MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

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MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

ABSTRACT

This project was awarded under U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) Program Solicitation DE-PS26-00NT40769 and specifically addresses Technical Topical Area 4 – Testing Novel and Less Mature Control Technologies on Actual Flue Gas at the Pilot Scale. The project team includes the Energy & Environmental Research Center (EERC) as the main contractor; W.L. Gore & Associates, Inc., as a technical and financial partner; and the Big Stone Plant operated by Otter Tail Power Company, host for the field-testing portion of the research.

Since 1995, DOE has supported development of a new concept in particulate control called the advanced hybrid particulate collector (AHPC). The AHPC has been licensed to W.L. Gore & Associates, Inc., and is now marketed as the *Advanced Hybrid*™ filter by Gore. The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper. The AHPC provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emissions with conventional ESPs, and it solves the problem of reentrainment and re-collection of dust in conventional baghouses. The AHPC appears to have unique advantages for mercury control over baghouses or ESPs as an excellent gas–solid contactor.

The objective of the three-task project is to demonstrate 90% total mercury control in the AHPC at a lower cost than current mercury control estimates. The approach includes bench-scale batch testing that ties the new work to previous results and links results with larger-scale pilot testing with real flue gas on a coal-fired combustion system, pilot-scale testing on a coal-fired combustion system with both a pulse-jet baghouse and an AHPC to prove or disprove the research hypotheses, and field demonstration pilot-scale testing at a utility power plant to prove scaleup and demonstrate longer-term mercury control.

This project, if successful, will demonstrate at the pilot-scale level a technology that would provide a cost-effective technique to accomplish control of mercury emissions and, at the same time, greatly enhance fine particulate collection efficiency. The technology can be used to retrofit systems currently employing inefficient ESP technology as well as for new construction, thereby providing a solution to a large segment of the U.S. utility industry as well as other industries requiring mercury control.

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ACI	activated carbon injection
AHPC	advanced hybrid particulate collector
A/C	air-to-cloth
COHPAC	compact hybrid particulate collector
CMM	continuous mercury monitor
DOE	U.S. Department of Energy
EB	eastern bituminous
EERC	Energy & Environmental Research Center
ESP	electrostatic precipitator
FF	fabric filter
FGD	flue gas desulfurization
IAC	iodine-impregnated activated carbon
LOI	loss on ignition
NETL	National Energy Technology Laboratory
OH	Ontario Hydro
PJBH	pulse-jet baghouse
PRB	Powder River Basin
PTC	particulate test combustor
PTFE	polytetrafluoroethylene
SD	spray dryer
SEA	sorbent enhancement additive
SDA	spray dryer absorber
TDF	tire-derived fuel
WSB	western subbituminous

MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

EXECUTIVE SUMMARY

Since 1995, the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) has supported development of a new concept in particulate control called the advanced hybrid particulate collector (AHPC). The AHPC has been licensed to W.L. Gore & Associates, Inc., and is now marketed as the *Advanced Hybrid*™ filter by Gore. The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper.

The objective of this project is to demonstrate 90% total mercury control with commercially available sorbents in the AHPC at a lower cost than current mercury control estimates. The approach includes three levels of testing: 1) bench-scale batch testing that ties the new work to previous results and links results with larger-scale pilot testing with real flue gas on a coal-fired combustion system, 2) pilot-scale testing on a previously proven combustion system with both a pulse-jet baghouse (PJBH) and an AHPC to prove or disprove the research hypotheses, and 3) field demonstration pilot-scale testing at a utility power plant to prove scaleup and demonstrate longer-term mercury control.

Initial bench-scale results were in good agreement with previous data. Results showed that the SO_2 and NO_2 concentration effects are additive and have a significant effect on sorbent performance. This finding should facilitate predicting sorbent performance in real systems when the SO_2 and NO_2 concentrations are known.

An initial field test of the 2.5-MW AHPC at the Big Stone Plant was completed the first week of November 2001. Results showed that the average inlet mercury speciation for seven samples was 55.4% particulate bound, 38.1% oxidized, and 6.4% elemental. A carbon injection rate of 24 kg of carbon sorbent/million m^3 of flue gas (1.5 lb of carbon sorbent/million acf) resulted in 91% total mercury collection efficiency, compared to 49% removal for the baseline case.

Following the initial field test, additional bench-scale tests, as well as the first planned pilot-scale tests, were completed. A key finding from the bench-scale tests was that the fixed-bed sorbent-screening tests using simulated flue gas were in good agreement with similar tests sampling real flue gas. This suggests that as long as the main flue gas components are duplicated, the bench-scale fixed-bed tests can be utilized to indicate sorbent performance in larger-scale systems.

In the pilot-scale tests, a baseline comparison was made between the AHPC and a PJBH in terms of the mercury speciation change across the device and the amount of mercury retained by the fly ash. Results showed that for both devices there was very little capture of mercury by the

fly ash. There was some increase in oxidized mercury, but no significant differences were noted between the AHPC and pulse-jet modes of operation.

Even though the same coal was used in the pilot-scale and initial field tests, there was a significant difference in inlet mercury speciation. For the pilot-scale tests, results were more similar to what is typically expected for Powder River Basin (PRB) coals in that most of the mercury was elemental, with little mercury capture by the fly ash. In contrast, for the November 2001 field test, there was much more oxidized than elemental mercury and significant mercury capture by the fly ash. Possible reasons for the difference include higher carbon in the field ash, somewhat higher HCl in the field flue gas due to the cofiring of tire-derived fuel (TDF), possible variation in the coal, cyclone firing for the field compared to pulverized coal firing for the pilot tests, longer residence time for the field tests, and a finer particle size for the field test.

During April–June 2002, a number of baseline and carbon injection tests were completed with Belle Ayr PRB subbituminous coal, one of the coals currently being burned at Big Stone. For the baseline case, approximately 70% of the inlet mercury was elemental, approximately 23% oxidized, and 2% or less was associated with particulate matter. Very little natural mercury was captured across the AHPC for the baseline tests, and the level of oxidized mercury increased only slightly across the AHPC during baseline operation.

With carbon injection, a comparison of short and long residence time in the AHPC showed that somewhat better mercury removal was achieved with longer residence time. No evidence of desorption of mercury from the carbon was seen upon continued exposure to flue gases up to 24 hours. This suggests that desorption of captured mercury from the carbon sorbent is not a significant problem under these flue gas conditions with the low-sulfur subbituminous coal.

At a carbon-to-mercury ratio of 3000:1, from 50% to 71% total mercury was achieved. When the ratio was increased to 6000:1, the removal range increased to 65%–87%. These results are highly encouraging because this level of control was achieved for the very difficult case with predominantly elemental mercury and very little natural capture of mercury by the fly ash.

A longer-term field test was completed with the 2.5-MW field AHPC August 6 through September 6, 2002. Carbon injection and mercury CMM (continuous mercury monitor) measurements were continuous (24 hours a day) for the entire month except for an unplanned plant outage from August 29 to September 2. The primary goal of the work was to demonstrate longer-term mercury control with the AHPC and evaluate the effect of the carbon injection on the AHPC operational performance. Another goal of the test was to evaluate the effect of supplemental TDF burning on the level of mercury capture for comparison with results from the previous test completed in November 2001.

The inlet mercury speciation during the August 2002 tests averaged 17% particulate bound, 32% oxidized, and 51% elemental. The significant difference in mercury speciation between the August field data and the November 2001 field data is likely the effect of a higher rate of cofiring of TDF with the coal during the November test.

In the November 2001 tests, 49% mercury capture was seen for the baseline conditions without carbon injection. The August tests indicated only 0% to 10% mercury capture with no carbon injection. Again, the most likely explanation is the much higher TDF cofiring rate and higher HCl in the flue gas for the November test.

Addition of activated carbon at a rate of 24 kg of carbon sorbent/million m^3 of flue gas (1.5 lb of carbon sorbent/million acf) resulted in an average of 63% mercury removal in the August tests without any TDF cofiring. A small TDF cofiring rate of about 23 tons per day resulted in an increase in mercury collection to 68%. At the highest TDF rate seen in the August tests of 150–177 tons per day, mercury removal of up to 88% was achieved. This compares with 91% removal seen during the November tests when the TDF feed rate was in the range from 90 to 250 tons per day. These results indicate that TDF cofiring has the effect of increasing the level of mercury control that can be achieved with a low carbon addition rate.

One of the main objectives of the August tests was to assess the effect of carbon injection on longer-term AHPC performance. When the carbon was started on August 7, there was no perceptible change in pressure drop or bag-cleaning interval. Similarly, there was no change in the K_2C_i value that relates to how well the ESP portion of the AHPC is working. These results indicate that low addition rates of carbon will have no perceptible effect on the operational performance of the AHPC.

Another short field test was completed with the 2.5-MW AHPC at the Big Stone Plant November 19–22, 2002, to coincide with the first test conducted at the inlet and stack of the full-scale *Advanced Hybrid*™ filter after it came on-line October 26, 2002. The primary purpose of the test was to evaluate the effect of injecting a small amount of HCl into the flue gas along with the activated carbon. Results showed that without supplemental HCl injection and a low carbon injection rate of 24 kg of carbon sorbent/million m^3 of flue gas (1.5 lb of carbon sorbent/million acf), 65% to over 90% total mercury removal was achieved. This is somewhat better than the results seen in the monthlong continuous test in August 2002. Part of the reason could be the higher temperatures in the AHPC during August, which typically were in the range of 132°–143°C (270°–290°F) compared to 121°C (250°F) for the November 2002 tests.

Little or no effect was seen with the supplemental HCl injection. This is somewhat surprising because an extensive amount of bench-scale sorbent work has demonstrated the benefit of HCl for capturing elemental mercury in a simulated flue gas over the temperature range of 107°–188°C (225°–370°F). However, the benefit of additional HCl may be marginal in cases where there is already a sufficient amount of HCl present to achieve good mercury control.

During October–December 2002, a 5.7-m^3/min (200-acfm) pilot-scale test was also completed with Springfield bituminous coal. The purpose of this test was to evaluate mercury control with the AHPC with a high-sulfur bituminous coal. The Springfield bituminous coal produced a flue gas that was high in all of the acid gases including SO_3, and most of the inlet mercury was in an oxidized form. A number of short- and longer-term tests with the NORIT Americas Darco FGD carbon at temperatures ranging from 135° to 160°C (275° to 320°F) showed that this sorbent is completely ineffective at mercury control under these conditions. This is in contrast to the extensive testing conducted previously with the AHPC and

subbituminous coal, where up to 90% mercury capture was seen at a low carbon addition rate. The data are consistent with previous bench-scale testing that has shown that flue gas conditions are critical to the mercury capture ability of an activated carbon.

The previous field studies performed in November 2001 and August 2002 showed there was a correlation between Hg^{2+} concentration in the flue gas and the amount of TDF fed into the boiler. However, because of the variability of the TDF feed rate, it was difficult to quantify the TDF effect on mercury removal. A 1-week pilot-scale test was conducted on the 5.7-m^3/min (200-acfm) EERC AHPC where the coal feed rate and the TDF feed rate were precisely controlled.

Cofiring of TDF with the subbituminous coal had a significant effect on mercury speciation at the inlet to the AHPC. Firing 100% coal resulted in only 19% oxidized mercury at the inlet compared to 47% cofiring 5% TDF (mass basis) and 85% cofiring 10% TDF. The significant increase in oxidized mercury may be partly the result of increased HCl in the flue gas with the TDF. However, since the actual increase of measured HCl was only a few ppm, other changes in combustion conditions or flue gas components may also be responsible for the increase in oxidized mercury.

The TDF not only enhances mercury oxidation in flue gas but also improves mercury capture when combined with FGD carbon injection. With 100% coal, test results have shown from 48% to 78% mercury removal at a relatively low FGD carbon addition rate of 24 kg of carbon/million m^3 (1.5 lb of carbon/million acf). With TDF, results showed from 88% to 95% total mercury removal with the same carbon addition rate while cofiring 5%–10% TDF. These results are consistent with previously reported results from the 2.5-MW pilot-scale AHPC.

W.L. Gore & Associates, Inc., has developed an innovative technology for control of mercury emissions in flue gas streams. Specifically, the configuration involves a mercury control filter placed inside the existing particulate control filter bag, essentially a bag-within-a-bag concept.

A week of testing was completed with two different cartridge filters on the 5.7-m^3/min (200-acfm) AHPC in March 2003. The filters were installed inside of the four cylindrical all-polytetrafluoroethylene (PTFE) bags in the AHPC unit. Operationally, the mercury filter elements did not appear to impair the pulse cleaning of the bags. Initial tests with these cartridges showed that nearly 100% mercury capture could be achieved, but early breakthrough results were observed. After reviewing these initial results and modification of the material, another week of testing is planned for fall 2003.

Another 1-month field test was completed in May–June 2003 with the 2.5-MW AHPC unit at the Big Stone Plant to demonstrate long-term mercury control with the AHPC and evaluate the impacts of various operating parameters such as filtration velocity, carbon feed rate, and carbon in-flight time on mercury control.

The inlet mercury vapor concentration in the flue gas during the May 2003 test ranged from 4.98 to 10.6 $\mu g/m^3$ with 20% to 70% Hg^0. The variation in mercury speciation is likely

caused by varying coal as well as the intermittent cofiring of TDF and waste seeds. The May 2003 test indicated 0%–30% mercury inherent capture with no carbon addition, typical for western subbituminous coal.

At low carbon feed concentrations ranging from 1 to 3 lb/Macf, the AHPC demonstrated high overall mercury collection efficiencies from 65% to 95%. Comparing with other research results, the AHPC clearly demonstrated higher mercury removal efficiency than an ESP under the same FGD carbon feed rate. The overall Hg removal with the AHPC was similar to a baghouse or COHPAC (compact hybrid particulate collector).

MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

1.0 INTRODUCTION

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2.0 EXPERIMENTAL

2.1 Objective and Goals

The overall project objective is to demonstrate 90% total mercury control with commercially available sorbents in the AHPC at a lower cost than current mercury control estimates.

Test goals include the following:

- Determine if the bench-scale mercury breakthrough results can be duplicated when real flue gas is sampled.

- Compare the level of mercury control between the AHPC and a pulse-jet baghouse (PJBH) with sorbents under similar conditions at the 55-kW pilot scale.

- Demonstrate 90% mercury capture for both a western subbituminous and an eastern bituminous coal.

- Demonstrate mercury capture with the 2.5-MW AHPC at Big Stone.

- Demonstrate 90% mercury capture over a longer time (3 months) with the 2.5-MW AHPC at Big Stone.

2.2 Planned Scope of Work

To meet the objectives, the work was organized into five tasks:

- Task 1: Project Management, Reporting, and Technology Transfer
- Task 2: Bench-Scale Batch Testing
- Task 3: Pilot-Scale Testing
- Task 4: Field Demonstration Pilot Testing
- Task 5: Facility Removal and Disposition

2.2.1 Task 1 – Project Management, Reporting, and Technology Transfer

Task 1 includes all of the project management requirements, including planning, coordination among team members, supervision of tests, review of results, meeting attendance, and all aspects of reporting.

2.2.2 Task 2 – Bench-Scale Batch Testing

The bench-scale tests are for the purposes of verifying previous results, expanding on the SO_2 and NO_2 concentration effect, linking the synthetic gas results to the results with real flue gas, and screening sorbents.

The 30 tests planned with the bench-scale unit are divided into three series that follow a logical progression. The purpose of the first series of tests is to ensure that results obtained by the EERC and others can be duplicated and, second, to include SO_2 and NO_2 as variables. Series 1 tests, shown in Table 1, are intended to verify the previous bench-scale work and expand on the SO_2 and NO_2 concentration effect. In previous work, no tests were completed in which both the SO_2 and NO_2 were reduced at the same time. In all of these tests, the inlet Hg^0 concentration is typically 15 $\mu g/m^3$, and each test is run for approximately 4 hr. The 150 mg of NORIT FGD activated carbon sorbent is equivalent to a sorbent-to-mercury ratio of 3700 after 3 hr of exposure. This concentration has been shown to provide consistent results in previous testing and is sufficient to accurately measure the amount of mercury in the spent sorbent for mass balance closure. The Series 1 tests were previously completed, and results were reported in the January–March 2002 quarterly report.

The second series of bench-scale tests (Table 2) is for the purpose of comparing the bench-scale fixed-bed results sampling real flue gas to those obtained with simulated flue gas for both a

Table 1. Bench-Scale Series 1 – SO_2 and NO_2 Concentration

Test No.	Sorbent Type	Temp., °C (°F)	Sorbent Concentration, mg	Flue Gas	SO_2, ppm	HCl, ppm	NO, ppm	NO_2, ppm
1	FGD	135 (275)	150	Simulated	1600	50	400	20
2	FGD	135 (275)	150	Simulated	500	50	400	20
3	FGD	135 (275)	150	Simulated	200	50	400	20
4	FGD	135 (275)	150	Simulated	1600	50	400	10
5	FGD	135 (275)	150	Simulated	500	50	400	10
6	FGD	135 (275)	150	Simulated	200	50	400	10
7	FGD	135 (275)	150	Simulated	1600	50	400	5
8	FGD	135 (275)	150	Simulated	500	50	400	5
9	FGD	135 (275)	150	Simulated	200	50	400	5
10	FGD	135 (275)	150	Simulated	Repeat test to be selected			

Table 2. Bench-Scale Series 2 – Real Flue Gas Comparison

Test No.	Sorbent Type	Temp., °C (°F)	Sorbent Concentration, mg	Flue Gas	SO_2, ppm	HCl, ppm	NO, ppm	NO_2, ppm
11	FGD	135 (275)	150	Real	Flue gas from western coal			
12	FGD	135 (275)	150	Real	Duplicate test of western coal			
13	FGD	135 (275)	150	Simulated*	400	4	300	5
14	FGD	135 (275)	150	Simulated Duplicate*	400	4	300	5
15	FGD	135 (275)	50	Simulated*	400	4	300	5
16	FGD	135 (275)	150	Real	Flue gas from eastern coal			
17	FGD	135 (275)	150	Real	Duplicate test of eastern coal			
18	FGD	135 (275)	150	Simulated*	1000	50	400	10
19	FGD	135 (275)	150	Simulated Duplicate*	1000	50	400	10
20	FGD	135 (275)	50	Simulated*	1000	50	400	10

* Simulated flue gases will be determined from actual flue gas measurements during combustion tests; values shown are estimates.

western subbituminous (WSB) and an eastern bituminous (EB) coal. The simulated flue gas concentrations are based on the actual concentrations measured in the combustion tests. In addition, tests with lower sorbent concentrations were planned with flue gases matched to the two coals to assist in selecting the best sorbent concentrations for the pilot-scale tests. The real

flue gas tests are part of the first two pilot-scale tests in Task 3, using a slipstream bench-scale system sampling flue gas from the particulate test combustor (PTC).

Tests 11–14 of the Series 2 tests were previously completed, and results were presented in the January–March 2002 quarterly report. Tests 16 and 17 were completed in the October–December 2002 quarter as part of pilot-scale tests with an EB coal. There are no current plans to complete Test 15 because it does not appear that 90% mercury control could be achieved by reducing the carbon concentration from what has already been tested. Tests 18–20 will also not be completed because the pilot-scale tests reported with the bituminous coal showed that the FGD carbon was ineffective at mercury control for the flue gas conditions produced from combustion of this specific bituminous coal.

The third series of bench-scale tests (Table 3) is for the purpose of screening alternative sorbents. The iodine-impregnated activated carbon (IAC) sorbent was initially chosen because of the excellent results seen in some of the previous EERC pilot-scale tests, especially at higher temperatures from 121°–177°C (250°–350°F). IAC also appears to be better at capturing Hg^0 than FGD. However, since IAC is more costly than FGD, it must be effective at lower concentrations than FGD. The plan was to evaluate the IAC for both a subbituminous and a bituminous coal at two concentration levels and two temperatures. However, since pilot-scale tests (reported later in this quarterly report) showed no improvement in mercury removal over the FGD carbon, there is no basis for doing these IAC tests.

Table 3. Bench-Scale Series 3 – Sorbent Type

Test No.	Sorbent Type	Temp., °C (°F)	Sorbent Concentration, mg	Flue Gas	SO_2, ppm	HCl, ppm	NO, ppm	NO_2, ppm
21	IAC	135 (275)	150	Simulated*	400	4	300	5
22	IAC	135 (275)	50	Simulated*	400	4	300	5
23	IAC	135 (275)	150	Simulated*	1000	50	400	10
24	IAC	135 (275)	50	Simulated*	1000	50	400	10
25	IAC	163 (325)	150	Simulated*	400	4	300	5
26	IAC	163 (325)	150	Simulated*	1000	50	400	10
27	New No. 1 **	135 (275)	150	Simulated*	400	4	300	5
28	New No. 2 **	135 (275)	150	Simulated*	400	4	300	5
29	New No. 3 **	135 (275)	150	Simulated*	400	4	300	5
30	New No. 4 **	135 (275)	150	Simulated*	400	4	300	5

* Simulated flue gases will be determined from actual flue gas measurements during combustion tests; values shown are estimates.

** New sorbents will be selected based on background data and availability.

The plan was to potentially conduct four additional screening tests on other promising alternative sorbents to be selected based on new information and availability, and then, depending on initial results, further evaluate them in pilot-scale testing in Task 3. Several versions of a non-carbon-based sorbent developed outside the EERC were tested. Initial results showed poor mercury removal which may have been partially due to the preparation and testing procedures, but there are no current plans for further testing of this specific sorbent. The one remaining possible alternative sorbent approach is the cartridge insert idea (explained in more detail in Section 3.2). However, because of the limitation of scale, this will be tested only with the pilot-scale AHPC under Task 3 rather than in the bench-scale system.

2.2.3 Task 3 – Pilot-Scale Testing

Six weeks of testing were planned under Task 3. A week of testing includes an 8-hr heatup period on gas and then approximately 100 hr of steady-state operation firing coal. This allows for four 24-hr test periods where the PTC is operated around the clock. The originally planned 6 weeks of tests are shown in Table 4. The first 2 weeks are for the purpose of generating baseline data without carbon injection for a bituminous and a subbituminous coal with both the PJBH and the AHPC. Each test is for a duration of approximately 48 hr. These tests were for the purpose of establishing the amount of mercury capture by fly ash and determining whether the

Table 4. Task 3 – Pilot-Scale Testing

Week/ Test	Purpose	Coal	Collection Device	Sorbent Type	C:Hg Ratio	Injection Method
1-1	Baseline	WSB	PJBH	None	NA[1]	NA
1-2	Baseline	WSB	AHPC	None	NA	NA
2-1	Baseline	EB	PJBH	None	NA	NA
2-2	Baseline	EB	AHPC	None	NA	NA
3-1	Hg capture, collection device	WSB	PJBH	FGD	3000[2]	Continuous
3-2	Hg capture, collection device	WSB	AHPC	FGD	3000[2]	Continuous
4-1	Hg capture, residence time	WSB	AHPC	FGD	3000[2]	Continuous
4-2	Hg capture, residence time	WSB	AHPC	FGD	3000[2]	Batch
5-1	Hg capture, residence time	EB	AHPC	FGD	3000[2]	Continuous
5-2	Hg capture, residence time	EB	AHPC	FGD	3000[2]	Batch
6-1	Sorbent type and concentration	WSB	AHPC	New No. 1[3]	3000[2]	Continuous[3]
6-2	Sorbent type and concentration	WSB	AHPC	New No. 1[3]	1000[2]	Continuous[3]
6-3	Sorbent type and concentration	WSB	AHPC	New No. 2[3]	3000[2]	Continuous[3]
6-4	Sorbent type and concentration	WSB	AHPC	New No. 2[3]	1000[2]	Continuous[3]

[1] Not applicable.
[2] Estimated concentrations; actual concentration will be based on previous testing.
[3] To be selected.

amount of mercury capture is different between the PJBH and the AHPC. Another purpose was to establish the inlet and outlet speciated mercury concentrations and whether there was a change

in mercury speciation across both devices. A second purpose for these baseline tests was to provide flue gas to support the bench-scale testing with real flue gas under Task 2.

Weeks 3 and 4 were designed to prove the ability of the technology to control mercury at the 90% level with a WSB coal. Week 5 was for testing mercury control in the AHPC with an EB coal.

Week 6 was for the purpose of testing alternative sorbents in the AHPC. The need for alternate sorbent testing is somewhat dependent on the results with the FGD sorbent. If 90% mercury capture was already demonstrated with both coals at a low sorbent concentration (for example, less than 3000:1), then there may be no need to further evaluate other sorbents. In this case, Week 6 would be cancelled, and testing with the field AHPC would proceed. However, if results with the FGD sorbent have not met expectations and other sorbents look more promising or if other unanswered questions remain that could be tested in the pilot tests, Week 6 would be completed.

From the pilot-scale test matrix listed in Table 4, the first 3 weeks of testing with a WSB coal have all been completed (Tests 1-1, 1-2, 3-1, 3-2, 4-1, and 4-2). Results from the first week of testing were reported in the January–March 2002 quarterly report. Results from Weeks 2–4 were presented later in the April–June 2002 quarterly report. The Week 5 test results with an eastern bituminous coal were presented in the October–December 2002 quarterly report. Because no other alternative sorbent was identified, Week 6 of testing with the FGD carbon was completed this last quarter cofiring tire-derived fuel (TDF). In addition to the original plan, 2 more weeks (Weeks 7 and 8) are planned to evaluate a mercury cartridge insert approach, for a total of 8 weeks of tests under Task 3. Initial results from Week 7 are presented in this report. Week 8 testing is planned for fall 2003.

2.2.4 Task 4 – Field Demonstration Pilot Testing

Demonstration of mercury control with the AHPC at the 2.5-MW scale at a utility power plant is the next logical step toward proving the commercial validity of this approach. A total of 5 months of field tests was originally planned. The first month was planned for baseline testing without sorbent injection to establish the mercury concentration, speciation, and amount of fly ash capture as well as to compare mercury emissions at the plant stack with the AHPC outlet.

The second month of field tests was planned for the purpose of establishing the sorbent addition rate to achieve 90% mercury control. Depending on the level of success with the FGD sorbent in the field and the pilot-scale test results with alternative sorbents, the third month was planned for the purpose of evaluating alternative sorbents. If alternative sorbent testing is not done, then 3 months of longer-term testing with the FGD sorbent will be completed. The longer-term operation will establish whether there are any longer-term problems associated with sorbent injection, such as bag-cleaning problems. If alternative sorbents are tested during Month 3, then the longer-term demonstration testing will last only 2 months.

According to the planned work, testing with the 2.5-MW AHPC at the Big Stone Plant was not scheduled to begin until after completion of the first pilot-scale tests. However, the project

team decided to conduct an initial field test the first week of November 2001 prior to the pilot-scale tests at the EERC.

The field test at Big Stone was completed the week of November 5–10, 2001, with baseline testing on the first day, followed by carbon injection in both AHPC and pulse-jet operational modes for the remainder of the week. The starting carbon addition rate was set at 24 kg of carbon sorbent/million m^3 of flue gas (1.5 lb of carbon sorbent/million acf), with the plan that it could be increased if necessary to achieve good mercury control. However, over 90% mercury control was seen at this carbon addition rate, so no testing was completed at higher carbon concentrations. The results from the November field test were previously reported in the October–December 2001 quarterly report.

An additional month of mercury control testing was completed with the 2.5-MW field AHPC August 6 – September 6, 2002. Carbon injection along with continuous mercury monitor (CMM) measurements was completed during the entire month except during an unplanned plant outage during the period from August 29 to September 2. Those results were presented in the July–September 2002 quarterly report.

During the October–December 2002 quarter, another short-term test was completed with the 2.5-MW AHPC on November 19–22, 2002, to coincide with stack mercury testing for the full-scale *Advanced Hybrid*™ filter at the Big Stone Plant. Those results were presented in the October–December 2002 quarterly report. The final month of field testing was completed May 6 to June 3, 2003, and results are presented in this quarterly report.

2.2.5 Task 5 – Facility Removal and Disposition

The field AHPC will be dismantled and removed at the end of this project if no further testing is anticipated in support of subsequent work at the Big Stone Plant. If further testing were to be completed with the field AHPC at another site (funded by possible subsequent projects), the AHPC components would be moved to that site. If no other AHPC testing is anticipated, the salvageable AHPC components will be returned to the EERC, and the larger steel components will be disposed of as scrap steel. The site will then be restored to its original condition. The Big Stone Plant will be responsible for removing the 24-in. ductwork that breeches the plant ductwork, electrical power lines, air supply lines, and communication lines once the project is complete.

3.0 RESULTS AND DISCUSSION

3.1 AHPC Mercury Control at the Big Stone Plant May–June 2003

A 1-month field test was completed with the 2.5-MW AHPC unit from May 6 to June 3, 2003. Carbon injection (Norit FGD and Barneby & Sutcliffe IAC) and CMM measurements were continuous (24 hours per day) for the entire month except for a planned plant outage on May 8, 2003, Memorial Day weekend break, and a 1-day shutdown on May 30, 2003. The primary goal of the work during this testing period was to demonstrate long-term mercury

control with the AHPC unit by carbon injection. Another goal was to evaluate the impacts of various operating parameters such as filtration face velocity, carbon injection rate, and location on mercury control with the AHPC technology. A summary of the testing parameters is listed in Table 5.

Table 5. Testing Parameters During May–June 2003 Test

Carbon	Norit FGD activated carbon, IAC
Filtration Face Velocity, m/min (ft/min)	1.8, 2.4, 3.0, 3.7, 4.3 (6, 8, 10, 12, 14)
Carbon Injection Concentration, kg/Macm (lb/Macf)	17, 20, 30 40, 48 (1.07, 1.25, 1.88, 2.51, 3.00)
Carbon Injecting Location	Inlet elbow, inlet transition

Since previous testing results (August–September 2002) had demonstrated that CMM instruments were able to precisely measure mercury in the flue gas by comparing with the Ontario Hydro sampling data, two CMMs were used during this test to monitor mercury concentrations both at the AHPC inlet and outlet, and no Ontario Hydro sampling was completed. The CMMs were normally set up to measure the AHPC inlet and outlet total mercury vapor concentrations, but during the day for several hours, they were manually switched to measure the elemental mercury vapor concentrations at the inlet and outlet.

3.2 Big Stone Fuel Burn Record

The fuel burn record from the plant data for this test period (May 6 – June 3, 2003) is shown in Table 6. During the majority of this test, the coals burned were from the Belle Ayr and Eagle Butte Mines, which are both similar low-sulfur subbituminous fuels from the Powder River Basin (PRB). Only on May 31, 2003, another PRB coal, Caballo coal, was burned. The amounts of TDF and waste seed fuel burned during this time are also listed in Table 6.

3.3 Mercury Species in Flue Gas

Figure 1 shows daily average mercury vapor concentrations, both total and elemental, in the flue gas for the entire test period. The error bars represent plus and minus one standard deviation. The inlet CMM sampling probe was set up prior to the carbon injecting location so that the collected data were reflective of mercury species entering the AHPC unit. The concentration of total mercury vapor (Hg^{gas}) at the AHPC inlet varied from 4.98 to 10.6 $\mu g/m^3$, while the elemental mercury concentrations were in the range of 0.83 to 5.36 $\mu g/m^3$. Figure 2 shows that the daily average ratios of Hg^0-to-Hg^{gas} for the entire test period ranged from 12.9% to 72.9%. The inlet mercury speciation may depend on a number of factors such as carbon content in the fly ash, chlorine level in the coal, and firing mode, etc. However, the current understanding

Table 6. Fuel Burn Record for the Big Stone Plant

Date	Coal Mine	Coal, tons	TDF, tons	Waste Seed, tons
5/6/2003	Belle Ayr	5945	46	0
5/7/2003	Eagle Butte	5759	0	0
5/8/2003	Eagle Butte	4741	0	0
5/9/2002	Belle Ayr	6216	49	46
5/10/2003	Belle Ayr	6429	0	0
5/11/2003	Belle Ayr	6585	0	0
5/12/2003	Eagle Butte	6301	0	0
5/13/2003	Belle Ayr	6073	22	180
5/14/2003	Belle Ayr	6003	46	183
5/15/2003	Belle Ayr	6222	0	0
5/16/2003	Belle Ayr	5882	27	140
5/17/2003	Belle Ayr	6158	0	0
5/18/2003	Belle Ayr	6133	0	0
5/19/2003	Belle Ayr	6011	69	71
5/20/2003	Belle Ayr	6156	70	73
5/21/2003	Belle Ayr	6109	0	94
5/22/2003	Belle Ayr	5943	22	48
5/23/2003	Belle Ayr	5777	45	24
5/27/2003	Belle Ayr	5637	22	24
5/28/2003	Belle Ayr	5847	45	0
5/29/2003	Belle Ayr	6051	0	0
5/31/2003	Caballo	5579	0	0
6/1/2003	Eagle Butte	5439	0	0
6/2/2003	Eagle Butte	5564	111	68
6/3/2003	Eagle Butte	4109	0	0

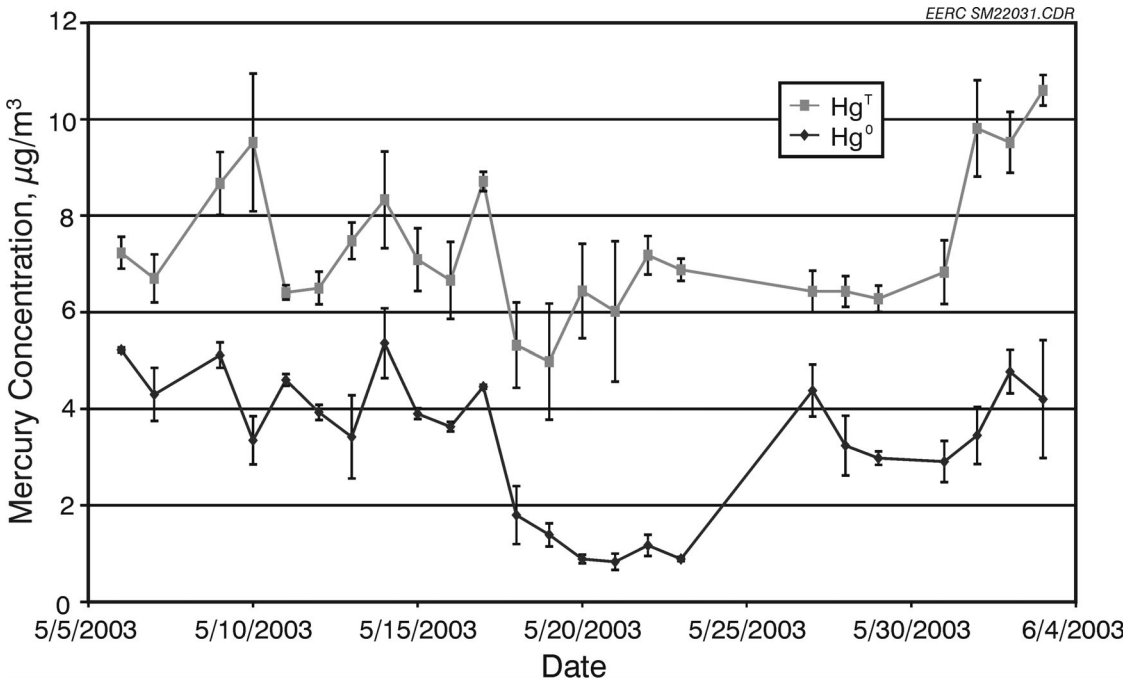

Figure 1. Daily average of inlet mercury in the flue gas for the 2.5-MW AHPC at Big Stone (CMM data).

of how these variables affect mercury species does not allow accurate predictions. In general, the low-sulfur and low-chlorine WSBs tend to produce more elemental mercury. During the previous test in August 2002 for the Belle Ayr and Eagle Butte coals, 60%–80% of total mercury vapor in the flue gas was elemental, while 20%–40% was oxidized mercury. The observed wide variations of Hg^0-to-Hg^{gas} ratio during this test were likely the result of the variation in the coal as well as the intermittent cofiring of TDF and waste seed. By correlating the fuel burn record with mercury species in the flue gas for both field tests, it appears that the Belle Ayr coal was more sensitive to cofiring TDF and waste seed in that more oxidized mercury in the flue gas was seen under relatively low levels of TDF additions. However, because the TDF and waste seed were fed into the plant intermittently, it is very difficult to precisely estimate the TDF effect on mercury species.

To further verify the CMM measurement, three coal and three hopper ash samples were analyzed for mercury content. The three ash samples were collected in the baseline tests without carbon injection. The results (Table 7) show that mercury concentrations in raw coal were in the range of 0.0689 to 0.109 μg/g. From combustion calculations, the predicted mercury concentration in the flue gas is in the range of 7.8 to 12.3 μg/m^3, with an average of 9.85 μg/m^3.

On May 20, 2003, the power plant burned Belle Ayr coal along with 1.1% TDF (mass basis) and 1.2% (mass basis) waste seed. The mercury content in the coal was 0.0836 μg/g, corresponding to a 9.45 μg/m^3 total mercury in the flue gas while the daily average mercury vapor concentration was only 6.44 μg/m^3. Based on the measured 0.233–0.256 μg/g mercury

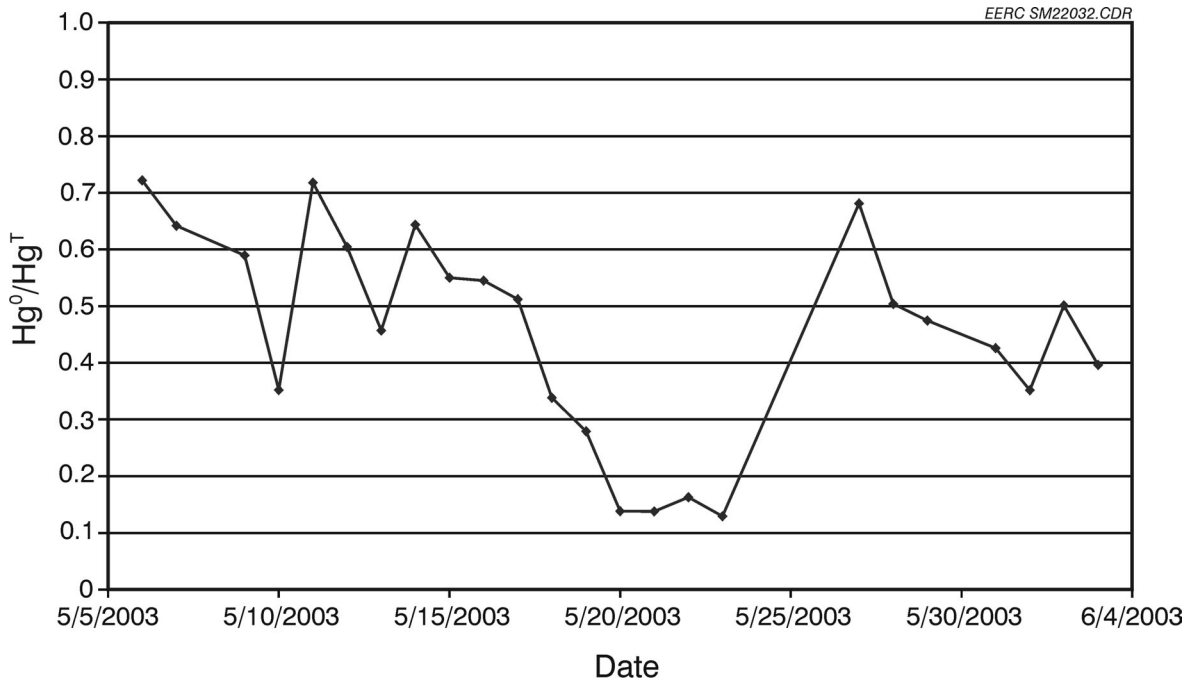

Figure 2. Hg^0-to-Hg^T ratio in the inlet flue gas for the 2.5-MW AHPC at Big Stone (CMM data).

Table 7. Mercury Content in the Coals and Hopper Ash

Coal Samples	Date	Coal Mine	Mercury Content, μg/g, dry basis
	5/20/03	Belle Ayr	0.0836
	5/31/03	Caballo	0.0689
	6/02/03	Eagle Butte	0.109
Ash Samples	Date	Mercury Content, μg/g, dry basis	
	5/09/03	0.256	
	5/27/03	0.233	
	5/31/03	0.438	

concentration on the Belle Ayr hopper ash collected in the baseline test and a typical dust loading of 2.83 g/m^3 (1.2 grains/scf), the inherent particulate associated mercury in the flue gas was in the range of 0.66–0.72 μm^3, giving a total mercury concentration of 7.16–7.76 $\mu g/m^3$. The discrepancy between the measured and predicted total mercury concentrations in the flue gas may be the result of analytical uncertainty or could be caused by some mercury collected on the CMM sampling filter, which occurs to greater extent when TDF is cofired.

On May 31, 2003, the power plant burned Caballo coal without any TDF and waste seed added. At the same time, the AHPC was operated under baseline situations without additional carbon injection. The mercury in the raw coal and AHPC hopper ash were 0.0689 and

0.438 μg/g, respectively. Assuming a typical dust loading of 2.83 g/m^3 (1.2 grains/scf) in the flue gas (based on previous sampling data), the mercury associated with particulate was about 1.13 μg/Nm^3 (dry basis). The average mercury vapor concentration measured at the AHPC inlet by the CMM during the day was 6.83 μg/m^3 (dry basis). Therefore, the total mercury concentration in the flue gas was 7.96 μg/m^3, close to the calculated mercury concentration of 7.8 μg/m^3 based on the mercury content in the raw coal. This agreement is easier to achieve when no TDF and waste seed are burned.

The coal collected on June 2, 2003, was Eagle Butte with a mercury concentration of 0.109 μg/g, corresponding to a total mercury concentration of 12.3 μg/m^3, which was higher than the measured 9.8 μg/m^3. Again, the TDF is a possible reason for the discrepancy.

Since the TDF was added into the plant intermittently during the entire test period, the total mercury vapor concentration measured by the CMM at the AHPC inlet may not accurately reflect the real total mercury concentrations in the flue gas. Therefore, the average 9.85 μg/m^3 from the combustion calculation was used as a typical inlet total mercury concentration in the flue gas for the mercury removal calculation.

3.4 Inherent Capture of Mercury Without Carbon Injection

Several baseline tests (no carbon addition) were conducted during the 1-month test. The inherent mercury removal efficiencies were calculated based on the measured mercury concentrations at the AHPC outlet and the average 9.85 μg/m^3 of total mercury in the flue gas (Figure 3). For the Belle Ayr coal, without cofiring TDF and waste seeds (May 10, 2003), there was virtually no inherent mercury capture by fly ash itself. However, when the power plant was cofiring with TDF as well as waste seed (May 6, 9, 27, and 28, 2003), the inherent mercury removal ranged from 2% to 18.9%. The above data indicate again the impacts of added TDF and waste seed on mercury species in the flue gas. Somewhat higher inherent mercury capture was seen with the Eagle Butte coal ranging from 24.7% to 30.5%, but this is somewhat overestimated because the average 9.85 μg/m^3 instead of 12.1 μg/m^3 was used for inherent capture calculation. In summary, the overall inherent mercury removal by the ash was low, with an average of 13.9% during the 1-month test.

3.5 Effect of Filtration Velocity on Mercury Removal with Carbon Injection

The carbon selected was the same DARCO FGD activated carbon that was used in the previous field tests as well as the EERC pilot-scale tests. It is a commercially available sorbent produced by NORIT Americas. DARCO FGD powdered activated carbon is a lignite coal-based activated carbon manufactured specifically for the removal of heavy metals and other contaminants typically found in flue gas streams.

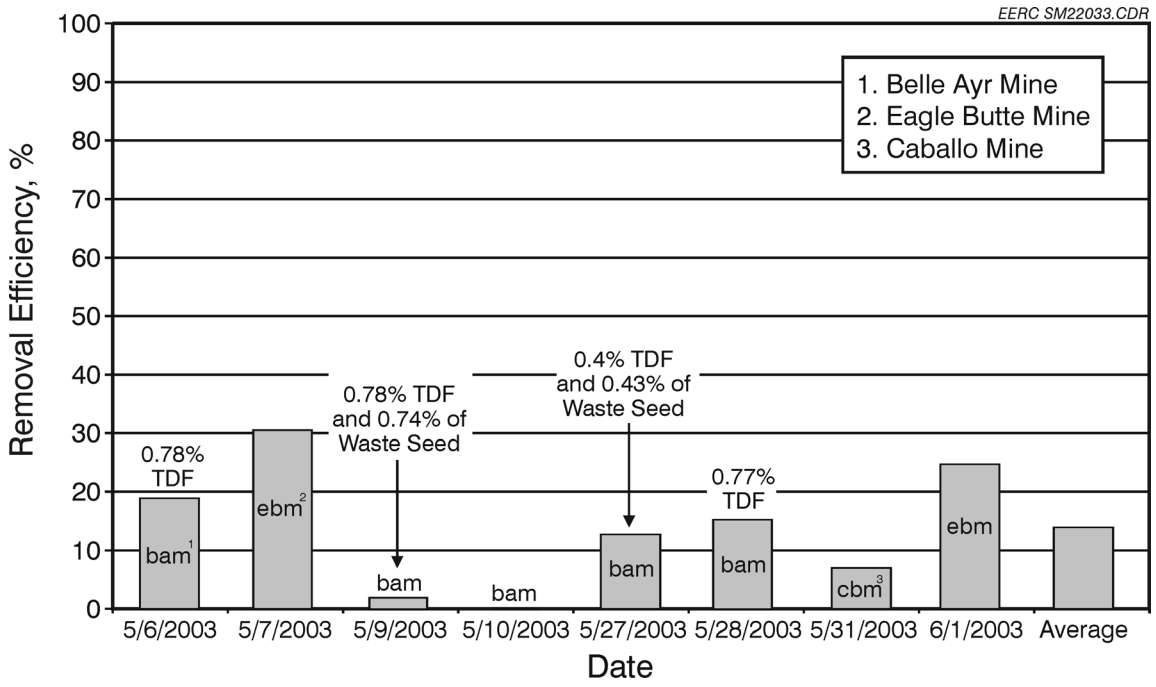

Figure 3. Inherent mercury removal efficiency (baseline).

The carbon was fed with a K-Tron dual-screw feeder at a starting rate of 24 kg of carbon sorbent/million m^3 (1.5 lb of carbon sorbent/million acf), which corresponds to 0.3 kg/hr (0.65 lb/hr) at an air-to-cloth (A/C) ratio of 3.0 m/min (10 ft/min). The carbon feeder was located in the enclosed area of the AHPC below the hopper. From the screw feeder, the carbon was introduced into an Air-Vac eductor that was driven by compressed air. From the outlet of the eductor, the carbon was then transported approximately 6.1 m (20 ft) through 0.019-m (0.75-in.) stainless steel tubing to the elbow location of the inlet piping. Approximately 0.9 m (3 ft) of straight tubing extended inside the duct so that the carbon was injected directly upstream at a single point in the center of the 0.610-m (24-in.)-diameter inlet pipe.

The feeder was calibrated prior to the start of carbon injection. In addition, the weight of carbon added during a day was divided by the time of injection to provide an average feed rate. According to the calibration data and weight-of-added-carbon data, the feeder appeared to provide a very steady and consistent feed rate within a few percent of the target rate. The carbon feed and injection system worked very well, and there were no problems with inconsistent feeding or plugging of the feeder or injection system.

By adjusting the flue gas flow rate through the AHPC unit, ranging from 122 to 285 m^3/min (4320 to 10,080 acfm), the velocity through the filter bags was varied from 2 to 4 m/min (6 to 14 ft/min), while the carbon injection rate was maintained at 0.3 kg/hr (0.65 lb/hr). As the flow rate and filtration velocity increase, the corresponding in-flight mercury adsorption would be expected to be reduced because of the decreasing contact time between mercury and the sorbent in-flight. However, at higher flow rates, less sorbent is collected in the electrostatic

precipitation zone and more sorbent is collected on the filter bags, which should result in improved mercury removal. Also, since the carbon injection rate was maintained at the 0.3 kg/hr (0.65 lb/hr) during the testing time, the carbon-to-mercury ratio was reduced when the flue gas flow rate was increased. The carbon injection concentration was in the range of 17–40 kg/Macm (1.07–2.51 lb/Macf) during this time. Increasing the flue gas flow rate at the 0.3 kg/hr (0.65 lb/hr) carbon injection rate resulted in 1) reduced carbon-to-mercury ratio, 2) decreasing contact time between mercury and the activated carbon in flight, and 3) more activated carbon on the filter bags. The first two factors would impede mercury removal with the AHPC, while the third one would promote mercury capture. The resulting mercury collection efficiencies were the results of these three factors. The calculated mercury removal efficiencies were determined based on the 9.85 μg/m^3 total mercury concentration in the flue gas and the time-average mercury emissions at the AHPC outlet during the test period. The flow rate tests were completed on May 14, 15, and 20, 2003. Since these were short-term tests, the results (Figures 4–6) demonstrate the effect of filtration velocity on mercury control without interference from the variations of mercury species concentration in the flue gas. Better mercury removal was seen at the lower filtration velocities. Since mercury capture on the filter bag surface is more dominant than mercury in-flight adsorption, the measured decreasing mercury collection efficiencies with increasing filtration velocity were likely caused by the reduced carbon-to-mercury ratio.

On May 14, 2003, the AHPC was initially operated at 3 m/min (10 ft/min) of filtration velocity with 24 kg of carbon sorbent/million m^3 (1.5 lb of carbon sorbent/million acf) injection concentration, with an average mercury collection efficiency of 55.3%. The flue gas flow rate

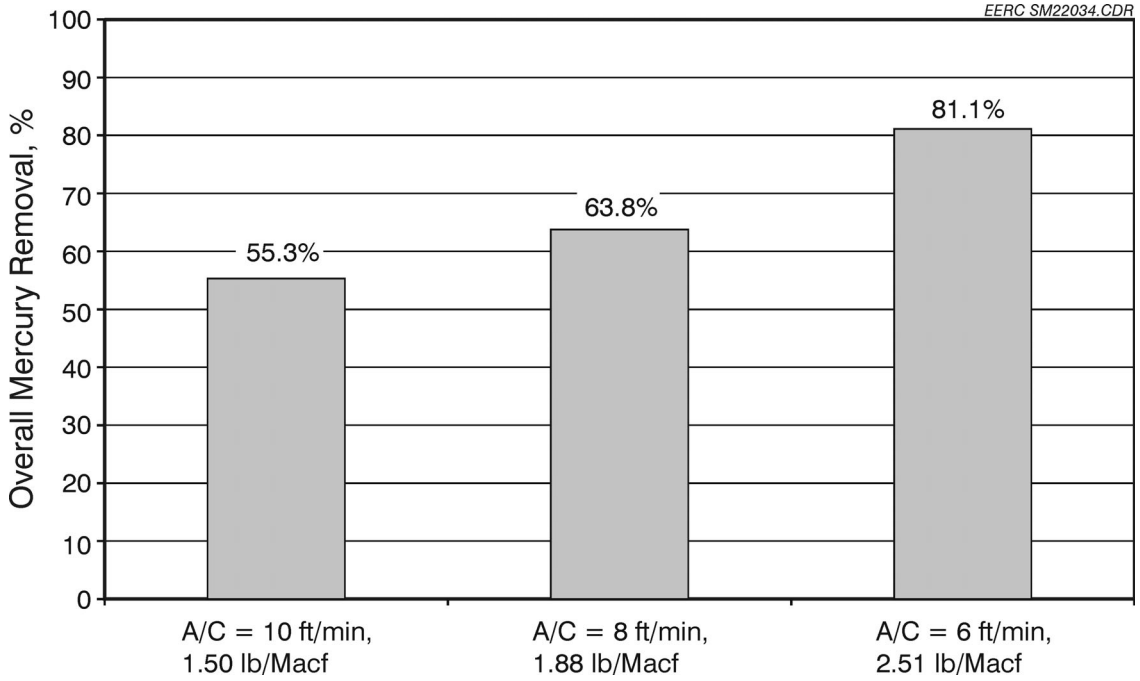

Figure 4. The effect of filtration velocity on mercury removal (May 14, 2003).

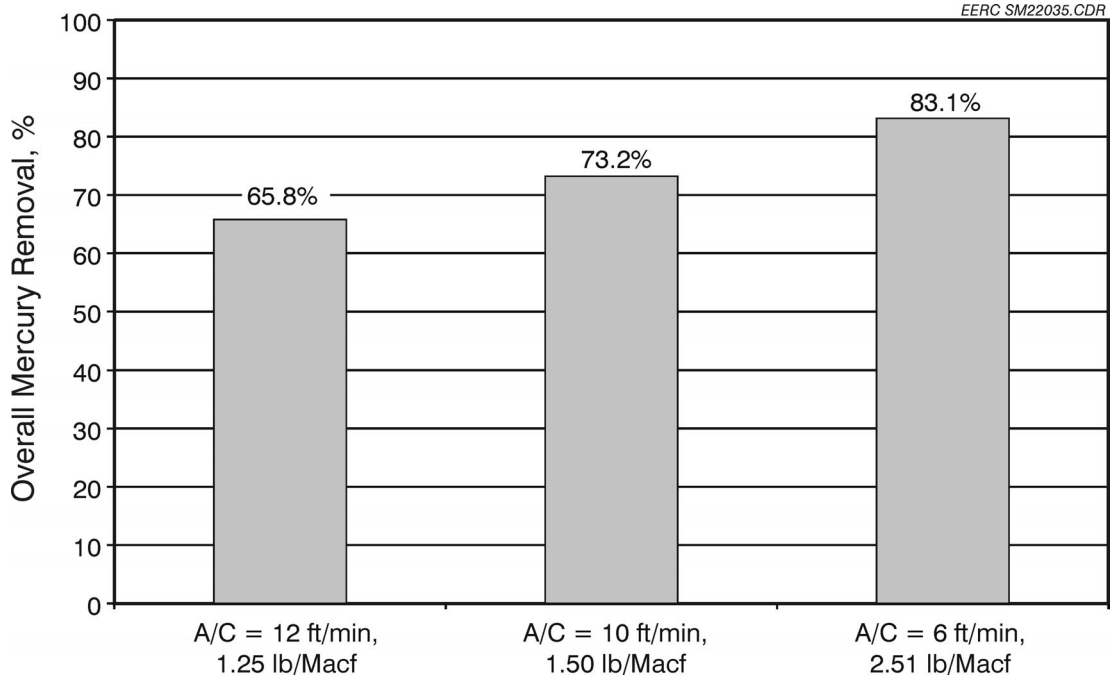

Figure 5. The effect of filtration velocity on mercury removal (May 15, 2003).

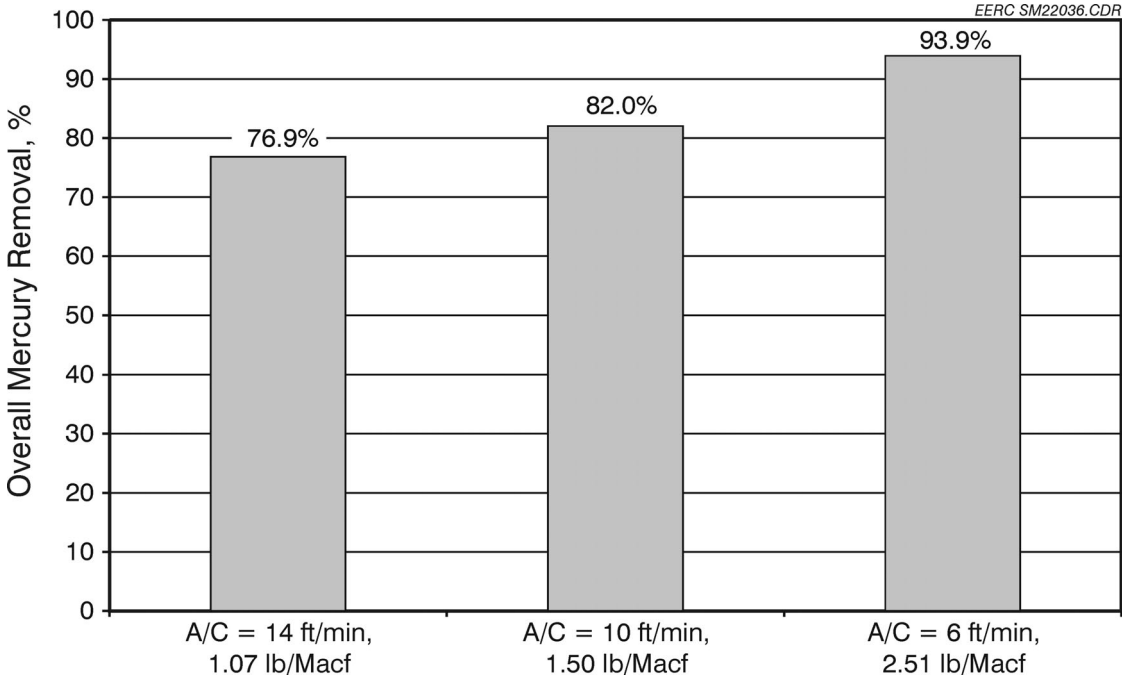

Figure 6. The effect of filtration velocity on mercury removal (May 20, 2003).

through the AHPC was then reduced to 163 m^3/min (5760 acfm) for a few hours and further reduced to 1317 m^3/min (4320 acfm) for the rest of the day (8 hours), resulting in decreased filtration velocities of 1.8 and 2.4 m/min (6 and 8 ft/min) with corresponding carbon injection concentrations of 30 and 40 kg/Macm (1.88 and 2.51 lb/Macf), respectively. The overall mercury removal increased to 63.8% at 2.4 m/min (8 ft/min) and further to 81.1% at 1.8 m/min (6 ft/min). The higher mercury removal at the reduced filtration velocity is likely the result of the raised carbon-to-mercury ratio. However, better contact of mercury with the carbon on the perforated plates is also expected of the reduced filtration velocity which should also contribute to better mercury removal.

On May 15, 2003, the AHPC was operated at filtration velocities of 1.8, 3.0, and 3.7 m/min (6, 10 and 12 ft/min). The overall mercury collection efficiency increased with decreasing filtration velocity from 65.8% at 3.7 m/min (12 ft/min) to 73.2% at 3 m/min (10 ft/min) to 83.1% at 1.8 m/min (6 ft/min). The better mercury removal at the 3 m/min (10 ft/min) and 1.8 m/min (6 ft/min), compared to May 14, 2003, may be the result of more oxidized mercury in the flue gas on May 15 (Figures 1 and 2).

To further confirm the filtration velocity effect on mercury removal with carbon injection, another test was conducted on May 20, 2003. Approximately 70 tons of TDF and 70 tons of waste seed (Table 6) were cofired with the Belle Ayr coal on May 19–20, which resulted in more oxidized mercury in the flue gas. The total mercury collection efficiency was 76.9% at 4.3 m/min (14 ft/min) and increased to 82% at 3 m/min (10 ft/min) and 93.9% at 1.8 m/min (6 ft/min), again showing the beneficial effect of reducing filtration velocity on mercury removal in the AHPC. The higher mercury removal in this test compared to the previous two tests was likely because of the high percentage of oxidized mercury and somewhat lower total mercury vapor in the flue gas (Figures 1 and 2).

All three individual tests showed that reducing the filtration velocity at a fixed carbon injection rate of 0.3 kg/hr (0.65 lb/hr) improved mercury removal in the AHPC. This improvement is likely the result of both increased carbon-to-mercury ratio and better contact between mercury and carbon on the perforated plates.

3.6 Effect of the Sorbent In-Flight Time on Mercury Removal

Mercury removal is divided into three stages in the AHPC configuration: 1) in-flight adsorption by carbon, 2) adsorption by carbon collected on the perforated pates, and 3) fixed-bed adsorption on the filter bag surface. The in-flight mercury adsorption is limited because of a short contact time between the bulk gas-phase mercury in the flue gas and the in-flight carbon. The activated carbon collected on the perforated plates would continue mercury capture. Its contribution to overall mercury removal may be somewhat greater than the in-flight mercury capture because of the following factors: 1) longer residence time of activated carbon in the AHPC unit, approximately 30 min or longer, depending on the plate-rapping and bag-cleaning intervals; 2) extended contact time between mercury in the flue gas and sorbent on the perforated plates due to the local recirculation of the flue gas; and 3) enhanced mass transfer from the bulk gas-phase mercury to the carbon surface since the flue gas flows straight toward the perforated plate instead of in a parallel flow with the plates across the conventional ESP.

The fixed-bed adsorption on the filter bags is capacity-limited rather than mass transfer-limited. To further understand the detailed mechanisms of mercury adsorption in the AHPC with carbon injection, the carbon injection location was switched from the normal inlet elbow location to the closer inlet transition zone on June 2–3, 2003, while other operating parameters were the same: 3 m/min (10 ft/min) filtration velocity and 0.3 kg/hr (0.65 lb/hr) FGD carbon injection rate. Subsequently, the in-flight time of activated carbon was reduced by roughly 50%. The measured mercury overall collection efficiencies, however, were similar 58.4%–60.9% (Figure 7), which was within measurement error. The slight dependence of mercury capture on sorbent in-flight time implies the kinetic characteristics of the sorbent are more important than the sorbent capacity for mercury capture in flight and the extended sorbent flight time does not benefit mercury removal significantly. At the end of this test, the ESP power was shut down when carbon was injected from the inlet transition zone, resulting in a 20% increase of mercury removal. The additional gain was because all of the activated carbon was uniformly collected on the filter bags. This indicates that in-flight mercury capture is not a dominant capture mechanism.

3.7 Effect of Carbon Injection Rate on Mercury Removal

On May 12, 2003, when the FGD carbon injection rate was set as 0.3 kg/hr (0.65 lb/hr), corresponding to 24 kg/Macm (1.50 lb/Macf), the mercury removal efficiency was 71.6%

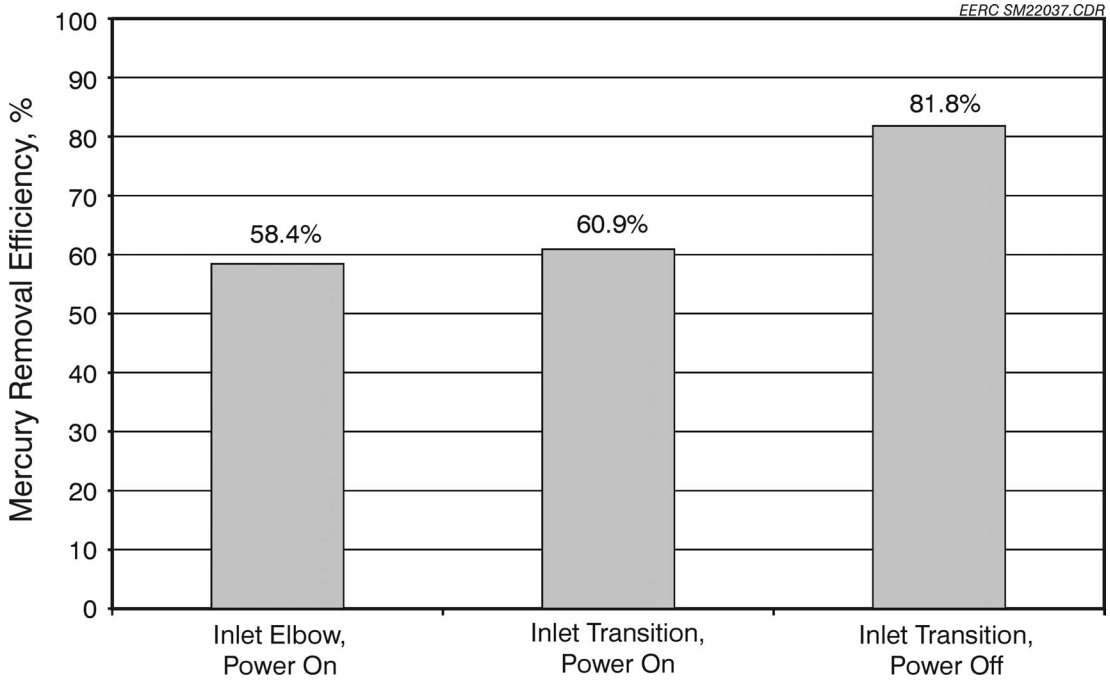

Figure 7. The effect of the sorbent in-flight time on mercury removal (June 2–3, 2003) (0.65 lb/hr FGD, A/C 10 ft/min).

(Figure 8). While keeping the filtration velocity constant at 3 m/min (10 ft/min), the FGD carbon injection rate was then doubled to 0.6 kg (1.3 lb/hr), corresponding to 48 kg/Macm (3.01 lb/Macf), while other operating parameters were the same. The overall mercury collection efficiency, however, only slightly increased to 74.0% (Figure 8), which was somewhat surprising. A possible reason for the marginal benefit gained from the double carbon injection rate is that the effectiveness of activated carbon to capture mercury may be limited by the amount of HCl in the flue gas.

3.8 Effect of ESP Power on Mercury Removal

During the 1-month test, the ESP power was shut down temporarily several times to confirm the maximum efficiency of the FGD activated carbon on mercury control at different filtration velocities. The AHPC unit was operated as a PJBH with a bag-cleaning interval of 60 min, the same as the AHPC operation. Because of the unique geometric configuration of the AHPC, the flue gas into the AHPC unit is evenly distributed among all of the filter bags when operated in pulse-jet mode.

However, the side inlet of the AHPC and the larger spacing between bag rows make gas distribution in the AHPC without ESP power more ideal than in a conventional PJBH. Therefore, a comparison of mercury removal in the AHPC with and without ESP power is not the same as a comparison between the AHPC and a conventional PJBH. A summary of mercury removal efficiencies with the ESP power on and off (Figure 9) shows consistently higher removal

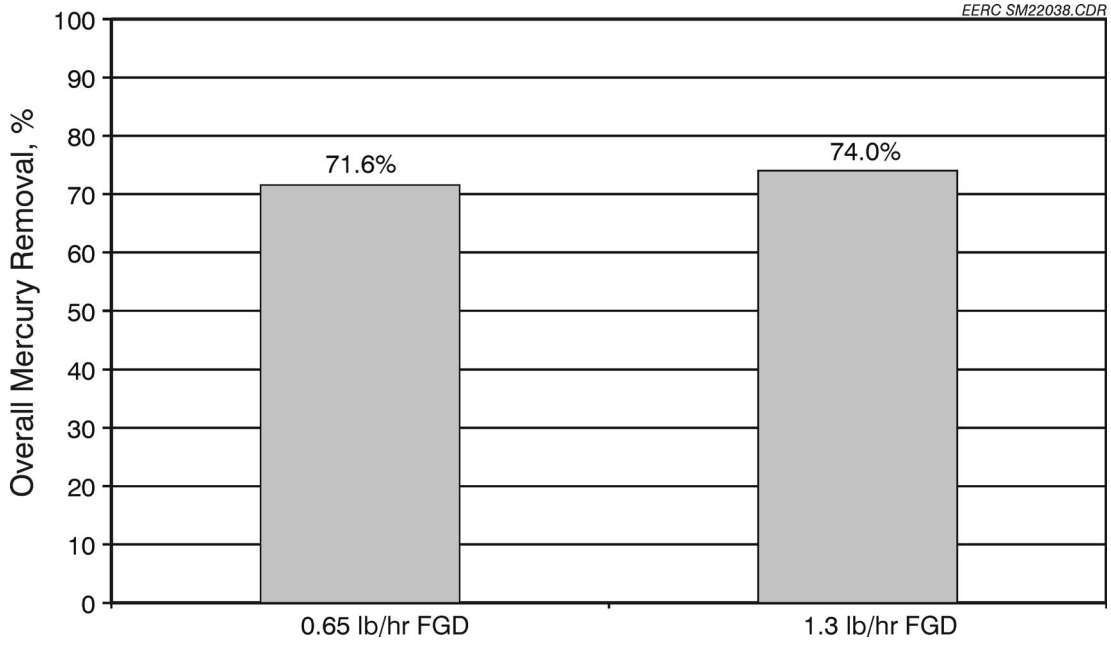

Figure 8. The effect of sorbent injection rate on mercury removal (May 12, 2003) (A/C of 10 ft/min with power on).

efficiencies when the ESP was shut down, which suggests better or more uniform gas–solid contact. The pressure drop across the AHPC unit, however, was dramatically increased when the ESP power was off, reaching as high as 13 in. W.C. (3.3 kPa) depending on filtration velocity.

3.9 Effect of Iodine-Impregnated Carbon on Mercury Removal

On May, 17 2003, IAC was injected into the AHPC unit at a injection rate of 0.2 kg/hr (0.46 lb/hr), corresponding to 17 kg/Macm (1.06 lb/Macf), to evaluate its effectiveness on mercury removal with the AHPC. The overall mercury collection efficiency, however, was only 57.3% (shown in Figure 10), which is lower than expected. A possible reason is that the particle size of the IAC is −200 mesh (less than 74 μm), which is larger than the Norit FGD carbon whose size is −325 mesh (less than 45 μm), according to supplier information. The larger-sized IAC results in a less efficient usage of the activated carbon. To further evaluate the IAC, the ESP power was shut off for a short time. However, the efficiency only increased to 64.5%, indicating a lower mercury capture than that of the FGD carbon.

3.10 Summary of AHPC Mercury Control with FGD Activated Carbon and Comparison with Other Control Technologies

During the 1-month long-term test, Norit FGD carbon was tested under several different conditions. Overall collection efficiencies are summarized in Figure 11, showing the average results for the 1-month test. Where multiple tests were completed, the error bar represents the highest and lowest efficiencies achieved for each specific test condition. At the test of 3 m/min

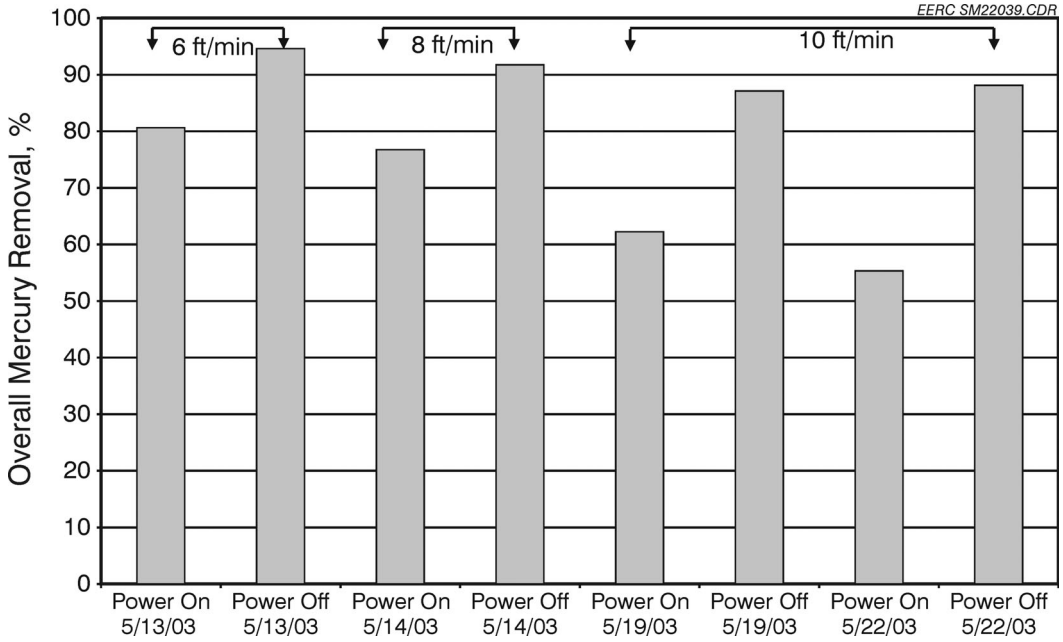

Figure 9. The effect of ESP power on mercury removal.

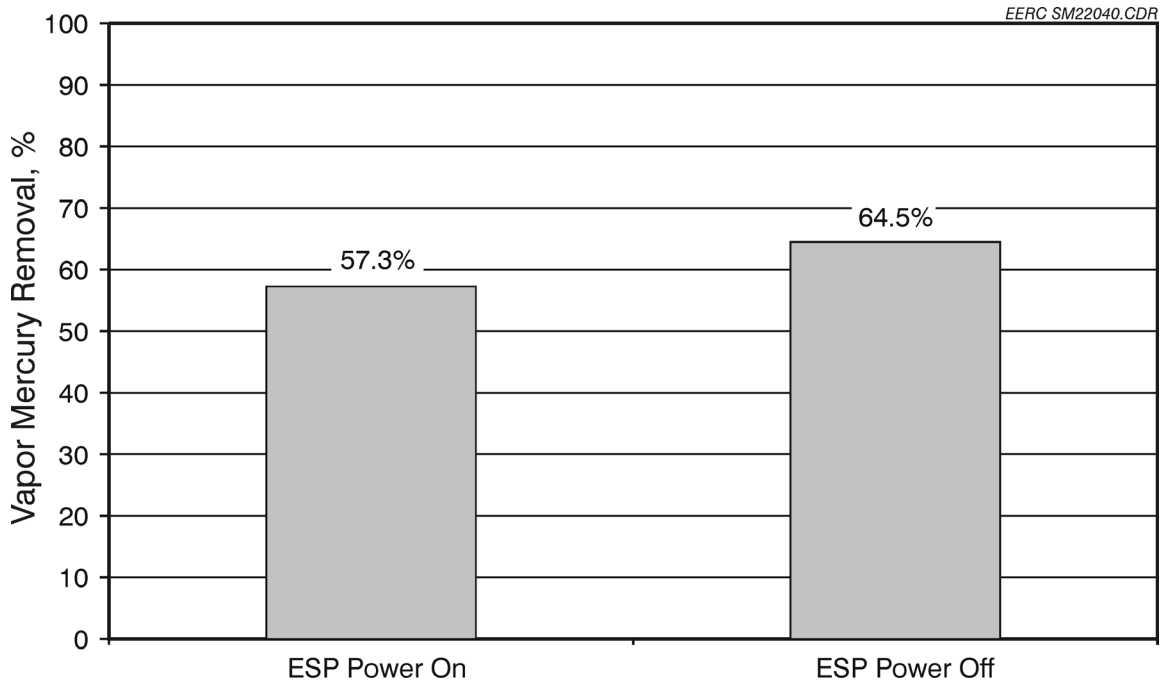

Figure 10. The effect of ESP power on mercury vapor removal based on CMM data at Big Stone (May–June 2003) (0.46 lb/hr IAC and A/C of 10 ft/min).

(10 ft/min) filtration velocity and 0.3 kg/hr (0.65 lb/hr) carbon injection rate, which was the condition for much of the 1-month test, the average mercury removal efficiency was 70% with a range from 55.1% to as high as 90.0%. With the decreasing filtration velocities through the filter bags, the AHPC demonstrated higher mercury removal likely due to the higher carbon concentration in the flue gas. The highest mercury collection efficiency was 93.9% at 2 m/min (6 ft/min) filtration velocity and 0.3 kg/hr (0.65 lb/hr) carbon feed rate, which was the highest achieved in the long-term field-scale test. By doubling the carbon feed rate at 3 m/min (10 ft/min) test, mercury removal increased marginally from 71.6 % to 74.0%, which was similar to the previous test in August 2002. The experimental data also showed that sorbent in-flight time was not the critical factor for AHPC mercury control with Norit FGD carbon injection, indicating that mercury was mainly removed on the filter bags or the perforated plates.

In Figure 12, the mercury removal efficiencies are plotted as a function of Norit FGD carbon injection concentrations for different air pollutant control devices, including ESPs, filter filtration (FF), COHPAC (compact hybrid particulate collector), and AHPC for both bituminous and PRB subbituminous coals. The related information such as mercury content in the coal and mercury species in the flue gas for the different testing units are summarized in Table 8. All of the results for the other control technologies were obtained from published conference papers (1–4). For ESPs, high carbon injection concentration (> 318 kg/Macm [20 lb/Macf]) was required to achieve efficient mercury control because the in-flight mercury capture within an ESP

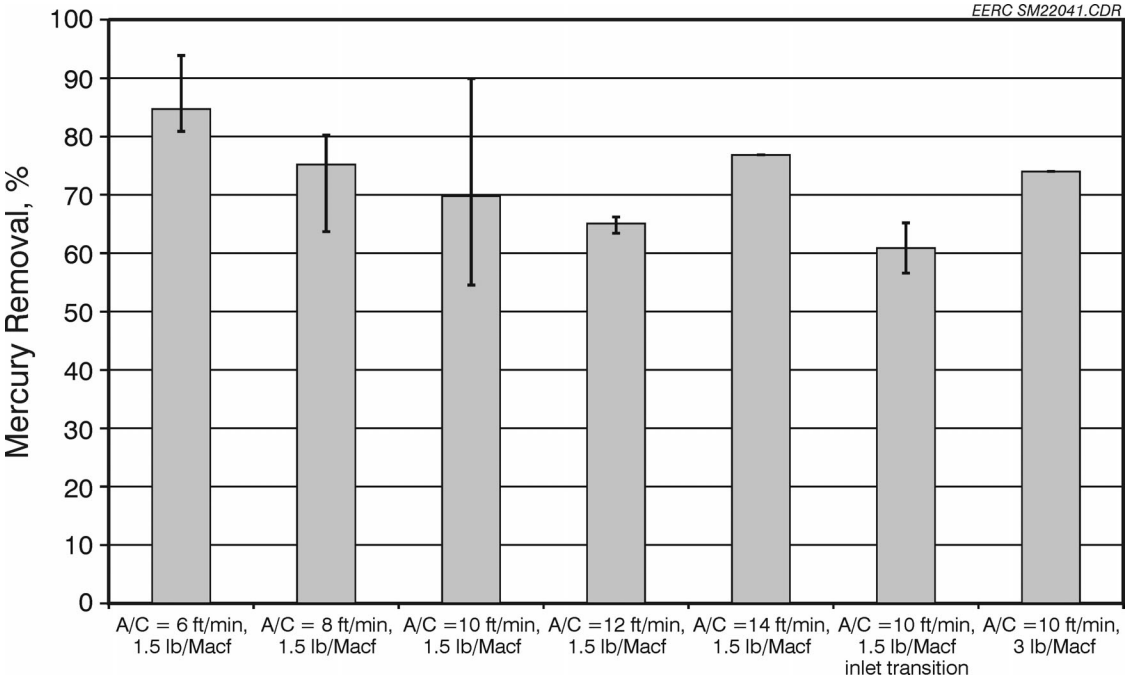

Figure 11. Summary of AHPC mercury control with Norit FGD carbon.

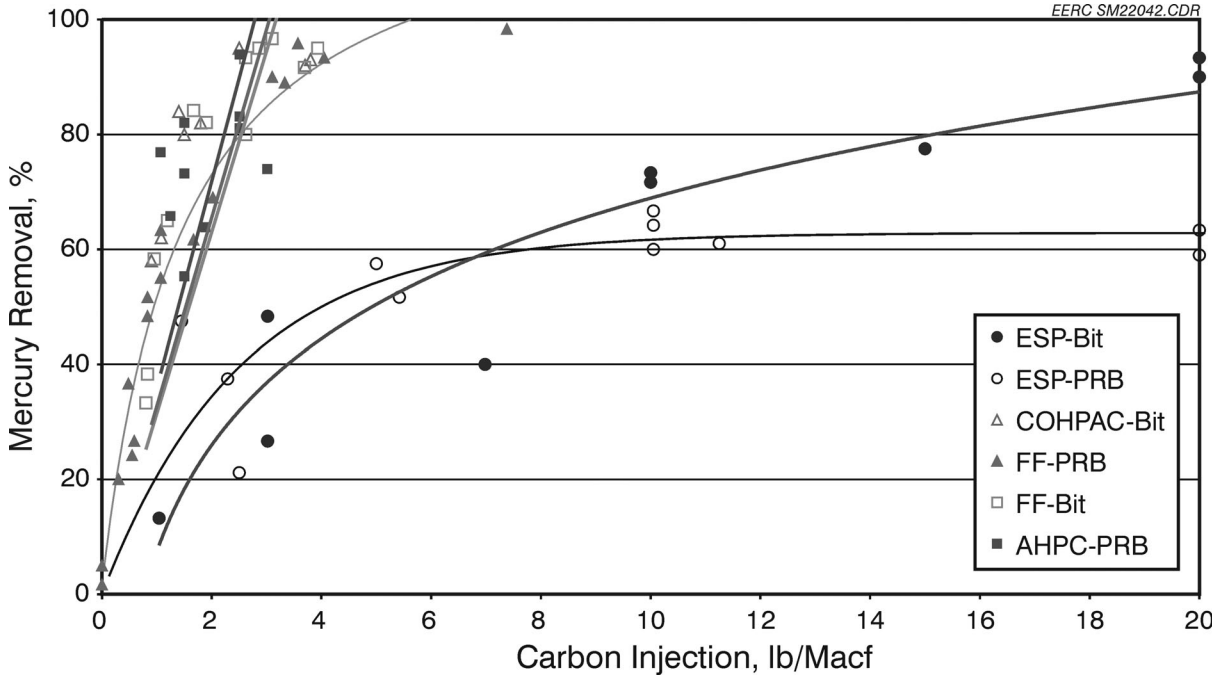

Figure 12. Comparison of AHPC mercury control with Norit FGD carbon with other control options.

is mass transfer-limited. AHPC, COHPAC, and FFs all demonstrated high mercury removal efficiencies at low carbon injection concentrations ranging from 16 to 64 kg/Macm (1 to 4 lb/Macf). COHPAC was only tested in a bituminous coal combustion flue gas with more Hg^{2+} than Hg^0, which may be easier to control. For the test at Big Stone, however, the inlet mercury was 60% elemental which is more difficult to control. The data clearly show the AHPC is superior to an ESP for mercury control. The mercury collection efficiencies for the AHPC and an FF or COHPAC appear to be similar.

A high level of caution should be exercised when comparing mercury removal results among different technologies at different plants. These AHPC results as well as reported longer-term data for other technologies show significant variability in the mercury speciation and level of control achieved for tests at a given plant. While the data do allow for general comparisons among different technologies, the most valid comparisons would be concurrent side-by-side testing at the same plant under constant conditions.

4.0 CONCLUSIONS

- The inlet mercury vapor concentration in the flue gas during the May 2003 test ranged from 4.98 –10.6 μg/m^3 with 20% to 70% Hg^0. The variation in mercury speciation is likely caused by varying coal as well as cofiring TDF and waste seeds.

Table 8. Information on Different Control Devices

Sampling Site	Coal	Control Device	Hg^p, μg/m^3	Hg^{2+}, μg/m^3	Hg^0, μg/m^3
Gaston Station	Bituminous, 0.05% Cl, 0.06–0.17 μg/g Hg	COHPAC	0.2	6.4	4.6
Pleasant Prairie	Subbituminous Powder River Basin, 0.0015% Cl, 0.099 μg/g Hg	ESP	1.0	1.7	14.7
Brayton Point	Bituminous, 0.08% Cl, 0.05 μg/g Hg	ESP	1.5	2.53	1.18
Gaston Station	Bituminous, 0.05% Cl, 0.06–0.17 μg/g Hg	FF	0.2	6.4	4.6
EPRI	Subbituminous Powder River Basin	FF	NA	NA	NA
Big Stone	Subbituminous Powder River Basin, 0.083 μg/g Hg, 0.0022% Cl	AHPC	1.98	3.08	7.68

- At low carbon feed concentrations, in the range of 16–48 kg/Macm (1–3 lb/Macf), the AHPC demonstrated high overall mercury collection efficiencies, from 65% to 95%.

- On further increasing carbon concentration in the flue gas, however, only a marginal benefit was seen on mercury removal, possibly due to the low level of HCl in the western subbituminous coal flue gas.

- Comparing with other published results, the AHPC clearly demonstrated higher mercury removal efficiencies than ESPs under the same FGD carbon feed rate. The overall mercury removal of the AHPC was similar to a baghouse or COHPAC.

5.0 REFERENCES

1. Starns, T. et al. Results of Activated Carbon Injection Upstream of Electrostatic Precipitators for Mercury Control. Combined Power Plant Air Pollutant Control Mega Symposium, May 19–22, 2003, Washington, D.C.

2. Bustard, C.J. et al. Full-Scale Evaluation of Sorbent Injection for Mercury Control on Coal-Fired Power Plant. Presented at Air Quality III, September 12, 2002, Arlington, VA.

3. Bustard, C.J. et al. Results of Activated Carbon Injection for Mercury Control Upstream of a COHPAC Fabric. Combined Power Plant Air Pollutant Control Mega Symposium, May 19–22, 2003, Washington, D.C.

4. Durham, M.D. et al. Field Test Program to Develop Comprehensive Design, Operating, and Cost Data for Mercury Control System on Non-Scrubbed Coal Fired Boilers. Presented at the A&WMA 2001 Annual Conference & Exhibition, Orlando, FL, June 24–28, 2001.

6.0 MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR – TASK 6 ADD-ON

6.1 Introduction

The current mercury control with the AHPC involved testing of sorbent injection upstream of the AHPC to demonstrate 90% total mercury control. This modification will test the application of the AHPC to capture mercury in flue gases that contain low levels of acid gases typical of lignite and spray dryer baghouse applications. Two technologies will be tested: mercury oxidation and an adsorbent.

Additional efforts to the existing scope of work involve testing advanced Hg oxidation and control agents for spray dryer and baghouse applications for control of elemental mercury emissions typical of North Dakota lignite-fired systems. The tasks include 1) Hg oxidation upstream of a lime-based spray dryer AHPC combination in order to control mercury emissions

using dry scrubbers and 2) field-testing of the W.L. Gore mercury adsorbent technology at a North Dakota power plant using a slipstream baghouse.

6.2 Background

Testing at the EERC has been conducted through the addition of oxidizing agents to the fuel that allow for the enhancement of activated carbon sorbent properties for mercury emission control. The addition of salts has been shown to oxidize elemental mercury, as shown in Figure 13. The results of the addition of materials with coal at very low levels along with the activated carbon injection (ACI) upstream of an ESP+FF, AHPC, and ESP only are illustrated in Figure 14. The first part of the figure shows the baseline data of mercury emission ranging from 9 to 12 μg/Nm^3 with 80% to 90% of the mercury being in elemental form. The second case is ACI followed by the addition of Additive 2, showing a reduction in mercury emissions by 90%. The third case is the AHPC that produced nearly 90% control efficiency. The final ESP-only case indicated up to 90% control. The control efficiency for the ESP-only case shows significant potential improvement over past results obtained with the ESP-only case illustrated in Figure 14. This technology also has the potential to improve the dry FGD baghouse control efficiency (5).

Recently, short-term testing conducted at Stanton Station by Great River Energy and EPRI indicated the injection of chloride salts resulted in increased Hg oxidation in the flue gas (6). Mercury oxidation of up to 70% was observed at a salt injection rate that resulted in an HCl concentration of 110 ppm in the flue gas. In addition, the injection of salt resulted in enhanced removal of mercury across the spray dryer absorbers (SDA) baghouse with removal efficiencies

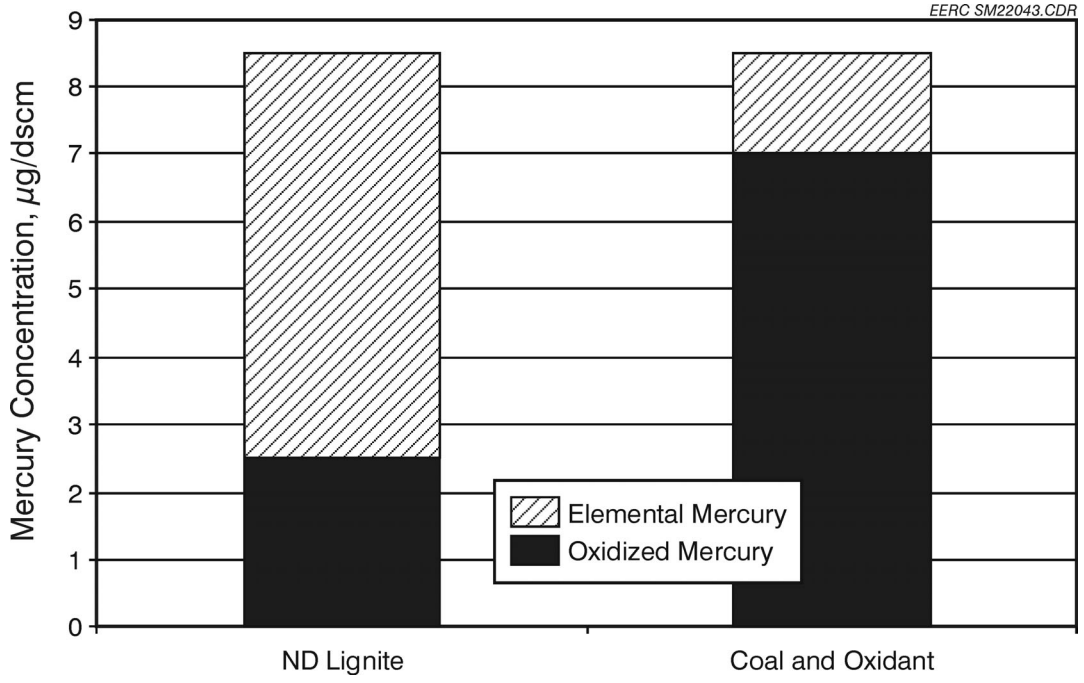

Figure 13. Impact of addition of chlorine-containing additive with fuel on the proportion of elemental and oxidized mercury.

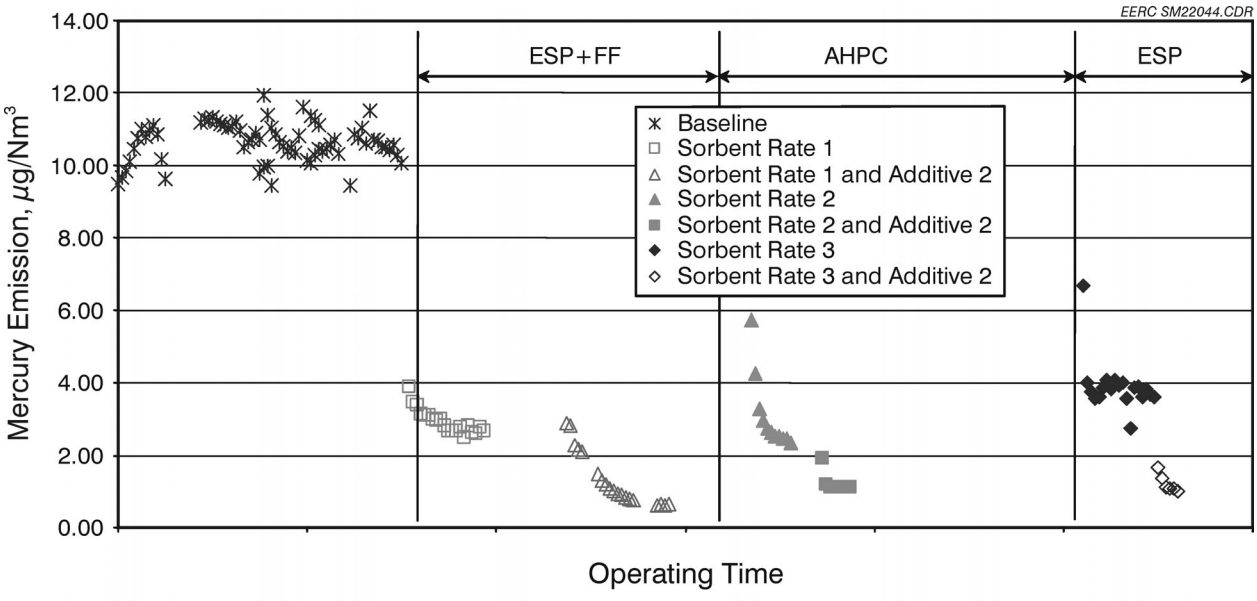

Figure 14. Mercury emissions for activated carbon injection combined with additives.

of up to 50% without ACI. Additional testing at this lignite-fired unit also showed that the use of ACI upstream of the SDA–FF system provided significantly better performance when small amounts of sorbent enhancement additive (SEA) were added in the furnace. Therefore, the use of these additives upstream of the APCD can improve Hg capture both by conversion of the Hg^0 to the more easily removed Hg^{2+} forms and by enhancing the reactivity of Hg^0 with activated carbons (ACs) and other sorbents. Testing at Stanton Station also indicated increased pressure drop across the air preheater as a result of injecting the salt materials. This is of significant concern since the chlorine-containing species can react with alkali and alkaline-earth elements present in the ash to produce low-melting-point phases that contribute to the deposition problem. Efforts must be conducted to determine the minimum quantity of oxidizing agent necessary to oxidize mercury in order to minimize the deposition problems.

6.3 Experimental

6.3.1 Objective and Goals

The goal is to develop advanced innovative mercury control technologies to reduce mercury emissions by 50% to 90% in flue gases typically found in North Dakota lignite-fired power plants at costs of ½ to ¾ of current estimated costs. Power plants firing North Dakota lignite produce flue gases that contain >85% elemental mercury that is difficult to collect. The specific objectives are focused on determining the feasibility of the following technologies: mercury oxidation for increased mercury capture in dry scrubbers and use of mercury adsorbents within a baghouse.

6.3.2 Planned Scope of Work

Subtask 6.1 – Mercury Control with Spray Dryer Scrubber Combined with AHPC or Baghouse

Pilot-Scale SDA Refurbishment. A pilot-scale SDA will be modified and installed on the EERC PTC to simulate the SDAs used in some North Dakota power plants.

Elemental Mercury Oxidation Additives. Potential Hg^0 oxidation additives will be evaluated using the PTC equipped with the refurbished SDA and AHPC. Pilot-scale testing will involve a North Dakota lignite coal with short-term (1–2 hr) screening tests of several oxidation additives including chloride compounds (e.g., sodium chloride, hydrogen chloride, calcium chloride) and potassium iodide, followed by longer-term (8–10-hr) evaluations of two or more of the most promising additives. In most cases, the additives will be blended with the coals. Gaseous HCl will be injected into the PTC.

Hg^0 and total Hg levels will be measured on a nearly continuous basis using a CMM at the inlet and outlet locations of the SDA. Slaked lime slurry feed and the SDA product solids will be analyzed for Hg content. Additive blend ratios and injection rates will be varied to evaluate the effectiveness of additives to oxidize Hg^0. Economic analyses will be performed for the additives that are most effective.

Subtask 6.2 – Field Testing of Sorbents and Gore Technology

This task will test how effectively Hg can be captured by using a sorbent-based technology and the recently announced Gore technology in conjunction with a PJBH at a power plant in North Dakota. The Gore technology consists of a proprietary baghouse insert downstream of the FF that has shown a high potential to control Hg. An existing baghouse will be skid-mounted and transported to a power plant in North Dakota and connected in slipstream fashion to allow for testing actual flue gases. Additions to the existing baghouse unit for remote field application will include a control room for remote operation, piping and flanges for connection to plant ductwork, a variable-speed fan, and a sorbent injection system for Hg control. The pulse-jet baghouse can be operated for much longer periods of time than can be conducted with the pilot-scale AHPC.

The skid-mounted baghouse will be installed downstream of an existing particulate control device such as an ESP at a North Dakota power plant. The Gore technology will be installed, tested, and monitored for Hg capture effectiveness for 4 months. For these measurements, EPA Method 101A will be used to determine the total Hg (only) removed across the baghouse system.

6.4 Results and Discussion

Pilot-Scale SDA Refurbishment. The following are design considerations that are being examined:

- Three types of spray atomizers are under consideration: two-fluid pneumatic atomization nozzle, sonic atomizer, or spinning disc.

- Two-fluid atomizer: compressed air atomizes liquid stream; laboratory or pilot scale.

- Sonic atomizer: liquid stream over a surface vibrated at ultrasonic frequencies; fine droplets at low flow rates.

- Spinning disc conventional; used on large-scale SDAs.

- Enough residence time in the vessel for complete evaporation and dry powder product.

- Avoid deposition of wet materials on the wall of dryer.

- Well-mixed flow pattern in the vessel.

The key design parameters being considered include:

- For a typical lignite fired in the PTC with coal S% = 1.1%, a feed rate of 75 lb/hr produces an SDA inlet gas flow rate of 218 acfm at 300°F, SO_2 = 1148 ppmv.

- Lime slurry flow rate of 0.17 lb/min with 20% solid content, stoichiometric ratio 1, SO_2 removal efficiency ~80%.

- Adiabatic gas temperature drop 44°F.

- SDA vessel I.D. = .76 m (2.5 ft), height = 2.2 m (7.2 ft), residence time ~10 sec.

- Gas relative humidity increase from inlet 2.6% to outlet 6.1%.

An existing Micron-motion (for slurry flow measurement) and a feed pump have been secured. NORIT Americas, Inc., DARCO® FGD and Barneby & Sutcliffe activated carbons have been ordered for testing mercury removal using the new spray dryer (Figure 15) in combination with a baghouse.

Recently, a commercially available SD has been identified that may meet the objectives of this project. The SD is available from Niro Inc. and is called the Production Minor Spray Dryer. A price quote has been requested, and we will further evaluate whether this is the best approach.

Elemental Mercury Oxidation Additives. Currently, literature and other information on various types of elemental mercury oxidation agents are being evaluated. In addition, the minimum additive type and rate necessary to oxidize elemental mercury are being examined to minimize ash deposition and plugging of the air preheater.

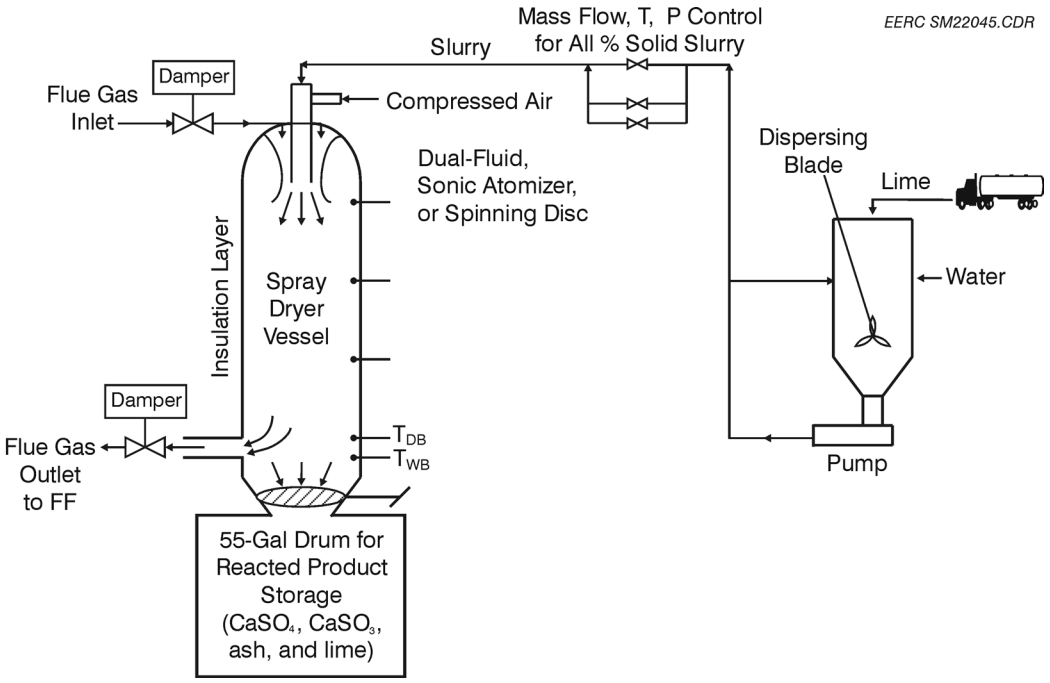

Figure 15. Schematic diagram of SD system.

Subtask 6.2 – Field Testing of Sorbents and Gore Technology

The existing baghouse has been removed from the EERC demonstration facility. A diagram of the existing baghouse is shown in Figure 16. We are currently finalizing a plan for modification to accommodate 6-in.-diameter bags between 2.4 and 3.7 m (8 and 12 ft) in length. The modification will is expected to include the installation of a chamber wall and splitting the bag compartment into ¼ and ¾ sections. The layout of the baghouse, fan, and other control equipment is ongoing. Currently, we are looking at two possibilities. The first is to create modular equipment and a control room that can be hauled on a flatbed to a test site and set up on concrete pads installed prior to arrival at the host site. The second option is to purchase a semitrailer and modify it to house the control room and equipment for transportation and use at the site. Once the modification plan and equipment layout have been finalized, the fan and other equipment will be ordered. Construction activities will begin during the last 2 weeks in July and will take approximately 4 weeks to complete.

6.5 Future Work – Next Quarter

- An SDA system will be purchased or the existing pilot-scale SDA will be modified to simulate SDAs used in some North Dakota power plants.

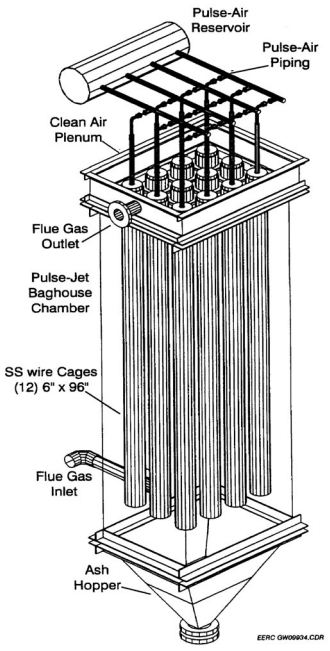

Figure 16. Existing baghouse at the EERC that will be modified.

- Mercury removal effectiveness of adding potential Hg oxidizing agents (e.g., NaCl, HCl, $CaCl_2$, KI) upstream of the refurbished SDA will be evaluated using a 550,000-Btu/hr combustion system.

- A skid-mounted baghouse will be constructed.

6.6 References

5. Pavlish, J.H.; Holmes, M.J.; Benson, S.A.; Crocker, C.R.; Galbreath, K.C. Mercury Control Technologies for Utilities Burning Lignite Coal. In Proceedings of Air Quality III, Mercury, Trace Elements, and Particulate Matter Conference; Arlington, VA, Sept 10–12, 2002; Energy & Environmental Research Center: Grand Forks, ND, 2002.

6. Chang, R.; Strohfus, M., *The Evaluation of Chemical Additives for Mercury Emission Control at Great River Energy*; Final Report submitted to the North Dakota Industrial Commission; Jan 2003.