COMPLIANCE BENEFITS OF POWDER RIVER BASIN COAL AND COAL REBURNING

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ABSTRACT

Cyclone-fired boilers are typically high emitters of NO_x, simply as a result of cyclone furnace design requirements. Babcock & Wilcox (B&W) developed the cyclone furnace originally to burn lower grade coals, high in ash and sulfur contents, with unremarkable heating values. To combust the lower grade fuels, the cyclone furnace develops very strong turbulence and extremely fast mixing of fuel and combustion air. A major portion of ash is thrown to the walls where it melts and runs out of the furnace through a slag tap. Large coal particles are trapped in this slag layer allowing complete carbon burn out to be achieved. In this way, the majority of ash and large coal particles are kept out of the main boiler. The resulting high combustion temperatures are conducive to NO_x formation. Typically, NO_x emissions range from about 0.80 to 1.8 lbs/10^6 Btu, with SO_2 emissions entirely a function for the fuel.

Standard low NO_x burner combustion technologies are not applicable for cyclone-equipped boiler operation. The emerging reburning technology offers cyclone boiler owners a promising alternative to expensive flue gas cleanup techniques for NO_x emission reduction. Reburning involves the injection of a supplemental fuel (natural gas, oil or coal) into the main furnace to produce locally reducing conditions which convert NO_x produced in the main combustion zone to molecular nitrogen, thereby reducing overall NO_x emissions.

B&W has obtained encouraging results from engineering feasibility studies,[1] pilot-scale proof of concept testing,[2] and a U.S. Department of Energy Clean Coal II project to demonstrate the cyclone coal reburning technology on a full size utility boiler. The host site for the demonstration was Wisconsin Power & Light's (WP&L) 110 MW_e Nelson Dewey Station. It was at Nelson Dewey that the benefits of fuel switching to a Powder River Basin (PRB) coal as an SO_2 compliance strategy with coal reburning for NO_x emissions reduction became apparent.

The addition of a reburn system capable of providing up to 30% additional fuel input to the furnace means that a utility could switch to lower Btu compliance coal and minimize or eliminate a derate. This paper describes the emissions and impact on boiler operations of coal switching and reburning on Nelson Dewey Unit No. 2.

INTRODUCTION

The Clean Air Act Amendments of 1990 pose significant challenges to electric utilities to reduce both SO_2 and NO_x emissions. The Act mandates an approximate 3.5 million ton/yr reduction in SO_2 emissions from 111 selected existing utility boilers by January 1, 1995. An additional 5.3 million ton/yr reduction is also mandated to occur by January 1, 2000 in order to reach a long term SO_2 emissions cap of 8.9 million ton/yr. Titles I and IV of the Act mandate NO_x reduction from stationary sources. Title IV (acid rain) requires the use of low NO_x burner technology and Title I (ozone non-attainment) requires reasonable, available control technology (RACT) to reduce NO_x. The impact on utilities is that by the year 2000, more than 200,000 MW_e must be retrofitted with low NO_x systems.

The limitations imposed by the Act are particularly challenging, especially for NO_x emissions from cyclone-fired boilers. The Coal Reburning for Cyclone Boiler NO_x Control Demonstration at WP&L was selected under Round II of the U.S. Department of Energy's Innovative Clean Coal Technology Program to address NO_x reduction in cyclone-fired boilers. As an addendum to this demonstration, testing was performed on a Western subbituminous PRB coal. Reburn NO_x reduction performance on the Western coal was very encouraging. The use of reburn to minimize or eliminate a unit derate as a result of fuel switching was also demonstrated. Consequently, cyclone reburn can be viewed as a NO_x reduction alternative which compliments and enhances a coal switching strategy used to comply with SO_2 regulations.

WP&L's involvement in this project was undertaken for several reasons. The State of Wisconsin enacted acid rain legislation in 1986, which will be fully implemented in 1993. The state law requires significant reduction of SO_2 emissions and the study of potential reduction of NO_x emissions. To meet SO_2 emission levels at the Nelson Dewey station, WP&L has switched from a medium sulfur bituminous to a low sulfur Western subbituminous coal. In addition, to investigate the potential of reducing NO_x emissions at Nelson Dewey Unit No. 2, WP&L retrofitted the coal reburning technology.

BACKGROUND

Compliance with SO_2 limits will require a utility to exercise a combination of options. These include post combustion flue gas desulfurization (wet scrubbers, dry scrubbers, etc.), repowering with fluidized beds or other technology, acquiring of additional allowances from over compliance at other plants in the utility's system, purchasing additional allowances from other utilities, and fuel switching. Of the 111 named sites more than 64% elected to switch fuels to meet SO_2 compliance.

NO_x is produced at high temperatures by oxidation of nitrogen from combustion air (thermal NO_x) and nitrogen in the fuel (fuel NO_x). Formation of NO_x is reduced by depressing combustion zone temperatures and by delaying the admission of sufficient oxygen to complete combustion. Compliance with NO_x limits for the majority of boilers will require use of an internally-staged low NO_x burner, and optional air staging with overfire air ports.

Reducing NO_x emissions from cyclone-fired boilers presents a different challenge. Typical delayed combustion techniques are not applicable to cyclones because they rely on developing an oxygen deficient or reducing atmosphere to hamper NO_x formation. A reducing condition in the confines of a cyclone barrel is unacceptable due to the potential for tube corrosion and severe maintenance problems. Generally, cyclone fuels are typically high in sulfur content which combined with high temperature in a reducing zone concrete major corrosion problems. Cyclone operation must occur under excess oxygen conditions. High temperatures and severe turbulence within the cyclone barrel attribute to the high NO_x levels typically observed from cyclone boilers. The 26,000 MW_e of generating capacity that cyclones represent is about 15% of pre-New Source Performance Standards (NSPS) coal-fired generating capacity, but contribute 21% of NO_x emitted by pre-NSPS coal-fired units.

Reburn Technology Definition

To address the special needs of the cyclone boiler population with respect to NO_x reduction, B&W developed the coal reburning technology. Reburning is a process by which NO_x normally produced in the cyclone is reduced (decomposed to molecular nitrogen) in the main furnace by injection of a secondary fuel with a very limited amount of combustion air. The secondary (or reburning) fuel creates an oxygen-deficient (reducing) region where hydrocarbon radicals produced under sub-stoichiometric conditions compete for available oxygen. Any NO_x in the reburning zone, by virtue of the thermodynamics of the process, is reduced to elemental N_2 while the oxygen is used to continue combustion of hydrocarbon radicles. This process accomplishes the NO_x decomposition. Because reburning occurs while the cyclone operates in a normal oxidizing condition, its effects on cyclone performance can be minimized.

The reburning process employs multiple combustion zones in the furnace, defined as the main combustion, reburn and burnout zones (Fig. 1). The main combustion zone is operated at a stoichiometry of 1.1 (10% excess air) and combusts the majority of the fuel input (70 to 80% heat input). The balance of fuel (20 to 30%) is introduced above the main combustion zone (cyclones) in the reburn zone through reburning burners. These burners are operated in a similar fashion to a standard wall-fired burner except that they are fired at extremely low stoichiometries. The combustion gases from the reburn burners mix with combustion products from the cyclones to obtain a furnace reburning zone stoichiometry in the range of 0.85 to 0.95 which is needed to achieve maximum NO_x reduction. A sufficient furnace residence time within the reburn zone is required for flue gas mixing and NO_x reduction kinetics to occur.

The balance of the required combustion air (totaling 15 to 20% excess air at the economizer outlet) is introduced through overfire air ports. As with the reburn zone, a satisfactory residence time within this burnout zone is required for complete combustion. The added capability to supply fuel to the furnace through the reburn burners is critical to maintaining full load operation while using a lower Btu value PRB fuel.

Reburn Equipment Optimization for PRB Fuels

In a fuel switching scenario, cyclone furnaces typically experience a 20 to 30% derate due to the volume limited nature of a cyclone furnace in addition to boiler performance. To maintain the original nameplate capacity, an additional 20 to 30% fuel volume is required to compensate for the lower heating value of the PRB coal (8500 Btu/lb versus 11,500 Btu/lb). This increase will not be tolerated by a cyclone furnace and major operational problems will result (high carbon carryover, reduced temperatures in the cyclone and difficult slag removal). To help eliminate this problem, the coal reburning system offers a means to increase fuel volume flow to the boiler.

The coal reburn system includes a pulverizer sized for 20 to 30% of the total fuel input to the boiler. When firing PRB coal, the cyclones continue to operate within design rating (ton/h and heat input) while the pulverizer provides the additional 20 to 30% of the heat input required through the reburn burners to approach full load on compliance coal. In this way, the coal reburn system can reduce or eliminate, on a site specific basis, the derate accompanying a fuel switch to PRB fuel as an SO_2 compliance strategy. The avoided cost of a unit derate can justify the price of a reburn system and at the same time allow the utility to achieve NO_x and SO_2 compliance goals.

BASELINE OPERATION

Boiler Description

Nelson Dewey Unit No. 2, shown in Fig. 2, is a B&W radiant boiler. The design rate is 100 MW_e but the current maximum continuous rating (MCR) is 110 MW_e. The boiler is fired with three cyclone furnaces located horizontally on the front wall with clockwise swirl. Hot combustion gases exit the cyclones at temperatures above 3000F. A target wall in the boiler directs the cyclone flow downward toward the floor of the boiler. The gas then turns upward and passes through slag screen tubes where it enters the main furnace. The lower furnace and slag screen are refractory-lined to keep the slag in a molten state.

The primary demonstration coal for cyclone reburn was Illinois Basin (Lamar) bituminous coal. The majority of the testing was done on this fuel to reflect the large cyclone utility contingent which fires higher Btu, high sulfur bituminous coal. Following the bituminous coal testing, subbituminous PRB coal tests were performed to evaluate the effect of coal switching on reburn operation. This work was important to Wisconsin Power & Light, since switching to the PRB coal for SO_2 compliance was to be implemented by January 1, 1993, within WP&L's system.

Baseline NO_x/CO Emissions

Baseline NO_x emissions tend to be 10 to 15% lower than those produced with bituminous coal when firing a cyclone boiler with subbituminous coal. The high moisture, low fixed carbon/volatile matter ratio and low fuel nitrogen content are factors which tend to suppress NO_x formation. Fig. 3 shows that this trend was observed at Nelson Dewey over the boiler's load range (8 to 10% reduced NO_x emissions).

The higher NO_x level at 38 MW_e with Lamar firing is due to single cyclone operation. The higher localized temperatures achieved in firing the single cyclone at a higher capacity results in higher NO_x levels. Also, the cooling air flow to the idle cyclones increases combustion gas oxygen content which is conducive to NO_x formulation. Although no baseline data at this load was available during PRB firing, the same trend is expected.

CO emission levels during baseline operation were low while firing either of the two coals. Generally speaking, the CO levels were slightly lower with PRB coal versus Lamar (30 to 45 ppm versus 60 to 70 ppm over the load range).

Baseline Boiler Operation with PRB Coal

In addition to the 20 to 30% derate often necessary when switching to higher moisture and lower heating value Western fuels, other related factors must be addressed. These include fouling/slagging problems, higher furnace exit gas temperatures (FEGT), exceeding convection pass metal alarm temperatures, increased attemperater spray flows, furnace overpressure alarms, and higher opacity. Based upon the testing at Nelson Dewey, the maximum load achievable during day to day operation firing PRB coal was about 108 to 110 MW_e without the reburn system in operation. WP&L's main load limitations were cyclone maximum loading and furnace overpressure alarms. With the reburn system operating, the unit was able to achieve 118 MW_e while burning PRB coal, equal to maximum load firing Lamar coal.

It should be emphasized that to address some of the problems characteristic of PRB coal, WP&L had already installed numerous furnace wall sootblowers (air and water blowers available). This was the result of proactive Western fuel firing testing. Also, the cyclone vortex burners were fired by minimizing primary air flow to improve the combustion process within the cyclone barrel. Because of the upgrades and testing experience which WP&L compiled, minimal (if any) problems with fouling/slagging, convection pass metal temperatures, spray flow limitations and opacity levels were encountered during this test project.

Baseline Percent Efficiency Loss Due to Unburned Carbon

Baseline percent efficiency loss due to unburned carbon (UBCL) versus boiler steam flow (load) is shown in Fig. 4. Both Lamar bituminous and PRB results are shown. Over the load range, UBCL for PRB coal was lower, particularly at low loads where reduced cyclone temperatures deteriorated combustion performance. With the higher volatile matter content of the PRB coal, these problems were offset at low load. For PRB coal, UBCL ranged from 0% to full load to about 0.3% at very low load. This is not considered a significant impact to overall boiler performance.

Baseline Furnace Exit Gas Temperature

Baseline FEGTs were slightly higher during PRB coal firing as compared to the Lamar testing. Fig. 5 shows increases in temperature of about 35, 90 and 10F at full, medium and low loads, respectively. With reburn operation, FEGT's at full load with Lamar coal were reduced by about 150F. FEGT depression with the PRB coal at full load was less, at about 50F. The difference is thought to be due to the reflective nature of PRB ash deposits in the furnace which reduce heat absorption in the furnace. Overall, FEGT with PRB coal and reburn in operation is very close to that of the bituminous coal baseline, offsetting the normally expected FEGT increase with PRB coal. These temperatures are based upon on-line boiler performance model calculations and confirmed via actual in-furnace temperature measurements.

REBURNING OPERATION

Reburning Test Parameters

Numerous variables are associated with the reburn system and a test matrix was established to determine optimized operation. The subsequent sections discuss the information collected throughout the parametric evaluations of PRB coal. Complete information on Lamar coal as well as test parameters and ranges tested have been presented in earlier papers.[3]

Reburning NO_x/CO Emission Levels

Reburn zone stoichiometry is the most critical factor in changing NO_x emission levels during coal reburning operation. The reburn zone stoichiometry can be varied by altering air flow quantities (oxygen availability) to the reburn burners, by changing the percent of reburn heat input, the gas recirculation flow rate, or the cyclone stoichiometry.

Fig. 6 shows economizer outlet NO_x and CO emissions corrected to 3% O_2 while firing PRB coal. A 50% NO_x reduction was achieved at a reburn zone stoichiometry of about 0.91. As presented in earlier papers[3], the 50% NO_x reduction point for Lamar bituminous coal was achieved at a reburn zone stoichiometry of about 0.89, a more aggressive reducing atmosphere. The data of Fig. 6 also show that the lowest reburn stoichiometry, 0.85, achieved 62.9% NO_x reduction. The CO emission levels increased from 45 ppm at baseline to 92 ppm with reburn operation.

It is apparent that reburning is more effective with PRB coal since a less aggressive reburn zone stoichiometry than that used for bituminous coal achieved 50% NO_x reduction. This infers that either less reburn fuel heat input or higher reburn burner stoichiometries could be used to obtain a given NO_x reduction with PRB coal.

Comparisons between the PRB and the Lamar coal tests for load versus NO_x emissions are shown in Fig. 7. PRB operation achieved lower overall NO_x emission levels and these levels are consistent across the load range. Two factors contribute to the lower NO_x emissions. First, the baseline NO_x levels are approximately 10% less with PRB fuel because of inherent fuel characteristics. Secondly, a higher percentage reduction is realized during reburn operation. This is probably due to the higher fuel volatile content and increased formation of hydrocarbon radicals in the substoichiometric region of the furnace. A change in overall mixing is also a possible explanation. An important observation from Fig. 7 is that NO_x emissions could be maintained at a constant level over the 110 to 41 MW_e load range during the PRB testing. The higher volatile content made possible more stable reburn burner flame characteristics at lower loads with lower air rates, than were necessary for flame stability with bituminous coal at low load. This allowed lower reburn zone stoichiometries at low load with corresponding improved NO_x reduction.

The direct comparison between the Lamar and PRB coal tests are shown in Tables 1 and 2. This direct comparison is based upon operating the reburn system under similar conditions (e.g., same reburn percentage heat input and reburn zone stoichiometries). Optimizing PRB operation further improved overall NO_x emission levels as shown in the Tables.

Increasing load above 110 MW_e while firing PRB resulted in higher NO_x emissions. At 118 MW_e, the resultant NO_x level was 275 ppm (0.37 lb/10^6 Btu). This increase in NO_x level was due to the fact that a lower percentage of reburn heat input could be supplied as a result of reburn feeder limitations. Also, no baseline NO_x emission levels were obtained at this higher load because the boiler could not accommodate it while firing PRB.

Reburning General Boiler Operation

Even though the project testing program is complete, WP&L continues to operate the reburn system. To compensate for the lower heating value of PRB fuel (8500 Btu/lb), WP&L operates the cyclones within design capacity, and uses the reburn system for an additional 30% coal flow. With this strategy, reburn operation minimized or eliminated the derate impact when switching fuels while accomplishing the primary objective of reducing NO_x emissions. WP&L's typical pre-retrofit low load was about 30 MW_e and without reburn in operation this level was not affected after the retrofit. Due to reburn flame stability issues and the fact that the cyclones have to maintain a minimum firing rate, the low load condition was increased to 37 MW_e with reburn in service. Although not ideal, the resultant boiler turndown was 66% with reburn in operation, exceeding the project's goal of 50% turndown.

Table 3 summarizes the remaining general results observed throughout coal reburn operation while firing both of the tested fuels.

CONCLUSION

The addition of a reburning system, in combination with a switch to Western subbituminous coal may provide utilities with the optimum strategy for both NO_x and SO_2 compliance in cyclone-fired boilers. Switching to lower sulfur content coal will lower SO_2 emissions to Phase I compliance levels, and the addition of the reburning system may negate the 20 to 30% capacity derate normally associated with such a switch. In addition, NO_x emissions are lowered with reburn in operation. The avoided cost of derating a unit could easily justify the price of a reburn system and at the same time allow the utility to achieve NO_x and SO_2 compliance.

Acknowledgements

The authors extend their appreciation to the following people for their help in the management and performance of this study:

- J. M. Campbell, Plant Manager - Nelson Dewey Station
- S. Gebhart, Power Plant Engineer - WP&L
- R. W. Corbett, Technical Project Manager - U. S. Department of Energy

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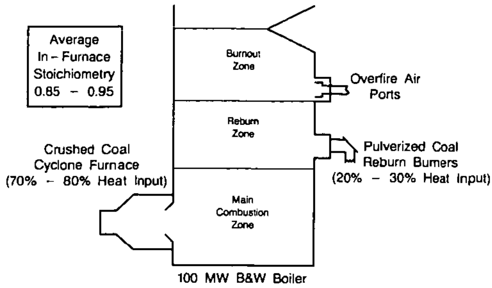

Fig. 1 Cyclone reburn combustion zones.

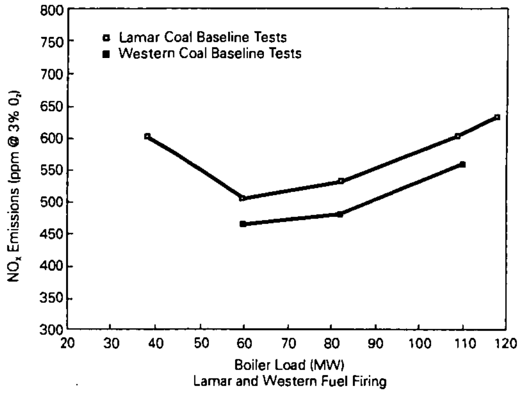

Fig. 2 Wisconsin Power & Light Company Nelson Dewey Station Unit No. 2.

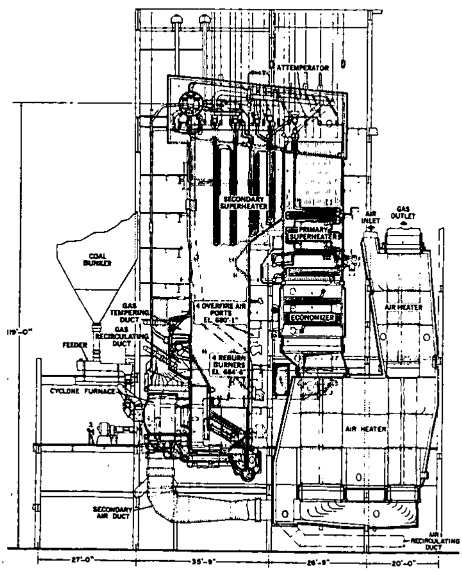

Fig. 3 Baseline NO_x emissions versus load at Nelson Dewey Unit No. 2.

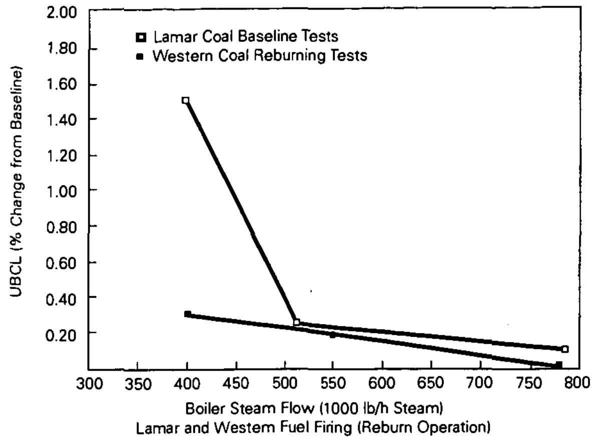

Fig. 4 Unburned carbon (UBCL) efficiency loss (percent change from base) versus load.

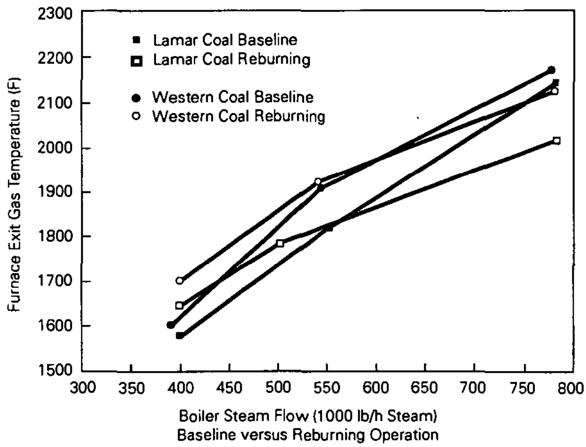

Fig. 5 Furnace exit gas temperature versus load.

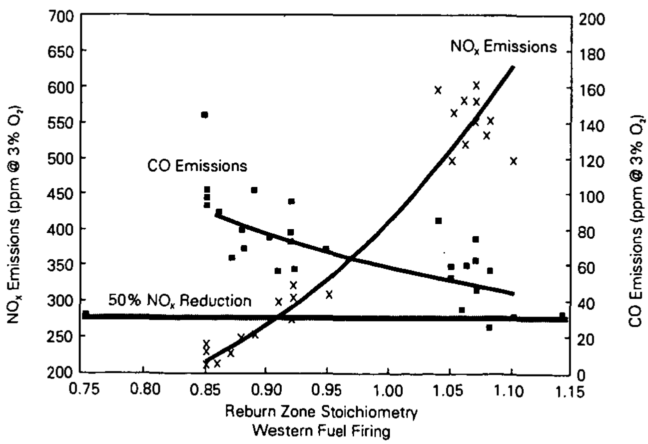

Fig. 6 NO_x and CO emissions versus reburn zone stoichiometry with PRB coal.

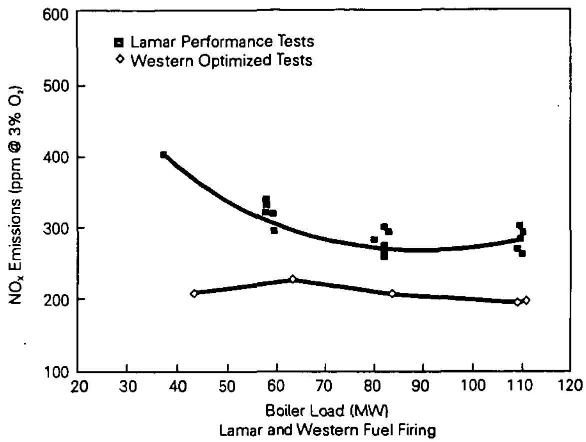

Fig. 7 NO_x emissions at different loads.

Table 1

Reburn NO_x Emissions, ppm at 3% O_2* versus Load					
Load MW$_e$	Baseline Lamar, ppm	Reburn Lamar, ppm	Baseline PRB, ppm	Reburn PRB, ppm	Optimized Reburn PRB, ppm
110	615	290	560	234	208
82	540	285	480	234	215
60	510	325	465	232	220
* 735 ppm = 1 lb/10^6 Btu NO_x					

Table 2

Reburn NO_x Emissions as a Percent Reduction from Baseline versus Load			
Load, MW$_e$	Lamar Coal	Reburn PRB Coal	Optimized Reburn, PRB Coal
110	52%	58%	62%
82	47%	51%	55%
60	36%	50%	53%

Table 3

Coal Reburning Effects on General Boiler Operation			
Parameter	Anticipated Results	Actual Lamar Results	Actual PRB Results
Slaggging/fouling	No change	No change	No change
Header/tube temperatures	25 to 50F higher	No increase from base	No increase from base
SSH and RH spray flows	30% higher	75% lower	25% lower
Opacity	5 to 10% higher	No increase from base	No increase from base
Furnace corrosion	No change	No change	No change
UBCL (full to low load)	Would increase	0.1 to 1.5%	0.0 to 0.3%
FEGT at full load	Would increase	Decrease 100 to 150F	Decrease 25 to 50F

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