COAL DRYING IMPROVES PERFORMANCE AND REDUCES EMISSIONS[1]

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ABSTRACT

Lignite and subbituminous coals from the western U.S. are attractive fuels for power plants, due their low cost and emissions. However, lignite and PRB coals typically contain high amounts of moisture and/or ash. When high moisture coals are burned in utility boilers, about 7 percent of the fuel heat input is used to evaporate fuel moisture. This results in higher fuel flow, higher stack flue gas flow, higher parasitic power, lower plant efficiency, and higher mill maintenance costs compared to low-moisture coals.

Efforts are underway in Europe and Australia to develop efficient coal dewatering and drying processes. Thermal drying and dewatering and mechanical dewatering are employed. The thermal processes typically employed depend on a high-grade heat to evaporate or remove moisture from the coal.

This paper describes results of field tests, conducted with dried lignite coal at a 550 MW unit in North Dakota, and a coal drying process that uses a low-grade waste heat to evaporate a portion of fuel moisture from the lignite feedstock. Process layout, coal drying equipment and impact of fuel moisture on plant performance and emissions are discussed.

The improvement in boiler and unit performance, achieved during the test by removing 6 percent of fuel moisture was in the 2.6 to 2.8 percent range. This performance improvement is primarily due to a reduction in moisture evaporation loss, lower stack loss, and a decrease in auxiliary power requirements. Assuming a capacity factor of 0.8, this 6 percent reduction in fuel moisture represents annual savings of $1,300,000 for both units at the Coal Creek Station. If implemented on all U.S. lignite and PRB units, it would represent annual savings of $19,000,000 for the lignite-fired plants, and $90,000,000 for the PRB-fired plants.

The field test results described here are for 6.1 percent moisture reduction. Future work will include test burns with lower moisture content to determine the impacts on boiler operations. This will also make it possible to determine the optimal coal moisture content.

INTRODUCTION

Although lignite power plants are designed to burn coals containing 40 percent or more moisture, a reduction in coal moisture content is attractive since it will result in significant improvements in operation and performance and reductions in stack emissions. High fuel moisture content adversely affects the material handling systems, such as coal pulverizers, the heat content of the fuel (HHV) and, consequently, boiler and unit efficiency. In addition, the fuel moisture evaporated during the combustion process increases the volume of the flue gas stream. This results in an increase in fan power and decreased performance of environmental control systems.

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The objective of the work described here is to demonstrate enhancement of the value of lignite fuel by incremental reduction of the moisture content of the lignite feedstock. The cost benefits from better performance, reduced emissions, station service power reductions and reduced tube and duct erosion are expected to outweigh the cost of the drying process, both capital and operational.

Effect of Fuel Moisture on Performance and Emissions

There are many effects of fuel moisture on unit operation, performance and emissions. Its complexity can be appreciated by following coal through a power plant and analyzing the effect of coal quality on equipment performance and maintenance. As fuel moisture content decreases, its heating value increases and, assuming constant electric power output of a power plant, less coal needs to be fired. This reduces the burden on the coal handling system, conveyers and crushers. Also, since dryer coal is easier to convey, this reduces maintenance costs and increases availability of the coal handling system.

Crushed coal is fed into the bunkers from where it flows by gravity to the coal feeders. Dryer coal flows more readily and causes less feeder hopper bridging and plugging problems. Coal feeders provide coal to the coal pulverizers (mills) where the coal is pulverized and dried. Dryer coal is easier to pulverize, and less mill power is needed to achieve the same coal fineness. Additionally, with less fuel moisture, more complete drying of coal can be achieved in the mill. This results in increased mill exit temperature (the temperature of the coal and primary air mixture at mill exit), better conveying of coal in the coal pipes and less coal pipe plugging problems.

The mixture of pulverized coal and air is combusted in the furnace. With drier coal, the flame temperature is higher due to less moisture evaporation and the heat transfer processes in the furnace are modified. The higher flame temperature results in larger radiation heat flux to the furnace walls. In addition, since the moisture content of the flue gas is reduced, the radiation properties of the flame are changed, which also affects the radiation flux to the wall. With higher flame temperature, the temperature of the coal ash particles is higher which could increase furnace fouling and slagging. Deposition of slag on furnace walls reduces heat transfer and results in a higher flue gas temperature at the furnace exit (FEGT). The total change in FEGT due to the drier fuel is, therefore, difficult to predict analytically. Test burns with incrementally dried coal are needed to accurately quantify the effect. Additionally, due to the reduction in coal flow rate, as fuel moisture is reduced, the amount of ash entering the boiler is also reduced. This reduces solid particle erosion in the boiler and reduces the need for boiler maintenance.

The flow rate of flue gas leaving the furnace firing drier coal is lower compared to the wet fuel. Also, the specific heat of the flue gas is lower due to the lower moisture content. The result is reduced thermal energy of the flue gas. Lower flue gas flow rate also results in lower rates of convective heat transfer. Therefore, despite the increase in FEGT with drier fuel, less heat will be transferred to the working fluid (water or steam) in the boiler convective pass. It is, therefore, anticipated that steam temperatures will be lower compared to operation with a wetter fuel. Some of the decrease in the steam temperature could be corrected by changing boiler operating conditions; raising burner tilts, changing surface area, or operating with higher level of excess air. Station service power will decrease with drier coal due to a decrease in fan power and mill power.

The combination of all these effects caused by firing drier coal will result in an improvement in boiler efficiency and unit heat rate, primarily due to the lower stack loss and lower station service power. In some cases this performance improvement will also allow higher power output with existing equipment.

The performance of the back-end environmental control systems (scrubbers and electrostatic precipitators) will improve with drier coal due to the lower flue gas flow rate and longer residence time.

The effect of drier coal on NO_x emissions is complex. Although the reduction in required coal flow rate will directly translate into reductions in mass emissions of NO_x, CO_2, SO_2, and particulates, the expected increase in FEGT is likely to affect formation of thermal NO_x in the furnace. Since NO_x is not affected by an increase in FEGT until a certain critical value of FEGT is exceeded and since lignite boilers are typically designed for low values of FEGT, the expected increase in FEGT due to firing of drier coal may not have a significant effect on formation of thermal NO_x. Test burns with drier coal are needed to quantify this effect.

UNIT DESCRIPTION

The Coal Creek Generating Station has two units with total gross generation exceeding 1,100 MW. The units fire a low-grade lignite fuel from the nearby Falkirk mine. The coal contains approximately 40 percent moisture and 12 percent ash. At full load, each unit fires approximately 900,000 lb/h of coal. The boilers are controlled circulation, radiant, single reheat, tangentially fired, balanced draft with divided furnace. Each boiler is equipped with eight mills feeding eight elevations of tilting fuel nozzles, and two tri-sector Ljungstrom rotating regenerative air preheaters. The main steam temperature is controlled by the main steam spray. The reheat steam temperature is controlled by burner tilts. Both units at Coal Creek are equipped with the LNCFS system for NO_x control.

Results of Theoretical Analysis

A theoretical analysis was performed by the authors to estimate the magnitude of heat rate improvement that could be achieved at Coal Creek Station by removing a portion of moisture from the fuel. The analysis accounted for the effects of fuel moisture on stack loss and pulverizer and fan power. The analysis did not account for the effects of firing reduced moisture lignite on flue gas temperature at the economizer exit, steam temperatures, desuperheating spray flows, and unburned carbon. A baseline level of 40 percent fuel moisture was assumed in the calculations.

The effects of coal moisture content on unit performance are presented in Figures 1 to 3. Figure 1 shows the reduction in total air, flue gas and coal flow rates as fuel moisture content is reduced. Corresponding reductions in fan and mill power are presented in Figure 2. Potential improvements in unit heat rate and boiler efficiency are presented in Figure 3. As discussed earlier, boiler efficiency increases as fuel moisture content decreases due to a decrease in the flow rates of fuel, combustion air, and flue gas, and reduction in moisture evaporation loss. The results show that performance improvement in the 2 to 5 percent range can be achieved by removing 5 to 15 percent of the coal moisture from the baseline value.

Predicted variation of the mill exit temperature (temperature of the coal-primary air mixture leaving the mill) with coal moisture content is presented in Figure 4. Until complete evaporation of fuel surface moisture entering the mill is achieved, the mill exit temperature is equal to the vapor saturation temperature. After complete evaporation of fuel surface moisture in the mill is achieved, it becomes possible to control the mill exit temperature by varying the proportion of the hot and cold primary air flows.

The predicted reduction in CO_2 and SO_2 mass emissions is presented in Figure 5 as a function of the coal moisture content. The predictions show that removal of 10 percent of fuel moisture would reduce CO_2 mass emissions by approximately 4 percent. This reduction is due to improved unit performance with dried coal. Predictions for NO_x reductions are not given since, as discussed before, coal drying affects NO_x concentration at the furnace exit and this cannot be estimated by the modeling method used in this study.

In summary, the analysis shows that a **substantial improvement** in unit performance is possible by removing a portion of the coal moisture. This performance improvement is primarily due to a reduction in moisture evaporation loss, lower stack loss, and a decrease in auxiliary power requirements. The mass emission rate of pollutants such as SO_2 and CO_2 would also be reduced. Firing drier coal would change boiler heat absorption patterns, flue gas temperature distribution in the boiler, furnace exit gas temperature, and, possibly, boiler slagging. These changes might also affect thermal NO_x. Since the effect of fuel moisture on these parameters is difficult to predict analytically, test burns with incrementally dried coal are needed for accurate determination of fuel moisture on NO_x emissions.

FIELD TESTING

Two coal burn tests were conducted at Unit 2 in August and October 2001. The results of the second test, conducted on October 23rd and 24th, 2001 are described here. Approximately 12,000 tons of lignite were dried for the second test by an outdoor stockpile coal drying system.

Stockpile Coal Drying

The outdoor stockpile coal drying system was designed to provide coal containing approximately 28 to 30 percent moisture for the test burn. Coal drying was accomplished by heated air (approximately 110°F) delivered by a network of pipes located beneath the coal pile. The flow rate of drying air was approximately 53,000 CFM. The coal was dried for about 50 days and during that time period, the coal moisture was reduced by 6.1 percent, from 37.5 to 31.4 percent. After 50 days of drying, the coal was visibly drier and dustier than the coal typically stacked out and reclaimed by the Coal Creek Coal Handling Crew.

Test Description

When the delivery of dried coal to Unit 2 started, coal samples were taken every hour during the test until all the dried coal in the storage silo had been conveyed to the Unit 2 bunkers. Hourly average coal flows were also recorded and used to determine weighted average coal quality delivered to Unit 2 during the test. The last 7 hour-weighted average was used to determine the quality of the coal remaining in the bunkers at the end of the test. Proximate and ultimate analyses were performed on collected coal samples.

The second test burn started at 9 PM on October 23rd, 2001 and ended at 5 PM on October 24th, 2001. The operator was instructed to maintain gross unit load of 590 MW, excess O_2 level at economizer outlet at 2.6 percent, throttle pressure of 2,520 psia, main steam temperature at 1,000°F and hot reheat steam temperature at 1,005°F. Scrubber bypass flow was controlled automatically to maintain the stack temperature set-point of 180°F. Unit operating data were collected automatically by the plant historian.

Field Test Results

Variations in coal HHV and moisture content with time during the test are presented in Figure 6. A gradual change in both quantities occurred at the beginning and end of the test due to the mixing of the dried and wet coals. At the beginning of the test, dried coal was loaded into the Unit 2 bunker on the top of 2,000 tons of wet coal. As the coal was flowing through the bunker, a mixing of the two coals occurred. Similarly, at the end of the test, wet coal was loaded into the bunker on the top of dried coal. On average, during the test, the HHV of the dried coal was approximately 9.25 percent higher, while the moisture content was 6.1 percent lower compared to the wet coal. This resulted in lower flow rate of coal and, consequently, lower flue gas flow rate. The reductions in coal and flue gas flow rates, measured during the test, are presented in Figure 7, while average values are summarized in Table 1. With dried coal the fuel flow rate was reduced on average by 10.8 percent, which compares well with the improvement in HHV. The flue gas flow rate was reduced on average by 4 percent. Results of theoretical calculations and field test results are compared in Figure 8 and are in good agreement.

Table 1: Coal Properties and Flow Rates of Coal and Flue Gas

Parameter	Average Measured Change Due to Drier Coal [%]
Coal Moisture Content	-6.1 (From 37.5 to 31.4 %)
Coal HHV	9.25
Coal Flow Rate	-10.8
Flue Gas Flow Rate	- 4

Mill Performance

The dry coal had a large impact on mill performance. The combination of lower coal flow and better grindability combined to reduce mill power consumption on average by approximately 17 percent, or 680 kW (see Table 2). This might allow full load operation with six mills, resulting in operating flexibility and reduced maintenance. Time variation of mill power and coal flow for the No. 21 mill are presented in Figure 9.

Due to time constraints, coal fineness was not determined during the second test burn. However, coal grind was checked on three mills during the first coal burn test and was found to be maintained or improved with the dried coal.

Fan Performance

Fan power was reduced due to lower air and flue gas flow rates. The reductions in FD, ID and PA fan power are presented in Table 2. The results show that reductions in FD and ID fan power are proportional to the reduction in flue gas flow rate. The reduction in PA flow was smaller because the discharge pressure setpoint was maintained constant during the test. Since with dried coal APH pressure losses are lower, on average by 7 percent, the PA fan discharge pressure setpoint can be reduced. The average reduction in total auxiliary power due to the drier coal, measured during the test, was approximately 3.8 percent (see Table 2). Variation in the auxiliary power reduction measured during the test is presented in Figure 10.

Table 2: Auxiliary Power Reduction Due to Firing Coal With 6.1% Less Moisture

Fan	Average Measured Change in Auxiliary Power [%]
Forced Draft Fan	-3.9
Primary Air Fan	-1.6
Induced Draft Fan	-3.8
Mill Power	-16.5
Auxiliary Power	-3.8

Boiler and Unit Performance

Unit output was constant during the test and averaged 590 MW_{gross}. The economizer excess O_2 level was maintained at 2.6 percent throughout the test. Burner tilt angle was controlled automatically to maintain constant reheat steam temperature. The main steam temperature decreased, on average by 4°F, while the hot reheat steam temperature remained constant during the test. The main steam desuperheating spray flow rate was approximately constant which might have contributed to a small decrease in main steam temperature.

Boiler efficiency and net unit heat rate, defined by Equations 1 and 2, were determined using the Input/Output and Boiler/Turbine Cycle Efficiency (BTCE) methods. Both methods produced similar results. The average improvement in unit and boiler performance is summarized in Table 3. As the results show, drier coal had a **significant impact** on boiler and unit performance. With drier coal, the improvement in boiler efficiency was approximately 2.6 percent. The improvement in net unit heat rate was 2.7 to 2.8 percent. These results agree with theoretical predictions (see Figure 11). Time variation of performance improvements during the test, determined by the BTCE method, is presented in Figure 12.

Boiler Efficiency = Boiler Thermal Duty/Fuel Heat Input **Eqn. 1**

Net Unit Heat Rate = Fuel Heat Input/Net Electrical Generation **Eqn. 2**

Table 3: Performance Improvements Due to Firing Coal With 6.1% Less Moisture

Parameter	Percent Improvement by the BTCE Method	Percent Improvement by the Input/Output Method
Boiler Efficiency	2.65	2.6
Net Unit Heat Rate	2.7	2.8

Emissions

NO_x mass emissions increased slightly during the second coal burn test. This was in contrast to the results from the first coal burn test, where NO_x emissions decreased by 10 percent (Figure 13). This difference in NO_x emissions can be explained by the fact that the PA flow was maintained constant during the second test in order to reduce mill spillage, while during the first test it was reduced by 6 percent (see Figure 13). Reducing the PA flow should correct this and lower NO_x emissions.

SO_2 mass emissions increased slightly for both tests. This was a result of maintaining a constant stack temperature. With dried coal the scrubber exit temperature decreased causing the scrubber by-pass damper to open and increase the flue gas flow rate bypassing the scrubber to maintain a constant stack temperature. This resulted in a slight increase in SO_2 emissions and in the opacity. Lowering the stack temperature set-point will decrease the untreated scrubber by-pass flow and reduce mass emissions of SO_2 and opacity. CO_2 mass emissions decreased by 1.8 percent during the second coal burn test. This is in agreement with theoretical predictions from Figure 5.

FUTURE WORK

The first and second coal burn tests provided an opportunity to the Coal Creek operating personnel to learn how to handle and fire the dried coal. In addition, good quality data concerning the effect of dried coal on boiler and unit performance and operation were obtained. Additional coal burn tests are needed to learn how to achieve lowest emissions (NO_x and SO_2). Dried coal for these tests will be provided by the outdoor stockpile coal drying system or by a modular drying system employing waste heat and coal driers of a fixed or fluidized bed design.

Sources of Waste Heat

Heat rejected in the steam condenser represents a large source of waste heat. For the Coal Creek station, heat rejection in the condenser is approximately 2,600 Million Btu/h. The cooling water leaving the condenser has a temperature of approximately 120°F. This warm cooling water is cooled in the cooling towers to approximately 90°F and is circulated back to the condenser. A portion of the cooling water could be diverted from the main stream and circulated through a water-to-air heat exchanger. The heated air would then be used in a coal drier to remove a portion of the fuel moisture. Analyses show that, at full unit load, approximately 2 to 3 percent of the heat rejected in the condenser/cooling tower is needed to decrease the coal moisture content by 5 percentage points.

Thermal energy in the flue gas leaving the plant represents another source of waste heat. For the Coal Creek station with a lignite feed containing 40 percent moisture, the waste heat in the flue gas is approximately 440 Million Btu/h. Analyses show that using waste heat in flue gas to remove 5 percent coal moisture would decrease the stack temperature by 30°F. Since the Coal Creek station uses a wet scrubber to remove SO_x from the flue gas, the stack temperature is already low and any further significant reduction might result in insufficient buoyancy in the stack and, possibly, condensation of water vapor on the stack walls. Therefore, at this station, thermal energy in the flue gas is not considered a suitable source of waste heat.

Modular Coal Drying System

The approach to lignite drying described in this paper is based on using waste heat from the main condenser to heat the air used for coal drying. The coal drying air is heated in the water-to-air heat exchanger to approximately 110°F and is then forced through a bed of coal to remove a portion of fuel moisture. The coal drying effectiveness depends on parameters such as the flow rate and temperature of drying air, type of the coal bed (fixed or fluidized), coal size, residence time, and initial coal moisture content. Additional work and analyses are needed to size coal driers and determine tradeoffs between the different drier designs.

It is expected the next coal drying system will be designed in a modular fashion to allow incremental drying of the coal up to the lowest practical coal moisture content. Each coal-drying module will dry a portion of the total coal flow and will also include environmental controls. With all coal-drying modules in service it will be possible to dry 100 percent of the coal feed. The dried coal will be burned in controlled tests to allow determination of the coal moisture effect on unit operations, performance and emissions. Tests will be performed with different coal moisture levels. This will make it possible to determine the optimal coal moisture level. Short and extended coal test burns are planned.

CONCLUSIONS

Theoretical analysis and two coal burn tests were performed at Coal Creek Unit 2 to determine the effect of dried coal on unit operation and performance. The coal required for these tests was dried by an outdoor stockpile drying system. For the second test, coal moisture was reduced by approximately 6 percentage points (from 37.5 to 31.4 percent) with the corresponding increase in fuel HHV of 9.25 percent.

Unit load and excess O_2 level were maintained constant during the test. The improvement in boiler and unit performance was in the 2.6 to 2.8 percent range. This performance improvement was primarily due to a reduction in moisture evaporation loss, lower stack loss, and a decrease in auxiliary power requirements. Drier coal also resulted in a reduction in flow rate of coal (10.8 percent) and flue gas (4 percent). These, experimental results are in agreement with theoretical results.

Assuming a capacity factor of 0.8, the improvements due to the 6.1 percent moisture reduction represent annual savings of $1,300,000 for both units at the Coal Creek Station. If implemented on all U.S. lignite and PRB fired units, the annual savings would be $19,000,000 for the lignite-fired plants, and $90,000,000 for the PRB-fired plants.

Mass emissions of CO_2 were reduced by approximately 2 percent, or 360,000 tons annually. Mass emissions of NO_x decreased by 10 percent during the first coal burn test, while they increased slightly during the second coal burn test. This difference in NO_x emissions is due to the PA flow that was maintained constant during the second test, while it was reduced during the first test.

SO_2 mass emissions increased slightly for both tests due to a larger scrubber by-pass flow that was required to maintain a constant stack temperature. This increase in the untreated by-pass flow has resulted in a slight increase in SO_2 emissions and opacity. Lowering the stack temperature set-point will correct this problem.

The field tests described here are for 6.1 percent moisture reduction. Future work will include test burns with lower moisture to determine the impacts on boiler operations. This would also make it possible to determine the optimal moisture level. Dried coal for these tests will be provided by a modular drying system employing waste heat and coal driers of a fixed or fluidized bed design.

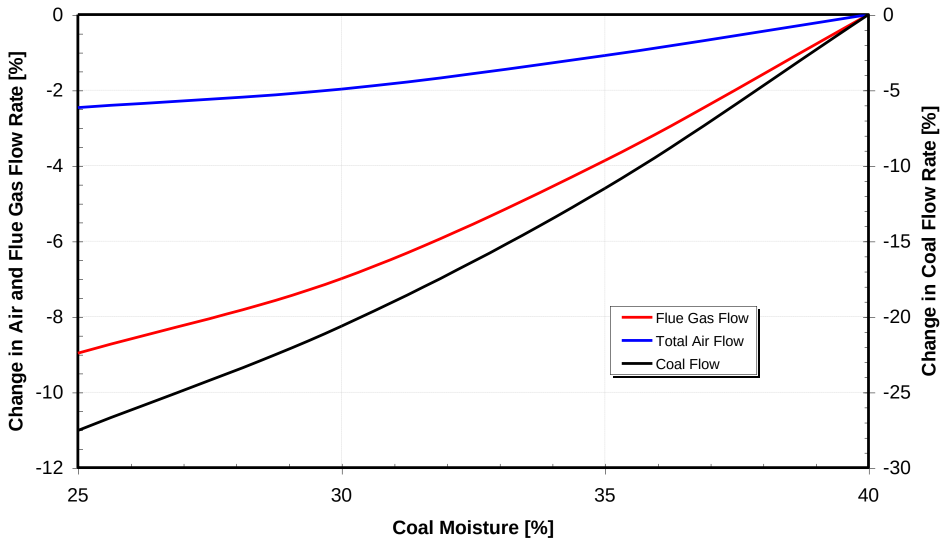

Figure 1: Effect of Coal Moisture on Flow Rates of Air, Flue Gas and Coal

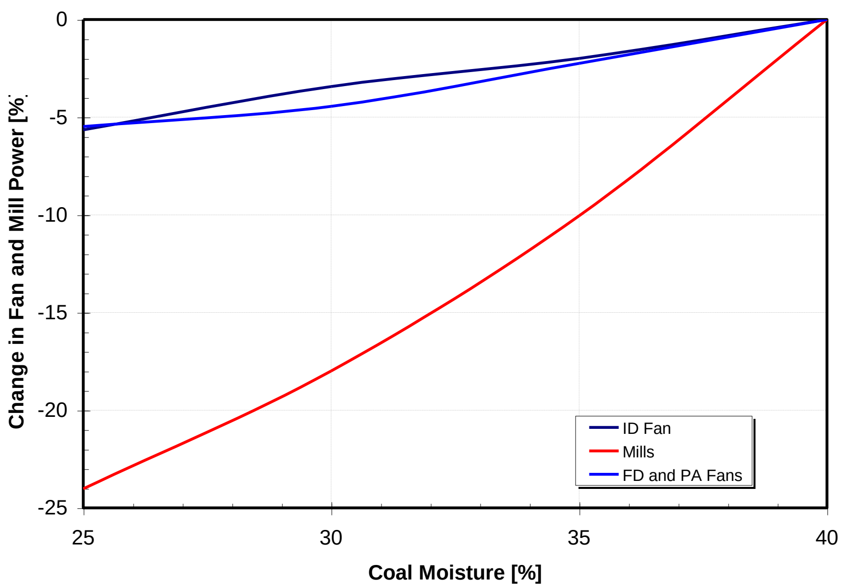

Figure 2: Effect of Coal Moisture on Fan Power

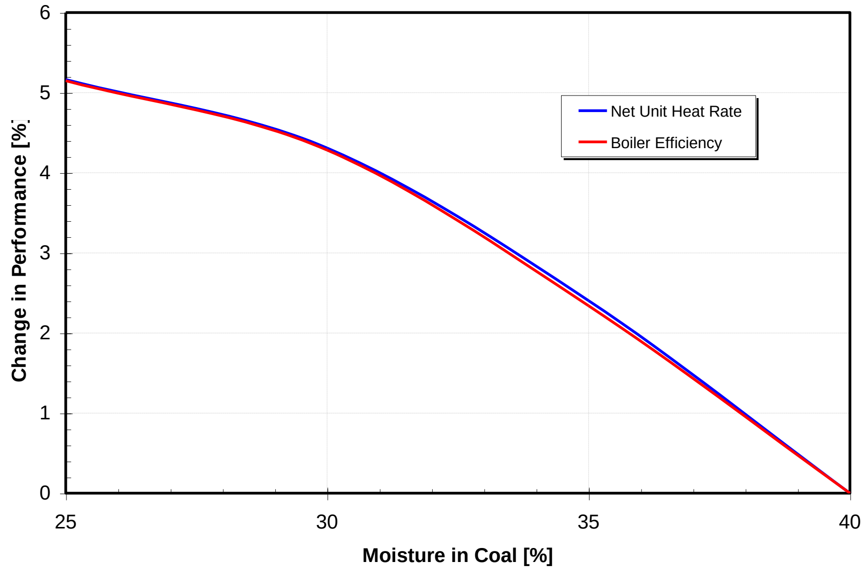

Figure 3: Effect of Coal Moisture on Boiler and Unit Performance

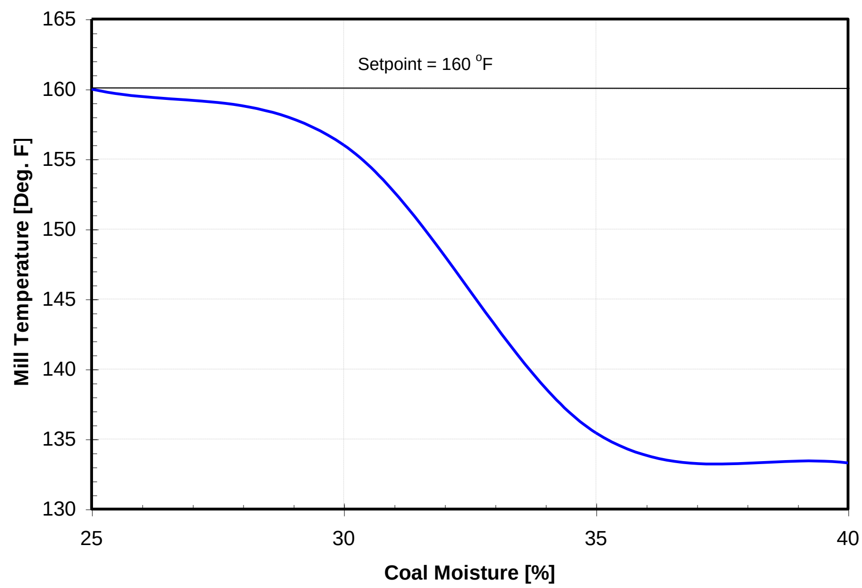

Figure 4: Effect of Coal Moisture on Mill Temperature

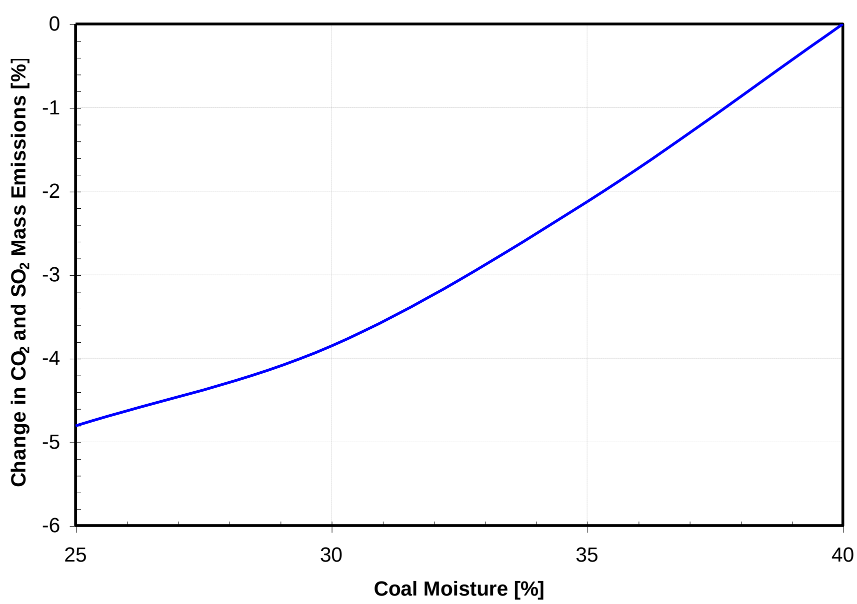

Figure 5: Effect of Coal Moisture on Mass Emissions of CO_2 and SO_2

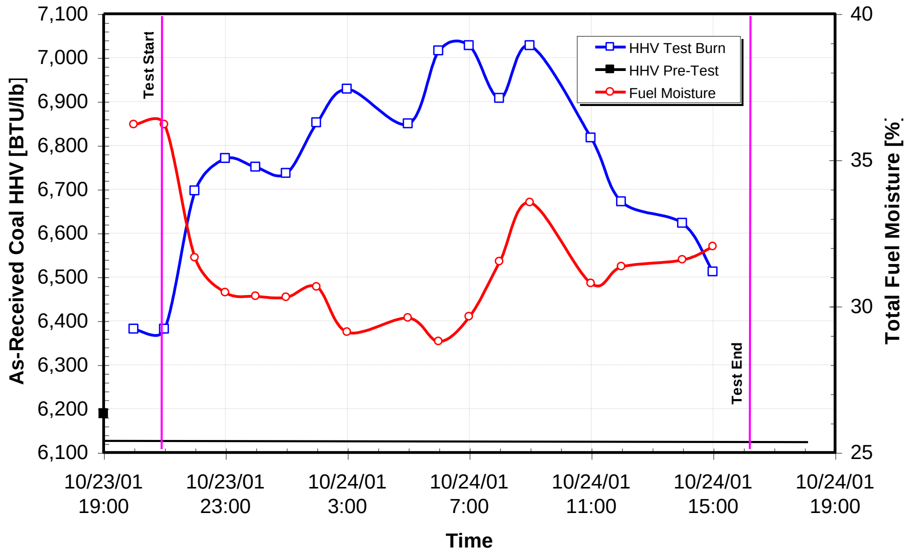

Figure 6: Variation of Coal HHV and Moisture Content During the Second Coal Burn Test

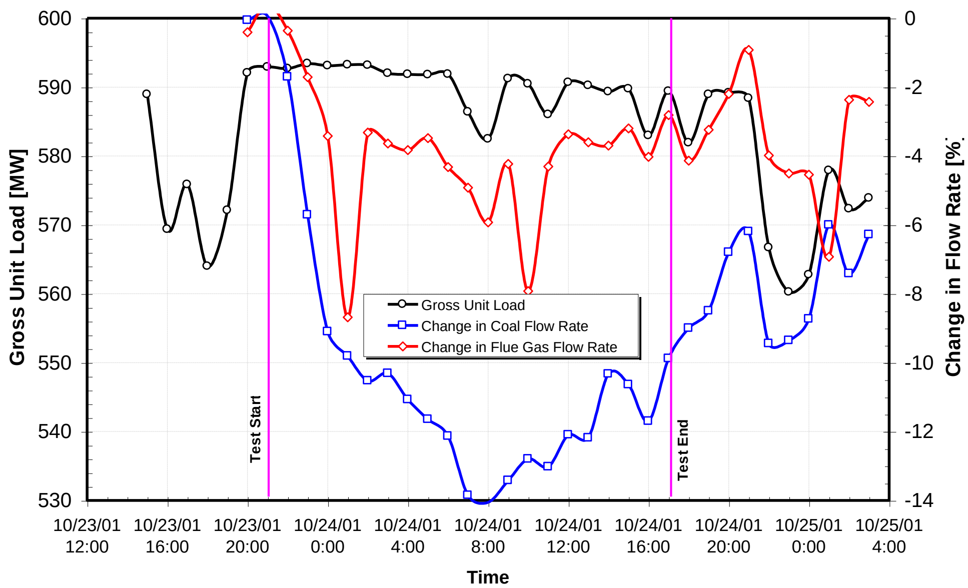

Figure 7: Variation of Coal and Flue Gas Flow Rates During the Second Coal Burn Test

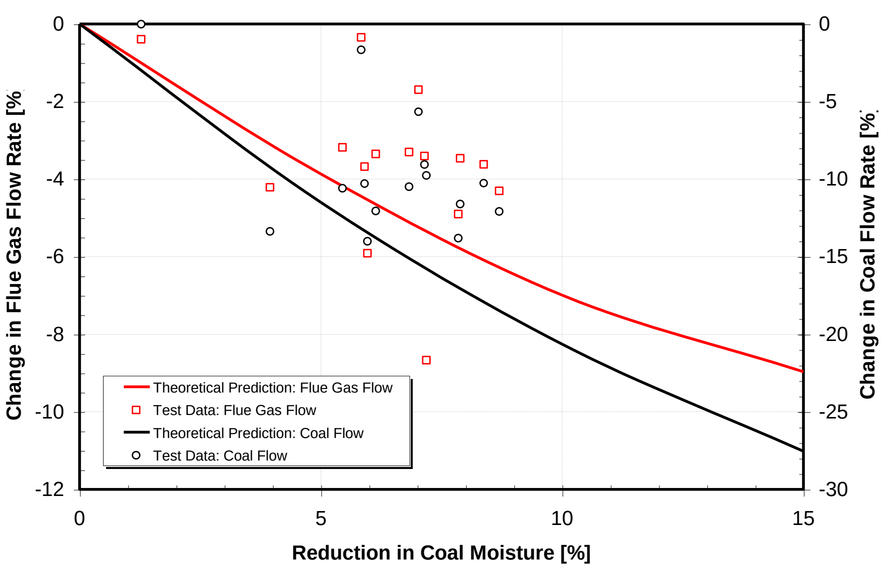

Figure 8: Change in Coal and Flue Gas Flow Rates with Coal Moisture

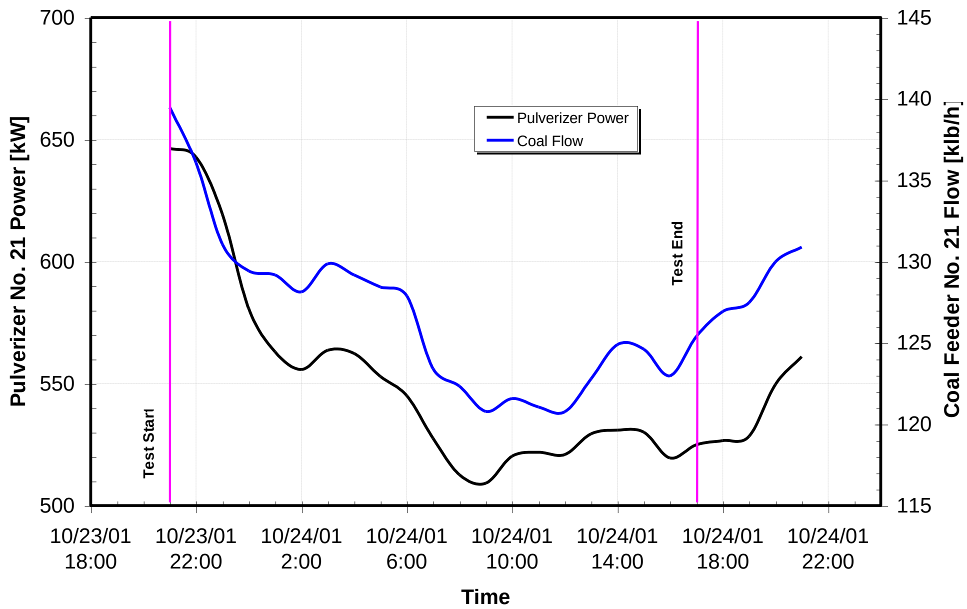

Figure 9: Variation of Pulverizer Power and Pulverizer Coal Flow During the Second Coal Burn Test for No. 21 Pulverizer

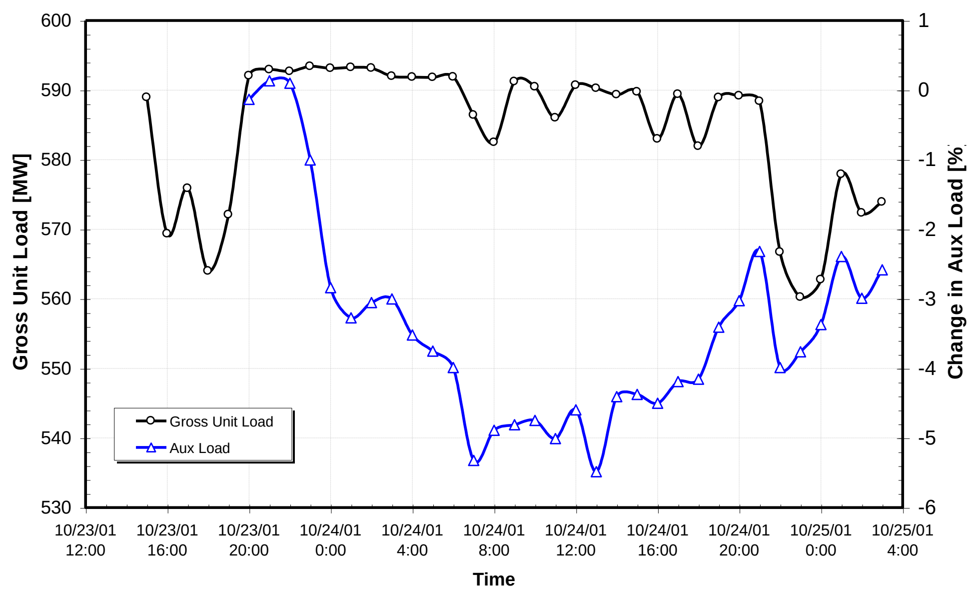

Figure 10: Reduction in Auxiliary Power Measured During the Second Coal Burn Test

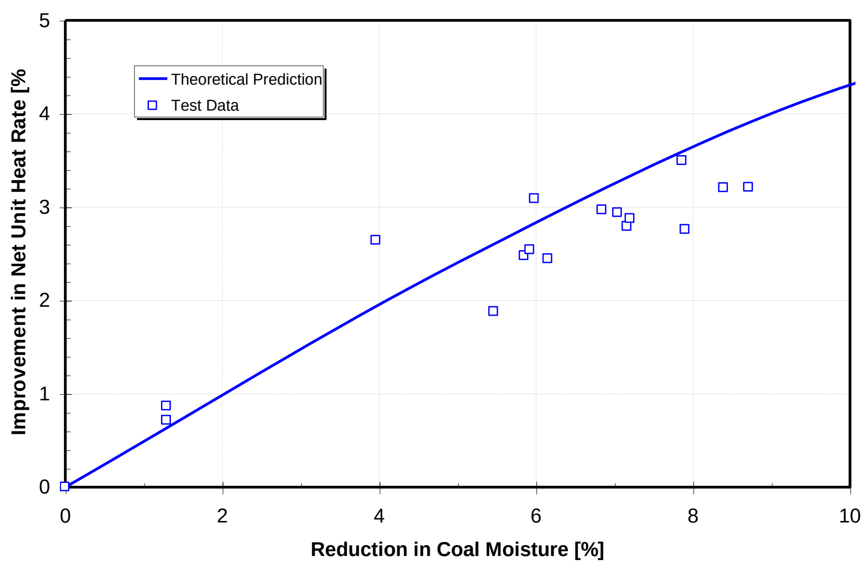

Figure 11: Improvement in Net Unit Heat Rate Versus the Reduction in Coal Moisture Content

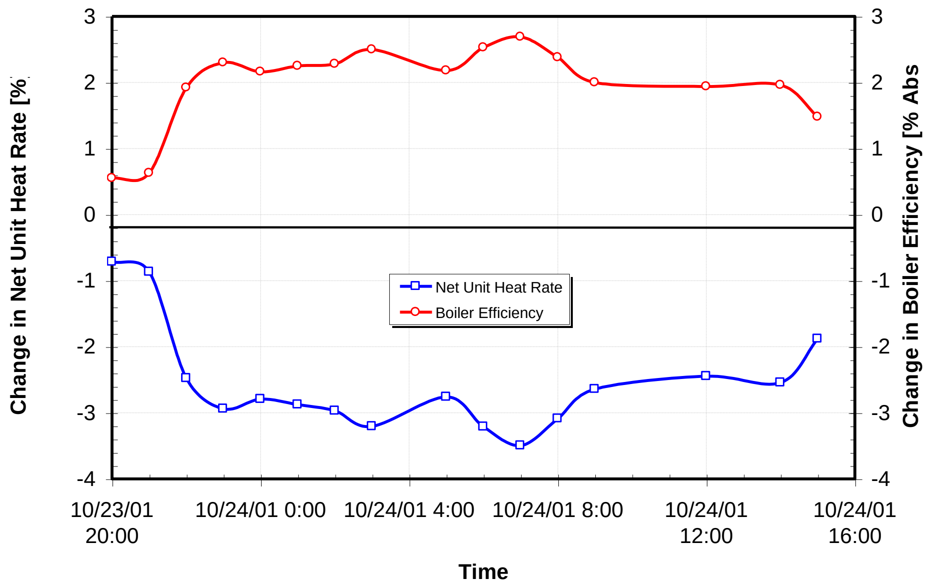

Figure 12: Variation of Boiler Efficiency and Net Unit Heat Rate During the Second Coal Burn Test

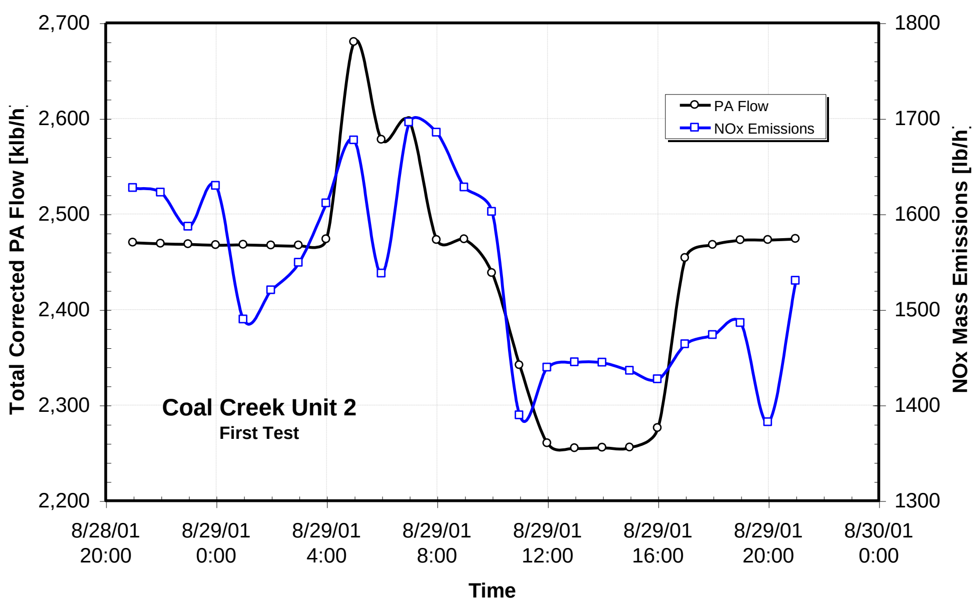

Figure 13: Variation in PA Flow and Mass Emissions of NO_x During the First Coal Burn Test