

Full-Scale Evaluation Of Mercury Control Across A Wet Particulate Scrubber

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ABSTRACT

In December 2000, EPA announced that it would regulate mercury emissions from coal-fired boilers under Title III of the Clean Air Act Amendments of 1990. However, there is limited information available on the capability of existing pollution control technologies for mercury control and the potential of control options such as sorbent injection. Data available through EPA's Information Collection Request (ICR) database suggests that, in general, low mercury removal can be expected across a wet particulate scrubber (< 50% for any coal type).

Since 1992, EPRI has been assessing the performance of sorbent injection for mercury control in pilot-scale systems installed at full-scale facilities. Much of this data indicates that sorbent injection is one of the most promising technologies to reduce mercury emissions from power generation facilities, particularly when used upstream of ESP's and baghouses. Before the current program, no data from full-scale evaluations was available to assess the potential of sorbent injection for mercury removal across a wet particulate scrubber.

EPRI, Minnesota Power and Xcel Energy are actively involved in several programs to increase the mercury control knowledge base by evaluating mercury emissions and control options for MP and Xcel plants. This paper represents efforts to characterize emissions at MP's Laskin Energy Center Unit 2 and determine the effectiveness of sorbent injection for mercury control for a wet particulate scrubber. Results from parametric testing using four different sorbents will be presented.

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) has submitted a Mercury Study Report to Congress that states that 52 of the 158 tons of anthropogenic Hg emissions in the United States are from coal-fired utility boilers. On December 14th 2000, EPA announced that it would regulate mercury emissions from coal-fired boilers under Title III of the Clean Air Act Amendments of 1990. EPA plans to issue final regulations by December 15th 2004 and is expected to require compliance by December 2007.

Mercury concentration measurements made at 8 units using WPSs are available through EPA's Information Collection Request (ICR) database². These data suggest that low mercury removal can be expected across a wet particulate scrubber (< 50% for any coal type). Laskin burns a subbituminous coal and the highest mercury removal measured during the ICR tests for this coal type was 23%.

Activated carbon injection (ACI) upstream of ESPs and baghouses is currently the most viable near term method for flue gas mercury control (this is especially true for control of elemental mercury). No data, however, exists for the effectiveness of ACI before a wet particulate scrubber (WPS). Thus, it is uncertain whether ACI before a WPS can be a cost-effective option, what is the maximum removal achievable, and what the impacts are on WPS outlet particulate emissions and waste disposal. In addition, recent ACI tests across an ESP in PRB flue gas showed that the mercury removal reached a maximum level even at very high carbon injection rates. It was hypothesized that HCl was needed in order for activated carbon to adsorb elemental mercury effectively and that high amounts of activated carbon may have removed all the trace HCl present in the flue gas. Activated carbons impregnated with halogens such as iodine have been shown to work in gases without HCl present. Tests to compare the effectiveness of iodine impregnated versus untreated activated carbon in PRB flue gas may provide a viable option to improve mercury control in low chloride flue gases.

This paper describes a field test program conducted to evaluate the effectiveness of ACI for mercury control at Laskin Energy Center (Aurora, MN) in conjunction with a WPS. This program was co-funded by EPRI, Minnesota Power (MP) and Xcel Energy (Xcel).

Plant Description and Test Locations

Mercury control tests were conducted on Unit 2 at the Laskin Energy Center located in Aurora, MN. Units 1 and 2 at Laskin are identical units with a common 300-foot stack. Figure 1 illustrates the gas path for Units 1 and 2. Each unit consists of a 55 MW Combustion Engineering PC-tangential-fired boiler firing Powder River Basin (PRB) coal. Downstream of the air preheater, flue gas passes through a Krebs Engineers Elbair two-stage, high-pressure, water spray wet particulate scrubber (WPS). The Krebs WPS also provides approximately 45 percent reduction of SO₂.

Flue gas was sampled at an "inlet" location upstream of the activated carbon injection point (upstream of the WPS) and an "outlet" location downstream of the WPS, to determine the vapor-phase mercury concentrations and the effectiveness of ACI for mercury removal across the WPS.

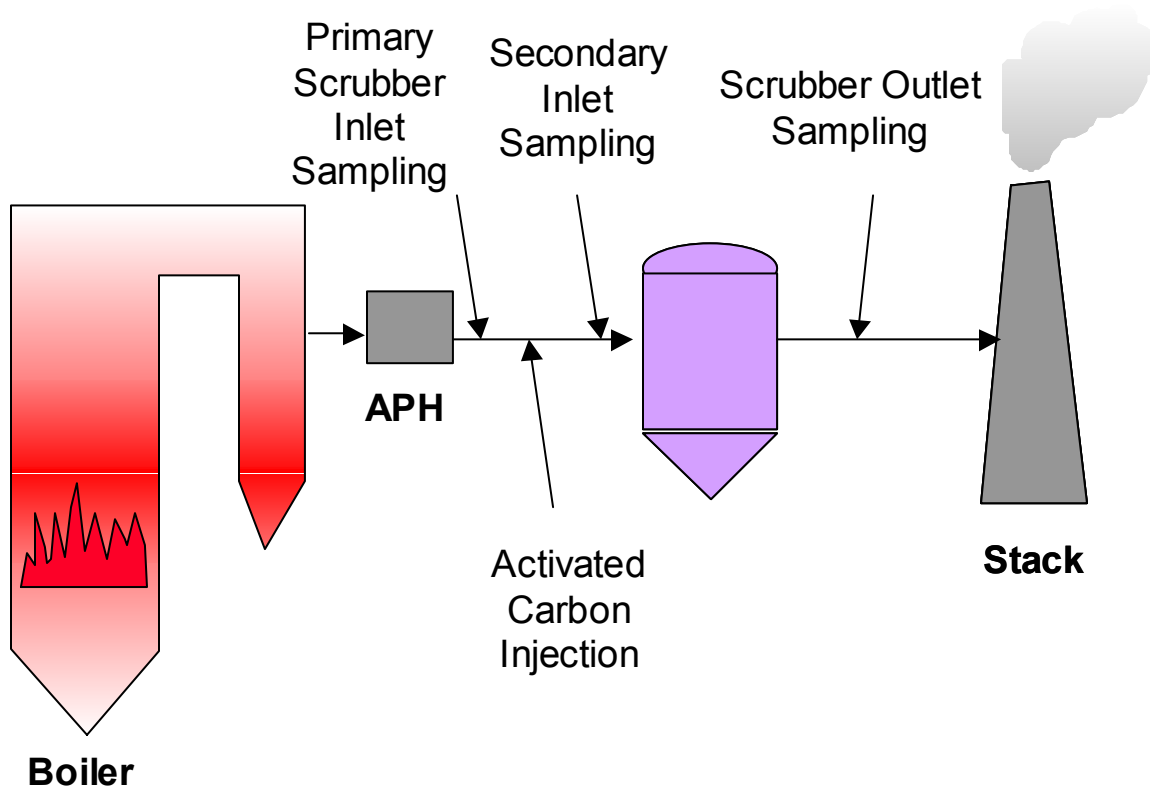
A “secondary inlet” was located downstream of ACI and immediately upstream of the WPS. This secondary location provided a measurement of the vapor-phase mercury removed “in-flight” by the activated carbon prior to entering the WPS. These three locations were sampled selectively during ACI testing.

Description of Equipment

Sorbent Injection Equipment

A photograph of the sorbent feeder used at Laskin Energy Center is shown in Figure 2. The feeder can deliver from 0 to 200 lb/hr of sorbent. The feed assembly is mounted on a load cell to provide continuous feedback of sorbent weight. The revolutions of the helix are also monitored and recorded. To provide an additional record of sorbent federate, the feed rate was checked manually with a batch collection before and after each test run.

Figure 1. Layout of Unit 1 or 2 Laskin Energy Center



The sorbent was conveyed from the feeder to a manifold near the injection location through a 1.5-inch line. The manifold delivered sorbent to four injection lances installed upstream of the scrubber. Sixteen pairs of nozzles oriented at 90 degrees (each were 45 degrees from parallel, co-current with gas flow) were placed at equal spacing along the length of each injection lance.

Mercury Monitors

Two semi-continuous mercury emissions monitors (S-CEM) were used to provide near real-time feedback during baseline, screening, and long-term testing. Continuous measurement of mercury at the inlet and outlet of the particulate collector is considered a critical component of a field mercury control program where mercury levels fluctuate with boiler operation (temperature, load, etc.) and decisions must be made concerning parameters such as sorbent feed rate and cooling. The analyzers used for these tests consisted of a cold vapor atomic absorption spectrometer (CVAAS) coupled with a gold amalgamation system (Au-CVAAS). The system is calibrated using vapor phase elemental mercury. The S-CEMs were configured to automatically switch from measuring total vapor phase mercury to vapor phase elemental mercury during these tests.

Table 1. Laskin Unit 2 Operation

Parameter	Description
Boiler	
Type	PC, Tangential -Fired
Equivalent MWe	55 Gross
Coal¹	
Coal Type	Wyoming PRB
Heating Value (Btu/lb, as received)	9319
Source (Mine)	Various
Mercury and Chlorine	
Mercury (ppm – as received)	0.341
Chlorine (% – as received)	0.02
Proximate Analysis, % as received	
Moisture	26.14
Volatile Matter	31.33
Fixed Carbon	38.00
Ash	4.53
Ultimate Analysis, % as received	
Hydrogen	3.27
Carbon	53.57
Nitrogen	0.82
Sulfur	0.48
Oxygen	11.19
Particulate Control	
Krebs Engineers Elbair Wet Particulate Scrubber	
SO₂ Control	
~45% by WPS	
Gas Flow Rate (scfm)	180,000

Coal samples collected August 9, 2002.

Although it is very difficult to transport non-elemental mercury in sampling lines, elemental mercury can be transported without significant problems. Since the Au-CVAAS measures mercury by using the distinct lines of the UV absorption characteristic of Hg^0 , the non-elemental fraction is either converted to elemental mercury (for total mercury measurement) or removed (for measurement of the elemental fraction) near the sample extraction point. This minimizes any losses due to the sampling system.

For total vapor phase mercury measurements, all non-elemental vapor phase mercury in the flue gas must be converted to elemental mercury. A reduction solution of stannous chloride in hydrochloric acid was used to convert Hg^{2+} to Hg^0 . To measure speciated mercury, an impinger of potassium chloride (KCl) solution mixed as prescribed by the draft Ontario Hydro Method is placed upstream of the stannous chloride solution to capture oxidized mercury. The impinger solutions are continuously refreshed to assure continuous exposure of the gas to active chemicals. Daily calibration audits of the impingers and sample lines are conducted by injecting elemental mercury upstream of the impingers.

Figure 2. Photograph of Sorbent Feeder and Mercury Control Test



Sorbent Description

Four carbon-based sorbents were evaluated during the parametric test period. The sorbents included three commercially available carbons: FGD, HOK300S, and CB. The fourth sorbent LAC is an experimental carbon made from North Dakota Lignite coal. The FGD and HOK300S are also made from lignite coal. The CB is produced from coconut shells and impregnated with iodine. Due to the extra processing steps for the type CB, the cost of this sorbent is over \$7/lb as compared to nominally \$0.5/lb for the FGD. Descriptions of these sorbents are included in Table 2.

Table 2. Summary of Injected Sorbents

Activated Carbon Type/Name	Description
Darco FGD	Texas lignite coal-based commercial carbon from Norit Americas, d50 = 18 μm
Barnebey Sutcliffe Type CB	Coconut-Shell-based, iodine impregnated commercial carbon, d50 = 25 μm
DESOREX HOK300S	German lignite coal-based commercial carbon from Donau Carbon, d50 = 19 μm
LAC	North Dakota lignite coal-based mildly-activated experimental carbon from ISGS, d50 = 19 μm

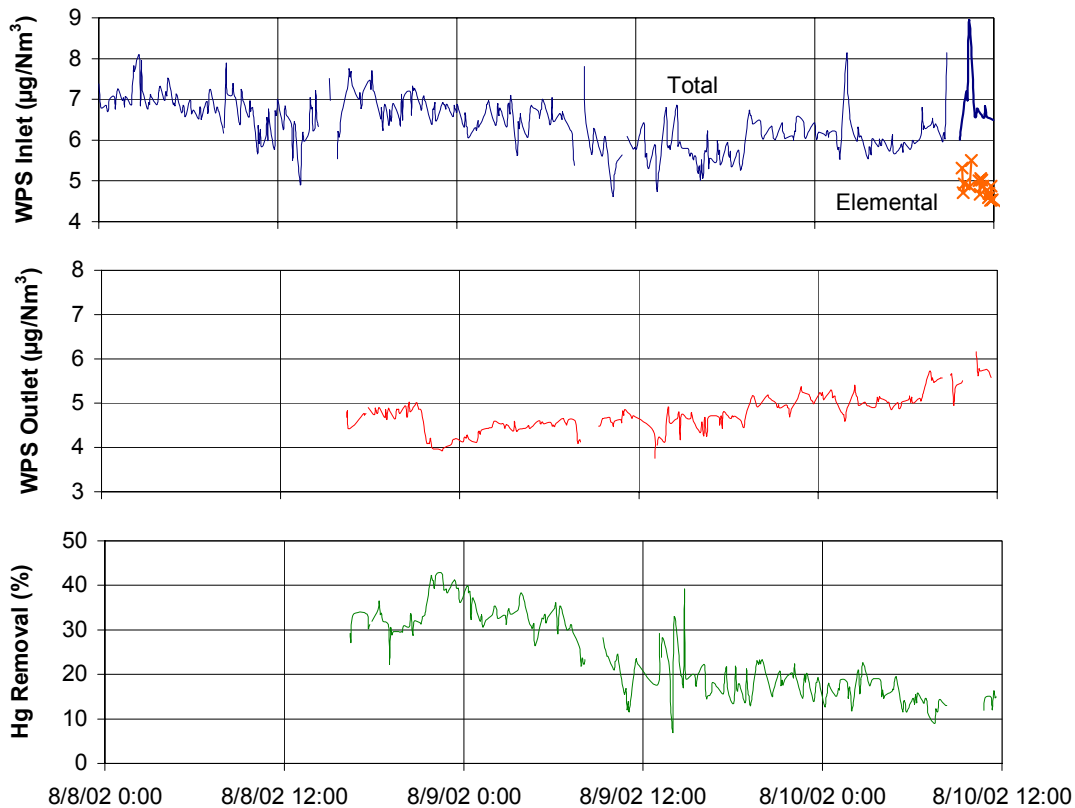
Summary and Discussion of Results

Nine days of mercury control tests were conducted at Laskin Energy Center from August 8 through August 17, 2002. During the first two days of testing, the baseline mercury concentrations at the inlet and outlet of the scrubber were monitored. From August 9 through August 16, a series of parametric tests were conducted to evaluate the performance of each sorbent and characterize the mercury removal as a function of sorbent feed rate.

Baseline Mercury Removal

Prior to beginning activated carbon injection, 44 hours of mercury concentration measurements were made across the APS to characterize baseline mercury removal. The mercury concentration at the inlet and outlet of the WPS and the mercury removal are shown in Figure 3. As shown, the baseline mercury removal ranged from nominally 10 to 40% during this 44-hour period. Data collected during the final few hours of baseline testing also indicates that nominally 70% of the vapor-phase mercury was in the elemental form. Presumably the remaining 30% of the mercury is a soluble, oxidized form of mercury that should be more effectively removed in the WPS (only 15% mercury removal was measured during the speciation sampling period).

Figure 3. Native Mercury Removal Across the WPS at LEC Without Activated Carbon Injection



Parametric Tests: The mercury removal measured across the WPS resulting from injecting different concentrations of each of the four sorbents is shown in Figure 4. Overall, the three untreated sorbents demonstrated poor effectiveness (< 15% mercury removal due to ACI) at injection concentrations up to 12 lb/MMacf. The mercury concentration measured at the secondary inlet location (upstream of the WPS but nominally 1 second downstream of sorbent injection) indicates that some of the mercury collected by the untreated sorbents may be released in the scrubber. For example, when FGD was injected at concentrations from 6 to 12 lb/MMacf, the in-flight mercury removal measured between the inlet and the secondary inlet was 20 to 25%, as compared with 11 to 13% removal measured from the inlet to the outlet of the scrubber. These in-flight removals are shown in Figure 5. The HOK and LAC demonstrated lower overall mercury removal, but adequate data is not available to observe in-flight removal and thus determine whether there was an increase in vapor-phase mercury across the scrubber for these sorbents.

The activated carbon treated with iodine (CB, IAC) demonstrated improved mercury removal performance over the untreated carbons. At the highest injection concentration, 11 lb/MMacf, the mercury removal across the scrubber was 54%. Mercury measurements collected at the secondary inlet (nominally 1 second downstream of sorbent injection) indicate that most of the

mercury removed was removed by the carbon in-flight, prior to entering the scrubber. Unlike the effect noted while testing the FGD, the mercury concentration did not increase across the scrubber. This indicates good retention of the mercury by the iodine-impregnated CB.

Figure 4. Mercury removal due to sorbent injection measured across the WPS at Laskin Energy Center

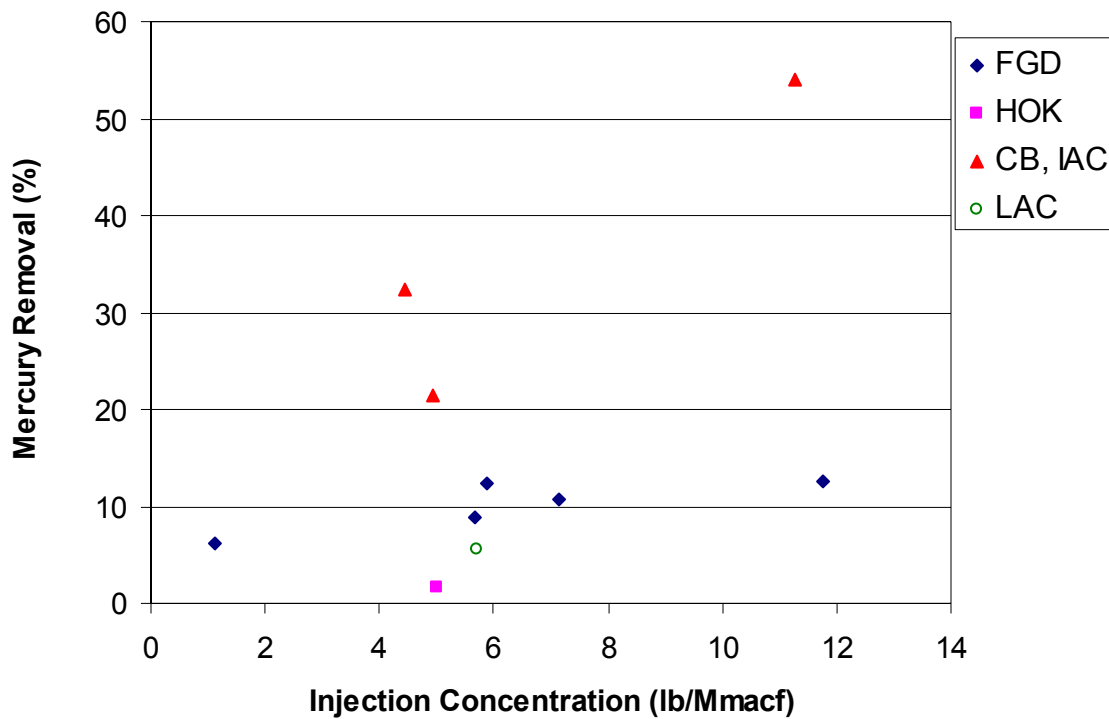
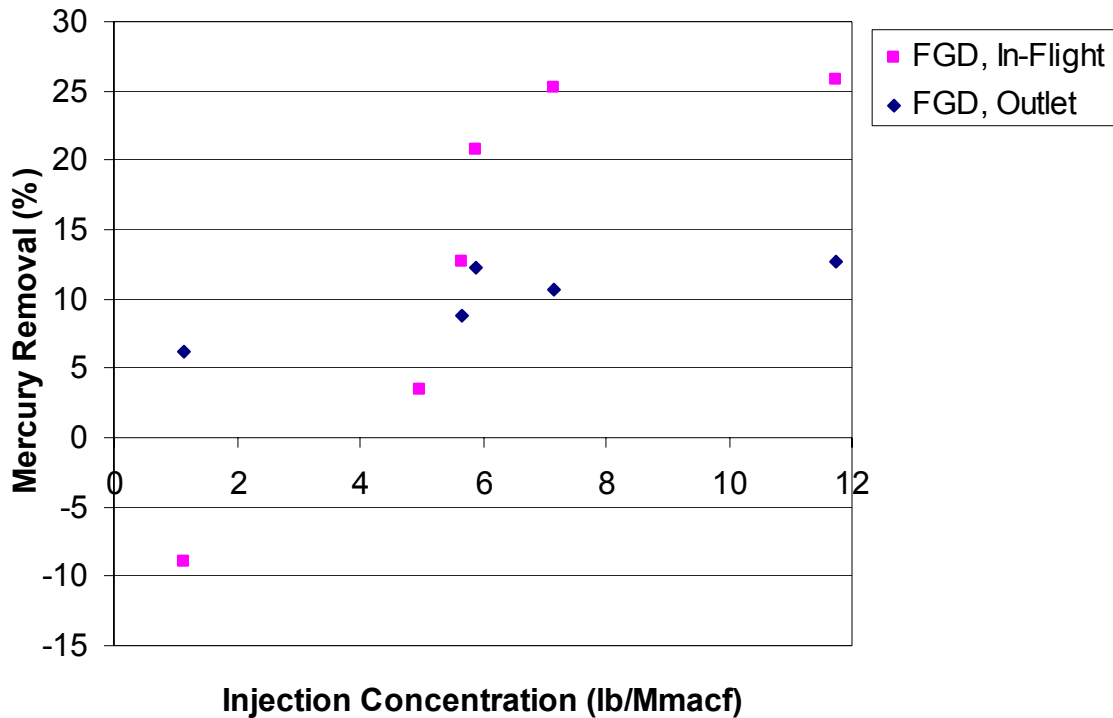


Figure 5. Mercury Removal Due to FGD Sorbent Injection at Laskin Unit 2



Extended 20-Hour Injection Test: The extended FGD injection period began August 14 at 22:47. At the onset of carbon injection, little change in the outlet mercury concentration was noted. However, as observed during the parametric tests, a step change in the mercury concentration at the secondary inlet location was observed. This location is identified as “in-flight” in the trend graphs presented in Figure 6. Unit 2 operation during extended FGD injection is presented in Figure 7.

On the morning of August 15 at approximately 10:00, a blend of 33% bituminous, 66% PRB coal began entering the boiler. Prior to this time, the fuel was 100% PRB. The coal blend resulted in a reduction in the total vapor-phase mercury concentration. At 12:50, the change in combustion characteristics due to the blend coal caused an upset. Unit 2 was back to full load by 13:50. The unstable operation with the blend coal makes interpreting the data difficult. The fraction of elemental mercury varied from 0 to 49% during blended coal tests. The mercury removal across the WPS varied from 0 to 61% during FGD injection, with higher removal corresponding to periods with lower fractions of elemental mercury (higher oxidized mercury). Similar to the 100% PRB trends, the total mercury concentration measured at the secondary inlet location was lower than the concentration measured at the outlet of the scrubber.

The FGD injection was turned off for nominally 2 hours following the boiler upset (14:11 through 16:22). During this period with no sorbent injection, the mercury removal across the WPS was insignificant. Unfortunately, no speciated mercury measurements were made while the sorbent feed was off to determine if the insignificant mercury removal across the WPS was due to an insignificant fraction of oxidized mercury.

During a portion of the extended FGD injection test period, the stack SO₂ and NO_x CEMs were malfunctioning. This data cannot be used to determine the variations in other gas emissions.

Figure 6. Mercury, NO_x, SO₂ Emissions and Sorbent Concentration During Extended FGD Injection Test

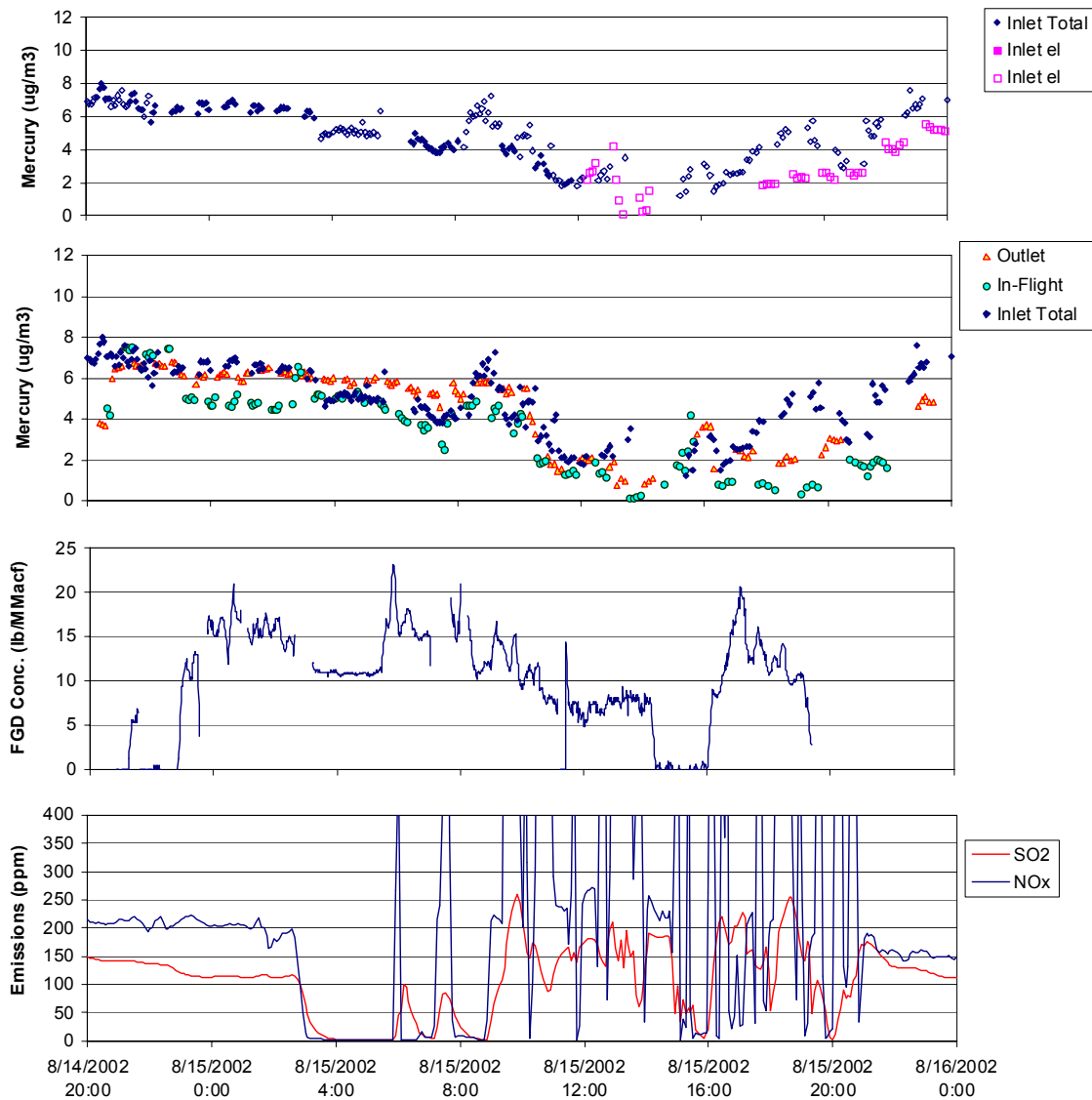
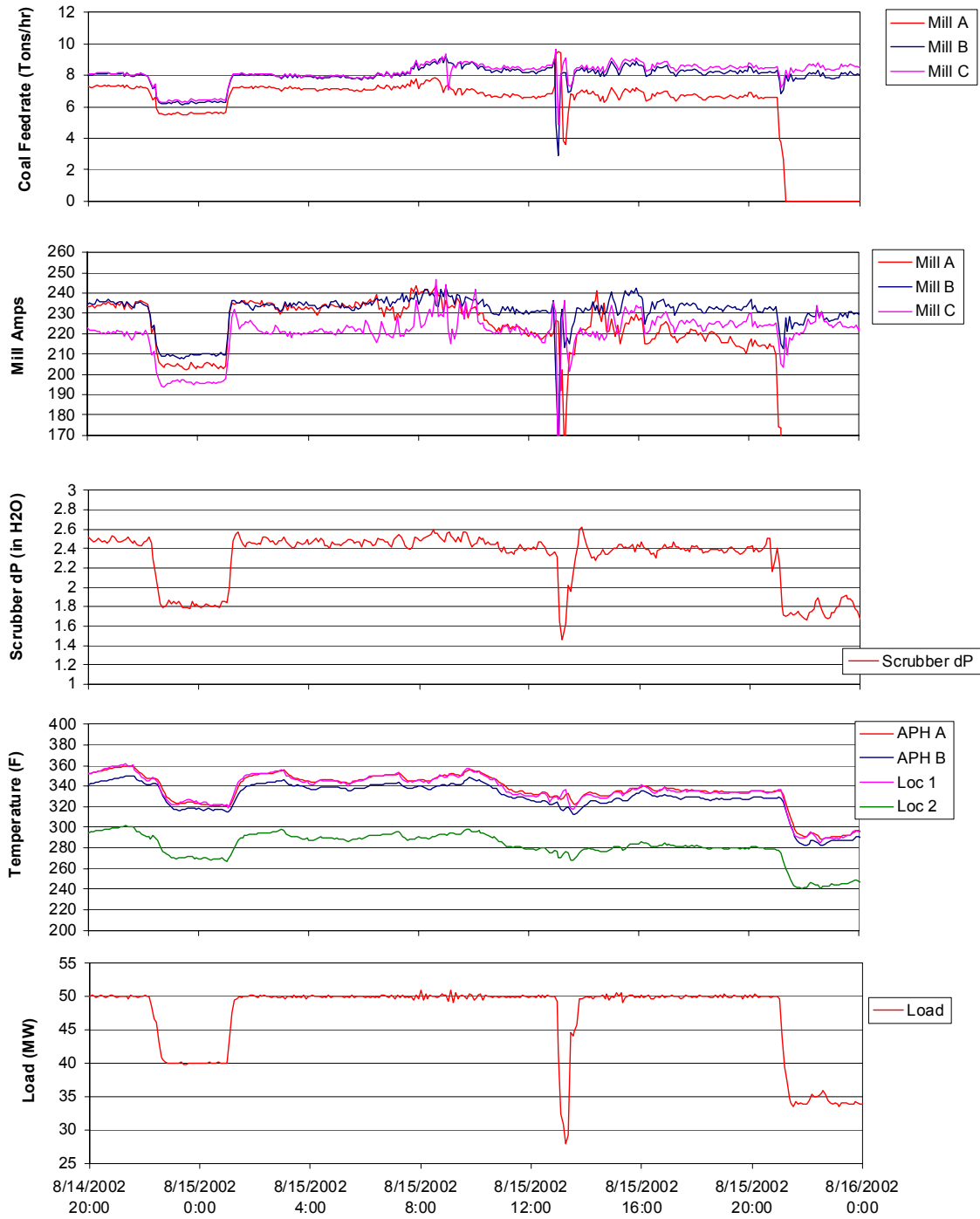


Figure 7. Plant Operation During Extended FGD Testing



CONCLUSIONS AND RECOMMENDATIONS

- Most of the vapor-phase mercury at Laskin was the elemental form.
- The three untreated sorbents demonstrated poor effectiveness (< 15% mercury removal) at injection concentrations up to 12 lb/MMacf. The HOK and LAC demonstrated lower overall mercury removal than the FGD.
- The activated carbon treated with iodine (CB, IAC) demonstrated improved mercury removal performance over the untreated carbons. At the highest injection concentration, 11 lb/MMacf, the mercury removal across the scrubber was 54%.
- The improved mercury control effectiveness using treated carbons may provide a potentially viable option to increase mercury removal with ACI. Further tests will be needed to determine the tradeoff of increased mercury removal versus higher sorbent costs.
- Mercury measurements collected at the secondary inlet, which captured in-flight removal nominally one second downstream of sorbent injection, indicates that the mercury that is captured is captured in-flight, and some of the mercury collected by the untreated sorbents may be released in the scrubber. For the treated carbon (CB, IAC), data indicates that most of the mercury was removed by the carbon prior to entering the scrubber and the mercury concentration did not increase across the scrubber.
- A very short, blended-coal test was conducted with ACI. Due to variations in the inlet mercury concentration and speciation during the blended coal test (33% bituminous, 66% PRB), no definite conclusions can be drawn regarding the effect of ACI with the blended fuel. The mercury removal across the WPS appeared to follow the level of oxidized mercury at the inlet to the scrubber. However, the removal was, at times, higher than the oxidized mercury measured.