FIELD DEMONSTRATION OF ENHANCED SORBENT INJECTION FOR MERCURY CONTROL

QUARTERLY TECHNICAL PROGRESS REPORT

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Prepared by

Shin G. Kang
Power Plant Laboratories
ALSTOM Power Inc.
2000 Day Hill Road
Windsor, Connecticut 06095

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LIST OF ABBREVIATIONS

AC	activated carbon
BOP	balance of plant
CMM	continuous mercury measurement
DOE	U.S. Department of Energy
EERC	Energy and Environmental Research Center
ESP	electrostatic precipitator
LOS/LOS1	Basin Electric's Leland Olds Unit 1
NETL	National Energy Technology Laboratory
NDIC	North Dakota Industrial Commission
PRB	Powder River Basin
SCA	specific collection area

Executive Summary

ALSTOM Power Inc., Power Plant Laboratories (ALSTOM-PPL) is currently carrying out a consortium-based, DOE-NETL program to demonstrate Mer-Cure™ technology, ALSTOM-PPL's novel and oxidation-based mercury control technology in coal-fired boilers. In the program, ALSTOM-PPL teams up with the University of North Dakota – Energy and Environmental Research Center (EERC), PacifiCorp, Basin Electric Power Cooperative (Basin Electric), Reliant Energy, North Dakota Industrial Commission (NDIC), and Minnkota Power.

The full-scale demonstration program consists of three seven-week long test campaigns in three independent host sites firing a wide range of coal ranks. These host sites include PacifiCorp's 240-MW_e Dave Johnston Unit 3 burning a Powder River Basin (PRB) coal, Basin Electric's 220-MW_e Leland Olds Unit 1 burning a North Dakota lignite, and Reliant Energy's 170-MW_e Portland Unit 1 burning an Eastern bituminous coal. These boilers are all equipped with an electrostatic precipitator (ESP).

In Mer-Cure™ technology, a small amount of sorbent (Mer-Clean™) is injected into a flue gas stream environment where the gaseous elemental mercury oxidation and removal is favorable. The sorbents are prepared with chemical additives that promote oxidation and capture of elemental mercury. The Mer-Cure™ mercury control technology offers a great opportunity for utility companies to control mercury in the most cost-effective manner while minimizing any balance-of-plant impact.

ALSTOM-PPL has made significant accomplishments in demonstrating the performance of Mer-Cure™ mercury control technology during the performance period. Highlights of the accomplishments are:

- Continued analysis of a majority of the test data from Basin Electric's Leland Olds Station 1;
- Held a meeting with Pennsylvania Department of Environmental Protection in preparation for the demonstration program at Reliant Energy's Portland Unit 1;
- Completed preparation for Reliant Energy's Portland Station testing; and
- Started the Portland Station test campaign.

The data analysis results from Basin Electric's Leland Olds testing are presented in this quarterly report. Analysis clearly demonstrates that ALSTOM-PPL's Mer-Cure™ system can achieve 90% removal of uncontrolled gaseous mercury at 1.5 lb/MMacf. In the next performance period, ALSTOM-PPL will complete Reliant Energy test campaign. Laboratory-scale testing will also be carried out in a test setup while burning PacifiCorp and Basin Electric fuels. The project is currently being executed on schedule and on budget.

INTRODUCTION

The overall objective of the DOE/NETL-sponsored project is to perform full-scale demonstration of Mer-Cure™ technology in three coal-fired boilers burning coals of various ranks. These host sites include PacifiCorp's 240-MW_e Dave Johnston Unit 3 (DJ3) burning a PRB coal, Basin Electric's 220-MW_e Leland Olds Unit 1 (LO1) burning a North Dakota lignite, and Reliant Energy's 170-MW_e Portland Unit 1 burning an Eastern bituminous coal. These boilers are each equipped with an ESP (Table 1).

In the program, ALSTOM-PPL will demonstrate that greater than 70% of gaseous mercury in the flue gas can be captured by injection of enhanced sorbent at a feed rate significantly lower than required by standard activated carbon. ALSTOM-PPL will also collect performance data that can be used to accelerate commercialization of our mercury control technology.

Mer-Cure™ technology applied to coal-fired power generation has the potential to be a cost-effective mercury control technology for the entire range of coals (bituminous, sub-bituminous, and lignite) and, in particular, the more challenging coals (for example, PRB and lignite coal). This control technology has low-capital costs (less than \$5/kW_e). It also requires a very small amount of additives for treatment, which results in low operating costs (0.5-0.75 mills/kWh) and minimal balance-of-plant (BOP) impact. As the technology is based on oxidation and adsorption of mercury, it is also applicable to all air pollution control configurations including wet scrubber and spray dryer-ESP/baghouse units. The main focus of the project, however, is coal-fired boilers with a cold-side ESP as the particulate control device, which represents 70% of the installed base in the United States.

The test program includes installation of equipment for the mercury control system, its operation under various firing conditions and measurement of elemental and oxidized mercury concentrations in the flue gas. The testing includes a one-week baseline mercury measurement and two weeks of parametric testing, followed by a four-week long-term testing. During the two-week parametric testing, the ALSTOM-PPL mercury control system will be operated with sorbents of several formulations at different sorbent injection rates to determine mercury oxidation and removal efficiencies. The optimum sorbent formulations and injection rates will be selected for the four-week testing to evaluate its long-term performance.

The EERC participates in the program by providing mercury measurement expertise. Continuous mercury measurement (CMM) will be carried out throughout the test period by installing CMM monitors before the injection location and after the ESP to provide both elemental and oxidized mercury concentrations in the stack gas. Ontario Hydro method will also be employed for some of the key test conditions to verify CMM data, to obtain mercury concentration and speciation measurements at ESP, and to ensure QA and QC of the measurements.

Table 1. Host site, coal and emission data for the field demonstration program

	PacifiCorp	Basin Electric	Reliant Energy
Unit	Dave Johnston 3	Leland Olds 1	Portland 1
Capacity (MW_e Gross)	240	220	172
Operation	Base-loaded	Base-loaded	Cycling
NO_x and SO_2 control	No low-NO_x Low sulfur coal	No low NO_x Low sulfur coal	Low-NO_x - LNCFS No sulfur control
Air Heater	Two Ljungstrom	Ljungstrom + Tubular	Ljungstrom
Particulate control (SCA in ft^2/kacfm)	CS-ESP (629)	CS-ESP (320)	CS-ESP (284)
Ash utilization	Sold for mine reclamation	Disposal	Disposal
Coal	Wyodak (PRB)	ND lignite	Bailey mine and Federal #2 coals
Higher Heating Value As-received(Btu/lb)	8,060	Lignite 6617	12,800 – 13,100
S in coal (%)	0.94	0.63	2-2.5%
Ash %	10.09	9.86	6-8%
Cl in coal (ppmwd)	<50		~1,500
Hg in coal (ppmwd)-dry	0.071	0.057-0.099	0.1-0.16
As-fired Hg level from Coal ($\mu g/Nm^3$)	7-9	6-10	10-16
Inlet Hg ($\mu g/m^3$)	10 – 12	8 – 9	11 – 13
Uncontrolled Hg Emission Stack ($\mu g/m^3$)	9 – 11	7 – 8	11 – 13
Removal Efficiency	0 – 20%	10%	0%
Carbon-in-ash	0.6 – 1.4%	< 0.2%	10-12%
Flue gas temp (ESP Inlet)	330-360°F	375°F	277°F – full load

EXPERIMENTAL

Following are the major tasks being performed to achieve the project goals:

Task 1A. Design, Engineering and Fabrication of the Mer-Cure™ System for PacifiCorp's Dave Johnston Unit 3
Task 2A. Field Demonstration at PacifiCorp's Dave Johnston Unit 3

Task 1B. Design, Engineering and Fabrication of the Mer-Cure™ System for Basin Electric's Leland Olds Unit 1
Task 2B. Field Demonstration at Basin Electric's Leland Olds Unit 1

Task 1C. Design, Engineering and Fabrication of the Mer-Cure™ System for Reliant Energy's Portland Unit 1
Task 2C. Field Demonstration at Reliant Energy's Portland Unit 1

Task 3. Technology Transfer
Task 4. Program Management and Reporting.

During the current reporting period, analysis of data from Basin Electric testing (Task 2B) has been completed. We have also started preparation for the upcoming Portland Unit 1 test campaign in March 2006 (Task 1C). Details of the project activities are described in this section.

Task 1A. Design, Engineering and Fabrication of the Mer-Cure™ System for PacifiCorp's Dave Johnston Unit 3

Task completed.

Task 2A. Field Demonstration at PacifiCorp's Dave Johnston Unit 3

Task completed.

Task 1B. Design, Engineering and Fabrication of Mer-Cure™ System for Basin Electric's Leland Olds Unit 1

Task completed.

Task 2B. Field Demonstration for Basin Electric Campaign

The samples and data have been analyzed during the reporting period. Some of the analysis results are reported in the quarterly report.

Task 1C. Design, Engineering and Fabrication of Mer-Cure™ System for Reliant Energy's Portland Unit 1

This task has been completed.

Task 2C. Field Demonstration for Reliant Energy's Portland Unit 1 Campaign

The task has been started in the current reporting period. Baseline measurement for mercury emissions has been completed; parametric testing has been started. Long-term testing will start subsequently and extend into the next reporting period.

Task 3. Technology Transfer

No activities for the task.

Task 4. Project Management and Reporting

During the reporting period, ALSTOM-PPL had two site visits for site preparation meetings with Reliant Energy. In the meetings, the work breakdown was discussed in greater detail. Communications with Pennsylvania Department of Environmental Protection (PADEP) were initiated in preparation for the upcoming test campaign. Documents were prepared and submitted for PADEP approval. Potential location for the mobile unit as well as UND EERC's sampling shack locations has been identified. Requirements for UND EERC's sampling tasks were reviewed.

RESULTS AND DISCUSSION

The full-scale demonstration at the LOS1 has been completed. The samples collected during field demonstration are being analyzed and the field data are currently being reduced. Some of the preliminary test results were reported in the last quarterly report. Additional analysis results are presented this section.

Table 2 lists the tasks carried out to complete the Basin Electric test campaign along with their associated timeline. As listed, the baseline measurement of mercury level was conducted first for five days; the parametric testing immediately followed for 10 days; finally, the long-term testing was conducted by continuously operating the Mer-Cure™ system over 30-day period. Between the parametric testing and the long-term testing, one day was allowed for the mercury level to recover from previous sorbent injection during parametric testing.

Table 2. Basin Electric Test Campaign Timeline

Tasks	Timeline
Baseline measurement	September 30 – October 4, 2005
Parametric Testing	October 5 – 14, 2005
Long-term testing	October 16 – November 14, 2005
System removal	November 15 – 18, 2005

Figure 1 shows a schematic diagram of the LOS1 plant layout showing various sampling locations. The boiler has two Ljungstrom™ air heaters and one tubular air heater. Only a portion of the flue gas – flue gas through one Ljungstrom™ air heater and one tubular air heater, or about two thirds of the total flue gas flow coming out of the boiler – has been treated by Mer-Cure™ system. (The shaded area shown in light blue in Figure 1 indicates the treated portion.)

The UND-EERC measured the air heater inlet and ESP outlet mercury levels using PS Analytical and Tekran mercury monitors, respectively. An inertial separation probe was used at the air heater inlet to sample solids-free flue gas. A dry sample gas treatment system was used for the Tekran monitor at the ESP outlet. Ontario Hydro measurements were made frequently during baseline, parametric and long-term testing to verify the CMM readings. Coal samples were collected from mills and composite samples were prepared; ash samples were collected from the ESP hoppers on a regular basis. Gas analysis data such as NOx, SOx and boiler exit O_2 have been obtained from the plant data collection system.

Also, the UND-EERC crew conducted independent measurements of flue gas composition as part of the Ontario Hydro measurement efforts. As shown in Figure 1, the average temperatures as measured by UND-EERC at the air heater inlet and the ESP outlet were 800°F and 330°F, respectively. The O_2 concentrations at the air heater inlet and the ESP outlet were 3.5% and 5.2% O_2, respectively. ESP operating parameters have been also monitored in order to evaluate the impact of sorbent injection on ESP operation.

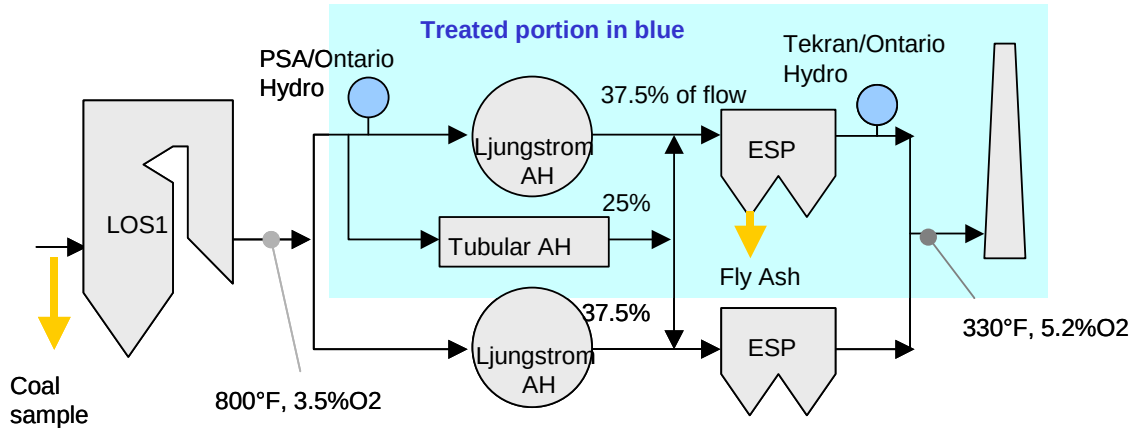


Figure 1. Schematic diagram of the plant layout and the sampling locations

Table 3 lists the average coal properties determined by analysis of coal composite samples. A total of ten (10) composite coal samples were collected and prepared from the four mills of LOS1 during test campaign. From these composite samples, the average mercury content of the coal and its standard deviation have been determined to be 0.054 µg/g dry coal, and 0.017 µg/g dry coal, respectively. The chlorine content of the coal was 72 (±39) ppm on a dry basis.

Table 3. Basin Electric Coal Properties (Average)

Proximate analysis	As received	Dry basis
Total moisture (%)	36.59	N/A
Volatile matter (%)	24.64	38.87
Fixed Carbon (%)	30.92	48.76
Ash (%)	7.84	12.37
HHV (BTU/lb)	6654	10494
Ultimate analysis	As received	Dry basis
Moisture	36.59	N/A
C	39.36	62.07
H	2.59	4.09
O	12.41	19.56
N	0.61	0.96
S	0.60	0.94
Cl	46 ± 25 ppm	72 ± 39 ppm dry
Ash	7.84	12.37
Total	100.00	100.00
Hg (µg/g dry coal)	N/A	0.054 ± 0.017
Hg (lb/TBTU)	4.86 ± 1.36	4.86 ± 1.36

Figure 2 shows the performance of Mer-Cure™ system at Leland Olds Station during parametric testing. In the figure, the mercury removal efficiency is reported for various sorbents (Mer-Clean™ sorbents 2, 4, 6, and 8) as a function of the sorbent feed rate in lb/MMacf (or pounds per million actual cubic feet, where the "actual" condition refers to the actual ESP outlet condition, i.e., 330°F and 5.2% O_2). The reported removal efficiency was calculated based on the uncontrolled (or baseline) ESP outlet concentrations of gaseous mercury measured before parametric testing.

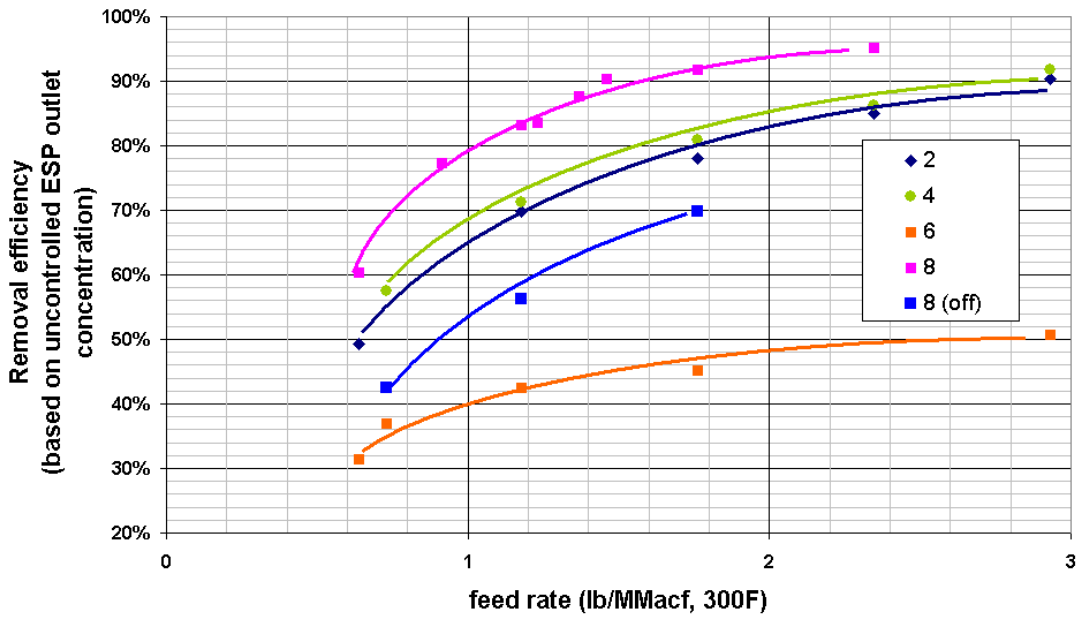


Figure 2. Mer-Cure performance curve obtained from parametric testing at Leland Olds Station

Among the Mer-Clean™ sorbents, Mer-Clean™ 8 demonstrated the best performance, exhibiting 80% reduction at 1 lb/MMacf (or 29 lb/hr), and 90% reduction at 1.5 lb/MMacf. Ninety five percent removal was achieved at 2.2 lb/MMacf. The performance of Mer-Clean™ 8 was significantly deteriorated, however, when the processor of the Mer-Cure™ system was turned off (8 (off) in Figure 2). At a feed rate of 1 lb/MMacf, the removal efficiency decreased from 80% mercury reduction to only 55% reduction.

From the viewpoint of sorbent consumption, the role of the processor in the Mer-Cure™ system is significant. For the same removal target, the sorbent consumption rate for the Mer-Cure™ system with its processor turned on was only half of that with it turned off. For example, for 60% removal, the Mer-Cure™ system in processor-off mode requires 1.2 lb/MMacf, whereas in processor-on mode it requires only 0.6 lb/MMacf.

The effect of the processor of the Mer-Cure™ system is also shown in Figure 3. At

13:30, the sorbent feed rate was increased to 1.2 lb/MMacf bringing the ESP outlet mercury level down to 3.2 μg/m^3. During this time, the Mer-Cure™ system was operated with its processor turned off. At 16:05, the processor was turned on while keeping the sorbent feed rate constant. This led to a step decrease in ESP outlet mercury level to 1.5 μg/m^3, clearly demonstrating significant improvement of the sorbent performance by the processor. The role of the processor has been reproduced several times in the test program.

Figure 3 also shows a typical recovery pattern of the outlet gaseous mercury observed at the Leland Olds Unit 1 as a function of sorbent injection rate. Under this test condition, an immediate recovery to 5 μg/m^3 has been observed as soon as the Mer-Cure™ system is turned off (18:00). This was followed by a slow, steady recovery to its baseline mercury level of 7.4 μg/m^3 over a 12-hour period. The step increase in mercury level demonstrates the effect of in-flight sorbent particles on mercury capture, whereas the subsequent slow recovery shows that of residual sorbent at the boiler backpass.

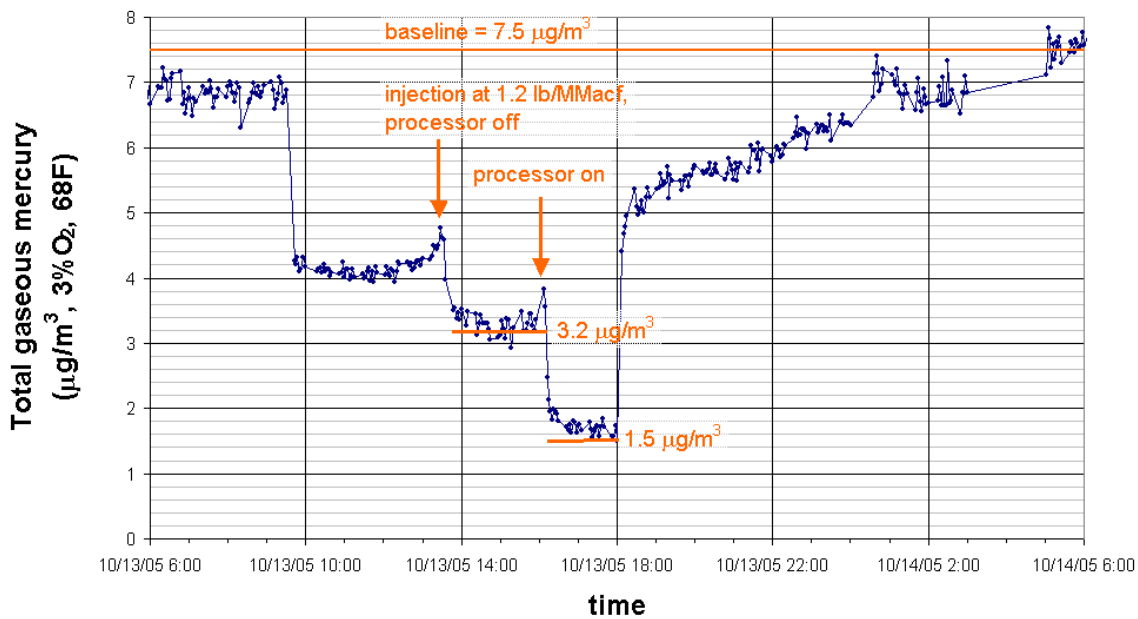


Figure 3. Effect of processor operation on the sorbent performance at Leland Olds Station. The mercury removal rate was increased from 56% to 80% by turning on the processor of the Mer-Cure™ system.

Figure 4 shows the gaseous mercury (total) levels measured at the ESP outlet by a Tekran continuous monitor over the entire 30-day long-term demonstration period of the Mer-Cure™ system. As shown, the baseline mercury (total) levels measured before and after injection are 7.48 μg/m^3 and 7.59 μg/m^3, respectively. The long-term demonstration program was broken into two test periods. Upon request from the host site (Basin Electric), testing for the first five days

was conducted with the mercury removal target set at approximately 75%. This goal was achieved at the sorbent injection rate of 0.9 lb/MMacf. This testing was then followed by the target removal rate of approximately 90%. This goal was achieved by continuous injection of sorbent at 1.4 lb/MMacf. It is clearly demonstrated that 90% mercury removal can be achieved at Basin Electric's Leland Olds Station.

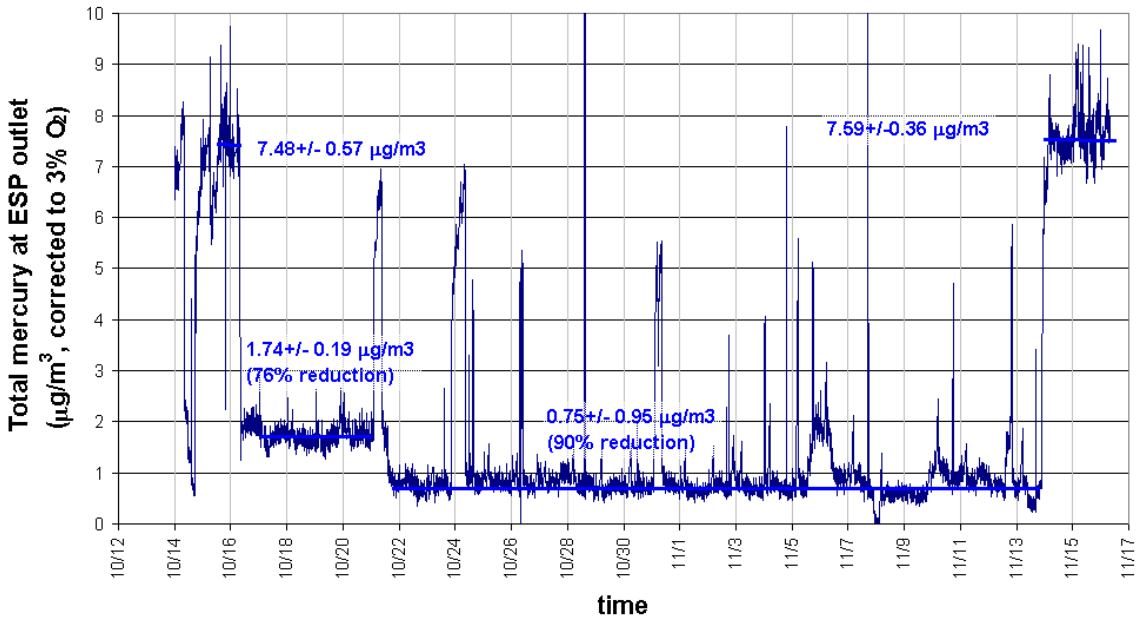


Figure 4. Long-term demonstration data of the Mer-Cure™ system showing 90% removal of uncontrolled gaseous mercury. The baseline mercury at the ESP outlet was 7.5 μg/m^3. Testing was carried out for two removal targets: 75% and 90%.

The CMM measurement of the long-term performance of the Mer-Cure™ system has been verified by another measurement method and is shown in Figure 5. The reported mercury levels are the total gaseous mercury levels measured by UND EERC throughout the long-term testing by employing the Ontario Hydro method. The mercury levels were corrected to 3% O_2 and reported in micrograms per dry standard cubic meter (μg/dscm). According to the Ontario Hydro measurements during the long-term test period, the air heater inlet level varied from 7.8 μg/dscm to 10.6 μg/dscm with its mean of 9.3 ± 1.0 μg/dscm. (When corrected to a wet basis, as for CMM readings, this mercury level is with a mean of 7.9 ± 0.85 μg/m^3 at the air heater inlet.) The mercury removal efficiency calculated based on the air heater inlet was 80% for the initial test period, and 92% for the rest of the test period, confirming the performance of the Mer-Cure™ system measured by CMMs.

Figure 6 shows a comparison between the CMM readings and Ontario Hydro measurements during long-term test period, both at the air heater inlet (Figure 6a) and at the ESP outlet (Figure 6b). For the air heater inlet comparison, a paired t-test for the 7 sets of air heater data have been carried out. The paired t-test gave a p-value of 0.14, indicating that we cannot conclude with 95% confidence that the two measurements differ from each other. In case of the ESP outlet data, the paired t-test for the 6 sets of data during long-term injection gave a p-value of 0.1, indicating that we cannot conclude with 95% confidence that the two measurements differ from each other.

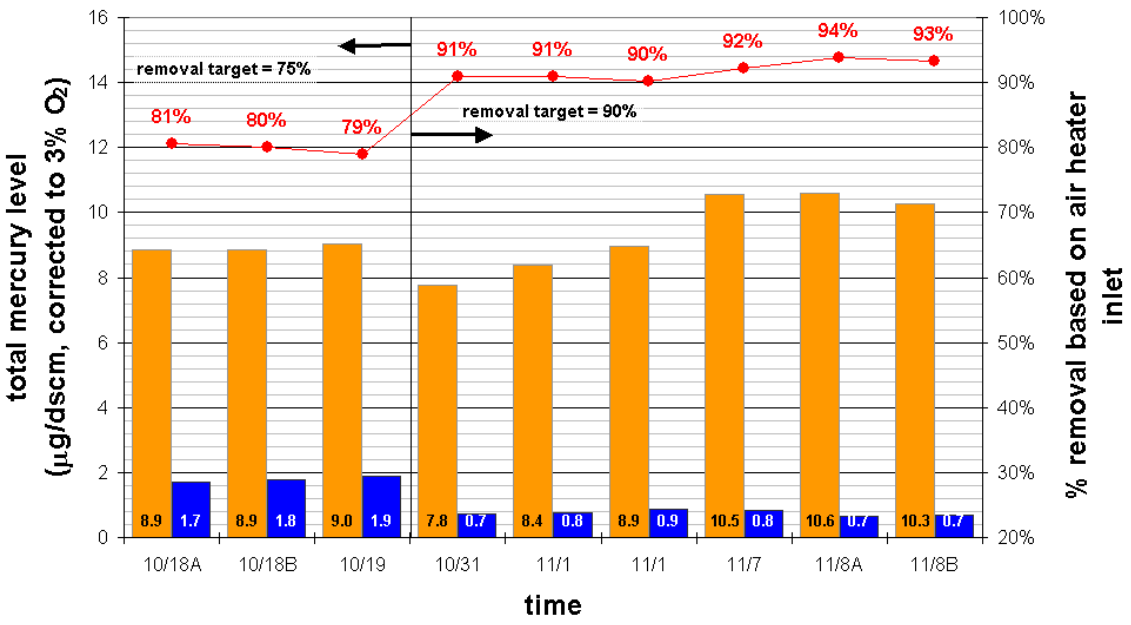
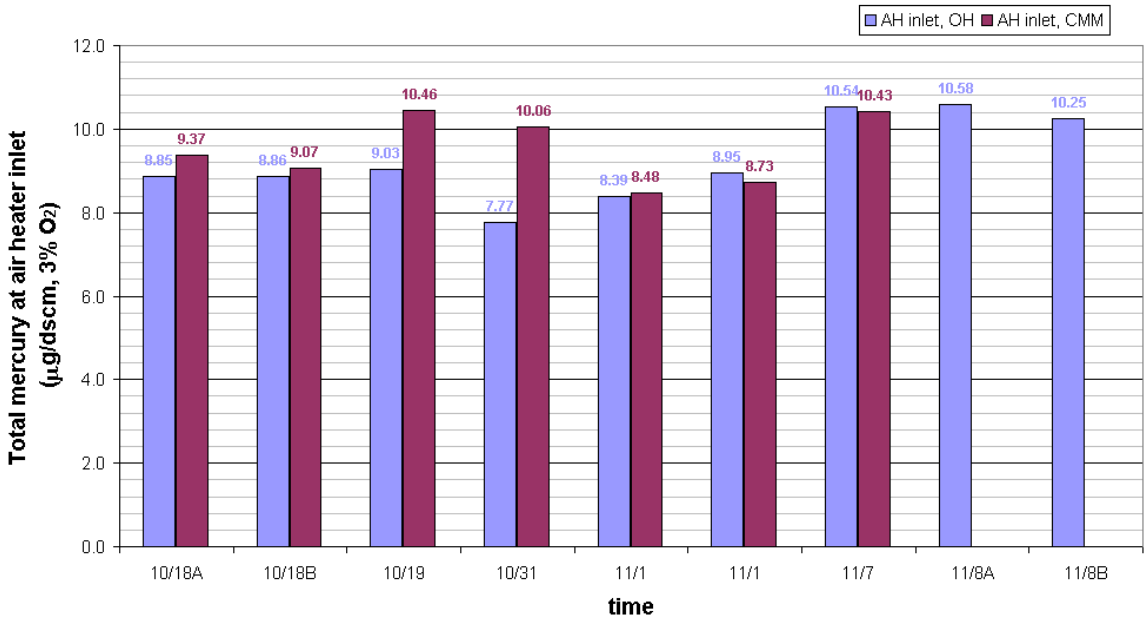
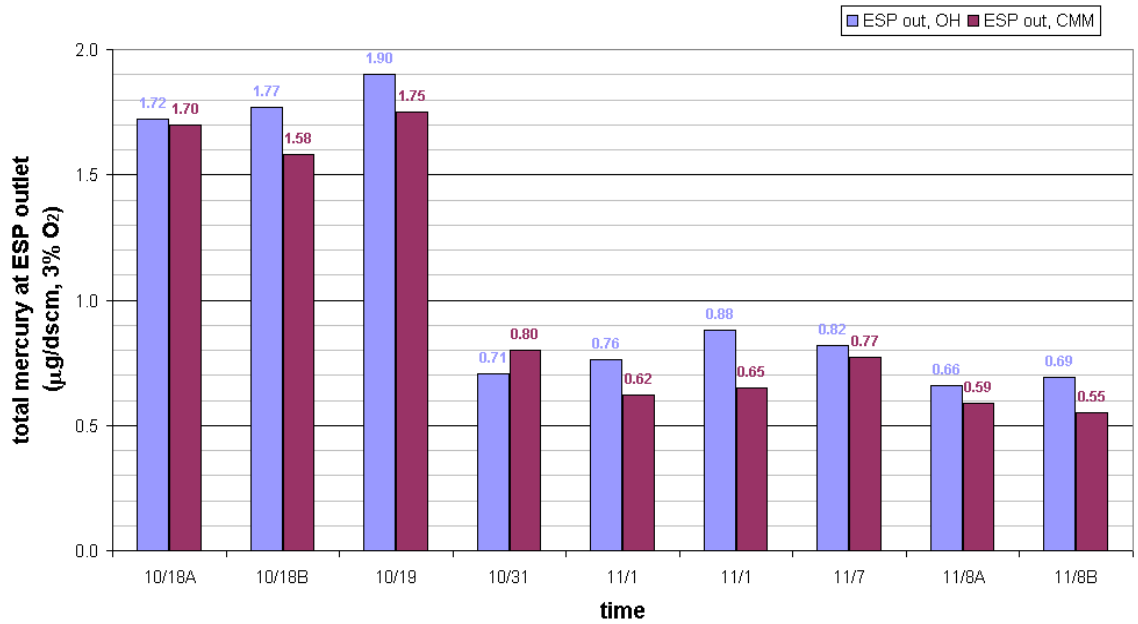


Figure 5. Long-term performance of the Mer-Cure™ system as measured by Ontario Hydro method. Data confirm that greater than 90% mercury removal can be achieved by the Mer-Cure™ system.

Figure 7 shows the change of mercury speciation between air heater inlet and ESP outlet. At the air heater inlet, most of the gaseous mercury was determined to be elemental. Only 3% of the total gaseous mercury was in oxidized form. Some of the gaseous mercury oxidizes at the backpass; at the ESP outlet, 23% of the gaseous mercury was determined to be oxidized before injection. During sorbent injection, however, the oxidized portion of the gaseous mercury further increased to 37%, suggesting that further oxidation takes place due to the presence of sorbent in the flue gas.



(a)



(b)

Figure 6 Comparison of CMM measurements with Ontario Hydro measurements for air heater inlet (a, upper) and ESP outlet (b, lower)

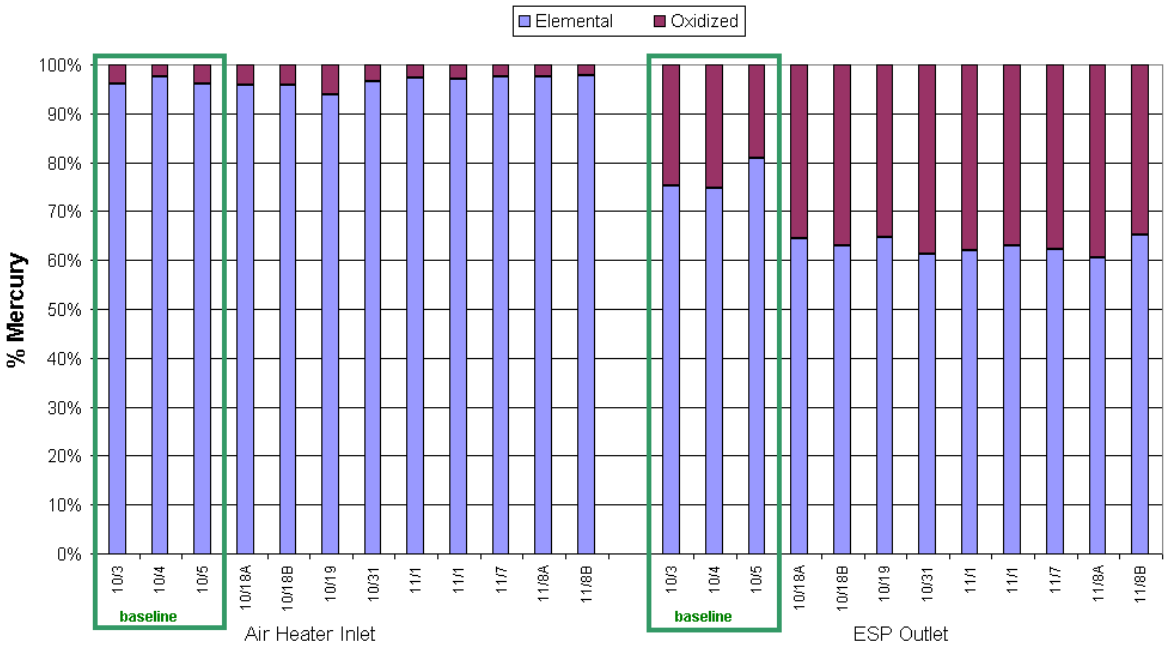


Figure 7. Mercury speciation at the air heater inlet and the ESP outlet. Mercury is oxidized between the air heater inlet and the ESP outlet. The percentage of the oxidized mercury increases at the ESP outlet in the presence of the sorbent.

CONCLUSION

Field demonstration of the Mer-Cure™ system has been completed at Basin Electric's LOS1. Data have been analyzed and presented in this report. Following are the summary of LOS1 test campaign:

- The long-term performance data show that at the air heater inlet, mercury was mostly elemental mercury (97% of total gaseous mercury); the mercury further oxidized at the backpass to give a total of 77% of the mercury as elemental at the ESP outlet. During injection of the sorbent, the elemental form of the total gaseous mercury at the ESP outlet further decreased to 63%, demonstrating the role of the sorbent as an oxidation catalyst. For boilers with scrubbers, most of this oxidized mercury at the ESP outlet will be further removed by the scrubbers. As a result, even higher removal efficiency will be achieved.

- The long-term performance of Mer-Cure™ system at Basin Electric's LOS1, as measured by both Ontario Hydro method and CMMs, shows that at an injection rate of 1.5 lb/MMacf, 90% removal of total gaseous mercury has been achieved with Mer-Cure™ system;

- The effect of the processor the Mer-Cure™ system on the sorbent performance improvement has been demonstrated. For a given mercury removal target, the sorbent consumption rate for the Mer-Cure™ system with its processor turned on was only half of that with it turned off.

MILESTONES AND SCHEDULE

Both PacifiCorp and Basin Electric test campaigns have been completed so far as scheduled and on budget. Data reduction for PacifiCorp test campaign has been completed and the results have been reported in previous reports. Basin Electric test data have been analyzed and reported in this quarterly report. The delivery of PacifiCorp site report has been revised to June 30th, 2006. The setup of the Mer-Cure™ system for the Reliant Energy testing has been completed. Field demonstration at Reliant Energy's Portland Station will continue in the next reporting period.

Table 4. Schedule for Mer-Cure™ demonstration

ID	Task Name
1	**Design, Engineering, and Fabrication, Dave Johnston Unit**
2	Design and Engineering of System Architecture
3	Component Fabrication and Testing
4	Assembly and Shipping
5	**Field Demonstration, Dave Johnston Unit 1**
6	Project Kickoff Meeting, Environmental/Regulatory Approvals
7	Installation, Checkout, and Commissioning
8	System Setup - Milestone 1
9	Testing
10	Removal
11	Data Analysis and Site Report
12	Site Report - Milestone 2
13	**Design, Engineering, and Fabrication, Leland Olds Unit 1**
14	Design and Engineering of System Architecture
15	Component Fabrication and Testing
16	Assembly and Shipping
17	**Field Demonstration, Leland Olds Unit 1**
18	Project Kickoff Meeting, Environmental/Regulatory Approvals
19	Installation, Checkout, and Commissioning
20	System Setup - Milestone 3
21	Testing
22	Removal
23	Data Analysis and Site Report
24	Site Report - Milestone 4
25	**Design, Engineering, and Fabrication, Portland Unit 1**
26	Design and Engineering of System Architecture
27	Component Fabrication and Testing
28	Assembly and Shipping
29	**Field Demonstration, Portland Unit 1**
30	Project Kickoff Meeting, Environmental/Regulatory Approvals
31	Installation, Checkout, and Commissioning
32	System Setup - Milestone 5
33	Testing
34	Removal
35	Data Analysis and Site Report
36	Site Report - Milestone 6
37	**Technology Transfer**
38	Technology transfer
39	**Program Management and Reporting**
40	**Program Management**
432	**Reporting - As Needed**
463	Final Report
464	Final Report - Milestone 7

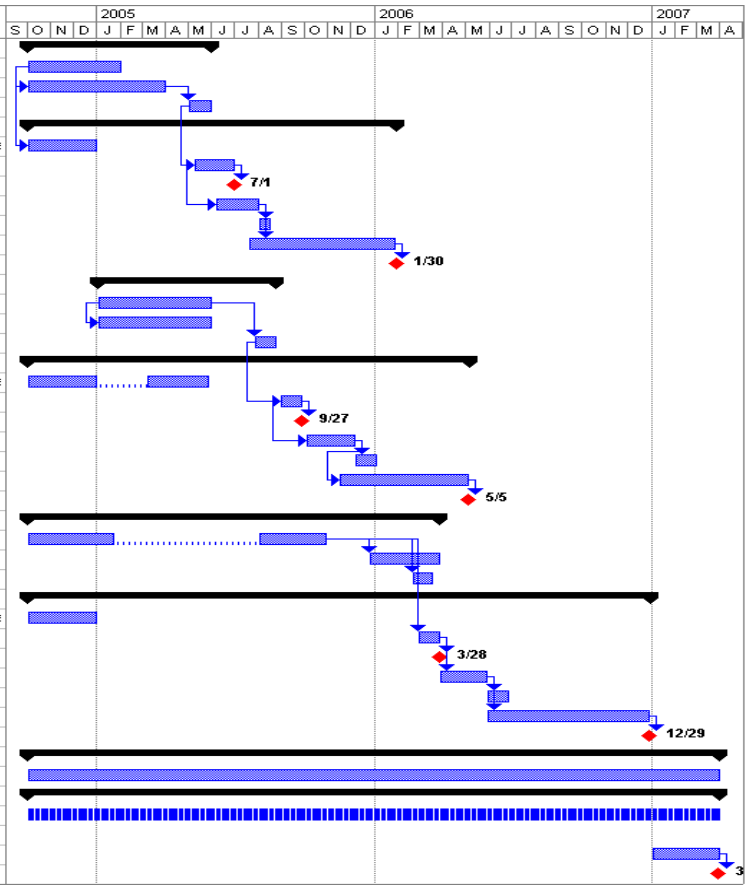


Table 5. Milestones and Deliverables

Milestone/ Deliverable	Original	Revised	Actual
1. System setup – Dave Johnston (PacifiCorp)	7/1/05		6/18/05
2. Site Report – Dave Johnston (PacifiCorp)	1/30/06	6/30/06	
3. System setup – Leland Olds (Basin Electric)	9/27/05		9/29/05
4. Site Report – Leland Olds (Basin Electric)	5/5/06	8/31/06	
5. System setup – Portland (Reliant)	3/28/06	3/24/06	
6. Site Report – Portland (Reliant)	12/29/06		
7. Final Report	3/30/07		