USE OF COAL DRYING TO REDUCE WATER CONSUMED IN PULVERIZED COAL POWER PLANTS

QUARTERLY REPORT FOR THE PERIOD July 1, 2004 to September 30, 2004

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DISCLAIMER

ABSTRACT

This is the seventh Quarterly Report for this project. The background and technical justification for the project are described, including potential benefits of reducing fuel moisture, prior to firing in a pulverized coal boiler.

Coal drying experiments were performed with lignite and Powder River Basin coals to determine the effects of inlet air moisture level on the equilibrium relationship between coal moisture and exit air relative humidity and temperature. The results show that, for lignite, there is a slight dependence of equilibrium moisture on inlet humidity level. However, the equilibrium relationship for PRB coal appears to be independent of inlet air humidity level. The specific equilibrium model used for computing lignite coal dryer performance has a significant effect on the prediction accuracy for exit air relative humidity; but its effects on predicted coal product moisture, exit air temperature and specific humidity are minimal.

Analyses were performed to determine the effect of lignite product moisture on unit performance for a high temperature drying system. With this process design, energy for drying is obtained from the hot flue gas entering the air preheater and the hot circulating cooling water leaving the steam condenser. Comparisons were made to the same boiler operating with lignite which had been dried off-site.

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INTRODUCTION

Background

Low rank fuels such as subbituminous coals and lignites contain significant amounts of moisture compared to higher rank coals. Typically, the moisture content of subbituminous coals ranges from 15 to 30 percent, while that for lignites is between 25 and 40 percent, where both are expressed on a wet coal basis. Please see Appendix A for more details on definitions of coal moisture used in this report.

High fuel moisture has several adverse impacts on the operation of a pulverized coal generating unit. High fuel moisture results in fuel handling problems, and it affects heat rate, mass rate (tonnage) of emissions, and the consumption of water needed for evaporative cooling.

This project deals with lignite and subbituminous coal-fired pulverized coal power plants, which are cooled by evaporative cooling towers. In particular, the project involves use of power plant waste heat to partially dry the coal before it is fed to the pulverizers. Done in a proper way, coal drying will reduce cooling tower makeup water requirements and also provide heat rate and emissions benefits.

The technology addressed in this project makes use of the hot circulating cooling water leaving the condenser to heat the air used for drying the coal (Figure 1). The temperature of the circulating water leaving the condenser is usually about 49°C (120°F), and this can be used to produce an air stream at approximately 43°C (110°F). Figure 2 shows a variation of this approach, in which coal drying would be accomplished by both warm air, passing through the dryer, and a flow of hot circulating cooling water, passing through a heat exchanger located in the dryer. Higher temperature drying can be accomplished if hot flue gas from the boiler or extracted steam from the turbine cycle is used to supplement the thermal energy obtained from the circulating cooling water. Various options such as these are being examined in this investigation.

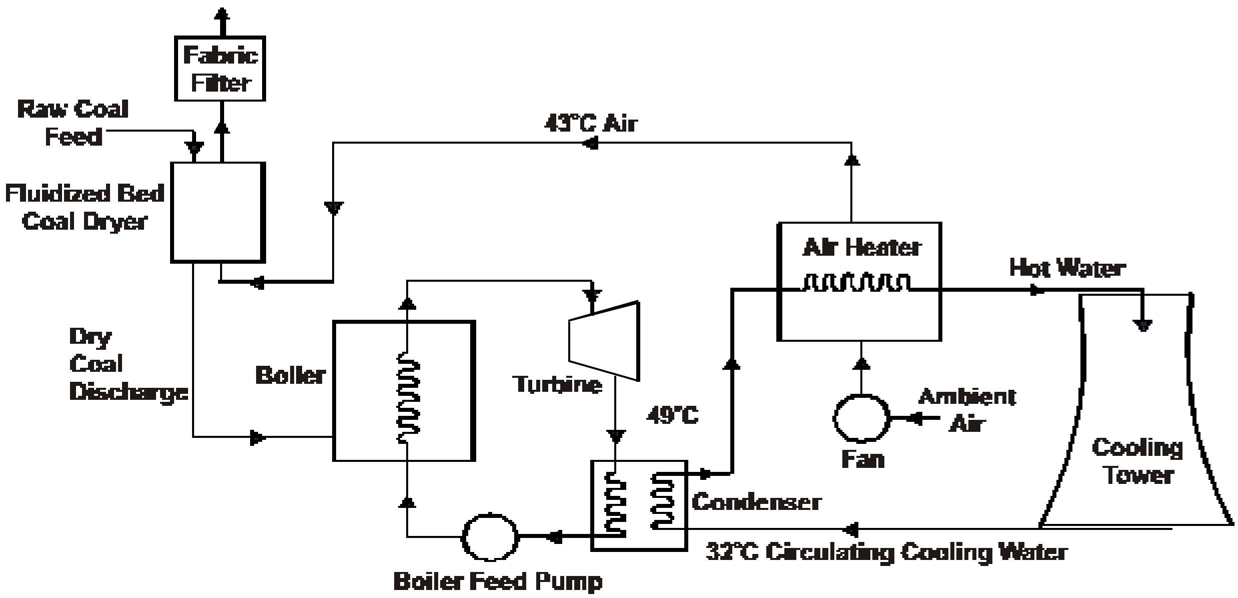

Figure 1: Schematic of Plant Layout, Showing Air Heater and Coal Dryer (Version 1)

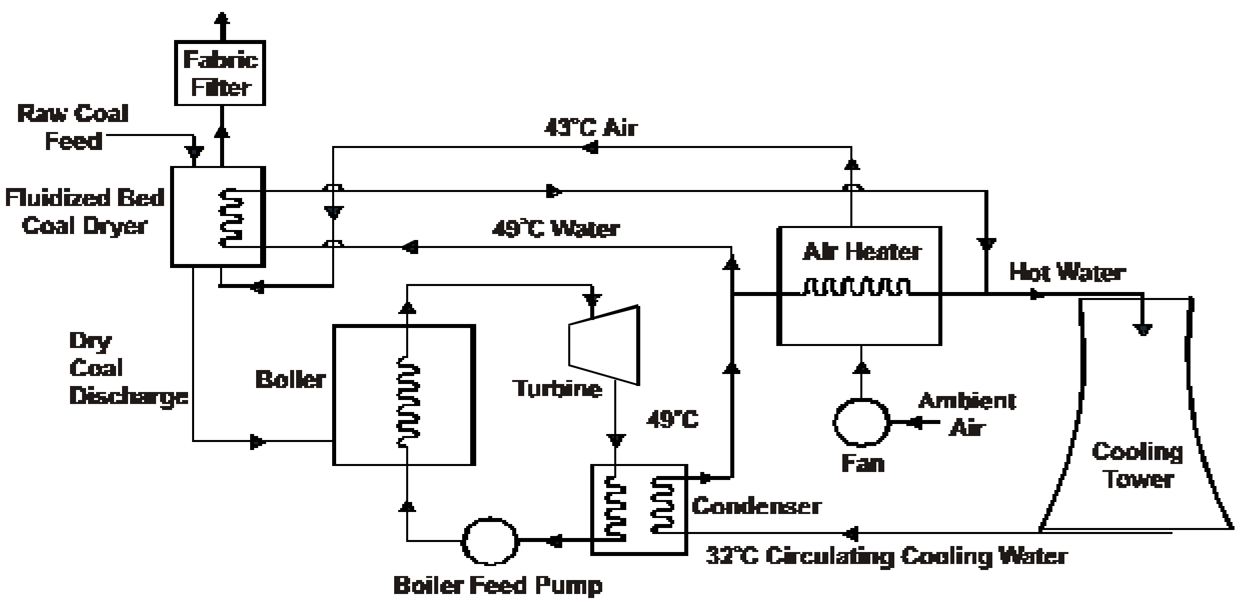

Figure 2: Schematic of Plant Layout, Showing Air Heater and Coal Dryer (Version 2)

Previous Work

Two of the investigators (Levy and Sarunac) have been involved in work with the Great River Energy Corporation on a study of low temperature drying at the Coal Creek Generating Station in Underwood, North Dakota. Coal Creek has two units with total gross generation exceeding 1,100 MW. The units fire a lignite fuel containing approximately 40 percent moisture and 12 percent ash. Both units at Coal Creek are equipped with low NO_x firing systems and have wet scrubbers and evaporative cooling towers.

The project team performed a theoretical analysis to estimate the impact on cooling water makeup flow of using hot circulating water to the cooling tower to heat the drying air and to estimate the magnitude of heat rate improvement that could be achieved at Coal Creek Station by removing a portion of the fuel moisture. The results show that drying the coal from 40 to 25 percent moisture will result in reductions in makeup water flow rate from 5 to 7 percent, depending on ambient conditions (Figure 3). For a 550 MW unit, the water savings are predicted to range from 1.17×10^6 liters/day (0.3×10^6 gallons/day) to 4.28×10^6 liters/day (1.1×10^6 gallons/day). The analysis also shows the heat rate and the CO_2 and SO_2 mass emissions will all be reduced by about 5 percent (Ref. 1).

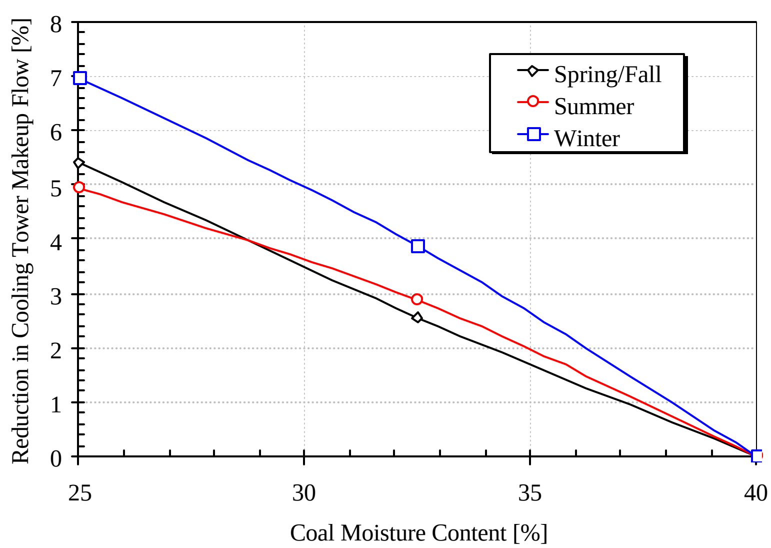

Figure 3: The Effects of Coal Moisture on Cooling Tower Makeup Water

A coal test burn was conducted at Coal Creek Unit 2 in October 2001 to determine the effect on unit operations. The lignite was dried for this test by an outdoor stockpile coal drying system. On average, the coal moisture was reduced by 6.1 percent, from 37.5 to 31.4 percent. Analysis of boiler efficiency and net unit heat rate showed that with coal drying, the improvement in boiler efficiency was approximately 2.6 percent, and the improvement in net unit heat rate was 2.7 to 2.8 percent. These results are in close agreement with theoretical predictions (Figure 4). The test data also showed the fuel flow rate was reduced by 10.8 percent and the flue gas flow rate was reduced by 4 percent. The combination of lower coal flow rate and better grindability combined to reduce mill power consumption by approximately 17 percent. Fan power was reduced by 3.8 percent due to lower air and flue gas flow rates. The average reduction in total auxiliary power was approximately 3.8 percent (Ref. 1).

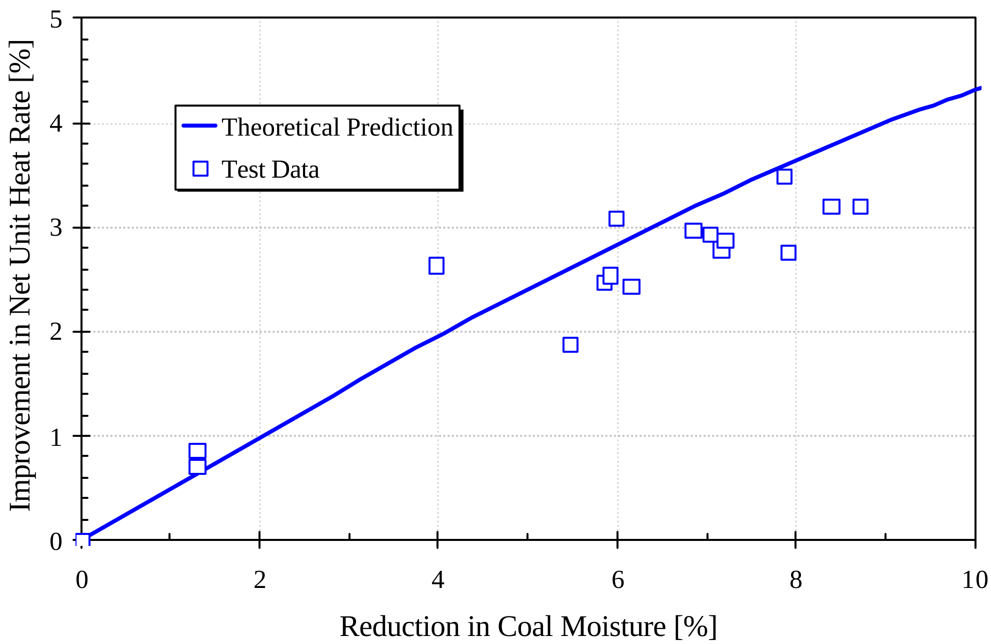

Figure 4: Improvement in Net Unit Heat Rate Versus Reduction in Coal Moisture Content

This Investigation

Theoretical analyses and coal test burns performed at a lignite fired power plant show that by reducing the fuel moisture, it is indeed possible to improve boiler performance and unit heat rate, reduce emissions and reduce water consumption by the evaporative cooling tower. The economic viability of the approach and the actual impact of the drying system on water consumption, unit heat rate and stack emissions will depend critically on the design and operating conditions of the drying system.

The present project is evaluating low temperature drying of lignite and Power River Basin (PRB) coal. Drying studies are being performed to gather data and develop models on drying kinetics. In addition, analyses are being carried out to determine the relative costs and performance impacts (in terms of heat rate, cooling tower water consumption and emissions) of the various drying options, along with the development of an optimized system design and recommended operating conditions.

The project is being carried out in five tasks. The original Task Statements included experiments and analyses for both fluidized bed and fixed bed dryers (see previous Quarterly Reports). After the project was started, it became clear there is no advantage to using fixed bed dryers for this application. For this reason, the technical scope was changed in June 2004 to emphasize fluidized bed drying. The Task Statements in this report reflect this change in emphasis.

Task 1: Fabricate and Instrument Equipment

A laboratory scale batch fluidized bed drying system will be designed, fabricated and instrumented in this task. **(Task Complete)**

Task 2: Perform Drying Experiments

The experiments will be carried out while varying superficial air velocity, inlet air temperature and specific humidity, particle size distribution, bed depth, and in-bed heater heat flux. Experiments will be performed with both lignite and PRB coals. **(Task Complete)**

Task 3: Develop Drying Models and Compare to Experimental Data

In this task, the laboratory drying data will be compared to equilibrium and kinetic models to develop models suitable for evaluating tradeoffs between dryer designs. **(Task Complete)**

Task 4: Drying System Design

Using the kinetic data and models from Tasks 2 and 3, dryers will be designed for 600 MW lignite and PRB coal-fired power plants. Designs will be developed to dry the coal by various amounts. Auxiliary equipment such as fans, water to air heat exchangers, dust collection system and coal crushers will be sized, and installed capital costs and operating costs will be estimated.

Task 5: Analysis of Impacts on Unit Performance and Cost of Energy

Analyses will be performed to estimate the effects of dryer operation on cooling tower makeup water, unit heat rate, auxiliary power, and stack emissions. The cost of energy will be estimated as a function of the reduction in coal moisture content. Cost comparisons will be made between dryer operating conditions (for example, drying temperature and superficial air velocity).

The project was initiated on December 26, 2002. The project schedule is shown in Figure 5.

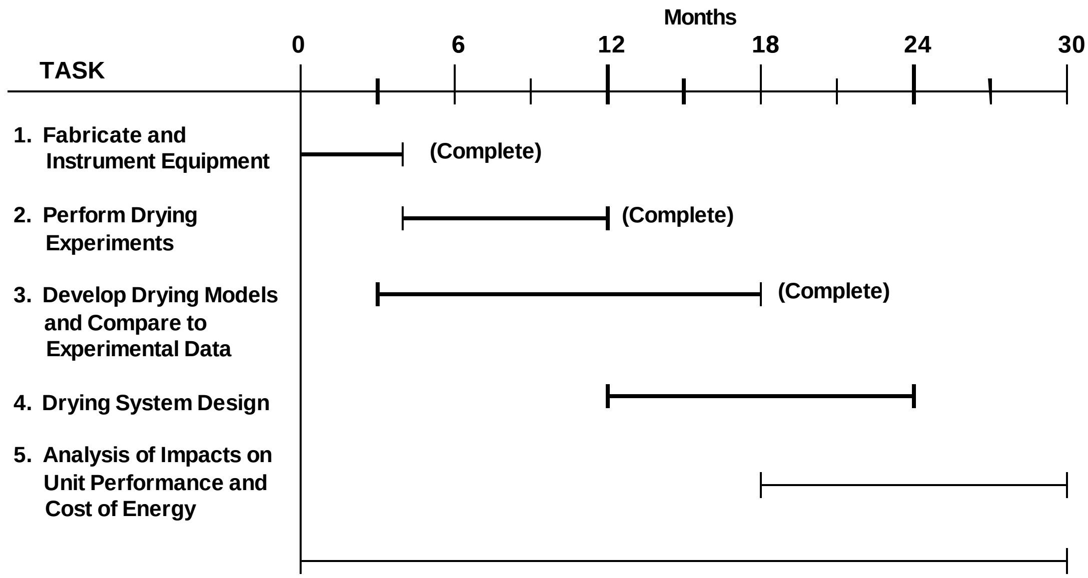

Figure 5: Project Schedule

EXECUTIVE SUMMARY

Background

Low rank fuels such as subbituminous coals and lignites contain relatively large amounts of moisture compared to higher rank coals. High fuel moisture results in fuel handling problems, and it affects station service power, heat rate, and stack gas emissions.

This project deals with lignite and subbituminous coal-fired pulverized coal power plants, which are cooled by evaporative cooling towers. The project involves use of the hot circulating cooling water leaving the condenser to provide heat needed to partially dry the coal before it is fed to the pulverizers.

Recently completed theoretical analyses and coal test burns performed at a lignite-fired power plant showed that by reducing the fuel moisture, it is possible to reduce water consumption by evaporative cooling towers, improve boiler performance and unit heat rate, and reduce emissions. The economic viability of the approach and the actual impact of the drying system on water consumption, unit heat rate and stack emissions will depend critically on the design and operating conditions of the drying system.

This project is evaluating alternatives for the low temperature drying of lignite and Power River Basin (PRB) coal. Laboratory drying studies are being performed to gather data and develop models on drying kinetics. In addition, analyses are being carried out to determine the relative costs and performance impacts (in terms of heat rate, cooling tower water consumption and emissions) of drying, along with the development of an optimized system design and recommended operating conditions.

Results

During the last Quarter, coal drying experiments were performed with lignite and Powder River Basin coals to determine the effects of inlet air moisture level on the equilibrium relationship between coal moisture and exit air relative humidity and temperature. The results show that, for lignite, there is a slight dependence of equilibrium moisture on inlet humidity level. However, the equilibrium relationship for PRB coal appears to be independent of inlet air humidity level. The specific equilibrium model used for computing lignite coal dryer performance has a significant effect on the prediction accuracy for exit air relative humidity; but its effects on predicted coal product moisture, exit air temperature and specific humidity are minimal.

Analyses were performed to determine the effect of lignite product moisture on unit performance for a high temperature drying system. With this process design, energy for drying is obtained from the hot flue gas entering the air preheater and the hot circulating cooling water leaving the steam condenser. Comparisons were made to the same boiler operating with lignite which had been dried off-site.

EXPERIMENTAL

Effect of Specific Humidity of Inlet Air on Equilibrium Moisture Curve

In previous Quarterly Reports, data were presented which show that the equilibrium moisture content of the coal (Γ) in the fluidized bed dryer is related to the temperature (T) and relative humidity (ϕ) of the air leaving the bed. Figure 6 shows data for lignite from several tests, where Γ is plotted versus Tlog (ϕ). All of these data follow the same trend, but with some scatter.

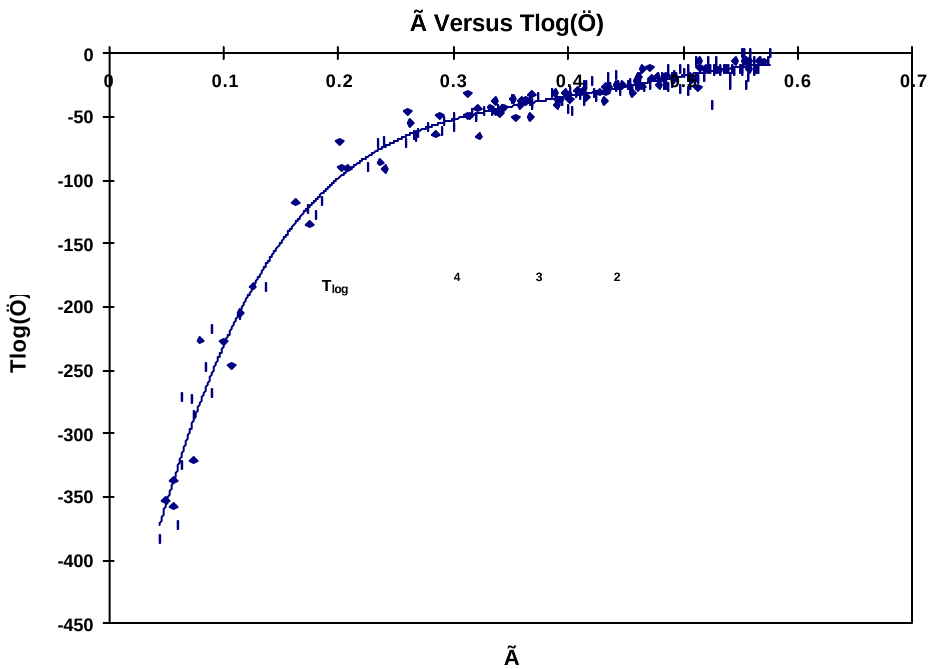

Figure 6: Equilibrium Moisture Curve for Lignite Based on Data Obtained with Low Inlet Air Specific Humidity

The data shown in Figure 6 were all obtained with relatively low inlet air specific humidities ($0.003<\omega_1<0.006$). Drying tests with low and high inlet air specific humidities were performed during the last Quarter, and these show the equilibrium coal moisture-relative air humidity relationship also depends slightly on the inlet air specific humidity (ω_1). This report contains these data and describes the magnitude of this effect.

A batch bed drying test is a transient process, where Γ, bed temperature, and temperature and relative humidity of the exit air vary with time. Sample results are shown in Figures 7 and 8. Data such as these are used to construct graphs of Tlog (ϕ) versus Γ typical of Figure 6.

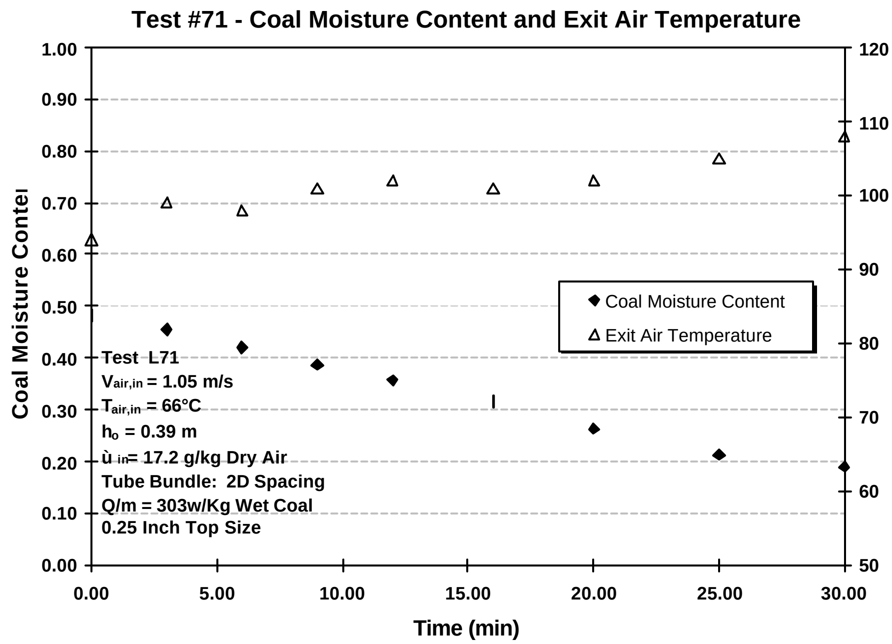

Figure 7: Transient Variations of Coal Moisture Content and Exit Air Temperature in Drying Test #71

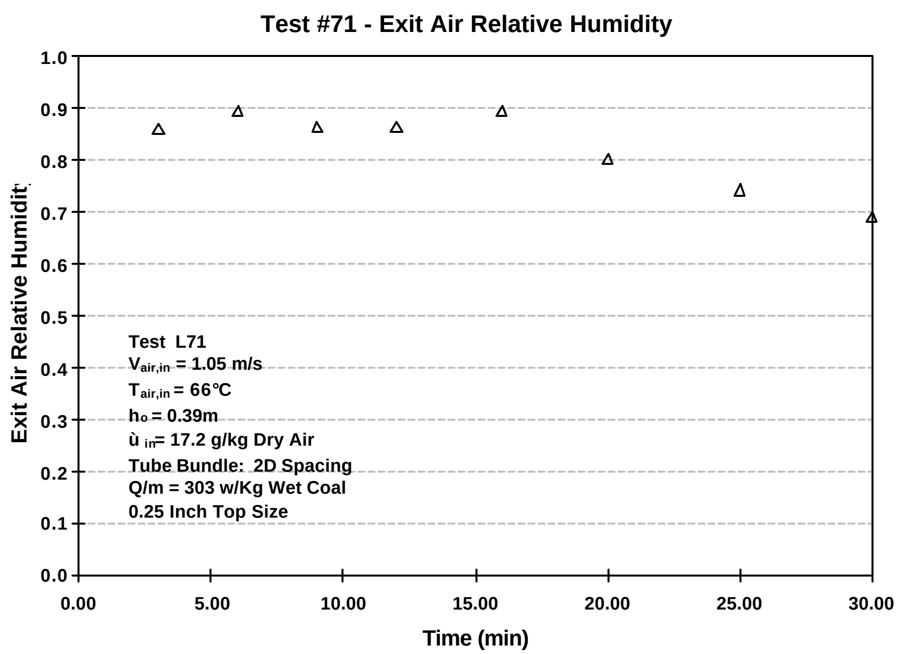

Figure 8: Transient Variation of Exit Air Relative Humidity in Drying Test #71

A sequence of tests was performed using lignite from the same barrel, in which the moisture content of the inlet air was varied between low and high values in successive tests. The resulting equilibrium moisture relationships for lignite are shown in Figure 9. These show distinct equilibrium moisture curves for three inlet air humidity levels (ω_1 = 0.003, 0.01 and 0.020 to 0.025).

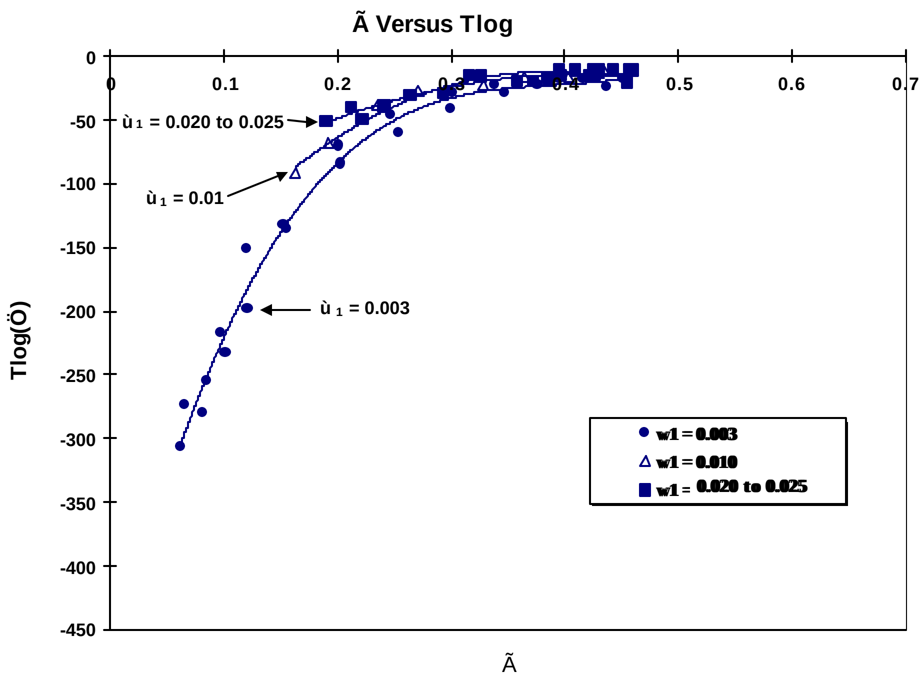

Figure 9: Effect of Inlet Air Specific Humidity on Equilibrium Moisture Curve

Calculations were then performed to determine the effect of the choice of equilibrium moisture model on predicted values of Γ, ϕ, T and ω_2. Figures 10 to 13 compare the measured values from data obtained with $\omega_1 \approx 0.020$ to 0.025 with the predictions using high ω_1 ($\omega_1 \approx 0.020$ to 0.025) and low ω_1 ($\omega_1 \approx 0.004$) moisture models for one set of test conditions. These show that for this set of high ω_1 data, the exit air temperature and relative humidity were predicted better using the equilibrium moisture model developed with high ω_1 test data. Impacts of choice of equilibrium moisture model on exit air specific humidity and coal moisture were less significant. Similar comparisons were made for other test conditions, and the results were averaged, as shown in Tables 1 and 2.

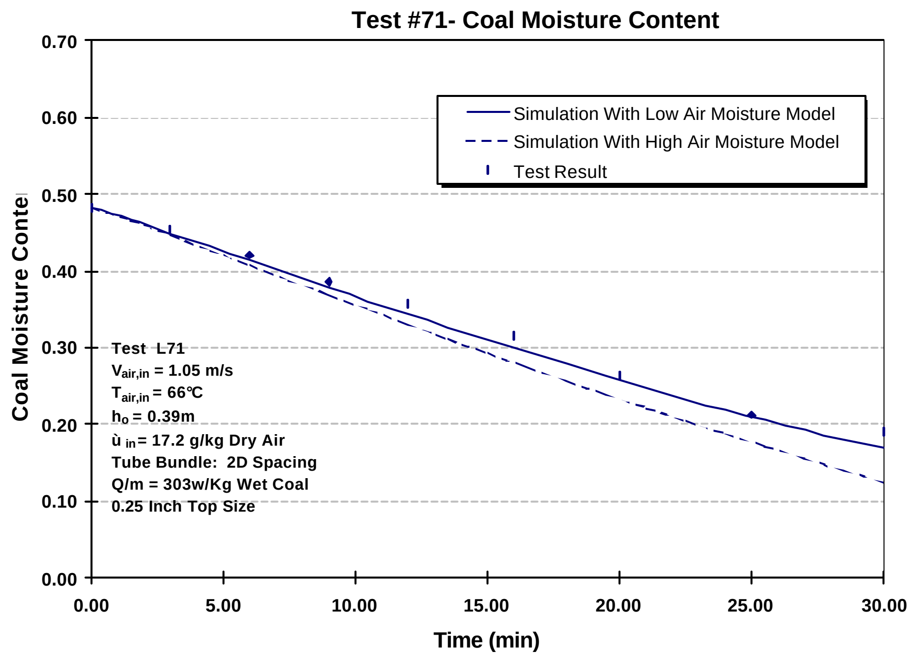

Figure 10: Comparison of Computer Simulations with Test Data for Coal Moisture. Test #71.

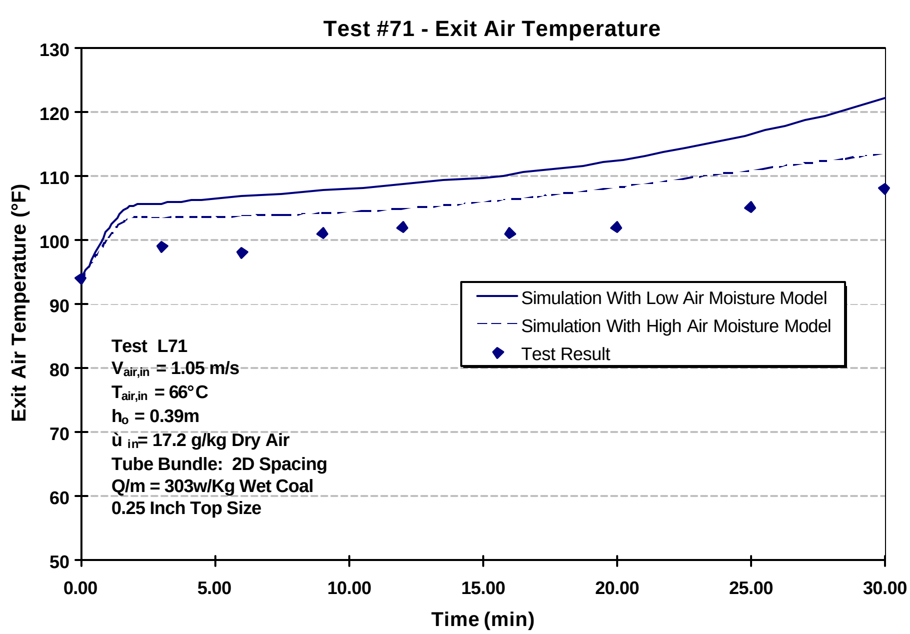

Figure 11: Comparison of Computer Simulations with Test Data for Exit Air Temperature. Test #71.

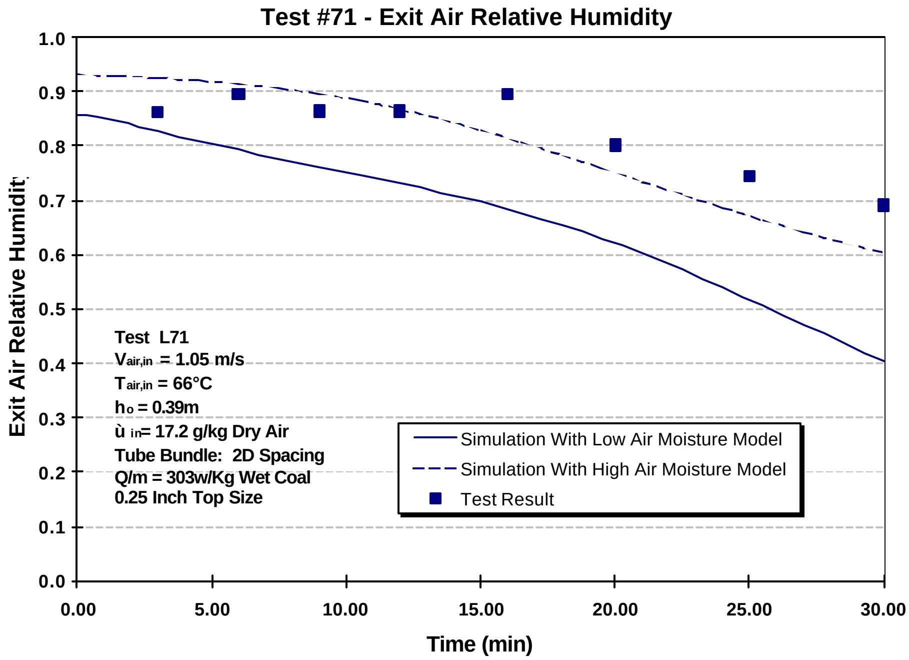

Figure 12: Comparison of Computer Simulations with Test Data for Exit Air Relative Humidity. Test #71.

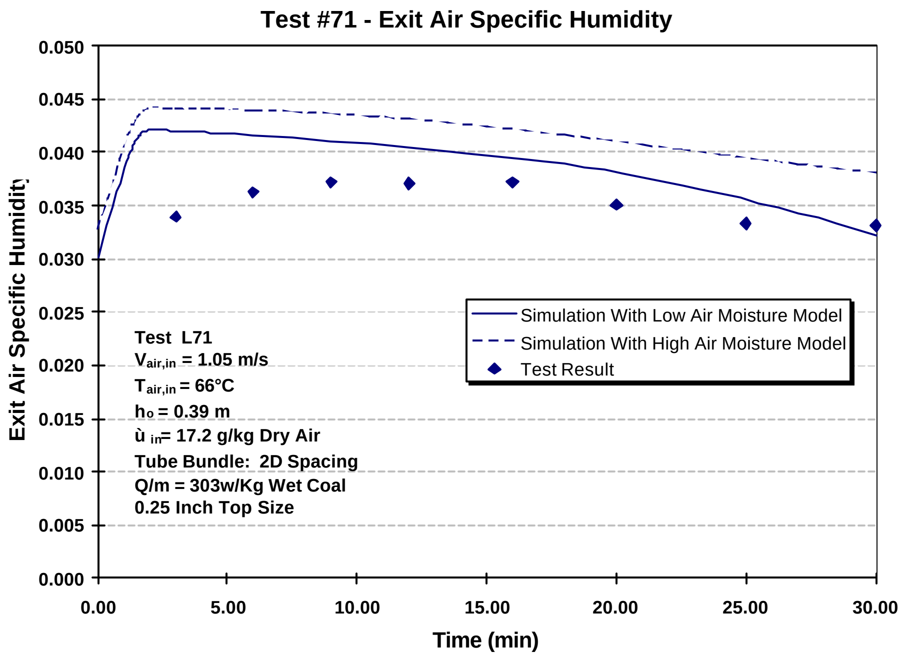

Figure 13: Comparison of Computer Simulations with Test Data for Exit Air Specific Humidity. Test #71.

Table 1

Average Relative Errors Between Measured and Predicted Values (ω_1 = 0.004 data)

ω_1	ε (ω_{2L})	ε (Γ_L)	ε (T_{2L})	ε (ϕ_{2L})
0.004	0.092	0.052	0.048	0.039

Table 2

Average Relative Errors Between Measured and Predicted Values (ω_1 = 0.021 data)

ω_1	ε (ω_{2L})	ε (ω_{2H})	ε (Γ_L)	ε (Γ_H)	ε (T_{2L})	ε (T_{2H})	ε (ϕ_{2L})	ε (ϕ_{2H})
0.021	0.086	0.148	0.030	0.075	0.072	0.040	0.156	0.043

Notes:

Subscript L – Data compared to equilibrium moisture model derived from low ω_1 data

Subscript H – Data compared to equilibrium moisture model derived from high ω_1 data

$T_{air\ in}$ = 43 to 66°C

Table 1 shows average relative errors in Γ and exit air temperature (T_2) and humidities (ϕ_2 and ω_2) for test data obtained with low ω_1 (ω_1 = 0.004) and for an equilibrium moisture model derived from low ω_1 drying data. The relative errors for three of the parameters were 5 percent or less, while ε (ω) was 9 percent.

Table 2 shows average relative errors for test data obtained with high ω_2 ($\omega_2 \approx$ 0.021) and equilibrium moisture models derived from both low and high ω_1 drying data. A comparison of Table 1 to Table 2 shows that at high ω_1, the average relative errors in ϕ_2 are greatly affected by the choice of the moisture model. For drying at ω_1 = 0.004 and an equilibrium moisture model based on the ω_1 = 0.004 data, ε (ϕ_{2L}) = 0.039. For drying at ω_1 = 0.021, ε (ϕ_{2L}) = 0.156 and ε (ϕ_{2H}) = 0.043. The other parameters (Γ, T and ω) are much less sensitive to the choice of moisture model.

The conclusion from these analyses for lignite is that the choice of equilibrium moisture model does not significantly affect the computed values of coal moisture, exit air temperature or specific humidity, but it does affect computed exit air relative humidity. For best prediction accuracy for ϕ, it is thus recommended that equilibrium moisture data be used which has approximately the same inlet air specific humidity as the conditions to be modeled.

Of the coals tested, the sensitivity of the equilibrium moisture model to inlet humidity level appears to be limited to lignite. Similar tests with PRB coal show no significant dependence of the equilibrium moisture model on inlet air specific humidity (Figure 14).

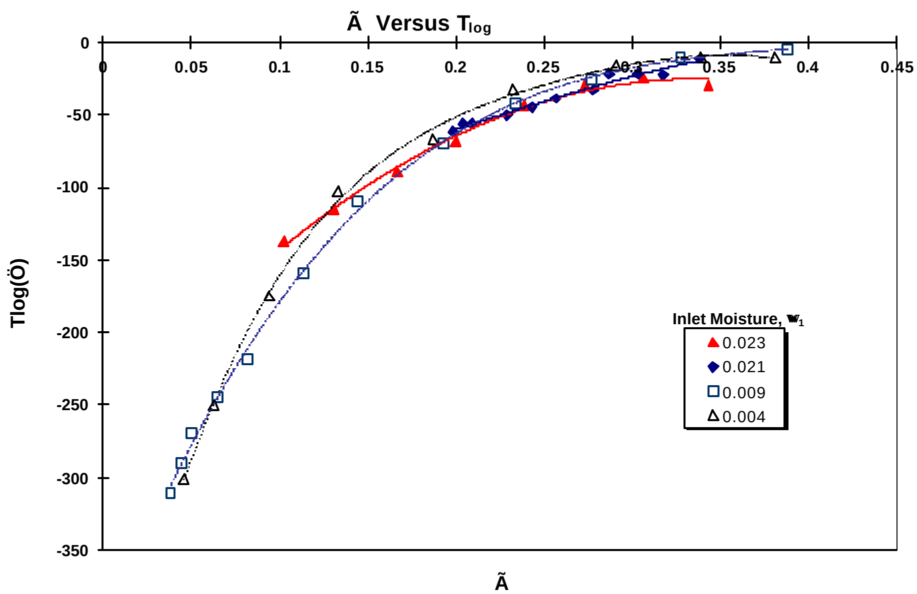

Figure 14: Effect of Inlet Air Specific Humidity on Equilibrium Moisture Data for PRB Coal

DRYING SYSTEM DESIGN AND ANALYSIS OF IMPACTS ON UNIT PERFORMANCE AND COST OF ENERGY

Background

Tasks 4 and 5 involve the design of drying systems for 600 MW lignite and PRB coal-fired power plants, analysis of the effects of dryer operation on cooling tower makeup water, unit heat rate, auxiliary power and stack emissions, and estimation of the cost of energy as a function of reduction in coal moisture content and dryer design. The work in these two tasks is progressing in the following subtasks:

Subtask 1: Estimate effects of firing dried coal on flow rates of combustion air and flue gas, required feed rate of coal to boiler, mill and fan power, boiler efficiency and unit heat rate. **(Complete)**

Subtask 2: Estimate required dryer size, flow rates of fluidizing air and amount of in-bed heat transfer as functions of drying temperature and coal product moisture. **(Complete)**

Subtask 3: Integrate dryer into boiler and turbine cycle and calculate overall impacts on heat rate, evaporative cooling tower makeup water and emissions. **(In Progress)**

Subtask 4: Size remaining components and develop drying system cost estimates.

Subtask 5: Perform calculations to select optimal drying system configuration and product coal moisture.

During this last Quarter, the effort has been focused on Subtask 3. A brief description of the work done so far is given below.

A calculation procedure, based, in part, on conservation of mass and energy, was developed for determining the effects of coal drying on coal, air and gas flow rates, fan and mill power, unit heat rate and cooling tower makeup water requirements. Using this procedure, a drying system configuration, referred to as the "High Temperature (HT) Case" was analyzed and compared to the case of off-site drying.

High Temperature Case

The HT case involves a bi-sector air preheater (APH), heat exchangers for preheating the primary air/secondary air (PA/SA) and fluidized bed air (FA) streams, a fluidized bed dryer (FBD) fan, a fluidized bed dryer, and heat exchangers, which use high temperature flue gas for heating the FA stream and for heating the water which flows through the in-bed heat exchanger (see Figure 15).

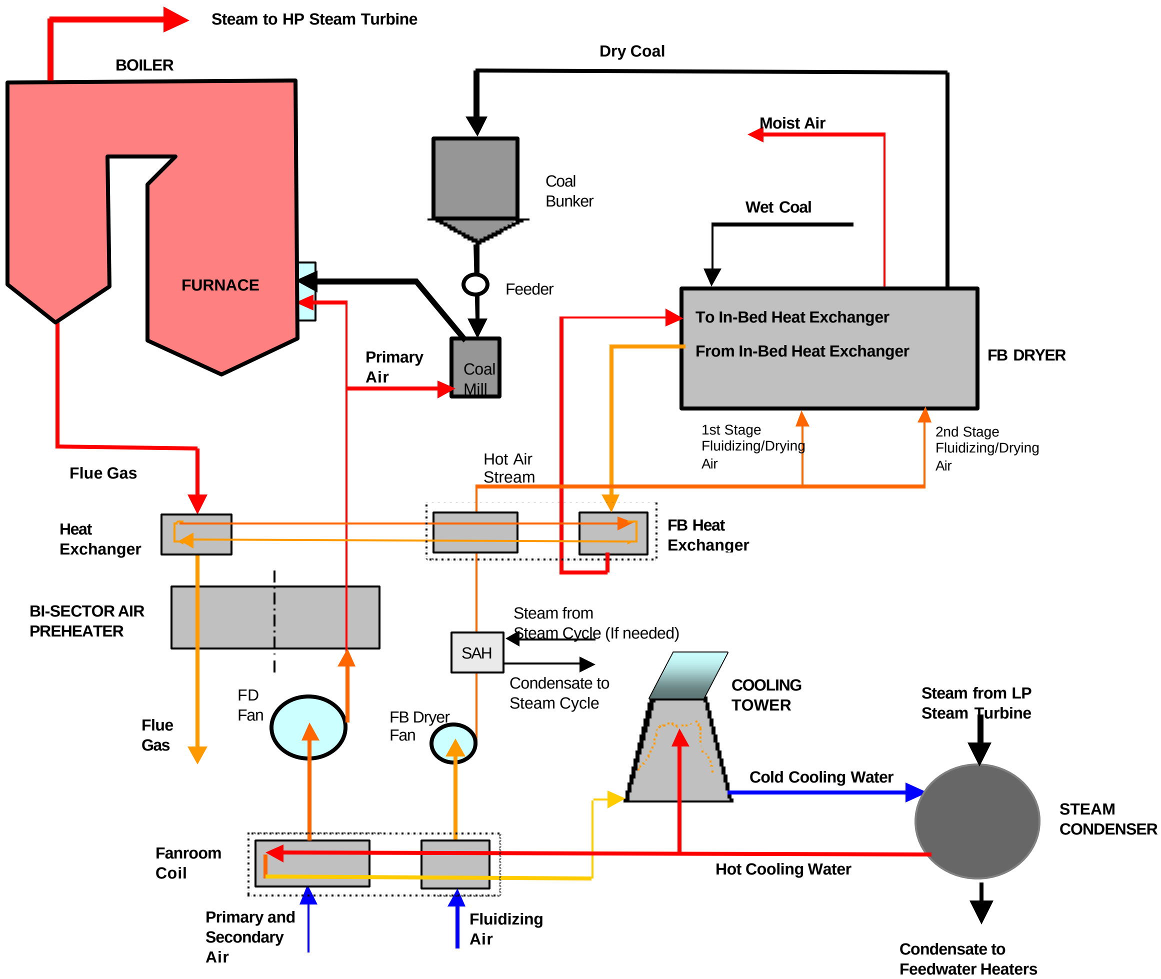

Figure 15: Process Diagram for High Temperature Drying System

Waste heat from the steam condenser is used to preheat the PA+SA and FA streams. This is achieved by diverting a small fraction of the hot condenser cooling water from the rest of the flow and passing it through a water-to-air heat exchanger where the PA + SA and FA streams are preheated to a temperature of approximately 100°F (38°C). The cold cooling water is then circulated back to the tower. This lowers cooling tower duty and reduces the amount of water required for a cooling tower.

The preheated primary (PA + SA) streams flow through the FD fan and then through the APH where they are further heated. PA is separated from the SA and is delivered to the coal pulverizers. The SA stream is delivered to the boiler windbox, where it is distributed to the burners.

The preheated FA stream is passed through the FBD fan. The FA stream then passes through the air-to-water heat exchangers, where its temperature is increased to the 200 - 240°F (93 to 115°C) range. The heated FA stream is then delivered to the fluidized bed dryer where it fluidizes and dries the coal. The water for the in-bed heat exchanger is heated in a water-to-water heat exchanger that is placed in a serial arrangement.

The heat for both heat exchangers is extracted from the hot flue gas upstream of the APH using, in this case, water or other suitable liquid as a heat transfer medium. Other, simpler arrangements are possible. For example, the heat transfer medium could be eliminated by combining the above-mentioned three heat exchangers into one combined heat exchanger. In such an arrangement, the FA stream would be heated in the flue gas-to-FA part of the combined heat exchanger and the water for the in-bed heat exchanger would be heated in the flue gas-to-water part of the combined heat exchanger. However, for the purpose of this analysis, the details of the heat exchanger arrangement are not important.

After passing through the heat exchanger, the flue gas flows through the bi-sector APH where it is further cooled. As a consequence of this heat exchanger arrangement, the temperature of flue gas, leaving the APH is lower compared to the case where there is no heat extraction upstream of the APH. However, since the PA + SA entering the APH is preheated by using waste heat from the condenser, the temperatures of the metal matrix in the cold end of the APH are high enough to prevent excessive corrosion and plugging of heat transfer surfaces caused by deposition of sulfuric acid.

For comparison purposes, performance calculations were also performed with the same unit, but without a fluidized bed dryer (Figure 16). In this case, coal, dried somewhere off site, is fed to the pulverizers. It is assumed the energy required to dry the coal is free and does not affect unit heat rate.

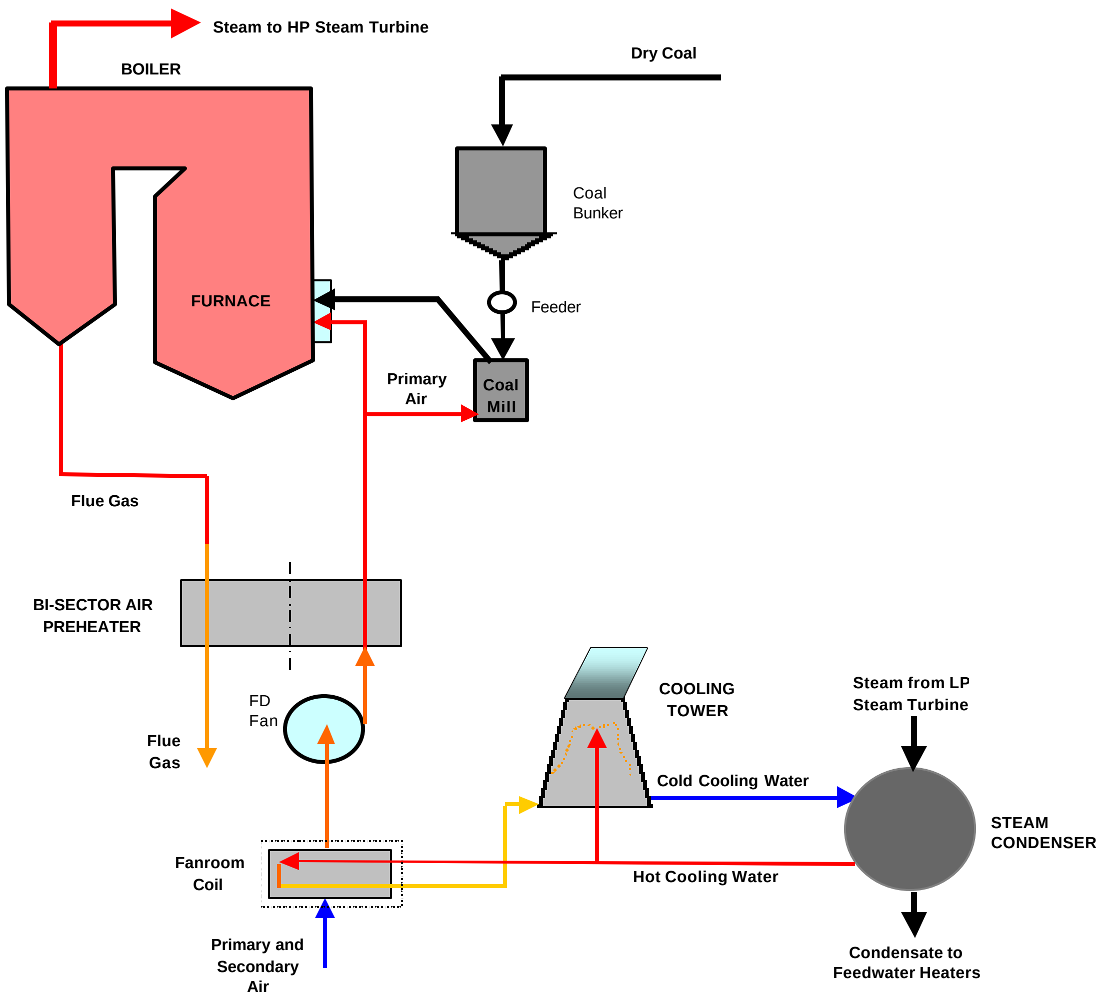

Figure 16: Process Diagram for Case Where Coal is Dried Off-Site

Analysis Methodology and Assumptions

- **Dryer Design**

  A fluidized bed dryer of fixed size, having a distributor area of 312 ft^2 with 11,105 ft^2 of in-bed heat exchange tubes, overall heat transfer coefficient of 30 Btu/ft^2-°F-hr and expanded bed height of 50” was used in this analysis. Coal is fed to the dryer at one end, flows horizontally along the distributor and is then discharged at the downstream end (Figure 17). Nominal dryer operating conditions are listed in Table 3.

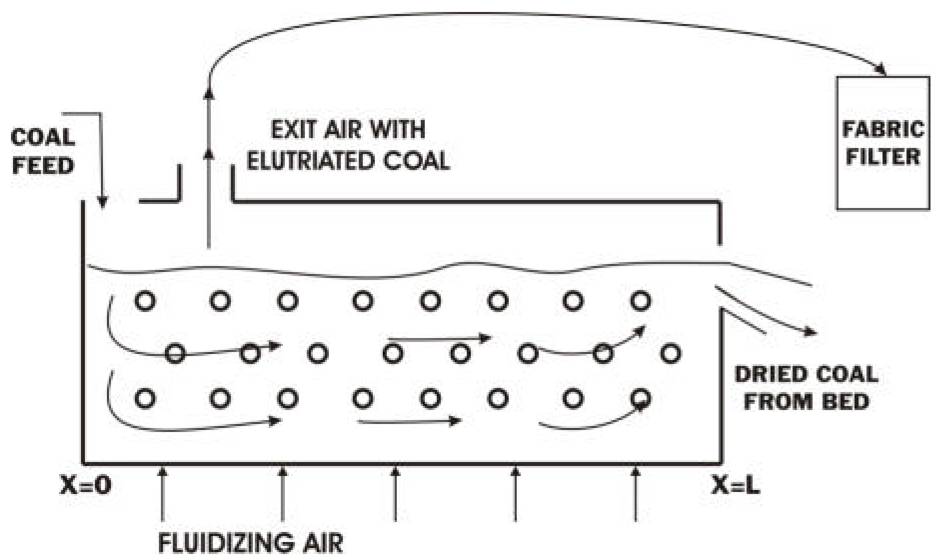

Figure 17: Sketch of Continuous Flow Dryer

Table 3

Dryer Dimensions and Operating Conditions

M_{coal}	75	tons/hr
M_{air}	300	klbs/hr
$T_{air,in}$	200	°F
$\omega_{air,in}$	0.010	lb/lb DA
C_1	38.5	%
$H_{Bed,Expanded}$	50	”
$A_{Distributor}$	312	ft^2
A_{Tubes}	11,105	ft^2
U	30	Btu/ft^2-°F-hr

The first principle model of a fluidized bed dryer, developed in this project (Ref. 2) was used to determine coal dryer performance, (i.e., outlet coal moisture (C_2), temperature ($T_{Bed,avg}$) and humidity of outlet air (ϕ_2), and amount of heat to be transferred to the in-bed heat exchanger coils (Q_{Bed}) for selected fluidization air temperatures ($T_{air,in}$) and average in-bed coil temperatures ($T_{coil,avg}$)).

Analysis of system performance was conducted for coal product moisture levels, C_2, ranging from 19 to 38.5 percent. For these runs, the average coil temperature varied in the 170 to 240° range (see Table 4).

Table 4

Sample Results of Dryer Performance

Tab (S-xx) Run No.	$T_{air,in}$ °F	$T_{coil,avg}$ °F	C_2 %	$T_{Bed,Avg}$ °F	$T_{Bed,Max}$ °F	Q_{Bed} MBtu/hr	ϕ_2 %
46	200	170	28.89	117.71	126.26	17.42	94.47
47	200	180	27.74	120.74	129.75	19.74	93.61
48	200	200	25.23	126.49	136.51	24.49	91.66
49	200	220	22.45	131.93	143.39	29.34	89.24
50	200	240	19.43	137.19	151.29	34.25	86.24

- **Fuel**

  North Dakota lignite was assumed as a fuel. The as-received (wet, non-dried) lignite contains 38.5 percent of fuel moisture and has a higher heating value (HHV) of 6,406 Btu/lb.

- **Air Preheater (APH)**

  A bi-sector type APH is used in the High Temperature (HT) case. The thermal performance of the bi-sector APH was modeled using the ε-NTU theory of heat exchangers and metal temperature software for APH analysis developed by the ERC. This modeling approach allows accurate determination of outlet flue gas and air temperatures as the flow rates of flue gas and air through the APH vary.

- **Fan Power**

  Accurate calculation of fan power is essential in determining differences in performance between different system layouts. Fan power was calculated as per industry practice, using expressions for fan power from (Ref 3). The assumed fan pressure rises were the following:

FD Fan ΔP_{FD} = 18” (Forced Draft Fan)

ID Fan	ΔP_{ID} = 15”	(Induced Draft Fan)
PA Fan	ΔP_{PA} = 50”	(Primary Air Fan)
FA Fan	ΔP_{FA} = 50”	(Fluidizing Air Fan)

- **Mill Power**

  Mill power was calculated using software developed by the ERC for analysis of thermal performance of fossil-fired power plants. A Hardgrove grindability index of 60 and coal fineness of 78% on 200 mesh were used in the calculations.

Combustion Calculations

Combustion calculations were also performed. The assumptions used in these calculations were the following:

Excess O_2 level at economizer exit	= 3.50 % by Volume
Unburned carbon in fly ash	= 0.1% by Weight
CO concentration in flue gas	= 10 ppm
Convection Pass Air In-Leakage	= 8 % by Weight
APH Air In-Leakage	= 10 % by Weight

In conducting the combustion calculations, a constant flue gas temperature of 825°F was assumed at the economizer exit. This assumption was used to conduct spreadsheet mass and energy balance calculations. For best predictions, the effect of reduced flue gas moisture content on furnace and convection pass heat transfer needs to be accounted for.

An ambient air temperature of 40°F was also assumed. This value was used in the spreadsheet calculations.

The combustion analysis provided results on the flow rate of coal (M_{coal}) and total (primary and secondary) air flow rates ($M_{air,tot}$) needed for combustion. These results were used as inputs to the mass and energy balance spreadsheet.

- **Energy Balance**

  Conservation of energy was used to calculate energy flows at various locations in the power plant. From these calculations, $\dot{Q}_T$, the net energy transferred with the steam from the boiler to the turbine cycle, and $\dot{Q}_{fuel}$, the energy entering the boiler with the coal, were computed. The boiler efficiency was then found from:

$$\varsigma_B = \frac{\dot{Q}_T}{\dot{Q}_{fuel}}$$

  The gross cycle heat rate, net power and net unit heat rate are:

$$HR_{cycle,gross} = \frac{\dot{Q}_T}{P_g}$$

$$P_{net} = P_g - P_{ss}$$

$$HR_{net} = \frac{\dot{Q}_{fuel}}{P_g - P_{ss}} = \frac{HR_{cycle,gross} \times P_g}{\varsigma_B (P_g - P_{ss})}$$

$$\text{where } P_g = \text{gross electrical power}$$

$$P_{ss} = \text{station service power}$$

This procedure makes it possible to determine net unit heat rate, if the gross cycle heat rate and gross electrical power are known. Values of 7951 Btu/kWh and 571.8 MW were used in this analysis.

Results for High Temperature Case

The methodology described above was used to determine the effects of coal product moisture on unit performance for the high temperature drying system. Figures 18 to 20 show the heat input with the fuel (Q_{fuel}), air preheater exit gas temperature and

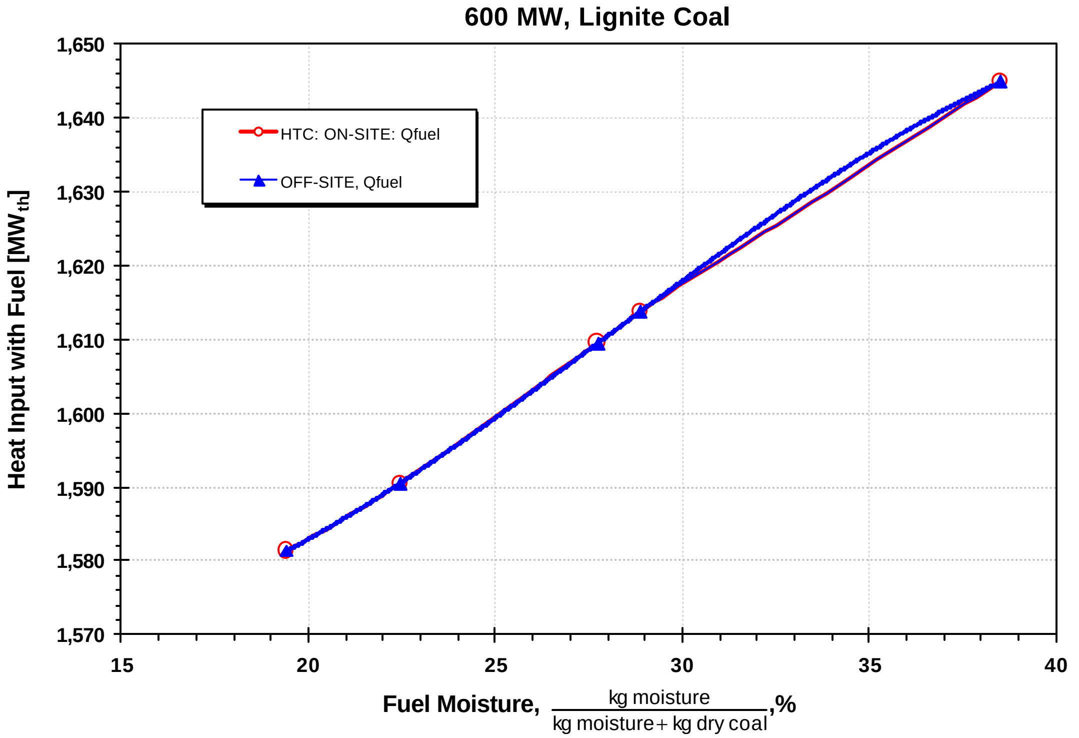

Figure 18: Effect of Coal Drying on Heat Input With Fuel

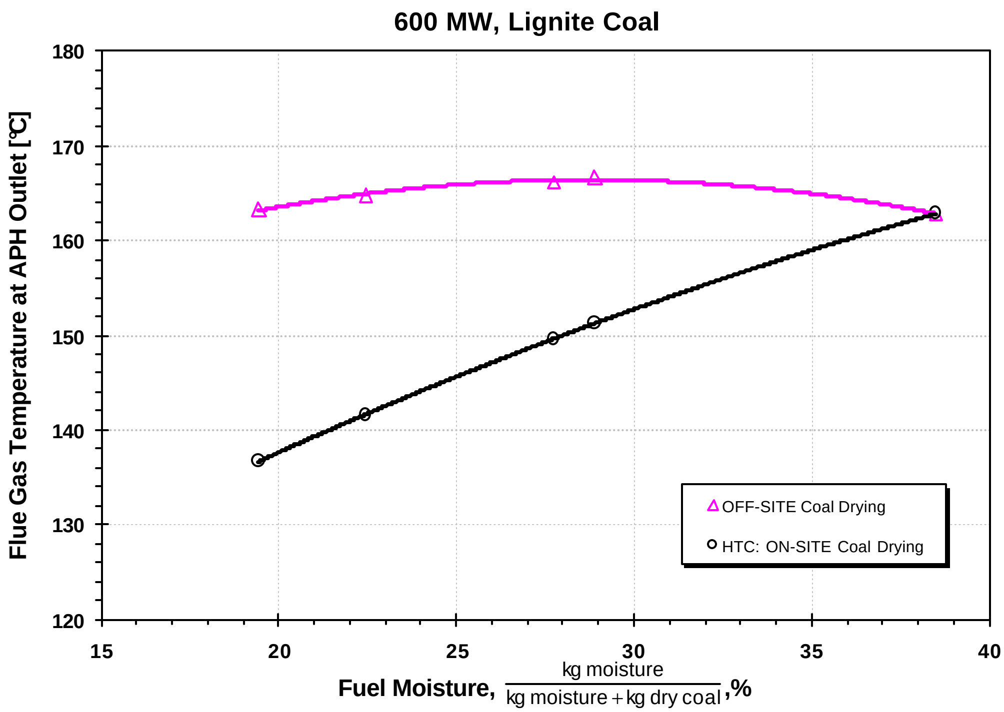

Figure 19: Flue Gas Temperature at APH Outlet

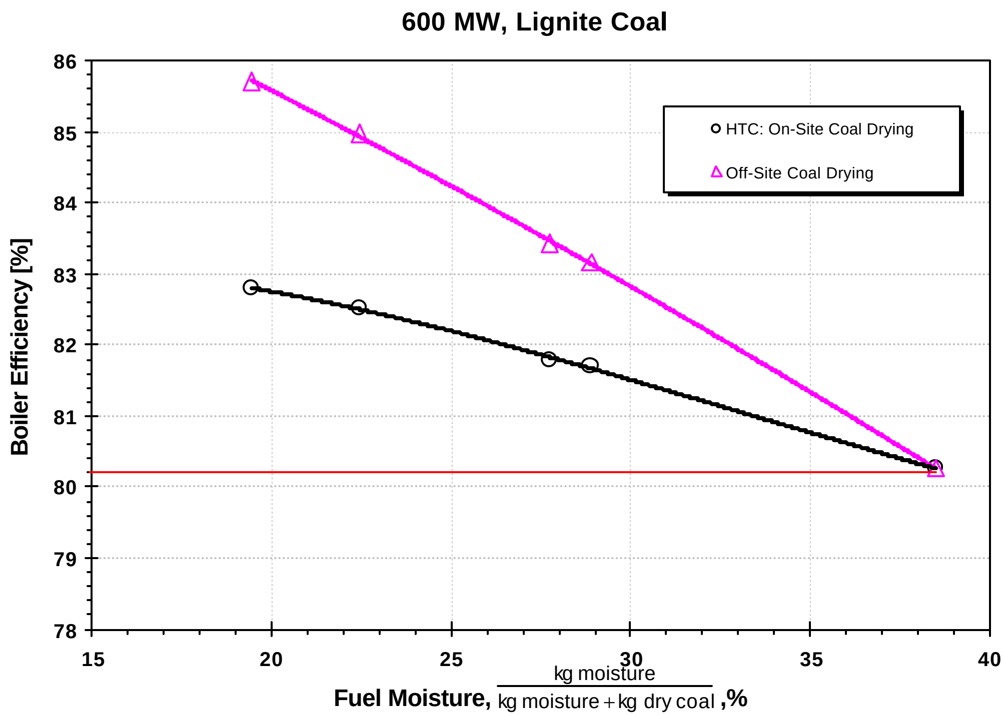

Figure 20: Effect of Coal Drying on Boiler Efficiency

boiler efficiency for both the high temperature case and off-site drying. Figures 21 and 22 show the station service power and net unit heat rate.

For constant gross electrical generation (P_g), as the amount of drying increases, the required fuel input to the boiler is reduced and the air preheater exit gas temperature becomes lower. As a consequence, the boiler efficiency increases due to reduced stack loss. The station service power (P_{SS}), changes due to the effects of flue gas moisture on induced draft fan power, reduction in required combustion air as less coal is burned and reductions in mill power as coal moisture changes. The power required to drive the fan for the fluidization air results in an increase in P_{SS} over that needed for the off-site drying case. Finally, the net unit heat rate decreases with deeper drying. For the high temperature case, the net unit heat rate improves by approximately 300 kJ/kWh as the coal moisture is reduced from 38.5% to 19%. The corresponding improvement in heat rate for off-site drying is approximately 700 kJ/kWh.

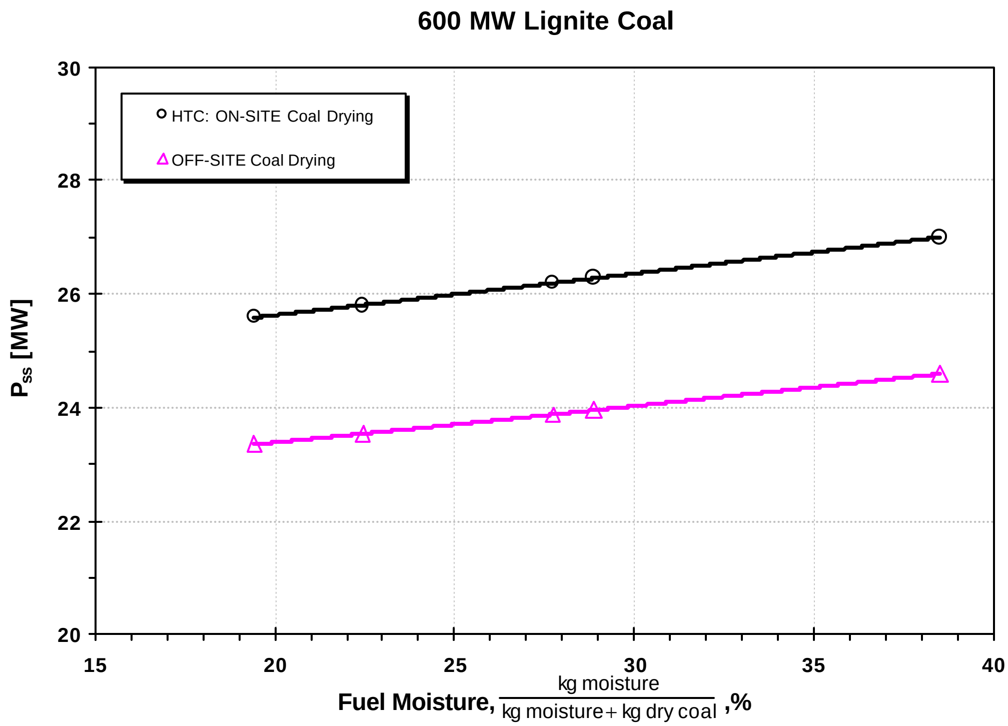

Figure 21: Effect of Coal Drying on Station Service Power

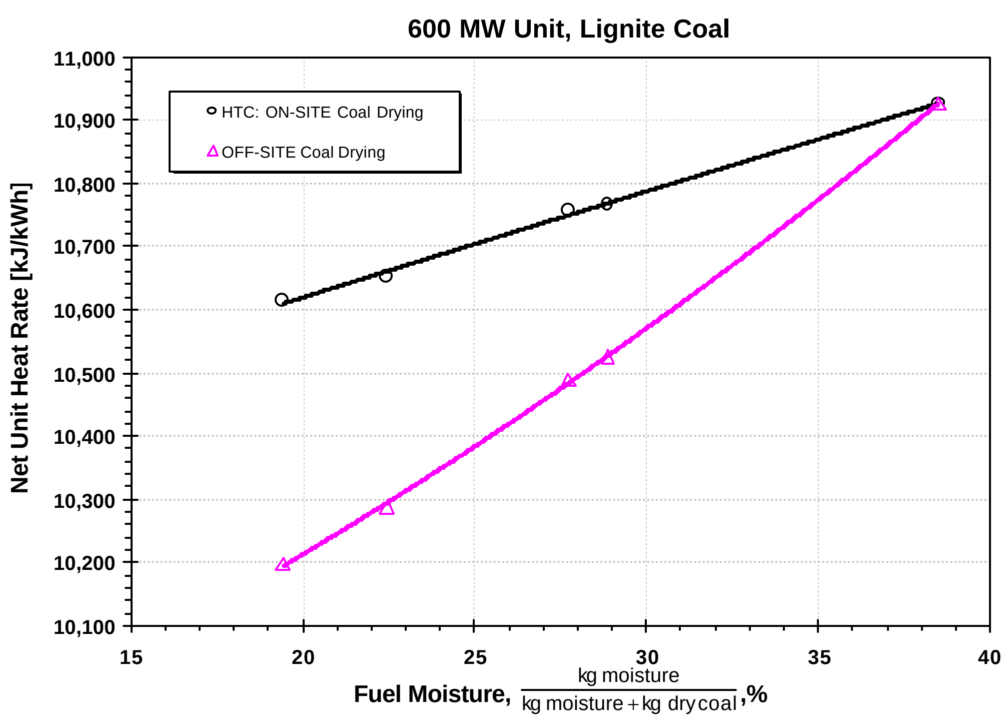

Figure 22: Effect of Coal Drying on Net Unit Heat Rate

Plans for Next Quarter

During the next quarter, work will continue on the Task 4 and 5 system drying analyses. The calculations will be extended to other drying systems, the projected impacts on emissions and cooling tower makeup water will be determined and work will begin on gathering cost data for components such as heat exchangers, fans and fluidized bed dryers.

NOMENCLATURE

A	Area
C	Coal Moisture (wet basis)
H	Bed Depth
M_{air}	Air Flow Rate
M_{coal}	Coal Flow Rate
ΔP	Pressure Increase
Q	Rate of Heat Transfer
T	Temperature
U	Overall Heat Transfer Coefficient
Γ	Coal Moisture (kg H_2O/kg dry coal)
ϕ	Relative Humidity
ω	Specific Humidity
Subscripts	
$_1$	Entering Dryer
$_2$	Leaving Dryer

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2. E. Levy et al. “Use of Coal Drying to Reduce Water Consumed in Pulverized Coal Power Plants,” DOE Project DE-FC26-03NT41729. Quarterly Report for the Period January 1, 2004 to March 31, 2004.

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APPENDIX A
DEFINITION OF COAL MOISTURE

It should be noted that two different definitions of coal moisture are used in this report. The moisture content of coal, Y, obtained as part of a Proximate coal analysis, is expressed on a wet coal basis, as Kg H_2O/Kg wet coal. The moisture contents in Figures 3, 4 and 18 to 22, rely on this definition. For purposes of theoretical predictions of coal moisture and analysis of dryer test data, it is much more convenient to express the moisture on a dry coal basis, Γ, as Kg H_2O/Kg dry coal. Figures 6, 7, 9, 10 and 14 express coal moisture on a dry basis. The parameters Y and Γ are related by the following equation.

$$Y = \frac{\Gamma}{1+\Gamma}$$

where $Y \equiv m_{H_2O} / (m_{H_2O} + m_{DC})$

$$\Gamma \equiv m_{H_2O} / m_{DC}$$

Figure A1 shows the relationship between Y and Γ.

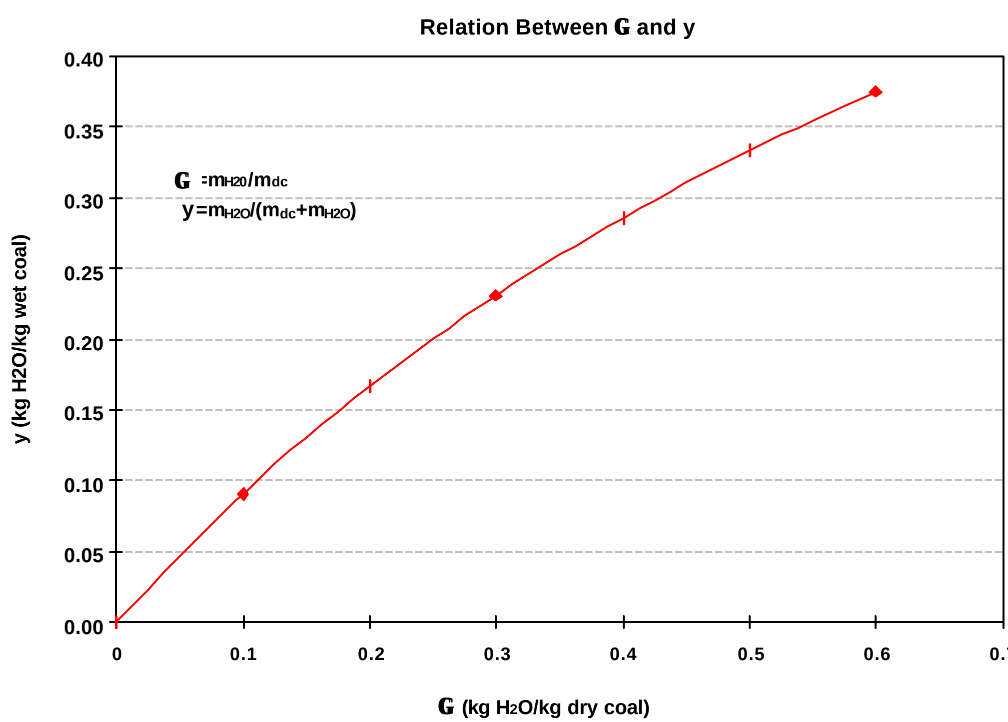

Figure A1: Relationship Between Two Different Definitions of Coal Moisture