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Boiler Cost Impact of Fuel Switching

by

C. E. Dalton
RILEY POWER INC.
a Babcock Power Inc. company
(formerly Riley Stoker Corporation)

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INTRODUCTION

As recent federal legislation has mandated more stringent emission levels from boilers, particularly utility boilers, more boiler owners firing high sulfur coals have considered switching to a low sulfur coal or to natural gas. With the Clean Air Act Amendments (CAAA) of 1990 and perhaps even more strict state regulations dictating emission levels, a utility is left to determine its most economical alternative to comply with the regulations. Fuel switching has been proven to be an effective and economical choice for compliance.

This paper discusses the reduction of sulphur dioxide (SO2) emissions with the options of switching from an existing boiler's high sulfur bituminous coal to natural gas or a low sulphur subbituminous coal. The discussion is centered around a pre-New Source Performance Standards (NSPS) designed boiler of 335 megawatts (MW) in size and its auxiliaries. The boiler does not have a scrubber, and is designed for heat release rates in the furnace of 80,000 Btu per hour per square foot (Btu/Hr/Ft2) and flue gas velocities in the convective sections of 60 feet per second (Ft/Sec).

The analyses of switching to both fuels in this boiler are limited to a point where no pressure part changes are to be made. The changes in auxiliary and fuel burning equipment and in boiler performance are reviewed, and the associated costs are summarized for both cases of fuel switching.

DISCUSSION

A typical utility boiler that may require changes to reduce SO2 emission levels may be of the high pressure, wall fired, dry bottom design. For the purpose of this discussion, a 335 MW unit with parallel backpasses (or two pass design), opposed firing burner configuration, and vertical spindle style mills will be used as a benchmark for making the fuel switches and their comparisons.

Table I illustrates the performance of the original 335 MW boiler. This performance is based on firing a low slagging bituminous coal. An ultimate analysis of the original coal is presented in **Table II**. Though the sulfur content is not particularly high at 1.09% by weight, it does exceed the Phase II limits of the 1990 Clean Air Act Amendments. SO2 is emitted at a rate of 1.744 pounds per million Btu (#/mmBtu) input, from the original coal. The Phase II limit is 1.2 #/mmBtu input.

NATURAL GAS CONVERSION

Fuel burning requirements and boiler performance dictate what changes are to be made to the boiler system. New fuel burning equipment must be supplied for natural gas firing. Given the CAAA regulations on nitrogen oxides (NOx) emissions, low-NOx burner technology must be considered as a part of the fuel switch analysis. Low-NOx burners along with fuel trains (piping and valves from a supply header to the burners) and controls are required for switching. Along with meeting the proposed CAAA requirements for NOx emissions, acceptable boiler performance is also achieved. The predicted performance resulting from the fuel switch, outlined in **Table III**, shows that the boiler's full load of 2,500,000 pounds per hour (#/Hr) of steam and 2,300,000 #/Hr of reheated steam is maintained. An increase in the primary superheater's heating duty results in a 90% increase in attemperator flows, requiring larger capacity spray nozzles. Sufficient margin exists in the primary superheater tube material design to maintain use of the original tubes. Downstream steam temperatures are maintained at acceptable levels, and thus no pressure part changes are required. No other major hardware changes on the boiler are required to facilitate natural gas firing.

Typical pulverized coal combustion requires 20% excess air, while natural gas firing requires only 10%, resulting in less total combustion air and less flue gas flow for natural gas firing than for pulverized coal. These reductions correlate to reduced pressure drops for the forced draft (FD) fan and the induced draft (ID) fan, and thus reduced power consumption. **Table IV** summarizes the pressure drops and power consumption values for the original bituminous coal and natural gas firing. These values have been determined assuming constant fan efficiency, and in actuality may change due to variations in efficiency. The largest pressure drop reduction for natural gas comes from the ID fan, resulting in a power consumption savings of approximately 376 kilowatts (KW). Gas firing's reduction in static pressure for the FD fan is minimal due to an increase in pressure drop through the ducts and dampers. For natural gas firing, all the combustion air passes through the ductwork used only for secondary air when firing PC. Therefore, an increase in the air flow through this ductwork occurs, relative to PC firing, creates an increase in pressure drop through this duct. However, an overall decrease in pressure drop does occur for the FD fan, due to the reduced air flow quantities through the remainder of the air path.

Additional savings are gained by the elimination of the pulverizer system, including the primary air (PA) fans, the seal air (SA) fans and the mills. These power consumption savings coupled with those from the FD and ID fans yields a total difference of 2975 KW. By assuming a capacity factor of 0.65 for the original coal and 0.66 for natural gas, and an energy cost of $0.05/KW-Hr, a savings of approximately $850,000 per year is achieved for natural gas firing, because of lower power consumption.

Given the higher capacity factor for natural gas firing, and again utilizing an energy cost of $0.05/KW-Hr, natural gas' power generation revenue increases over the original coal's by approximately $1,470,000 per year.

Expenditures stemming from this fuel conversion are due to hardware changes and increased fuel costs. The new hardware includes low-NOx gas burners, local fuel piping systems (fuel trains), and burner controls. To engineer, procure and install all this equipment totals approximately $4,500,000.

The largest cost of switching to natural gas firing is the cost of the fuel itself. Based on a price of $2.75 per million Btu ($2.75/mmBtu) of natural gas and a price of $45 per ton for the original coal, an additional cost of approximately $21,640,000 per year is required for gas firing. This value is calculated in today's dollars incorporating the capacity factors for both fuels, referenced previously.

Table V summarizes the differences in cost between firing natural gas and the original coal, for one year. The present worth of the cost differences, over a 10 year cycle, totals approximately $139,530,000. This figure coupled with the initial investment cost of $4,500,000 yields a total sum, in today's dollars, of $144,030,000.

SUBBITUMINOUS COAL CONVERSION

A second choice for fuel switching is with Rawhide Coal, from the Powder River Basin of Wyoming. Rawhide Coal can be successfully used to lower the SO2 emission levels to below the Phase II limits of the CAAA, while obtaining desirable boiler performance. Rawhide Coal's low sulphur content of 0.35% by weight produces an SO2 output of 0.86 #/mmBtu. The sulphur content and other key characteristics of the coal are summarized in **Table VI.**

As with natural gas firing, boiler performance will dictate what changes are to be made to the boiler system. The first change to be made to the system is to limit the output to 74% of the original capacity. Successful experience burning Rawhide Coal has utilized heat release rates in the furnace of approximately 57,000 - 62,000 Btu/Hr/Ft2. A conservative rate of 60,000 Btu/Hr/Ft2 limits the boiler to 74% of its rated capacity, or 1,850,000 LB/Hr of steam. The new performance is summarized in Table VII.

As previously stated, the analyses for both fuel switching options are based on the premise no pressure part changes will be made. However, for changing to Rawhide Coal, pressure part changes can be very beneficial[1].

Though the boiler is limited to 74% of its original load, fuel burning equipment must be altered to process and burn the 8115 Btu per pound and nearly 31% moisture coal. This entails increasing the PA flow rate and temperature to provide adequate drying for pulverizing and transporting the coal through the coal pipes. Larger PA fans, PA ducts, coal pipes and burner nozzles are necessary to support the increased volumes of primary air. As was the case with natural gas firing, low-NOx burners must be considered with the fuel burning equipment changes. Riley Stoker Corporation's patented CCV burners provide the capabilities to meet and exceed the CAAA proposed 0.5 #/mmBtu limits on NOx emissions, when burning Rawhide coal. The large scale of fuel burning equipment modifications totals $9,710,000, including erection. Changes to other auxiliaries are limited to altered power consumption rates.

Excess air for firing Rawhide Coal remains at 20%. With the reduction in boiler load, the new FD and ID fan flow rates and static requirements are reduced from the original coal requirements. These values have also been presented in Table IV. The PA fans' static pressures have increased by two inches and the SA fan pressure remains constant. The power consumption savings from the Rawhide Coal fan arrangement is nearly $450,000 per year.

Mill power consumption decreases from approximately 360 KW to 290 KW per mill. The Rawhide coal's Hardgrove Index increases 25 points over the original coal's allowing for this reduction, and yields a power consumption savings of approximately $110,000 per year.

The reduction in power generation for Rawhide Coal, by limiting the load to 74% of total capacity, creates a substantial loss in generating revenue of $24,790,000 per year. This figure is relative to the original coal and maintains a capacity factor of 0.65 and an energy cost of $0.05/KW-Hr.

The cost of Rawhide Coal coming out of the mine is relatively inexpensive at approximately $3.50 per ton. Adding a typical transportation cost of $25.00 per ton to the mine price, a savings over the original coal of $8,620,000 per year is gained.

The final evaluation for firing Rawhide Coal is for an electrostatic precipitator (ESP). The operation of an ESP is very sensitive to the level of sulphur in flue gas. The sulphur content of Rawhide Coal is low enough, at approximately 0.35%, that the ESP operation must be altered to successfully remove particulate from the flue gas. Introducing a chemical additive to the flue gas or altering the applied voltage and current to the ESP are two modifications that would allow an existing ESP to provide continued service.

A proven method of altering the power supply to an ESP is to introduce an Intermittent Energization system[2]. This effectively reduces problems associated with collecting flue gas particulate with high ash resistivities (due to the low sulphur content of the fuel) and reduces overall power consumption. For this application a reduction in power consumption of nearly 25% may be achieved yielding a value of 350 KW. By again applying an energy cost of $0.05/KW-Hr with a 0.65 availability factor, the yearly cost of running the ESP is nearly $100,000. This provides a savings of $30,000 per year over the original coal's ESP power cost.

Table VIII presents a summary of one year cost differentials for firing Rawhide Coal, relative to the original coal. The present worth of the costs totals $111,420,000 over a 10 year cycle. Along with the $9,710,000 cost to modify the unit, the total for the initial investment and the present worth of costs is $121,130,000.

CONCLUSION

Natural gas has become a popular choice for fuel switching, producing no sulphur emissions, reducing maintenance costs, and eliminating some of the capital equipment required for pulverized coal firing. Rawhide Coal also offers very favorable conditions with its extremely low sulphur content and cost. For this analysis, both fuels have been evaluated to illustrate the major impacts on a utility boiler and compare the associated costs over a 10 year cycle. The results show a total present worth and initial investment of $144,030,000 for natural gas, and $121,130,000 for Rawhide Coal. A savings of approximately $22,900,000 is realized for Rawhide Coal operation relative to natural gas firing.

The entire analysis of this paper has been based on several assumptions and limitations of operating parameters stated within the discussion. The results from **Tables V and VIII** clearly indicate that the two parameters that strongly influence the economics are generating revenues and fuel costs. Changes to the price of any one of the fuels could substantially alter the total cost of a project over the 10 year cycle. Current forecasts for natural gas prices are expecting steady increases in the fuel's price for the coming years. This would certainly make the option of natural gas firing less attractive. Additionally, substantial increases in generating capabilities can be regained, for Rawhide Coal firing, with pressure part modifications. Based on the experience discussed in the previously referenced paper 91-JPGC-FACT-19, an investment in pressure part modifications pays for itself and provides additional revenues through increased generating in a very short period of time.

Other factors may influence decisions on fuel switching, such as regulations more strict than those of the CAAA. However, to comply with the CAAA limitations on sulphur emissions, Rawhide Coal can be an economical choice as demonstrated by this analysis.

1. A detailed case study of a pre-NSPS boiler that underwent a switch to Rawhide Coal from an Eastern bituminous coal, and maintains full load capabilities on natural gas, is presented in the American Society of Mechanical Engineers technical paper 91-JPGC-FACT-19, by W. A. Kitchen and C. E. Dalton. This paper details the engineering and economics of pressure part and fuel burning equipment changes used to successfully switch fuels. This may be referenced to compare and further evaluate the findings of this paper.

2. Information from "Standard Handbook of Powerplant Engineering" by T. C. Elliott, McGraw-Hill, 1989.

TABLE I

ORIGINAL BOILER PERFORMANCE

Steam Flow	PPH	2,500,000
Reheat Flow	PPH	2,300,000
Steam Temp	°F	1005
Hot Reheat Temp	°F	1005
Cold Reheat Temp	°F	635
Feedwater Temp	°F	486
Final Steam Press	PSIG	2520
Drum Press	PSIG	2695
Reheat Outlet Press	PSIG	567
Reheat Inlet Press	PSIG	592
Gas Temp Exiting Airheater (uncorrected)	°F	290
Excess Air In Economizer Exit Gases	%	20
Boiler Efficiency	%	88.47

TABLE II

KEY ASPECTS OF THE ORIGINAL BITUMINOUS COAL

ULTIMATE ANALYSIS

Moisture	8.95
Ash	8.75
Sulphur	1.09
Nitrogen	1.34
Carbon	70.66
Hydrogen	4.60
Oxygen	4.61

HHV 12,500 Btu/Lb

GRINDABILITY

HGI 42

TABLE III

NEW BOILER PERFORMANCE
NATURAL GAS FIRING

Steam Flow	PPH	2,500,000
Reheat Flow	PPH	2,300,000
Steam Temp	°F	1005
Hot Reheat Temp	°F	1005
Cold Reheat Temp	°F	635
Feedwater Temp	°F	486
Final Steam Press	PSIG	2520
Drum Press	PSIG	2695
Reheat Outlet Press	PSIG	567
Reheat Inlet Press	PSIG	592
Gas Temp Exiting Airheater (uncorrected)	°F	285
Excess Air In Economizer Exit Gases	%	10
Boiler Efficiency	%	84.08

TABLE IV

FAN PERFORMANCE

STATIC PRESSURES AND POWER CONSUMPTIONS

FAN		ORIGINAL COAL	RAWHIDE COAL	NATURAL GAS
FD	Static IWC	13.50	7.40	13.35
ID	Static IWC	14.00	8.30	11.70
PA	Static IWC	34.00	36.00	–
SA	Static IWC	50.00	50.00	–

TABLE V

COST SUMMARY FOR NATURAL GAS OPERATION RELATIVE TO THE ORIGINAL COAL

Cost Item	1 Year Cost Change
Power Consumption	+ $850,000
Fuel Costs	- $21,640,000
Generating Revenue	+ $1,470,000
Maintenance	+ $1,250,000
1 Year Total	- $18,070,000
Present Worth of Cost Items Over 10 years	- $139,530,000
Initial Investment (Engineering, Materials, Construction, etc.)	- $4,500,000
Total for Present Worth and Initial Investment	- $144,030,000

Notes:

(1) Present Worth calculations are based on a 10 year cycle at 5% escalation.

(2) Dollar figures with a "+" sign indicate a reduction in cost or additional revenues, while a "-" sign indicates lost revenues or added costs.

TABLE VI

KEY ASPECTS OF RAWHIDE COAL

Ultimate Analysis

Moisture	30.79
Ash	5.43
Sulfur	0.35
Nitrogen	0.53
Carbon	47.51
Hydrogen	3.53
Oxygen	11.86

HHV 8115 BTU/LB

GRINDABILITY

HGI 67 @ 18.75% moisture

TABLE VII

NEW BOILER PERFORMANCE
RAWHIDE COAL FIRING

Steam Flow	PPH	1,850,000
Reheat Flow	PPH	1,685,000
Steam Temp	°F	1005
Hot Reheat Temp	°F	1005
Cold Reheat Temp	°F	600
Feedwater Temp	°F	460
Final Steam Press	PSIG	2520
Drum Press	PSIG	2600
Reheat Outlet Press	PSIG	530
Reheat Inlet Press	PSIG	540
Gas Temp Exiting Airheater (uncorrected)	°F	275
Excess Air In Economizer Exit Gases	%	20
Boiler Efficiency	%	84.57

TABLE VIII

COST SUMMARY FOR RAWHIDE COAL OPERATION
RELATIVE TO THE ORIGINAL COAL

Cost Item	1 Year Cost Change
Power Consumption	+ $590,000
Fuel Costs	+ $8,620,000
Generating Revenue	- $24,790,000
Maintenance	+ $1,150,000
1 Year Total	- $14,430,000
Present Worth of Cost Items Over 10 Years	- $111,420,000
Initial Investment (Engineering, Materials, Construction, etc.)	- $9,710,000
Total for Present Worth and Initial Investment	- $121,130,000

Notes:

(1) Present worth calculations are based on a 10 year cycle at 5% escalation.

(2) Dollar figures with a "+" sign indicate a reduction in cost or an increase in revenue, while a "-" sign indicates a decrease in revenue or added cost.