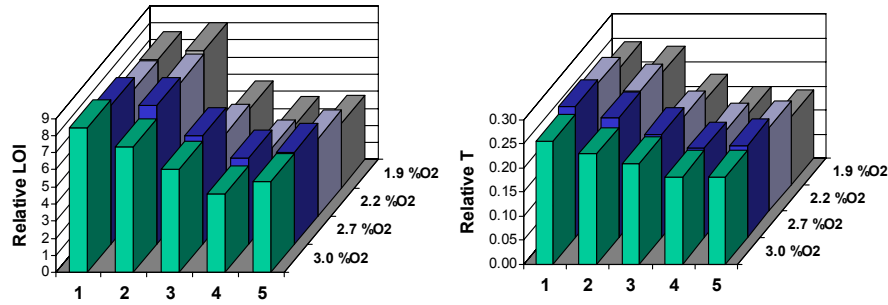
Figure 2-15. Impact of excess oxygen on in-furnace sensor measurements.

Relative LOI and Relative Temperature values show a side-to-side bias in combustion quality and heat flux. This bias is commensurate with the bias observed in the other parameters (oxygen, CO, and FEGT) discussed above and is suggestive of imbalances in the combustion process between the two sides of the furnace. In addition, the output of each sensor responds to changes in the boiler excess oxygen level.

Figure 2-16 more clearly shows the impacts of the boiler excess oxygen level on the sensors on the left and right sides of the furnace. The values shown in the plot represent the average output of the two sensors on that side of the furnace. It is interesting that both the Relative LOI and Relative Temperature appear to decrease as the excess oxygen level is decreased.
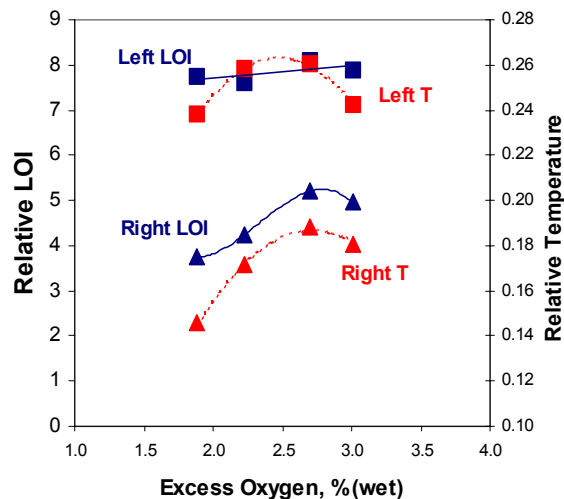
Figure 2-16. Variation in in-furnace sensor output verses boiler excess oxygen.

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Overall, balancing the fuel and air to the burners is expected to help control CO emissions when operating at reduced excess oxygen levels. Balancing fuel and air to the burners and improving the overall combustion process is expected to help to improve the side-to-side FEGT balance. The combustion sensors and CO sensors provide useful data on the extent of non-uniformities in fuel and air and their impacts on combustion and can serve as useful tools in optimizing performance.

2.1.6   Task 1.6 – PSD Review

In this task, a regulatory review is being performed to assure that the project will not impact the ambient air quality of the region.

During the previous reporting period, an analysis of the impacts of increased emissions arising from the increased energy production from the unit was completed. The preliminary results from this analysis showed that there are no impacts on ambient air quality brought about by the proposed changes in operating conditions of the unit.

To support the PSD analysis, a BACT evaluation was performed. This evaluation is under review and will thereafter be submitted to the Kansas Department of Health and Environment for regulatory review and approval. A draft permit revision to accompany the BACT review and the PSD permit application is being prepared.

2.2   Task 2.0 – Phase II – Low-NOx Burner Modifications

The objective of Phase II is to demonstrate the effectiveness of low-cost modifications to the existing, first generation low-NO_X burners to reduce NO_X emissions. This phase will also include modifications to the existing pulverized coal (PC) piping to permit automated fuel balancing among all burners. The scope of work for the Low-NO_X Burner Modifications Phase is being performed in the following three tasks.

2.2.1 Task 2.1 – Low-NOx Burner Modifications

In this task, the existing twenty-five B&W dual-register burners installed on Holcomb Station Unit 1 were modified to improve flame stability and reduce NO_X emissions, particularly when operated in conjunction with the overfire air system that will be installed in Phase III.

The design of the low-NO_X burner modifications is illustrated in Figure 2-17. The modifications consist of the addition of a coal pipe expander and flame stabilizing ring to the coal pipe, extension of the secondary air sleeve, and the addition of a sliding sleeve over the tertiary air register to control the combustion air split to the burner. The components were fabricated and installed during the plant outage in March 2003. Overall, the modified low-NO_X burners generate a stable flame over a wide range of burner settings and over the normal boiler load and mill operation.

2.2.2 Task 2.2 – PC Piping Coal Flow Control and Balancing System/Testing

In this task, the five pulverizers were equipped with a coal-flow balancing system consisting of the installation of an automated coal-balancing damper on each coal pipe. The automated coal-balancing damper will be integrated with the coal-flow monitoring system to provide for
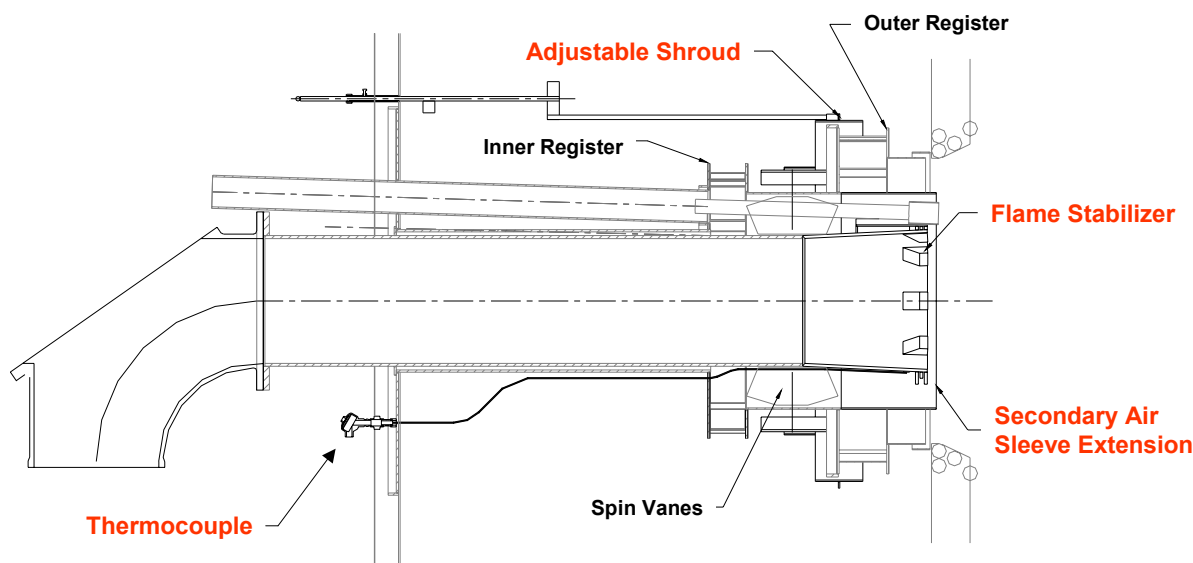
Figure 2-17. Low-NO_X burner modifications.

automatic balancing of all the burners over the boiler load range.

The design of the automated coal-balancing damper is shown in Figure 2-18. Twenty-five dampers were fabricated and installed during the plant outage in March 2003. One damper was installed on each coal pipe exiting the five coal mills. A photograph of the installation on one mill is shown in Figure 2-19. Each damper is equipped with a control drive. During this reporting period, the drives were operated manually to balance the coal flow. During the next reporting period, the plan is to demonstrate automatic balancing of the coal flow on one mill. Mill C was selected for the demonstration since it provides a good opportunity to show the benefits of automated balancing. During this reporting period, the coal balancing control logic was developed and plans were made for installation of a purge air system on the Mill C dampers and for installation of the programmable logic controller (PLC) that will interface the dampers with the coal flow measurement system. The purpose of the purge air system is to periodically clean coal dust out of the guide vanes on the damper.
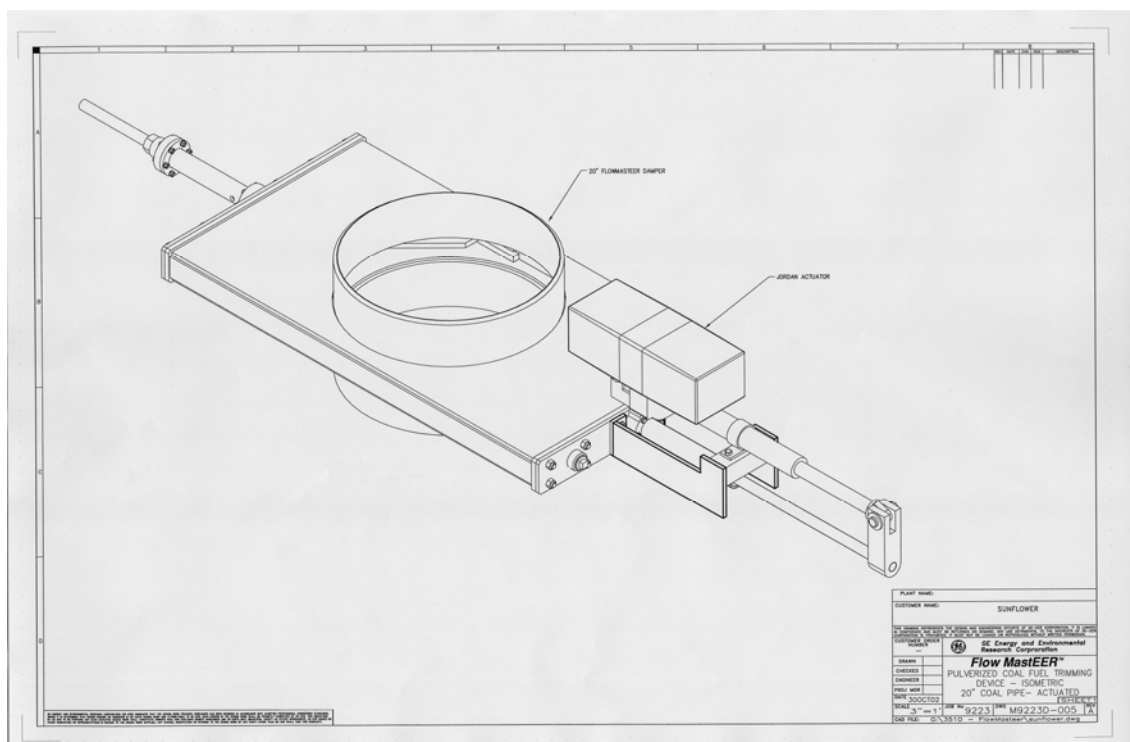
Figure 2-18. Automated coal-balancing damper.

Figure 2-19. Photograph of damper installation.

Following installation of the low-NO$_X$ burner modifications, coal flow measurement system, and coal trimming dampers in March 2003, tests were performed to characterize the unit operation and to determine optimum settings for the installed equipment. Initially, efforts were focused on balancing the coal flow to each burner using the coal trimming dampers and coal flow measurement system. Once the coal flow was believed to be sufficiently balanced, tests were performed to demonstrate the use of the sensors and burner air registers and dampers in balancing air flow and reducing CO emissions. Finally, tests were performed to identify the burner register settings yielding the lowest possible NO$_X$ and CO emissions. During all of the tests, the impacts of the installed equipment on boiler performance were monitored. Two specific variables of interest were the side-to-side imbalance in measured plant oxygen and FEGT. The results of the post-outage tests are summarized in the following.

Following start up of the unit and calibration of the coal flow measurement system, the coal trimming dampers were used to balance the coal flow. Initially, it was found that good balance

could be obtained on Mills B, D, and E, but that for Mill C, it was difficult to achieve good balance without producing low indicated velocities (i.e., velocities less than 50 ft/sec) in several of the coal pipes. In addition, for all of the mills, operation of the mill at lower output resulted in periods of time when the indicated velocities could drop below an acceptable threshold. To correct this problem, the primary air curves were adjusted upwards to limit the lower velocities that would be obtained. Once the air curves were adjusted and mill controls retuned, final balancing on the coal pipes was performed.

The chart shown in Figure 2-20 compares the baseline and balanced coal flow distribution. The chart shows the baseline and post-balancing coal flow for each pipe expressed as the absolute deviation from the average for that mill. For most of the coal pipes, the deviation in coal flow was less than 10%, and many had a deviation under 5%. As discussed in Section 2.1.3, the sensors on Mill A showed significant fluctuation and, therefore, it was difficult to improve the balance to less than 15%. The improvement in coal flow balance is illustrated in Figure 2-21 where the data are plotted as a normal distribution. This chart shows that coal balancing significantly improved the pipe-to-pipe coal flow distribution in comparison to the baseline distribution measured in October 2002.
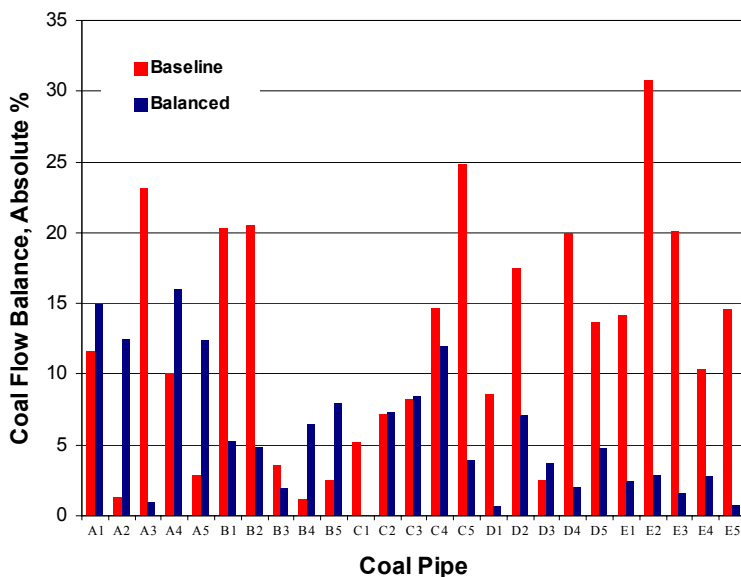

Figure 2-20. Comparison of baseline and balanced coal distribution.
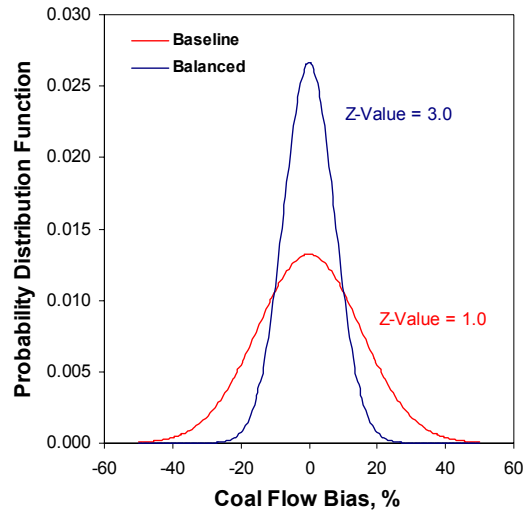
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Figure 2-21. PDF plot comparing baseline and balanced coal distribution.

To demonstrate that the CO sensors could be used to tune burner-operating settings, a sequence of tests was performed where the model relating the sensor output to the burners was applied. The results of these tests are shown in Figure 2-22. The contour plots in this figure show the distribution of CO in the flue gas as viewed from above the sensors. Figure 2-22a shows the CO profile as measured after the coal was balanced to the levels shown in Figure 2-20. At this time, high CO levels were noted in the lower left corner. The sensors in this region primarily see flue gas from the rear wall burners and are most significantly impacted by the upper burners. Therefore, the dampers on the upper rear wall burners were adjusted to move air from the burners on the right to the burners on the left. As shown in Figure 2-22b, this adjusted increased CO levels in the corner region and in a region closer to the right hand side. The dampers on the upper burners were adjusted back to the original settings and the dampers on the lower rear wall burners were adjusted to move air from the burners on the right to the burners on the left. This successfully reduced the CO levels seen in the corner region and in the region closer to the right hand side (Figure 2-22c). To further reduce CO levels seen on the right hand side, the dampers on the upper rear wall burners were adjusted to move air from the right to the burners in the center (Figure 2-22d). Finally, after conditions were stabilized the next day, the profile shown in Figure 2-22e was obtained. Overall, these results show that it is possible to combine the sensors

a) CO profile after coal flow balancing.

b) Adjust right-to-left air balance using upper rear wall burners.

c) Adjust right-to-left air balance using lower rear wall burners.

d) Adjust right-to-center air balance using upper rear wall burners.
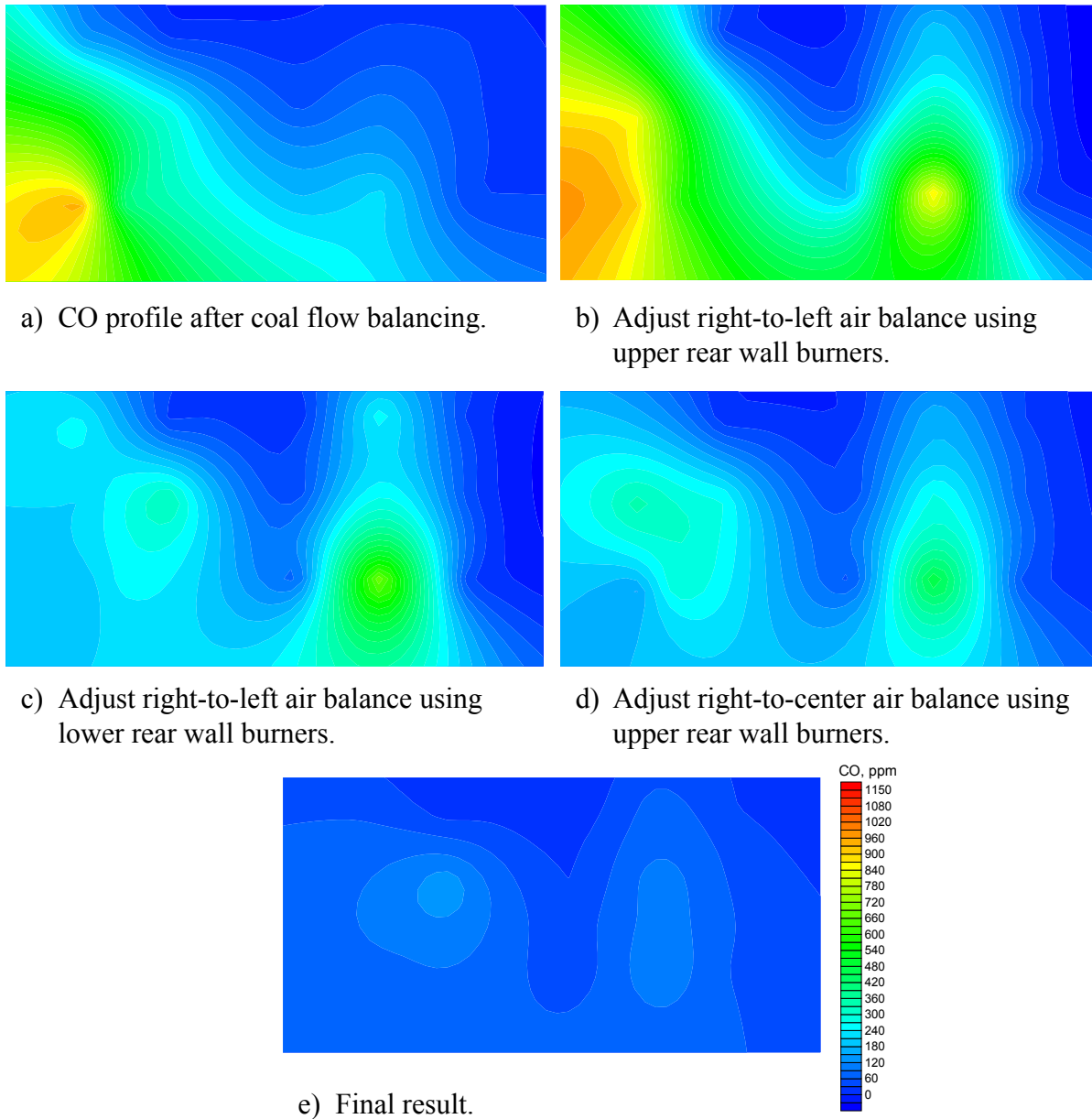

e) Final result.

Figure 2-22. CO grid profiles during burner tuning sequence.

and controls installed on the unit with an optimization algorithm to improve overall combustion performance.

Figure 2-23 compares the results of the balancing and tuning tests performed from March though May in 2003 and the baseline tests performed in February 2003. The chart in the figure shows
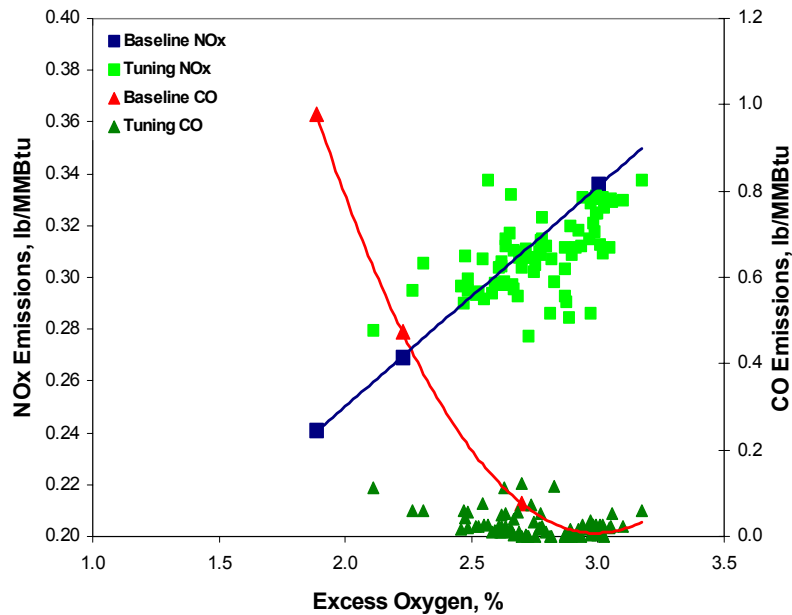
Figure 2-23. Comparison of baseline NO_X and CO emissions to tuning results.

NO_X and CO emissions as a function of the boiler excess oxygen level. The wide degree of variation in NO_X emissions during the tuning tests is due to changes in the burner settings and fuel and air balance. With respect to NO_X emissions, the comparison in Figure 2-23 shows that, for the most part, NO_X emissions levels were similar between the baseline and the post-retrofit tests, but that it was possible operate at conditions that result in lower NO_X emissions at the same excess oxygen level. With respect to CO emissions, the comparison shows that CO emissions were lower during the tuning tests than during the baseline tests particularly as the boiler excess oxygen level was reduced below the current set point, which can primarily be attributed to improvements in fuel and air balance.

During the balancing and tuning tests, the burner air distribution was adjusted to minimize CO emissions and to attempt to balance the side-to-side oxygen distribution measured by the plant oxygen probes. It was also observed that the burner air distribution had an impact on the side-to-side FEGT difference. Figure 2-24 plots the stack CO emissions against the difference between the right and left oxygen measurements. As shown in this figure, balancing the side-to-side oxygen differential could reduce CO emissions. However, lowest emissions could be obtained by
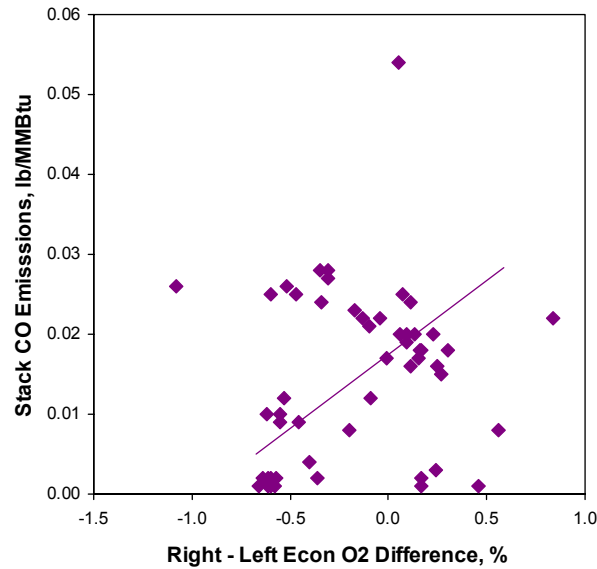
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Figure 2-24. Impact of side-to-side oxygen balance on stack CO emissions.

operating with slightly higher oxygen in the left duct. This result suggests that there may be measurement artifacts present in the system. One potential source of error in the plant oxygen measurement is stratification of the flow at the measurement plane due to its location directly after the flow turns horizontally into the ducts feeding the air preheater. The effects of the flow distribution should be taken into account when averaging the plant oxygen measurements. Figure 2-25 plots the difference between the right and left FEGT measurements against the difference between the right and left oxygen measurements. As shown in this figure, balancing the side-to-side oxygen difference appears to reduce the side-to-side bias in FEGT. However, the lowest FEGT difference was obtained by operation with slightly higher oxygen in the right duct. It is not clear whether this result is due to both a measurement artifact in the plant oxygen probe measurement and a possible measurement artifact in the FEGT measurement or to the complex nature of the flow and temperature flow field in the boiler. Overall, the results shown in Figures 2-24 and 2-25 indicate that it was not possible to simultaneously reduce CO and minimize the side-to-side FEGT differential. The overfire air system installed in Phase III should help to overcome this limitation since it should provide effective control over CO and improve the ability to control and adjust the overall air distribution to the furnace.
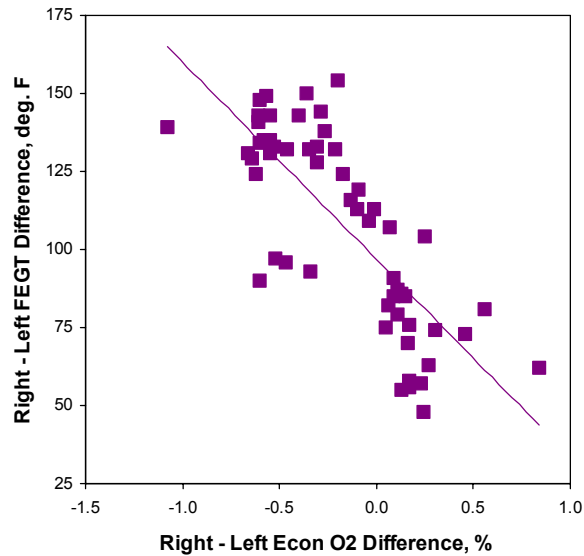
Figure 2-25. Comparison of side-to-side oxygen balance and side-to-side FEGT balance.

2.2.3 Task 2.3 – Design of OFA Penetrations

To support implementation of Phase III, this task will consist of the detailed design of an optimum overfire air system for this unit.

During this reporting period, this task supported the design of the overfire air system and development of installation estimates. The preliminary design of the overfire air system was completed. The plant approved the preliminary design drawings of the overfire air injectors and ductwork. A bid package for the overfire air system was then developed and provided to several construction contractors for estimates of the installation costs. Bids were received and used to update the cost estimates for Phase III of the project.

2.3 Task 3.0 – Phase III – Advanced Overfire Air System

The objective of this phase of the project will be to demonstrate deep NO_X control competitive with SCR installations with the addition of an overfire air system coupled with the existing Phase I and II modifications to optimize overall system performance. The integration of all three phases of these improvements will provide the opportunity to reduce NO_X emissions permit

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improvements in power plant performance and output. This phase of the project has not been initiated.

Appendix A – Gantt Chart

ID	Task Name
1	
2	DOE Project Funding Release
3	
4	**Task 1.0 - Phase I - Advance Sensors Upgrade**
5	Task 1.1 - Process Design and Performance Analysis
6	Task 1.2 - Design and Fabrication/Construction Documents
7	Task 1.3 - Boiler Combustion Optimization Sensors
8	Task 1.4 - Sensor Integration / Testing
9	Task 1.5 - Baseline Testing
10	Task 1.6 - PSD Review
11	
12	M1.1 Furnace Modeling/ Overall Process Complete
13	M1.2 Boiler Sensor Installation Complete
14	M1.3 Boiler Sensor Integration and Shakedown Complete
15	M1.4 PSD Review Complete
16	
17	**Task 2.0 - Phase II - Low-NOx Burner Modifications**
18	Task 2.1 - Low-NOx Burner Modifications
19	Task 2.2 - PC Piping Coal Flow Control and Balancing System/Testing
20	Task 2.3 - Design of OFA Penetrations
21	M2.1 Burner Design Complete
22	M2.2 Burner Modifications Complete
23	M2.3 Install Coal Flow System
24	M2.4 Burner Modification Testing Complete
25	M2.5 Sunflower Decision to proceed Phase III
26	
27	**Task 3.0 - Phase III - Advanced Overfire Air System**
28	Task 3.1 - Overfire Air Ductwork and Injectors
29	M3.1 OFA System Design Complete
30	M3.2 OFA Installation Complete
31	M3.3 Conclude Unit SU and Shakedown, & Optimization
32	
33	**Task 4.0 - Management and Implementation (Phases I, II, and III)**
34	Task 4.1 - SEP Project Team Coordination
35	Task 4.2 - Construction and Start-up (Phases I, II, and III)
36	Task 4.3 - Operation and Maintenance Manuals (Phases I, II, and III)
37	Task 4.4 - Tuning/Optimization Testing (Phases I, II, and III)
38	Task 4.5 - Supplemental Reporting Requirements

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