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 original 5-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 scale-up 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.

The scope of work was modified to include an additional sixth task, initiated in April 2003. The objective of this task is to evaluate the mercury capture effectiveness of the AHPC when used with elemental mercury oxidation additives, a spray dryer absorber, and novel baghouse sorbent inserts downstream of the fabric filter.

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LIST OF ABBREVIATIONS AND ACRONYMS

AC	activated carbon
ACI	activated carbon injection
AHPC	advanced hybrid particulate collector
APCD	air pollution control device
ASTM	American Society for Testing and Materials
COHPAC	compact hybrid particulate collector
CMM	continuous mercury monitor
DOE	U.S. Department of Energy
EB	eastern bituminous
EERC	Energy & Environmental Research Center
EPA	U.S. Environmental Protection Agency
ESP	electrostatic precipitator
FF	fabric filter
FGD	flue gas desulfurization
IAC	iodine-impregnated activated carbon
LOI	loss on ignition
LOS	Leland Olds Station
NETL	National Energy Technology Laboratory
OH	Ontario Hydro
pc	pulverized coal
PCD	particulate control device
PJBH	pulse-jet baghouse
PRB	Powder River Basin
PTC	particulate test combustor
PTFE	polytetrafluoroethylene
SDA	spray dryer absorber
SEA	sorbent enhancement additive
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 scale-up 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 removal 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 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 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 and 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%–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 a day resulted in an increase in mercury collection to 68%. At the highest TDF rate seen in the August tests of 150–177 tons a 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 a 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 online 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), from 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 parts per million, 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. Another week of testing was planned for fall 2003, but Gore has made the recent decision to discontinue development of this technology. Instead, the last week of testing will focus on evaluation of the amount of mercury captured on the perforated plates compared to the total mercury capture across the AHPC.

Another 1-month field test was completed during 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%–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%. When compared 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).

The project scope of work has been modified to include an additional sixth task, initiated in April 2003. The objective of this task is to evaluate the mercury capture effectiveness of the AHPC when used with elemental mercury oxidation additives and a spray dryer absorber and with novel baghouse sorbent inserts downstream of the fabric filter. 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 a sorbent.

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 activities 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 mercury sorbent technology at a North Dakota power plant using a slipstream baghouse. Note that this is a change in the scope of work reflecting Gore's recent decision to cease its mercury research program.

The pilot-scale Niro spray dryer system installed on a 580-MJ/h (550,000-Btu/h) combustion system upstream of a baghouse was included in pilot-scale test runs accomplished in December 2003. Several additives and sorbents were tested for mercury control on a Center coal flue gas generated in the EERC particulate test combustor (PTC). DARCO® FGD activated carbon supplied by NORIT Americas, Inc.; was tested as a shakedown of the system. One mercury oxidation furnace additive for which the EERC is assessing intellectual property issues was evaluated under the spray dryer–fabric filter configuration.

An existing baghouse was modified and mounted on a flatbed trailer for ease of transport and installation at any location for slipstream field testing. It has been installed at Leland Olds station where mercury sorbent testing was performed during this quarter.

MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

1.0 INTRODUCTION

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 Topic 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, which is hosting 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. In Phase II of the DOE-funded AHPC project, a 2.5-MW-scale AHPC was designed, constructed, installed, and tested at the Big Stone Plant. For Phase III, further testing of an improved version of the 2.5-MW-scale AHPC at the Big Stone Plant was conducted to facilitate commercialization of the AHPC technology. The AHPC appears to have unique advantages for mercury control over baghouses or ESPs as an excellent gas–solid contactor.

An additional task designed to evaluate the mercury capture effectiveness of the AHPC when used with elemental mercury oxidation additives and a spray dryer absorber and with novel baghouse sorbent inserts downstream of the fabric filter was initiated in April 2003 with DOE funding. The project scope of work has been modified to incorporate this change.

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 activities 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.

1.1 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 1. The results of the addition of materials with coal at very low levels along with the activated carbon injection (ACI) upstream of an ESP + fabric filter (FF), AHPC, and ESP only are illustrated in Figure 2. The first part of the figure shows the baseline data of mercury emissions ranging from 9 to 12 $\mu g/Nm^3$, with 80%–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 showed potential improvement over past results obtained with the ESP-only case illustrated in Figure 2. This technology also has the potential to improve the dry flue gas desulfurization (FGD) baghouse control efficiency (1).

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 (2). 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 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

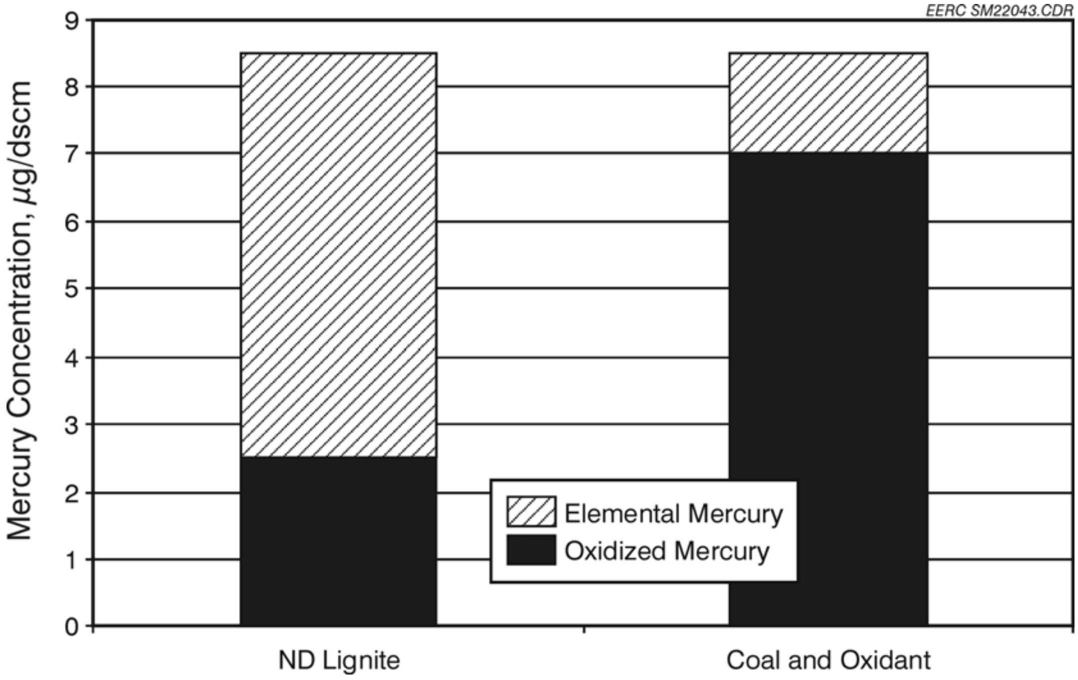

Figure 1. Impact of addition of chlorine-containing additive with fuel on the proportion of elemental and oxidized mercury.

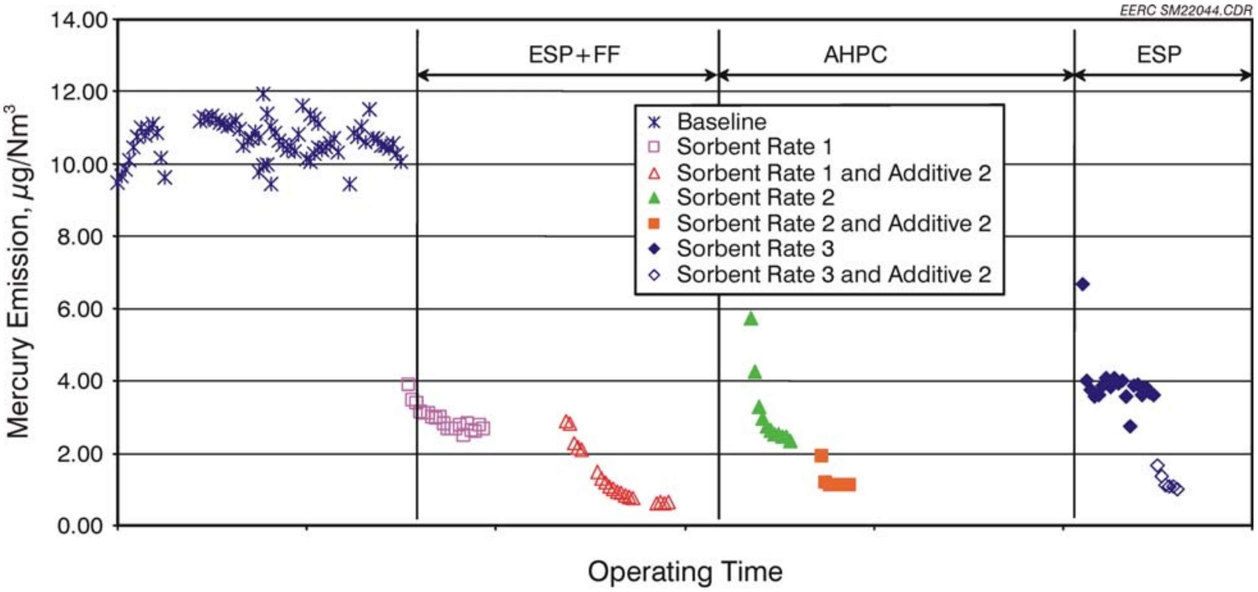

Figure 2. Mercury emissions for activated carbon injection combined with additives.

these additives upstream of the air pollution control device (APCD) can improve Hg capture both by conversion of the Hg^0 to the more easily removed Hg^{2+} form and by enhancing the reactivity of Hg^0 with activated carbons (ACs) and other sorbents. Testing at Stanton Station also indicated an 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.

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. The specific objective for the add-on task is to reduce mercury emissions by 50%–90% in flue gases typically found in North Dakota lignite-fired power plants at costs of one-half to three-quarter of current estimated costs.

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 (200-acfm) pilot scale.

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

- Demonstrate mercury capture with the 2.5-MW (9000-acfm) AHPC at Big Stone.

- Demonstrate 90% mercury capture over a longer time (3 months) with the 2.5-MW (9000-acfm) AHPC at Big Stone.

- Evaluate the mercury capture effectiveness of the AHPC when used with elemental mercury oxidation additives and a SDA (Task 6 add-on).

- Evaluate the mercury capture effectiveness of the AHPC and baghouses when used with novel baghouse sorbent inserts downstream of the FF (Task 6 add-on).

2.2 Planned Scope of Work (revised February 2004)

To meet the objectives, the work was organized into six 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
- Task 6: Pilot and Field Testing in Spray Dryer and Baghouse Applications (6.0 add-on)

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

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			

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 h. The 150 mg of NORIT FGD AC sorbent is equivalent to a sorbent-to-mercury ratio of 3700 after 3 h 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) was for the purpose of comparing the bench-scale fixed-bed results sampling real flue gas to those obtained with simulated flue gas for both western subbituminous (WSB) and eastern bituminous (EB) coals. 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.

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.

The third series of bench-scale tests (Table 3) was 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° to 177°C (250° to 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 the April–June 2003 Quarterly Report) showed no improvement in mercury removal over the FGD carbon, there is no basis for doing these IAC tests.

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

Eight weeks of testing were planned under Task 3. A week of testing included an 8-h heatup period on gas and then approximately 100 h of steady-state operation firing coal. This allows for four 24-h test periods where the PTC is operated around the clock. The originally

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.

planned 6 weeks of tests are shown in Table 4. The first 2 weeks were 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 duration was approximately 48 h. These tests were for the purpose of establishing the amount of mercury capture by fly ash and determining whether the 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.

Weeks 7 and 8 were intended to test an innovative new sorbent technology developed by W.L. Gore & Associates, Inc., one of the project’s sponsors and primary partners. The development of mercury adsorbents with capacities far greater than conventional activated

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]
7	Sorbent type and concentration	WSB	AHPC	Gore[4]	NA	NA
8[5]	Plate capture vs. total capture	WSB	AHPC	FGD	3000[2]	Continuous[3]

[1] Not applicable.
[2] Estimated concentrations; actual concentration will be based on previous testing.
[3] To be selected.
[4] Bag insert within the AHPC.
[5] Newly added test.

carbon is the basis of this work. Specifically, the configuration involves a mercury control filter placed inside the existing particulate control filter bag, essentially a bag-within-a-bag concept. Prior testing, funded by Gore, at the U.S. Environmental Protection Agency (EPA) research facility in Research Triangle Park, North Carolina, has shown significant levels of both elemental and ionic mercury capture. This approach is highly compatible with the AHPC and offers many advantages as an alternative to the use of disposable AC. The plan was to conduct two 1-week tests with the pilot-scale AHPC to evaluate the mercury capture performance of the Gore technology. The first week of tests was conducted with a subbituminous coal at an AHPC temperature of 149°C (300°F). However, since that time, Gore has discontinued development of this technology. An alternative Week 8 test will evaluate the amount of mercury collected on the perforated plates in the AHPC compound to the total mercury removal across the AHPC.

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 EB 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 cofiring tire-derived fuel (TDF) and presented in the April–June 2003 Quarterly Report. Initial results from Week 7 were presented in the April–June 2003 Quarterly Report. Week 8 testing is planned for the second quarter of 2004.

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.

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 during May 6 – June 3, 2003, and results were presented in the April–June 2003 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 was 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.

2.2.6 Task 6 – Mercury Control with the Advanced Hybrid Particulate Collector

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

Pilot-Scale SDA Refurbishment. A pilot-scale SDA was purchased 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 were evaluated using the PTC equipped with the SDA. Pilot-scale testing were involved a North Dakota lignite coal with short-term (1–2-h) screening tests of several oxidation additives including chloride compounds (e.g., sodium chloride and calcium chloride) and a SEA. The additives will be blended with the coals.

Hg^0 and total Hg levels were 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 were analyzed for Hg content. Additive blend ratios were varied to evaluate the effectiveness of additives to oxidize Hg^0.

2.2.6.2 Subtask 6.2 – Field Testing of Sorbents and Gore Technology

This task was originally to determine how effectively Hg can be captured by using a sorbent-based technology in conjunction with a PJBH at a power plant in North Dakota. This task work plan formerly included evaluation of a Gore technology consisting of a proprietary baghouse insert downstream of the FF that has shown a high potential to control Hg. However, Gore’s recent decision to abandon their mercury research program has resulted in elimination of its inclusion in the planned scope of work. An existing baghouse was skid-mounted and transported to Leland Olds Station (LOS) 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 included 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 PJBH can operate for much longer periods of time than can the pilot-scale AHPC.

The skid-mounted baghouse was installed downstream of the existing particulate control device (PCD). CMMs were used to measure Hg^0 and total Hg vapor at various monitoring ports in the system. Mercury sampling with the Ontario Hydro (OH) method were conducted to provide Hg species information, dust loading, and particulate collection efficiencies.

3.0 RESULTS AND DISCUSSION

Activities during this quarter were performed under Task 6.

3.1 Task 6 – Mercury Oxidation Upstream of Wet and Dry Scrubbers

As part of the effort to obtain information on possible Hg control technology options for North Dakota lignite-fired power plants, pilot-scale Hg control testing was conducted December 8–11, 2003, using a 580- MJ/hr (550,000-Btu/hr) pulverized coal (pc)-fired unit equipped with a Niro Inc. Production Minor Spray Dryer, Model I, and baghouse. This unit, shown schematically in Figure 3, is designed to generate fly ash and flue gas representative of that produced in a full-scale utility boiler. The combustor is oriented vertically to minimize wall deposits. A refractory lining helps to ensure adequate flame temperature for complete combustion and prevents rapid quenching of the coalescing or condensing fly ash. Based on the superficial gas velocity, the mean residence time of a particle in the combustor is approximately 3 seconds. The coal nozzle fires axially upward from the bottom of the combustor, and secondary air is introduced concentrically to the primary air with turbulent mixing. Coal is introduced to the primary air stream via a screw feeder and eductor. An electric air preheater is used for precise control of the combustion air temperature. Instrumentation enables system temperatures, pressures, flow rates, flue gas constituent concentrations, and particulate control device operating data to be monitored continuously and recorded on a data logger.

The SD is shown schematically in Figure 4. The drying chamber is 1.2 m (3.9 ft) in diameter with a 0.75-m (2.5-ft) cylindrical height and a 60° conical bottom. The inner shell is constructed of 2-mm stainless steel, Type AISI 316, with a 220-grit finish. A Niro Inc. Type FS-1 rotary atomizer, capable of speeds ranging from 10,500 to 30,000 rpm, was used for atomizing lime slurry. An air disperser, supplied with the rotary atomizer, was used to introduce the properly heated (149°C, 300°F) airflow pattern throughout the chamber.

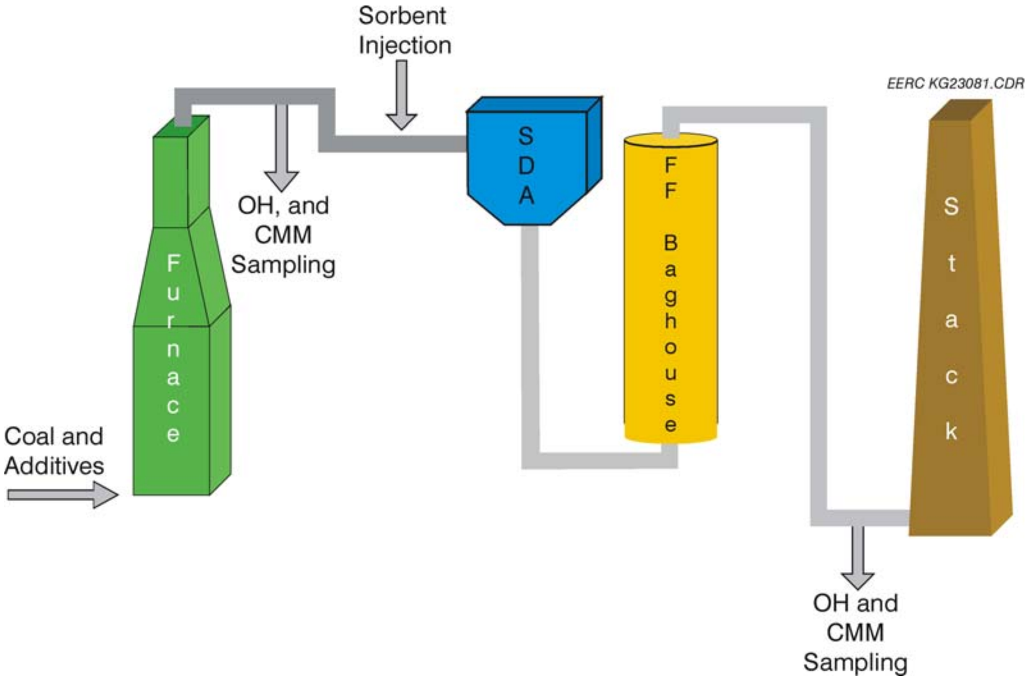

Figure 3. Schematic of the 580-MJ/hr (550,000-Btu/hr) combustion unit equipped with a FF and Niro Inc. Production Minor Spray Dryer, Model I.

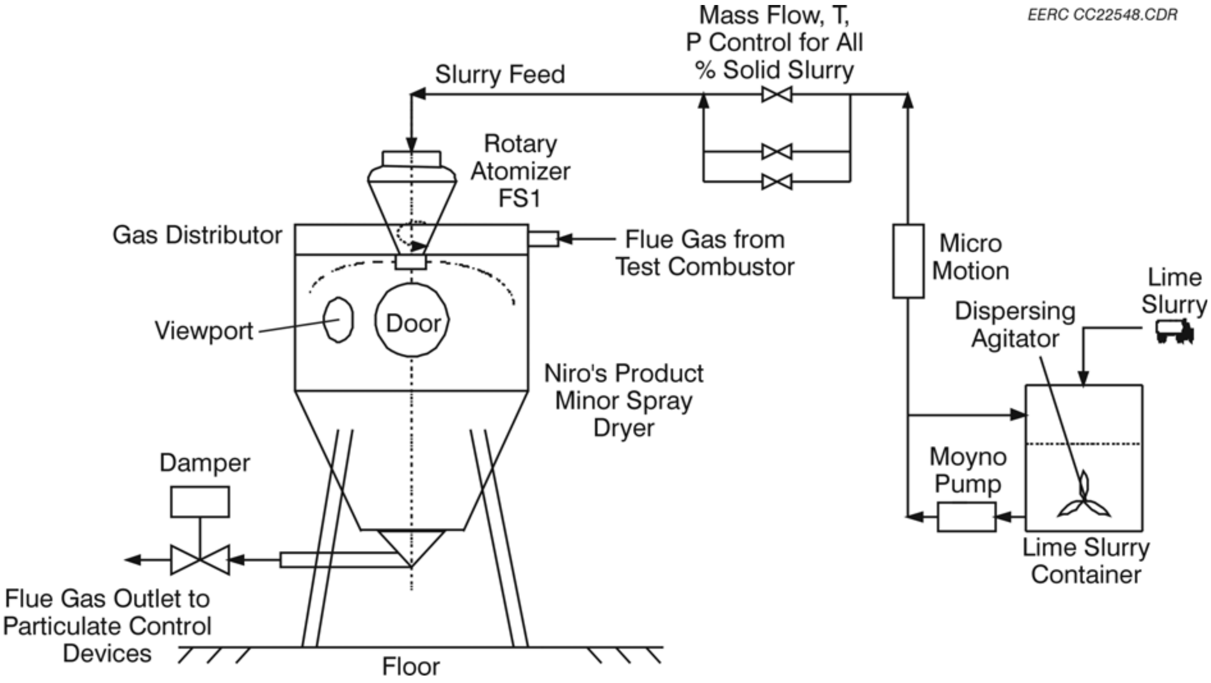

Figure 4. Schematic (not drawn to scale) of the Niro Inc. Production Minor Spray Dryer, Model I.

The lime slurry for the SD was prepared by adding deionized distilled water to slaked lime and fly ash obtained from the Antelope Valley Station in North Dakota. High-purity water was used to avoid the unintended introduction of chlorine into the system via a chlorinated water supply. Lime slurry compositions are presented in Table 5. The solid contents of the prepared slurries averaged 38 wt% on December 8 and 9 and 33 wt% on December 10 and 11.

Table 5. Lime Slurry Compositions, wt%

Component	December 8 and 9, 2003	December 10 and 11, 2003
$Ca(OH)_2$	4	4
Fly Ash	34	29
Distilled Water	62	67

A North Dakota lignite from the Center Mine was burned in the pilot-scale combustion system to test various Hg control strategies. The Center Mine is located in an extensive Tertiary basin Great Plains coal area which is centered in North Dakota and Montana and extends northward into Saskatchewan and southward into Wyoming and South Dakota. The coal combustion flue gas was cooled to approximately 149°C (300°F) before entering the SD and FF. Tests were completed to evaluate the effectiveness of a potential Hg sorbent (DARCO® FGD), and Hg^0 oxidation and a sorbent enhancement additive (SEA 2) to remove Hg using a SD and FF. The test matrix is presented in Table 6.

Table 6. Mercury Control Test Matrix

Coal Additive	Feed Rate, lb/Macf	Sorbent	Injection Rate, lb/Macf
None	NA[a]	None	NA
None	NA	DARCO® FGD	1.84, 3.67, 7.35, and 11.0
SEA 2	1.84 and 3.67	None	NA
SEA 2	1.84 and 3.67	DARCO® FGD	1.84

[a] Not applicable.

3.2 Coal and Combustion Flue Gas Compositions

Proximate and ultimate analysis results for the North Dakota Center Mine lignite are presented in Tables 7 and 8, respectively. The Hg and Cl contents of the Center lignite are presented in Table 9. Based on the proximate and ultimate analysis data, it was calculated that a pound of Center lignite coal would produce 125 scf of dry flue gas normalized to a 3.0% O_2 concentration. Theoretically, the Hg(total) and HCl concentrations of the Center lignite combustion flue gas should be 13.8 $\mu g/Nm^3$ (9.16 lb Hg/TBtu) and 1.59 ppmv, respectively (on a dry flue gas at 3.0% O_2 basis).

Table 7. Center Lignite Coal Proximate Analysis Results

Analysis Parameters	Concentration, as-received, wt%
Moisture	30.5
Volatile Matter	33.4
Fixed Carbon	29
Ash	7.19
Heating Value, Btu/lb	7330

Table 8. Center Lignite Coal Ultimate Analysis Results

Analysis Parameters	Concentration, as-received, wt%
Carbon	43.8
Hydrogen[a]	2.82
Nitrogen	0.83
Sulfur	0.84
Ash	7.19
Oxygen (by difference)[a]	14
Total Moisture	30.5

[a] Hydrogen and oxygen do not include H and O in sample moisture.

Table 9. Center Lignite Coal Hg and Cl Concentrations, moisture-free

Analysis Replicate	Hg	Cl
1	0.0935	18
2	0.0999	19
3	0.0964	18
Average	0.0966	19
Standard Deviation	0.0032	<1

Presented in Figures 5 and 6 are hourly average O_2, CO_2, CO, NO_x, and SO_2 concentrations measured at the SD inlet and FF outlet, respectively, as a function of testing time. Analysis results for December 8, 2004, are not presented because of a CMM data-recording error that occurred during the first day of testing. CO concentrations ranged from <50 to 145 ppmv, which is indicative of efficient coal combustion and thus very low concentrations of unburned carbon in the fly ash. SD inlet SO_2 concentrations ranged from 438 to 854 ppm, which is similar to the calculated SO_2 concentration, based on proximate and ultimate coal analysis (Tables 7 and 8), of 1010 ppmv (@ 6% O_2). The daily average SO_2 removal efficiencies of the SD are reported in Table 10. Although the Center lignite combustion flue gas was anticipated to contain 1.59 ppmv

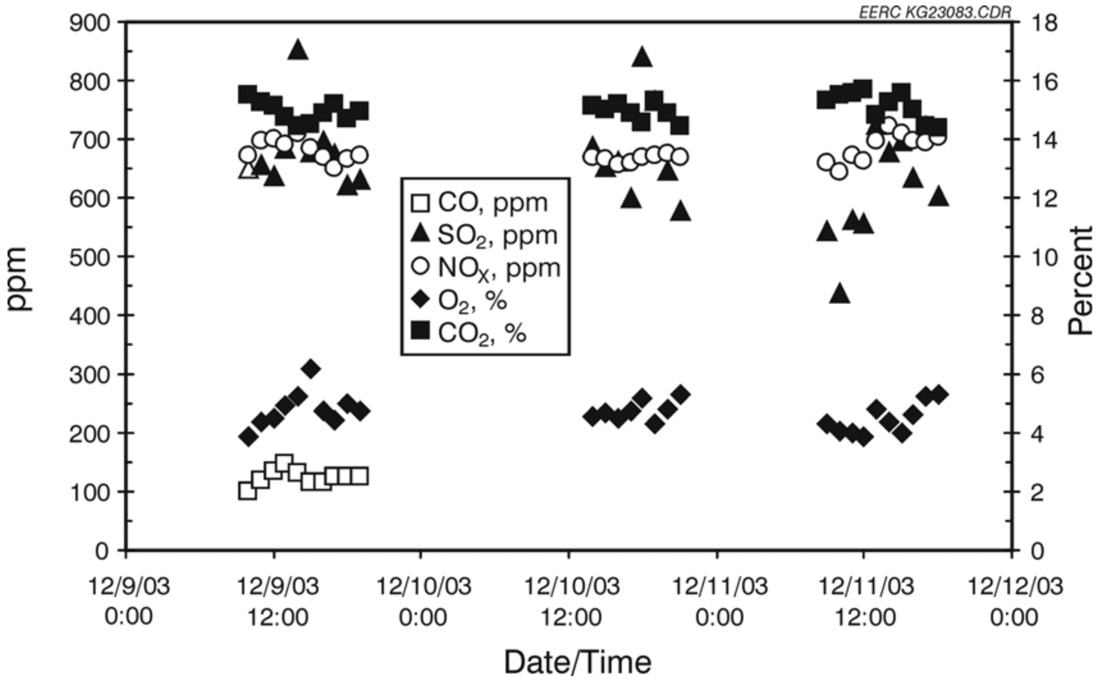

Figure 5. Hourly average Center lignite coal combustion O_2, CO_2, CO, NO_x, and SO_2 flue gas concentrations measured at the SD inlet as a function of testing time.

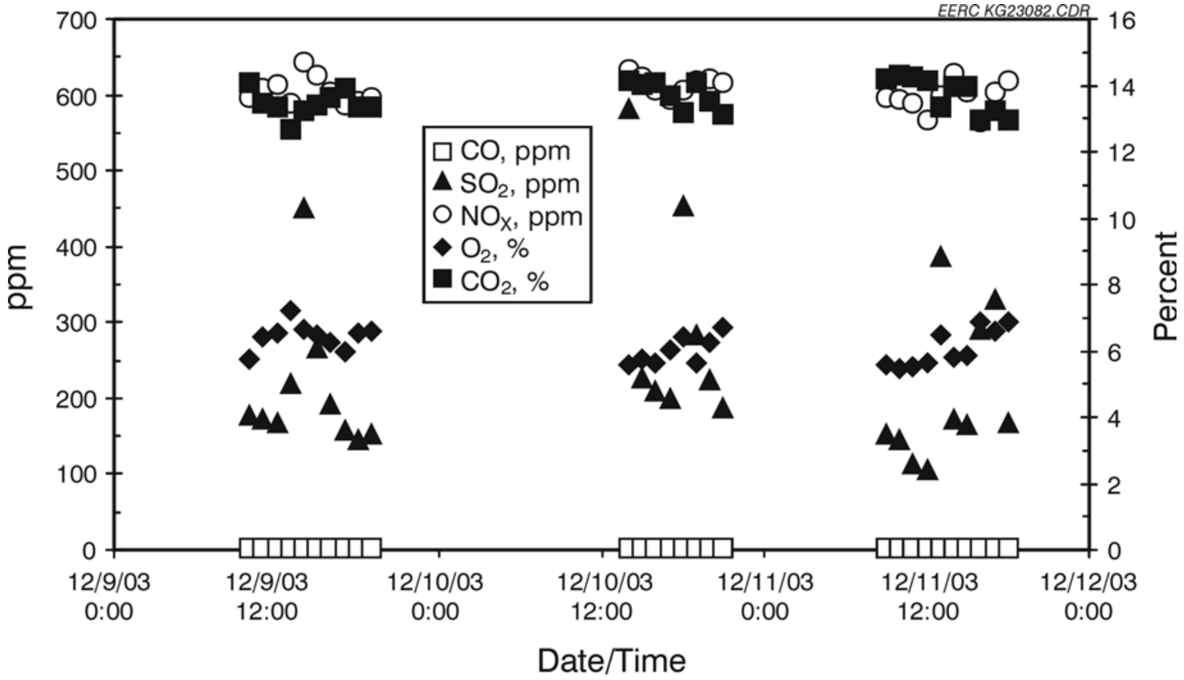

Figure 6. Hourly average Center lignite coal combustion O_2, CO_2, CO, NO_x, and SO_2 flue gas concentrations measured at the FF outlet as a function of testing time.

Table 10. Average Daily SO_2 Removal Efficiency of the SD–FF

	Dec. 9, 2003	Dec. 10, 2003	Dec. 11, 2003
Removal Efficiency, %	69.8	63.2	67.8
95% Confidence Limit, %	5.5	5.4	7.5

HCl, it was not detected using infrared spectroscopy primarily because the Model 15C HCl analyzer was calibrated over a very wide range of HCl concentrations to accommodate the expected high HCl concentrations resulting from the addition of chloride compounds.

3.3 Evaluation of CMM Analysis Results

ASTM Method D6784-02 was performed twice at the SD inlet and three times at the FF outlet during these mercury control testing to evaluate the validity of the CMM measurements. Compared in Table 11 are results that were obtained simultaneously using ASTM Method D6784-02 and a CMM. A major limitation of the CMM measurements is that Hg(p) cannot be monitored. This limitation is most apparent in the results obtained at the SD inlet, where significant amounts of fly ash were entrained in the flue gas. CMM measurement results for the SD inlet were biased very low during tests involving mercury oxidation enhancements added to the furnace because of the formation of Hg(p) upstream of the SD inlet. Based on the comparisons in Table 11, SD inlet CMM results are generally invalid for calculating the Hg(g) removal efficiency of the SD–FF when an effective Hg^0 oxidation and sorbent enhancement additive is used. ASTM Method D6784-02 and CMM results were very similar downstream from the FF, where Hg(g) concentration differences between the two methods were $\leq$6%.

3.4 Mercury Sorbent Performance

3.4.1 DARCO® FGD

Presented in Figure 7 are SD inlet and FF outlet CMM results for Hg(g) and a calculated Hg(g) removal efficiency for each pair of CMM measurements that were conducted simultaneously or within a minute of each other. The results in Figure 7 are for the baseline Center lignite combustion flue gas and during the injection of DARCO® FGD at four different rates. The average Hg(g) removal efficiencies and corresponding 95% confidence limits were calculated from the results in Figure 7 and are presented in Table 12. Baseline results indicate that the SD–FF was ineffective in removing Hg(g) in the absence of DARCO® FGD injection. During DARCO® FGD injection, the Hg(g) removal efficiency of the SD–FF greatly improved immediately and continued to improve with increasing injection rates until it approached about 60% at an injection rate of 7.35 lb/Macf. The SD–FF continued to remove Hg(g) after DARCO® FGD injection because of the presence of residual DARCO® FGD on the FF.

Table 11. Comparison of ASTM Method D6784-02 (OH) and CMM Results Obtained Simultaneously at the Two Sampling Locations Indicated in Figure 3

		Hg by OH, µg/Nm^3	Hg by CMM, µg/Nm^3
SDA Inlet			
Baseline Test Conditions	Hg(p)	2	0
	Hg^{2+}	0.7	0
	Hg^0	10	0
	Hg(g)	0	11.6
SEA Injection at 3.67 lb/Macf	Hg(p)	5.6	0
	Hg^{2+}	5.0	3.6
	Hg^0	0.4	1.0
FF Outlet			
Baseline Test Conditions	Hg^{2+}	0.3	0
	Hg^0	11	0
	Hg(g)	0	11.5
Darco® FGD Sorbent Injection at 1.84 lb/Macf	Hg^{2+}	0	0.6
	Hg^0	7.8	7

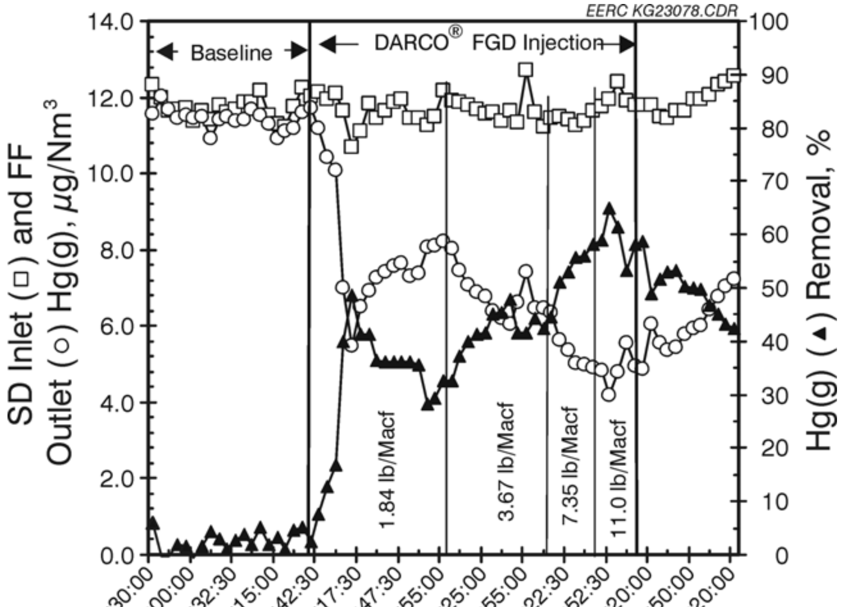

Figure 7. Paired SD inlet and FF outlet CMM results and SD–FF Hg(g) removal efficiencies for baseline and DARCO® FGD containing Center lignite coal combustion flue gas.

Table 12. SD–FF Hg(g) Removal Efficiencies (%) Before and After DARCO® FGD Injection

Injection Rate, lb/Macf	0	1.84	3.67	7.35	11
Average	2.5	36.5	43.2	55.5	59.3
95% Confidence Limit	±0.82	±2.5	±1.3	±2.2	±3.4

3.5 Hg^0 Oxidation and Sorbent Enhancement Additive Performance

3.5.1 SEA 2

Presented in Figure 8 are calculated SD–FF Hg(g) removal efficiencies for pairs of SD inlet and FF outlet CMM measurements made during SEA 2 additions and DARCO® FGD injection into the Center lignite coal and combustion flue gas, respectively. An average SD inlet CMM Hg(g) value was used in Figure 8 when SEA 2 was being added because of the formation of Hg(p) upstream of the SD inlet, which negatively biased CMM Hg(g) measurements. The initial FF outlet Hg(g) concentrations measured before the addition of SEA 2 are lower than typical baseline conditions, resulting in Hg(g) removal of about 17%. Apparently, some residual DARCO® FGD remained on the FF from the previous test. The SEA 2 additive greatly improved the Hg(g) removal effectiveness of the SD–FF, especially at the greater addition rate of 3.67 lb/Macf. After SEA 2 addition, the FF outlet Hg(g) concentration gradually increased over about a 30-minute period to its pre-SEA 2 addition concentration. The combination of DARCO® FGD injection at 1.84 lb/Macf and SEA 2 addition provided exceptional SD–FF Hg(g) capture, >90%, even at the lower addition rate of 1.84 lb/Macf. Compared in Figure 9 are the average SD–FF Hg(g) removal efficiencies of SEA 2 addition and DARCO® FGD injection alone and in combination. The size of the data points in Figure 9 are greater than the variability, at the 95% confidence level, of the SD–FF Hg(g) removal efficiencies except in the case of SEA 2 addition at 1.84 lb/Macf, where the variability was greater as indicated by the error bar in Figure 9.

4.0 CONCLUSIONS

The applicability of a potential Hg sorbent (DARCO® FGD) and an Hg^0 oxidation and sorbent enhancement additive (SEA 2) to improve the Hg(g) removal efficiency of a SD–FF pollution control system was evaluated using a pilot-scale (580-MJ/hr, 550,000-Btu/hr) pulverized coal-fired unit. A Center lignite coal was burned in the unit while Hg(g) concentrations were measured using CMMs at the SD inlet and FF outlet to evaluate Hg removal performance. The average inherent Hg(g) removal efficiency of the SD–FF was 2.5% ± 0.82%. The Hg sorbent and Hg^0 oxidation and sorbent enhancement additive were evaluated separately and in combination. Test results are summarized in Table 13. The SEA 2 additive alone and especially in combination with DARCO® FGD injection most effectively enhanced SD–FF Hg(g) removal performance.

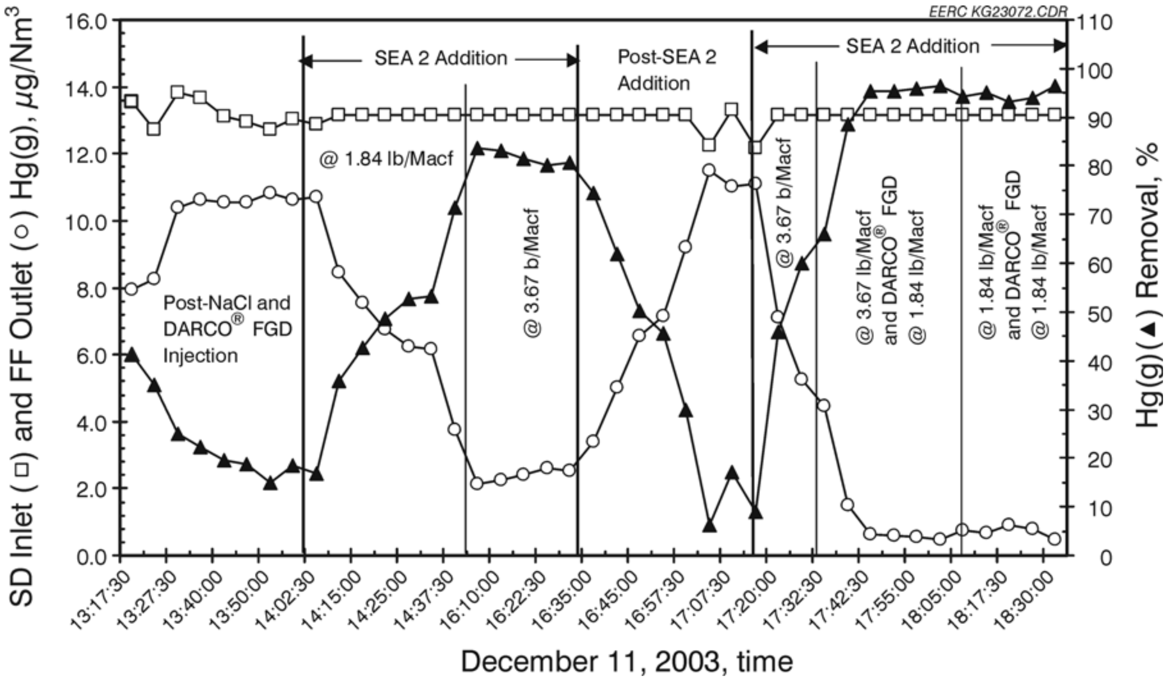

Figure 8. SD inlet and FF outlet CMM results and SD-FF Hg(g) removal efficiencies before, during, and after SEA 2 additions and DARCO® FGD injection into the Center lignite coal and combustion flue gas, respectively.

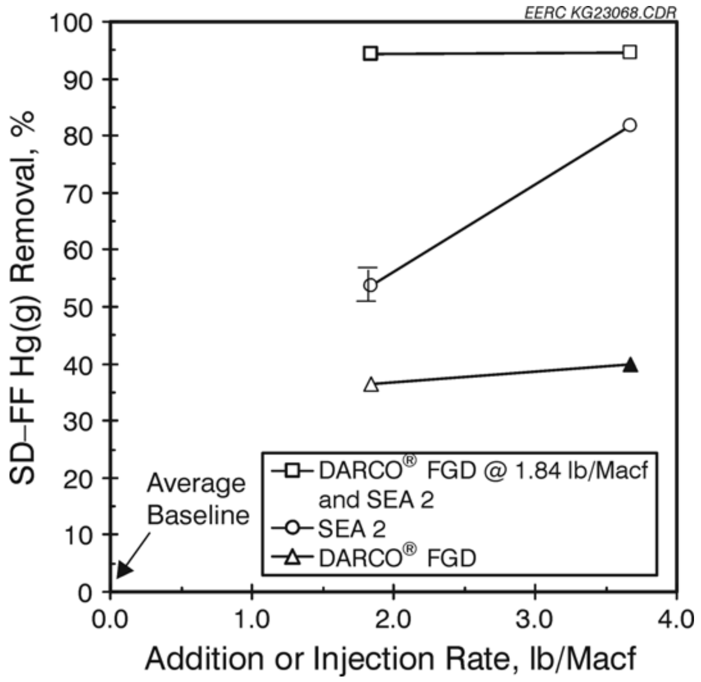

Figure 9. Comparison of the average SD–FF Hg(g) removal efficiencies of SEA 2 additions and DARCO® FGD injections alone and in combination.

Table 13. Average (±95% confidence limit) SD–FF Hg(g) Removal Efficiencies for Sorbent and Additive, %

	Injection or Addition Rate, lb/Macf			
Sorbent and/or Additive	1.84	3.67	7.35	11
DARCO® FGD	36.5 ±2.5	43.2 ±1.3	55.5 ±2.2	59.3 ±3.4
SEA 2	53.7 ±5.3	81.8 ±1.2	NT[a]	NT
DARCO® FGD @ 1.84 lb/Macf and SEA 2	94.6 ±0.9	94.3 ±2.6	NT	NT

[a] Not tested.

Pilot-scale testing demonstrated the utility of an activated carbon sorbent and coal chemical additive alone and in combination to improve Hg(g) capture in a SD–FF pollution control system. Longer-term full-scale demonstration tests are recommended to evaluate not only Hg(g) removal effectiveness but also potential power plant operational impacts on FF blinding, ash fouling, corrosion, plume opacity, etc. The initial full-scale tests should be conducted using a pilot-scale SD–FF on a slipstream of power plant flue gas to verify whether the activated carbon and additive identified through pilot-scale combustion testing provide effective and reliable Hg(g) removal over a lengthy time frame when Center lignite coal quality is varying. Assuming that the slipstream tests are successful, then additional activated carbon injection, sorbent enhancement addition, and Hg monitoring testing should be conducted using the actual boiler unit and its associated pollution control devices.

5.0 REFERENCES

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