# 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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## LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AHPC | advanced hybrid particulate collector |
| CMM | continuous mercury monitor |
| DOE | U.S. Department of Energy |
| EB | eastern bituminous |
| EERC | Energy & Environmental Research Center |
| ESP | electrostatic precipitator |
| 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 |
| TDF | tire-derived fuel |
| WSB | western subbituminous |
| XRF | x-ray fluorescence |

# 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 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 pulse-jet baghouse 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 (TFD), 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. There was very little natural mercury capture across the AHPC for the baseline tests and only a slight increase in the level of oxidized mercury 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 increased the range 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 0.3 kg/hr (1.5 lb/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 recent November 2002 tests.

There was little or no effect 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 the last quarter, 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°–160°C (275°–320°F) showed that this sorbent is completely ineffective at mercury control under these conditions. This is in contrast to the extensive previous testing 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.

# 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.

## 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 with sorbents under similar conditions at the 55-kW pilot scale between the AHPC and a pulse-jet baghouse.

- 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 | | | |

* Flue gas desulfurization.

**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 and an eastern bituminous coal. The simulated flue gas concentrations are based on the actual concentrations measured in the combustion tests. In addition, tests with lower sorbent concentrations will also be conducted 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 this last quarter as part of pilot-scale tests with an eastern bituminous coal. Tests 15 and 18–20 have not been completed yet.

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 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. IAC will be evaluated with flue gas concentrations for both a subbituminous and a bituminous coal at two concentration levels and two temperatures. Four additional screening tests will be conducted on other promising alternative sorbents to be selected based on new information and availability. The results from these tests will be used to prescreen alternative sorbents that have the potential to provide better mercury capture than FGD. The most promising sorbent would then be further evaluated in pilot-scale testing in Task 3. Several tests were completed this last quarter with a new promising non-carbon-based sorbent being developed outside the EERC. However, initial results showed poor mercury removal which may have been due to the preparation and testing procedures. The EERC is consulting with the supplier to determine if the procedure needs to be changed.

**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 (523) | 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.

### *2.2.3 Task 3 – Pilot-Scale Testing*

Six weeks of testing are 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 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 pulse-jet baghouse and the AHPC. Each test is for a duration of approximately 48 hr. These tests will establish the amount of mercury capture by fly ash and will determine whether the amount of mercury capture is different between the pulse-jet baghouse and the AHPC. It will also establish the inlet and outlet speciated mercury concentrations and whether there is a change in mercury speciation across both devices. A second purpose for these baseline tests is to provide flue gas to support the bench-scale testing with real flue gas under Task 2.

**Table 4. Task 3 – Pilot-Scale Testing**

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

[1] Western subbituminous.
[2] Pulse-jet baghouse.
[3] Not applicable.
[4] Eastern bituminous.
[5] Estimated concentrations; actual concentration will be based on previous testing.
[6] To be selected.

Weeks 3 and 4 are designed to prove the ability of the technology to control mercury at the 90% level with a western subbituminous coal. Week 5 is for testing mercury control in the AHPC with an eastern bituminous coal.

Week 6 is for the purpose of testing alternative sorbents in the AHPC. The need for alternate sorbent testing will be 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 western subbituminous 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 are presented in the quarterly report. At least 1 week of testing (Week 6) is planned for next quarter.

#### *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 were 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 are to be completed. The longer-term operation will establish whether there are any longer-term problems associated with the sorbent injection such as bag-cleaning problems. If alternative sorbents are tested during Month 3, then the longer-term demonstration testing would 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 last 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. These results are presented in this quarterly report. Following completion of the last pilot-scale tests, at least one more month of field testing is expected to be completed by the end of June 2003.

#### *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

### 3.1 November Field Test with the 2.5-MW AHPC

A short field test was completed with the 2.5-MW AHPC at the Big Stone Plant from November 19–22, 2002. This test period was planned 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. From earlier testing with the 2.5-MW AHPC at Big Stone Plant, it was shown that when the plant was cofiring a small amount of tire-derived fuel (TDF), there was an increase in HCl in the flue gas and a higher fraction of oxidized mercury (1). In addition, better mercury control was seen with the addition of activated carbon when the plant cofired TDF. It is not know whether the better mercury control was the

result of more oxidized mercury, higher HCl in the flue gas, more unburned carbon in the ash, or possibly a combination of these factors.

Since the inlet and stack measurements were being completed for the full-scale *Advanced Hybrid*™ filter, no Ontario Hydro (OH) measurements were completed on the 2.5-MW AHPC. Two mercury CMMs were used to monitor mercury concentrations at the inlet and outlet of the 2.5-MW AHPC. However, the total mercury at the inlet (including particulate mercury) could only be estimated based on the inlet Method 29 measurements completed for the full-scale tests. Method 29 was used instead of the OH method because of the need to measure a number of trace elements in addition to mercury. Results from three pairs of plant inlet and stack Method 29 mercury tests are shown in Figure 1. Since Method 29 can provide an accurate split between the particulate and vapor-phase mercury but not between oxidized and elemental mercury, the data are shown with only particulate and vapor-phase fractions. The totals are within the range of previously measured inlet values for the 2.5-MW AHPC, but appear to vary significantly, especially in the particulate-bound fraction. Because of this variability the exact total inlet mercury for specific tests in the 2.5-MW AHPC is somewhat uncertain. During the test period, Big Stone burned coal from the Belle Ayr Mine. The plant fuel burn record (Table 5) shows that some supplemental TDF and waste seed were cofired on two of the test days, November 19 and 22.

A summary of the tests completed with the 2.5-MW AHPC is shown in Table 6. A total of 11 different tests was completed, but many of these were shorter tests of just a few hours each. For the first 8 tests the 2.5-MW AHPC was set to pulse when the pressure drop reached 8 in.

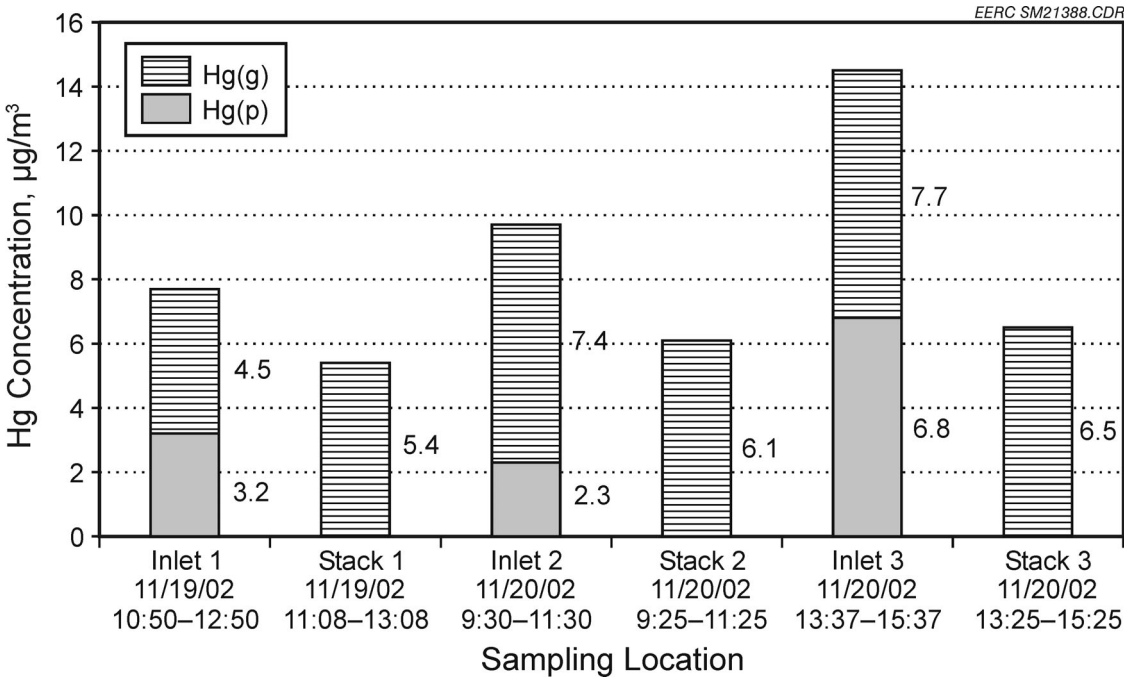


Figure 1. Inlet and stack mercury concentrations at Big Stone full-scale *Advanced Hybrid*™ filter – November 2002.

**Table 5. Big Stone Fuel Record for November 2002**

| Date | Coal Mine | Coal, tons | TDF, tons | Waste Seeds, tons |
|---|---|---|---|---|
| November 1, 2002 | Eagle Butte | 5988 | 22 | 189 |
| November 2, 2002 | Eagle Butte | 6001 | 0 | 0 |
| November 3, 2002 | Caballo Rojo | 5641 | 0 | 0 |
| November 4, 2002 | Caballo Rojo | 4601 | 90 | 980 |
| November 5, 2002 | Eagle Butte | 5871 | 23 | 36 |
| November 6, 2002 | Eagle Butte | 6182 | 45 | 48 |
| November 7, 2002 | Cordero | 6062 | 0 | 0 |
| November 8, 2002 | Cordero | 5519 | 250 | 98 |
| November 9, 2002 | Eagle Butte | 5418 | 0 | 0 |
| November 10, 2002 | Eagle Butte | 6080 | 0 | 0 |
| November 11, 2002 | Belle Ayr | 6316 | 0 | 0 |
| November 12, 2002 | Belle Ayr | 6170 | 45 | 24 |
| November 13, 2002 | Belle Ayr | 6140 | 92 | 23 |
| November 14, 2002 | Belle Ayr | 6306 | 117 | 49 |
| November 15, 2002 | Belle Ayr | 6202 | 46 | 85 |
| November 16, 2002 | Belle Ayr | 6511 | 0 | 0 |
| November 17, 2002 | Belle Ayr | 6185 | 0 | 0 |
| November 18, 2002 | Belle Ayr | 5797 | 44 | 160 |
| November 19, 2002 | Belle Ayr | 6013 | 23 | 195 |
| November 20, 2002 | Belle Ayr | 6290 | 0 | 0 |
| November 21, 2002 | Belle Ayr | 6365 | 0 | 0 |
| November 22, 2002 | Belle Ayr | 6037 | 139 | 180 |
| November 23, 2002 | Belle Ayr | 4781 | 0 | 0 |
| November 24, 2002 | Belle Ayr | 6276 | 0 | 0 |
| November 25, 2002 | Belle Ayr | 6342 | 23 | 0 |
| November 26, 2002 | Belle Ayr | 6249 | 0 | 0 |
| November 27, 2002 | Belle Ayr | 6152 | 0 | 78 |
| November 28, 2002 | Eagle Butte | 5913 | 0 | 0 |
| November 29, 2002 | Eagle Butte | 5652 | 46 | 0 |
| November 30, 2002 | Caballo Rojo | 6338 | 0 | 0 |

**Table 6. Summary of Test Matrix for the November 2002 Big Stone Plant Field Sampling**

| Test | Mode | Carbon Injection | HCl Injection | Test Time |
|---|---|---|---|---|
| 1 | 8.0 in. W.C. (2.0 kPa) Pulse trigger | None | NA | 11/19, 8:00–11/20, 13:00 |
| 2 | 8.0 in. W.C. (2.0 kPa) Pulse trigger | 0.3 kg/hr (0.65 lb/hr) | NA | 11/20, 13:00–15:02 |
| 3 | 8.0 in. W.C. (2.0 kPa) Pulse trigger | 0.3 kg/hr (0.65 lb/hr) | 10 ppm HCl at feeder | 11/20, 15:02–17:00 |
| 4 | 8.0 in. W.C. (2.0 kPa) Pulse trigger | 0.9 kg (2 lb) power-off batch | NA | 11/20, 17:11 |
| 5 | 8.0 in. W.C. (2.0 kPa) Pulse trigger | 0.3 kg/hr (0.65 lb/hr) | NA | 11/20, 20:00–11/21, 11:00 |
| 6 | 8.0 in. W.C. (2.0 kPa) Pulse trigger | 0.3 kg/hr (0.65 lb/hr) | 10 ppm HCl at feeder | 11/21, 11:00–13:00 |
| 7 | 8.0 in. W.C. (2.0 kPa) Pulse trigger | 0.3 kg/hr (0.65 lb/hr) | NA | 11/21, 13:00–15:00 |
| 8 | 8.0 in. W.C. (2.0 kPa) Pulse trigger | 0.3 kg/hr (0.65 lb/hr) due to plug at feeder | 16 ppm HCl at feeder | 11/21, 15:00–17:00 |
| 9 | 20-min pulse interval | 0.3 kg/hr (0.65 lb/hr) | NA | 11/21, 17:12–11/22, 9:30 |
| 10 | 20-min pulse interval | 0.3 kg/hr (0.65 lb/hr) | 10 ppm HCl at AHPC inlet pipe | 11/22, 9:30–11:00 |
| 11 | 20-min pulse interval | 0.6 kg/hr (1.3 lb/hr) | NA | 11/22, 11:30–13:30 |

W.C. (2.0 kPa), which resulted in a pulse interval of about 3 hours and an average pressure drop of 6.5 in. W.C. (1.6 kPa). For the 20-min timed pulse interval tests, the average pressure drop was 5.0 in. (0.013 m).

#### *3.1.1 Baseline Test 1*

The 2.5-MW AHPC was operated under baseline conditions without any carbon or HCl injection from 12:00 on November 19 until 13:00 on November 20. The inlet and outlet mercury CMM data for this time (Figures 2 and 3) indicate no vapor-phase mercury capture. However, some baseline level of capture of the particulate-bound mercury was occurring. Based on an average inlet Method 29 mercury concentration of 10.6 $\mu g/m^3$ (Figure 1), the CMM data in Figure 2 indicate from 2 to 3 $\mu g/m^3$ of particulate-bound mercury was captured in the AHPC. For the later part of Test 1 (Figure 2), the outlet CMM mercury concentration was higher than the indicated inlet values. From previous work, we know that this can be caused by accumulation of

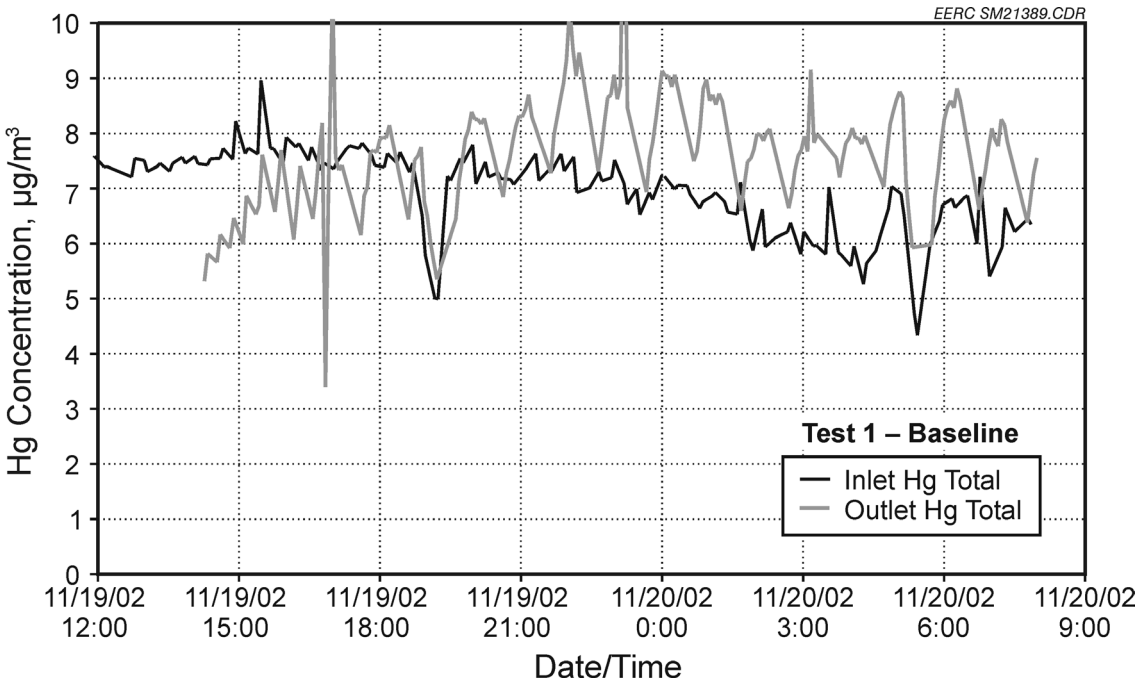


Figure 2. Test 1 baseline – CMM inlet and outlet mercury concentrations for the 2.5-MW AHPC.

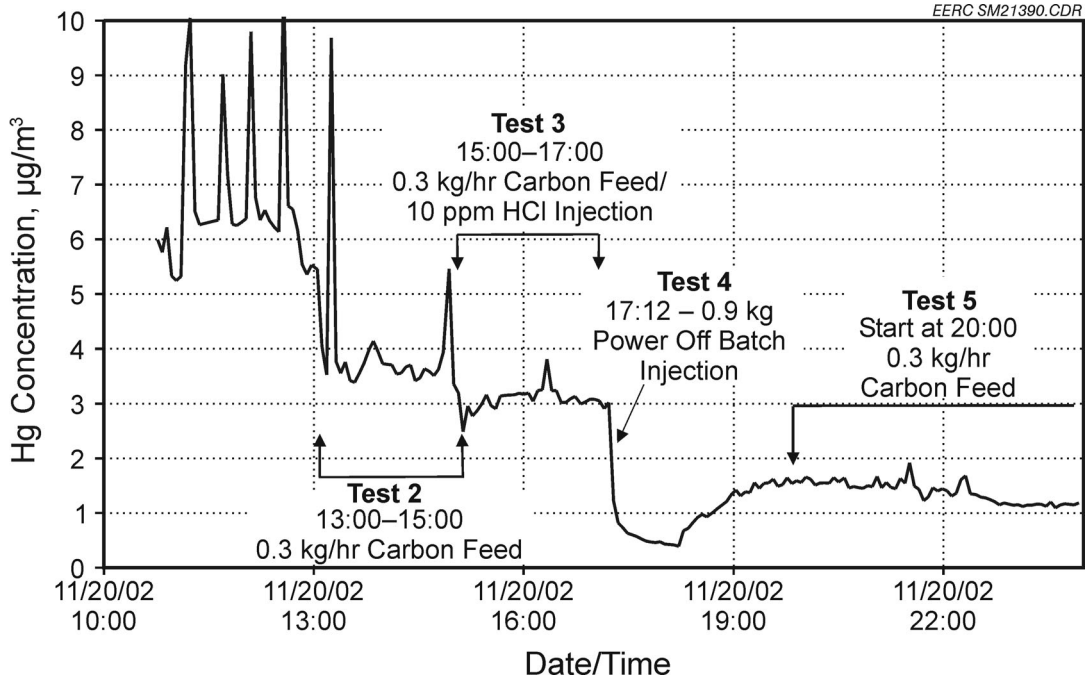


Figure 3. Tests 2–5 – CMM outlet mercury concentration for the 2.5-MW AHPC.

dust on the inlet sampling filter. In cases where the fly ash has a tendency to capture some of the mercury, this causes a low bias to the measured inlet mercury. Because of this effect, and the highly variable CMM inlet data, only the outlet CMM data are shown for the remaining tests.

### *3.1.2 Test 2 (0.3 kg/hr carbon injection)*

From 13:00 to15:00 on November 20, carbon injection took place at a rate of 0.3 kg/hr (0.65 lb/hr). This is equivalent to a carbon inlet concentration of 1.5 lb of carbon per million acf of flue gas. The carbon was the same NORIT FGD carbon that was used in previous tests (1, 2). During this time, the outlet mercury dropped to 3.7 $\mu g/m^3$, which corresponds to 65% total mercury removal (based on the average inlet total value of 10.6 $\mu g/m^3$) (see Figure 3).

### *3.1.3 Test 3 (0.3 kg/hr carbon injection plus 10 ppm HCl)*

While continuing the carbon injection, 10 ppm HCl was injected directly into the carbon feed line just downstream from the carbon feeder. Over the 2-hour test from 15:00 to 17:00 (Figure 3), it appears that there was a slight decrease in outlet mercury to about 3.1 $\mu g/m^3$, corresponding to 71% total mercury control. The somewhat lower mercury may be attributable to the added HCl. However, there was concern that the mercury monitor might be biased high, so the decision was made to try a power-off batch injection of carbon.

### *3.1.4 Test 4 (power-off batch carbon injection, no HCl)*

At 17:12, 0.9 kg (2 lb) of carbon was injected within about a minute with the high-voltage power shut off. Based on previous testing, this was expected to reduce the outlet mercury to near zero, at least for a short time. From the data in Figure 3, the outlet mercury concentration dropped as low as 0.4 $\mu g/m^3$, which indicated that the mercury monitor was providing valid readings. After 1 hour, the mercury started increasing again. During this time, the carbon feeder was keep on at a rate of 0.3 kg/hr (0.65 lb/hr).

### *3.1.5 Test 5 (0.3 kg/hr carbon injection)*

The carbon remained at a constant feed rate of 0.3 kg/hr (0.65 lb/hr) while the mercury emissions were monitored overnight. After recovering from the batch carbon injection, it can be seen in Figures 3 and 4 that the outlet mercury increased only to 1.7 $\mu g/m^3$ and then slowly dropped to 1.0 $\mu g/m^3$ by 1:00 on the next day where it remained until 5:30. This corresponds to a total mercury removal of 91% without any supplemental HCl injection. Interestingly, during this time, there was also no cofiring of TDF, so the reasons for the excellent removal for this test are unclear. The plant load (Figure 5) was reduced slightly from midnight until 6:00 on November 21, but the drop in mercury already started before the drop in plant load. The AHPC inlet and outlet temperatures (Figure 6) did decrease slightly from midnight until 6:00, which may have affected the mercury retention. It is also expected that with longer-term carbon injection, some additional capture of mercury might occur until all of the carbon retained in the unit has reached its maximum capacity. From the time of starting carbon injection on

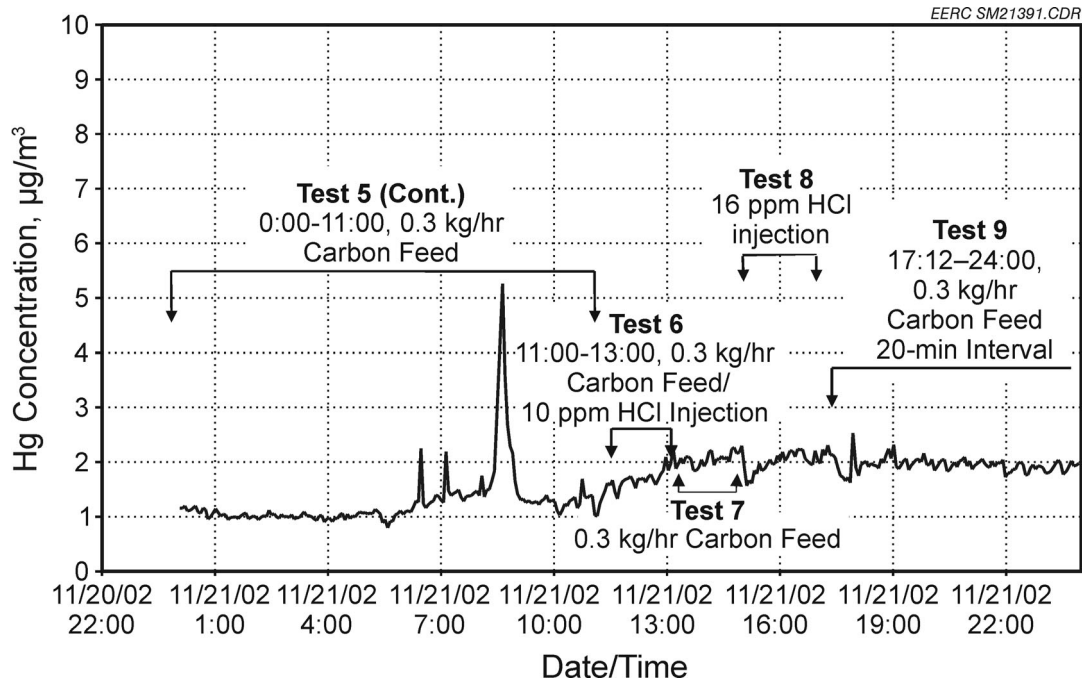


Figure 4. Tests 5–9 – CMM outlet mercury concentration for the 2.5-MW AHPC.

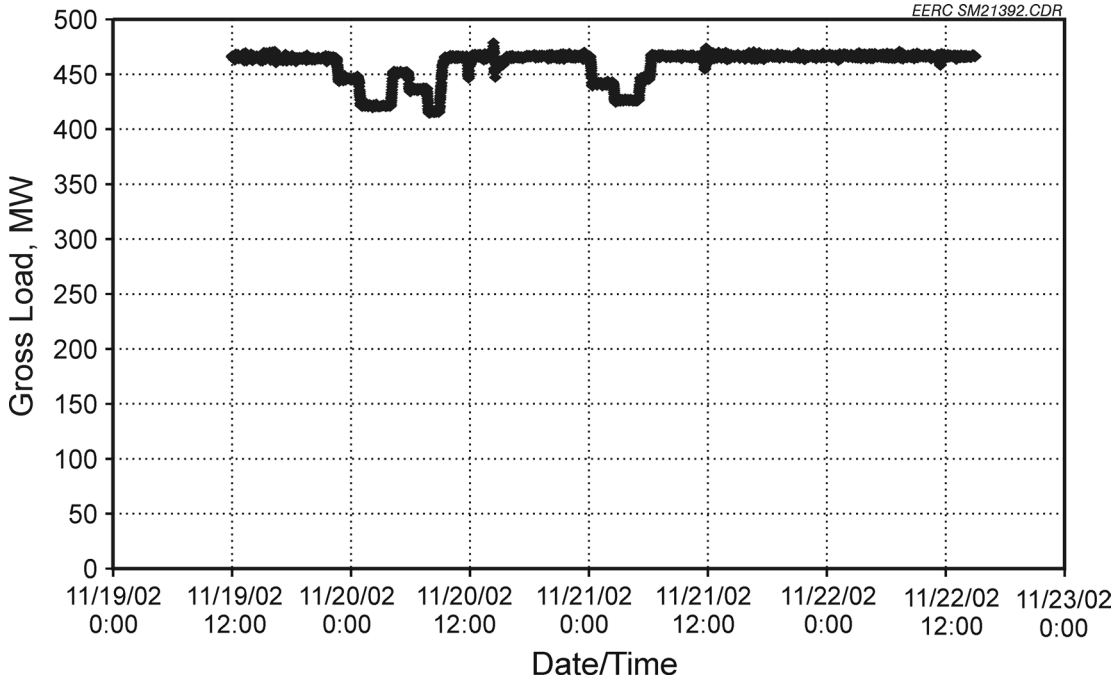


Figure 5. Big Stone Plant load during field sampling at the 2.5-MW AHPC.

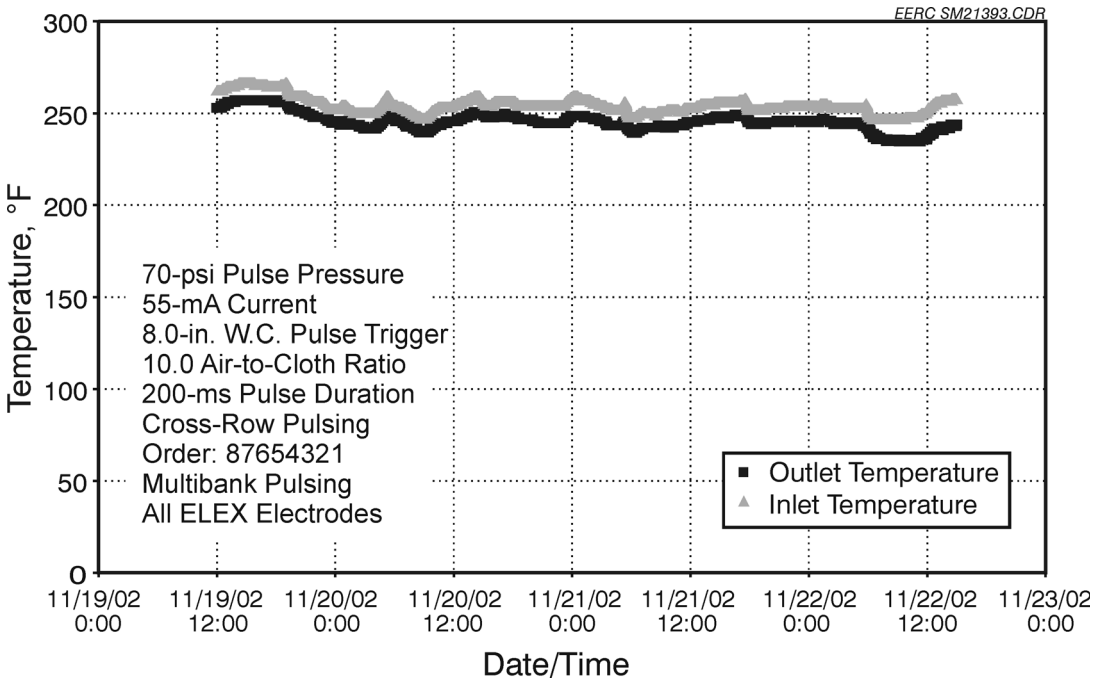


Figure 6. Inlet and outlet temperatures for the 2.5-MW AHPC.

November 20 until 5:30 on November 21, it is possible that some additional carbon buildup would occur and this could account for the gradual drop in mercury emissions. At 5:30, the mercury started to increase again, corresponding to a return to full plant load and a gradual increase in temperature. This suggests that the level of mercury control may be sensitive to even small changes in plant conditions.

#### *3.1.6 Test 6 (0.3 kg/hr carbon injection plus 10 ppm HCl)*

This was a repeat of Test 3 to determine the effect of additional HCl on mercury removal. After the outlet mercury was shown to be fairly steady at about 1.5 μg/m$^3$, 10 ppm of HCl was again injected into the carbon feed line from 11:00 to 13:00. However, from the results shown in Figure 4, the outlet mercury actually increased from 1.5 to 2.0 μg/m$^3$. During this time, the AHPC temperature was also increasing somewhat, so the increase in mercury is more likely associated with the temperature increase rather than the injected HCl. After shutting off the HCl, there was no change in mercury, so these Test 6 results along with the Test 3 results indicate little or no benefit to adding 10 ppm HCl.

#### *3.1.7 Test 7 (0.3 kg/hr carbon injection)*

The HCl was shut off again from 13:00 to 15:00, and the mercury concentration remained at 2.0 μg/m$^3$, which corresponds to a total mercury removal of 81%.

### *3.1.8 Test 8 (0.3 kg/hr carbon injection plus 16 ppm HCl)*

The HCl was started again from 15:00 to 17:00 and increased to the maximum controller setting, which allowed up to 16 ppm HCl. During this time, there was a short-term plug in the carbon feeder that may have contributed to some variability in the outlet mercury, but comparing the mercury concentration while injecting the HCl with the times before and after the test without HCl injection indicates little or no effect of the HCl.

### *3.1.9 Test 9 (0.3 kg/hr carbon injection and 20-minute timed pulse interval)*

From 17:12 on November 21 until 9:30 on November 22, the carbon feed was held constant at 0.3 kg/hr (1.5 lb/ million acf), but the bag pulse controller was set to a 20-min timed interval rather than the 8-in. W.C. (2.0-kPa) trigger for all of the previous tests. At the 8-in. W.C. (2.0-kPa) pulse trigger pressure, the bags typically pulsed about every 3 hours, which allowed for a fairly long carbon residence time in the AHPC chamber. A 20-min timed pulse interval possibly could limit the carbon residence time and result in lower mercury capture. However, much of the carbon is likely deposited on the perforated collection plates, which were rapped at a constant 40-min interval for all of the tests. Results in Figures 4 and 7 indicate no immediate change in mercury concentration after starting the 20-min timed bag pulsing. From 19:00 on November 21 until 3:00 on November 22, the outlet mercury was very steady at about 1.9 $\mu g/m^3$, but from 3:00 to 6:00 it dropped to 0.9 $\mu g/m^3$. During this time, the plant was at steady full load and the AHPC temperatures did not fluctuate. Inspection of the plant fuel burn record shows that supplemental TDF and waste seed burning were started again on November 22, but the exact time that the fuels reached the boiler is unknown. From previous tests, similar effects were seen when TDF was started, but the drop could also be the result of variation in the inlet mercury concentration or speciation.

### *3.1.10 Test 10 (0.3 kg/hr carbon injection plus 10 ppm HCl at inlet duct)*

Test 10 consisted of one further attempt to determine if supplemental injection of HCl would affect the mercury emissions. In this case the HCl was injected directly into the AHPC inlet duct just upstream of the carbon injection location. From the results shown in Figure 7, there was again no obvious effect of the HCl injection. However, the mercury removal during the test as well as just before and just after the test was over 90%, so there may have already been a sufficient amount of HCl in the flue gas. During Test 10, there was a short-term spike in the mercury emission up to 6 $\mu g/m^3$. It is not know whether it was caused by a process upset or some transient condition in the sampling and analytical instrumentation.

### *3.1.11 Test 11 (1.3 kg/hr carbon injection)*

One final short-term test was completed in which the carbon injection rate was doubled to 1.3 kg/hr (3 lb/million acf). From the results shown in Figure 7, there was not an immediate drop in outlet mercury, but there did appear to be a gradual decrease in mercury. By the end of the 2-hour test, the mercury was only 0.6 $\mu g/m^3$, which corresponds to 94% total mercury removal. The excellent mercury removal seen here may have been at least partially due to the burning of TDF on November 22.

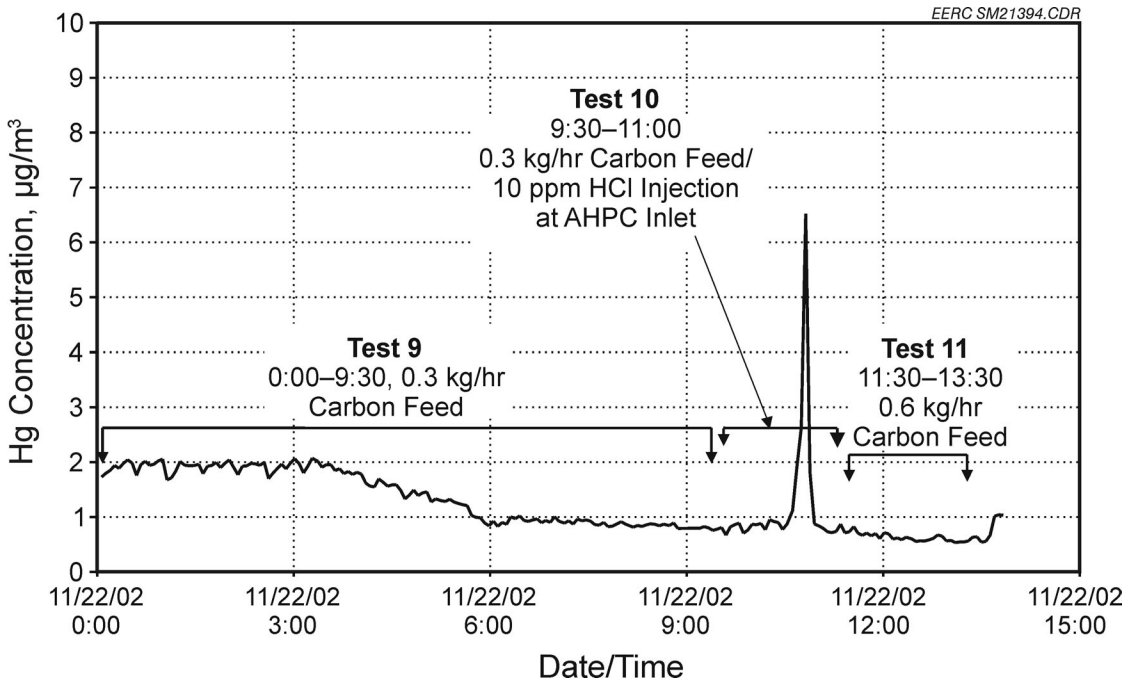


Figure 7. Tests 9–11 – CMM outlet mercury concentration for the 2.5-MW AHPC.

### 3.2 200-acfm Pilot-Scale Tests with Springfield Bituminous Coal

The purpose of this test was to evaluate mercury control with the AHPC with a high-sulfur bituminous coal. An earlier test was completed with Shade Creek bituminous coal, but because of the very high fixed carbon content with the Shade Creek coal, the fly ash had a significant amount of unburned carbon and a high fraction of mercury was retained by the ash (2).

The proximate–ultimate analysis and concentrations of mercury and chlorine for this coal are presented in Table 7. Combined with a theoretical combustion calculation based on proximate and ultimate analysis results, the theoretical mercury concentration in the flue gas was 13.9 µg/m$^3$ of dry flue gas at 3.0% $O_2$. The measured total mercury concentration (by OH method) at the AHPC inlet was in the range of 12.8–15.6 µg/m$^3$, which was in good agreement with the theoretical amount.

The concentrations of the major and minor elements in the Springfield ashed coal as measured by x-ray fluorescence (XRF) are presented in Table 8. Average flue gas concentrations for the test are shown in Table 9. Care was taken to maintain good combustion conditions to avoid generating significant amounts of CO and to minimize the amount of unburned carbon in the ash. Measured loss on ignition (LOI) for the baseline tests without carbon injection was 0.4%. The $NO_x$ level is higher than might be seen in full-scale boilers, especially with the implementation of low-$NO_x$ burners. The high $NO_x$ level seen here is the result of trying to maintain very hot flame conditions with sufficient excess air to ensure good carbon burnout. Note that the $SO_3$ level was also fairly high at 31.7 ppm.

**Table 7. Coal Analysis for the PTC-SF-635 Test***

| Proximate Analysis | As Received, wt% |
|---|---|
| Moisture Content | 5.40 ± 0.27 |
| Volatile Matter | 39.2 ± 0.6 |
| Fixed Carbon | 45.8 ± 0.8 |
| Ash | 9.56 ± 0.15 |
| Ultimate Analysis | |
| Hydrogen | 4.64 ± 0.03 |
| Carbon | 67.0 ± 0.2 |
| Nitrogen | 2.22 ± 0.05 |
| Sulfur | 3.1 ± 0.07 |
| Oxygen | 8.11 ± 0.31 |
| Ash | 9.56 ± 0.15 |
| Hg Concentration in Raw Coal, μg/g, as received | 0.111 |
| Cl Concentration in Raw Coal, μg/g, as received | 350 |

* Results from Final Topical Report for Task 28, "Pilot-Scale Evaluation of the Impact of Selective Catalytic Reduction for $NO_x$ on Mercury Speciation" (DE-FC26-98FT40321).

**Table 8. PTC-SF-635 Coal Ash – Major and Minor Element Oxide Compositions, wt%***

| | |
|---|---|
| $SiO_2$ | 46.2 |
| $Al_2O_3$ | 20.9 |
| $Fe_2O_3$ | 23.6 |
| MnO | ND** |
| $TiO_2$ | 1 |
| BaO | ND** |
| $P_2O_5$ | 0.1 |
| CaO | 1.73 |
| MgO | 1.5 |
| $Na_2O$ | 0.4 |
| $K_2O$ | 2.2 |
| $SO_3$ | 2.28 |
| Total | 99.8 |

* Results from Final Topical Report for Task 28, "Pilot-Scale Evaluation of the Impact of Selective Catalytic Reduction for $NO_x$ on Mercury Speciation" (DE-FC26-98FT40321).

** Not detectable.

**Table 9. Characteristics of Flue Gas for the PTC-SF-635 Test, dry flue gas basis**

| | |
|---|---|
| $O_2$, % | 4.6 |
| $CO_2$, % | 14.3 |
| CO, ppm | 5.3 |
| NO, ppm | 1334 |
| $NO_2$, ppm | 8.5 |
| $SO_2$, ppm | 2000–2300 |
| HCl, ppm | 32.0–42.9 |
| $SO_3$, ppm | 31.7 |

The planned variables to be evaluated included residence time of the ash in the AHPC chamber, activated carbon feed rate, and carbon injection method. An additional unplanned variable tested included AHPC temperature. Because of the very poor mercury removal results seen at 135°C (275°F), additional tests were completed at 160°C (320°F). At the measured $SO_3$ level of 31.7 ppm, 135°C (275°F) is below the acid dew point. There was concern that operation below the acid dew point might be the cause of the poor mercury removal, so some tests were repeated at 160°C (320°F), which is well above the acid dew point for 31.7 ppm $SO_3$. A summary of the tests completed is given in Table 10.

### *3.2.1 Inlet Mercury Concentration and Speciation*

The four OH inlet mercury samples completed are shown in Figure 8 to be predominantly oxidized mercury and almost an undetectable amount of particulate mercury. Interestingly, even though the concentrations of all of the acid gases are high, there is still some elemental mercury present. The total average inlet mercury is in good agreement with the CMM inlet data, which typically were in the range of 12 to 14 $\mu g/m^3$. In cases with little particulate mercury, it is usually possible to get good agreement between the CMM and OH measurements.

### *3.2.2 Tests 1 and 2 – Baseline Comparison of 30-min and 24-hr Residence Times*

For Test 1, there was no carbon injection and the AHPC was operated with a timed pulse interval of 30 min. The plates were also rapped every 30 min, and the hopper was emptied every hour. For Test 2, the pulse pressure set point was set to 8 in. W.C. (2.0 kPa), which resulted in a pulse interval of about 1 hour, and the plates were rapped every 3 hours. Ash was allowed to accumulate in the hopper for 24 hours before it was emptied. These tests were designed to evaluate whether the residence time of the ash in the AHPC chamber had any effect on mercury retention by the fly ash or in oxidation of mercury across the AHPC.

The OH results shown in Figure 9 indicate no collection of mercury across the AHPC but do show some increase in the level of oxidized mercury at the AHPC outlet. For the Test 1 inlet, the oxidized mercury was already high so the increase across the AHPC is minor. For Test 2, there was a significant increase in oxidized mercury across the AHPC. However, since the

**Table 10. Summary of the Test Scenarios for PTC-SF-635**

| Test | Description | Date/Test Time | Mode | Temp, °C (°F) | OH Sample Times | |
|---|---|---|---|---|---|---|
| | | | | | Inlet | Outlet |
| 1 | Baseline, 30-min residence time | 12/9, 8:42–16:40 | AHPC | 135 (275) | 11:05–13:05 | 11:05–13:05<br>13:45–15:15 |
| 2 | Baseline, 24-hr residence time | 12/9, 16:40–12/10, 17:04 | AHPC | 135 (275) | 8:36–10:16 | 8:36–10:16<br>13:25–14:55 |
| 3 | FGD, 7.5 g/hr | 12/10, 17:04–18:20<br>12/10, 19:12–12/11 12:41 | AHPC | 135 (275) | 9:46–10:30 | 9:46–10:30 |
| 4 | FGD, 37.5 g/hr | 12/10, 18:20–18:32 | AHPC | 135 (275) | | |
| 5 | FGD 37.5 g/hr | 12/10, 18:32–18:57 | Pulse jet | 135 (275) | | |
| 6 | FGD 15 g, power-off batch | 12/10, 18:57–19:12 | AHPC | 135 (275) | | |
| 7 | FGD 22.5 g, power-off batch | 12/11, 12:41–13:25 | AHPC | 135 (275) | | |
| 8 | FGD, 7.5 g/hr | 12/11, 19:51–20:42<br>12/11, 22:12–12/12 10:30 | AHPC | 160 (320) | 9:45–10:30 | 9:45–10:30 |
| 9 | FGD, 30 g/hr | 12/11, 20:42–22:12 | AHPC | 160 (320) | | |
| 10 | FGD, 7.5 g/hr | 12/12, 10:30–10:45 | Pulse jet | 160 (320) | | |
| 11 | FGD 30 g/hr | 12/12, 10:45–11:05 | Pulse jet | 160 (320) | | |
| 12 | Sorbent X 15 g/hr | 12/12, 13:23–14:27 | AHPC | 160 (320) | | |
| 13 | Sorbent X 15 g, power-off batch | 12/12, 14:37–15:01 | AHPC | 160 (320) | | |
| 14 | Limestone 15 g, power-off batch | 12/12, 15:01–5:30 | AHPC | 160 (320) | | |
| 15 | 15 g limestone + 15 g FGD, power-off batch | 12/12, 15:30–6:09 | AHPC | 160 (320) | | |

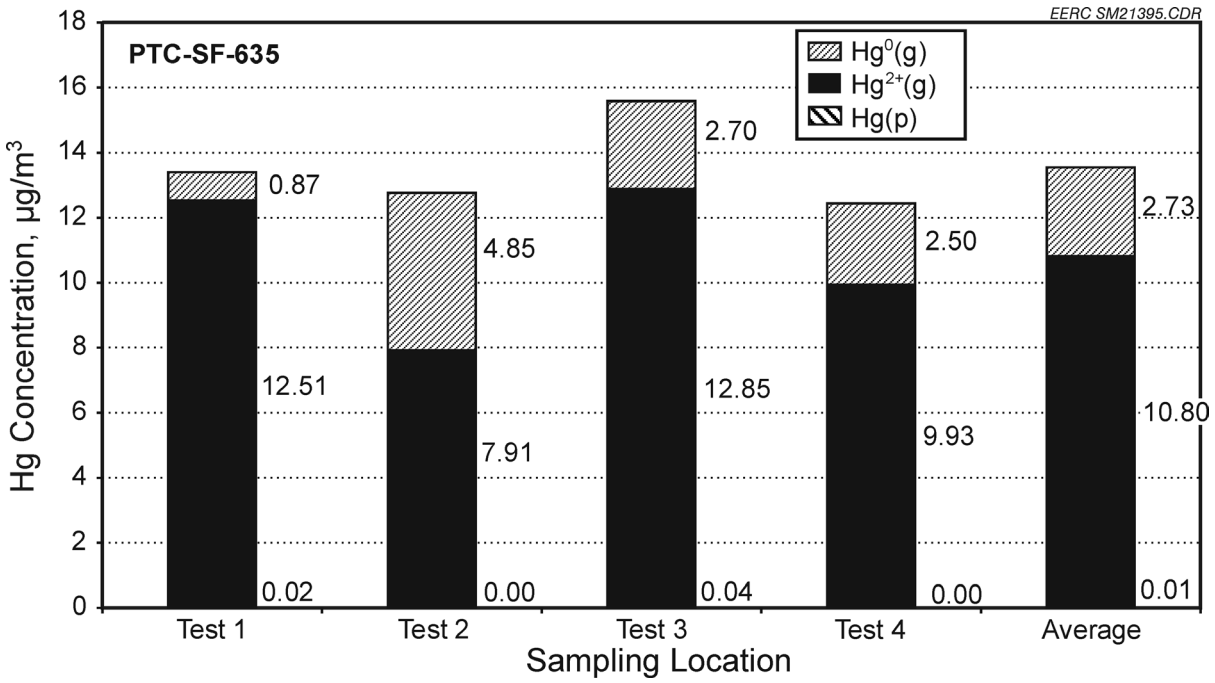


Figure 8. OH mercury concentration in the flue gas at the AHPC inlet (PTC-SF-635).

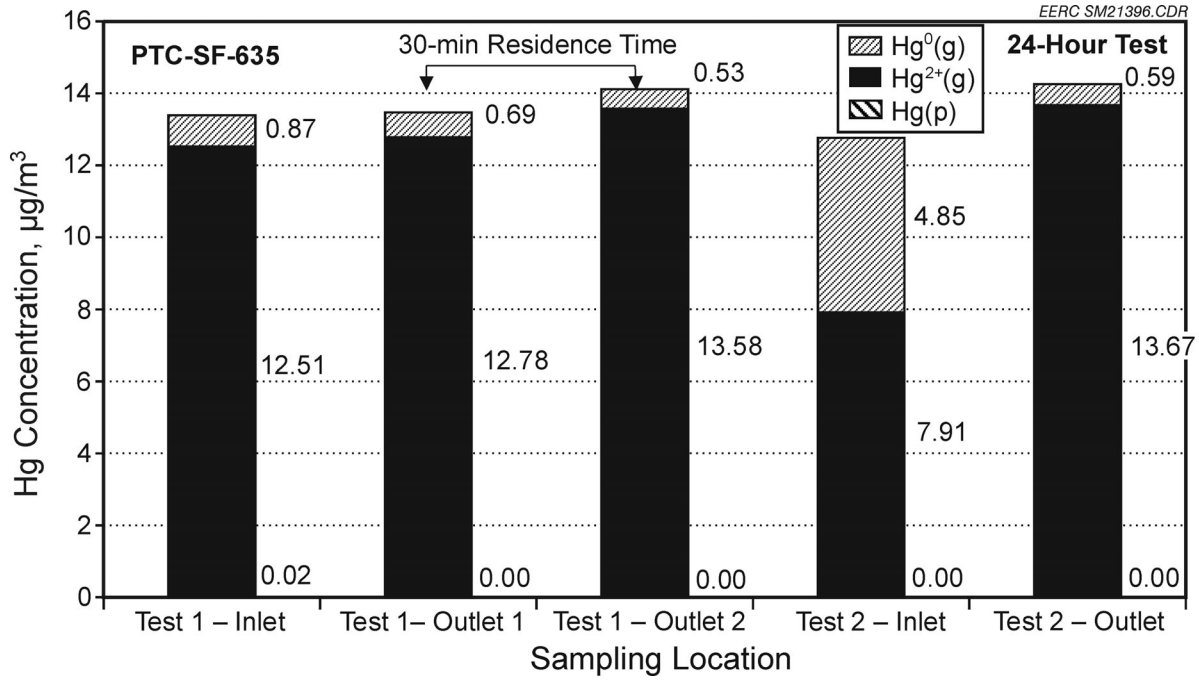


Figure 9. Tests 1 and 2 – OH mercury speciation in the flue gas at the AHPC inlet and outlet (PTC-SF-635).

amount of elemental mercury at the outlet is similar to Test 1, we cannot conclude that this increase in oxidation is attributed to residence time. The Test 2 OH data indicate somewhat higher total outlet mercury than the inlet. This difference may be within the normal variability of the measurements, but the CMM data also show higher outlet than inlet mercury concentrations near the end of the 24-hour residence time (Figure 10). Again, the difference could be within the variability of the instruments, but a comparison of the mercury in the hopper ash shows that the mercury concentration after 24 hours of exposure to flue gas was 7 times lower (0.00490 µg/g compared to 0.34 µg/g for the 30-min residence time sample). From previous bench-scale work, high $SO_2$ and $NO_x$ concentrations led to the most significant desorption of mercury from activated carbon, so the same mechanism could be responsible for desorption of mercury from fly ash. Later tests also indicate that desorption may be occurring with the activated carbon.

### *3.2.3 Tests 3–7 (carbon injection tests at 135°C)*

Following the 24-hr residence time test, the plates were rapped, the bags were pulsed, and the hopper was emptied of all of the accumulated ash. The NORIT FGD carbon was then started at a rate of 7.5 g/hr (1.5 lb of carbon/million acf), which is equivalent to a carbon-to-mercury ratio of about 3000:1. From the CMM data in Figure 11, it can be seen that there was no measurable reduction in mercury emissions. The inlet and outlet OH data (Figure 12) also indicate less than 10% mercury removal. The common perception is that oxidized mercury is easier to capture with activated carbon than elemental mercury, but these data indicate otherwise. Previous pilot-scale work at the EERC evaluating carbon injection with Blacksville bituminous coal and a baghouse showed that mercury capture was highly temperature dependent and that good mercury capture was achieved only at temperatures of 121°C (250°F) and lower (3, 4).

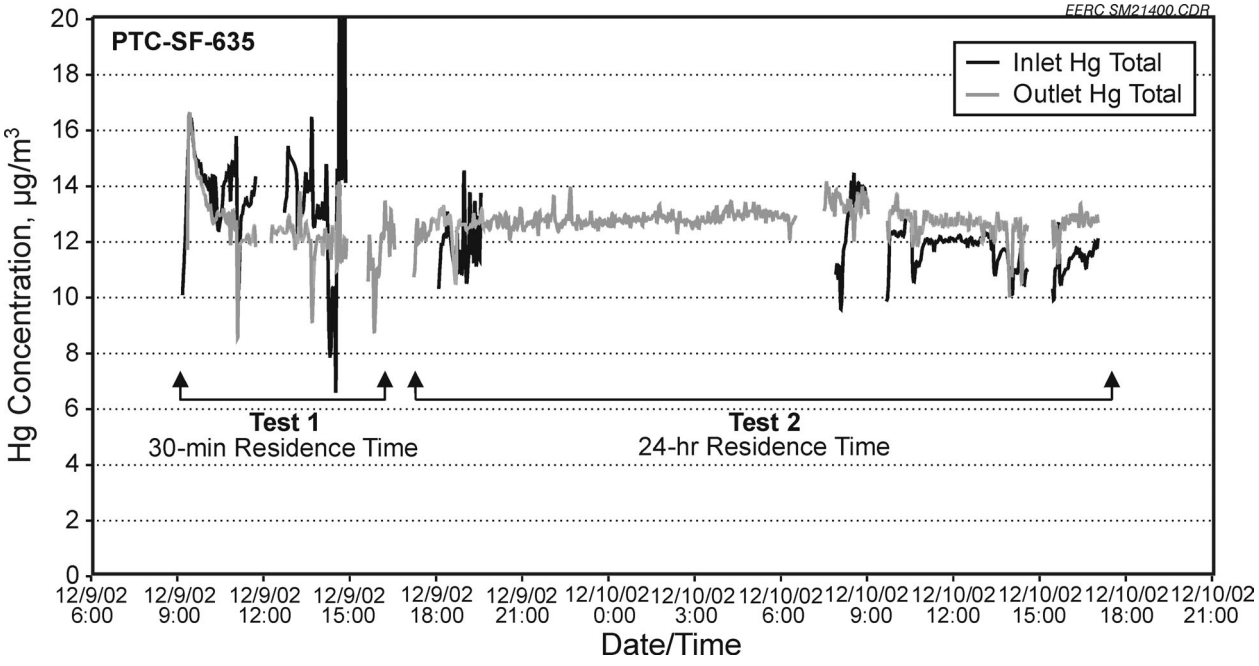


Figure 10. Tests 1 and 2 – baseline CMM mercury concentration in the flue gas at the AHPC inlet and outlet (PTC-SF-635).

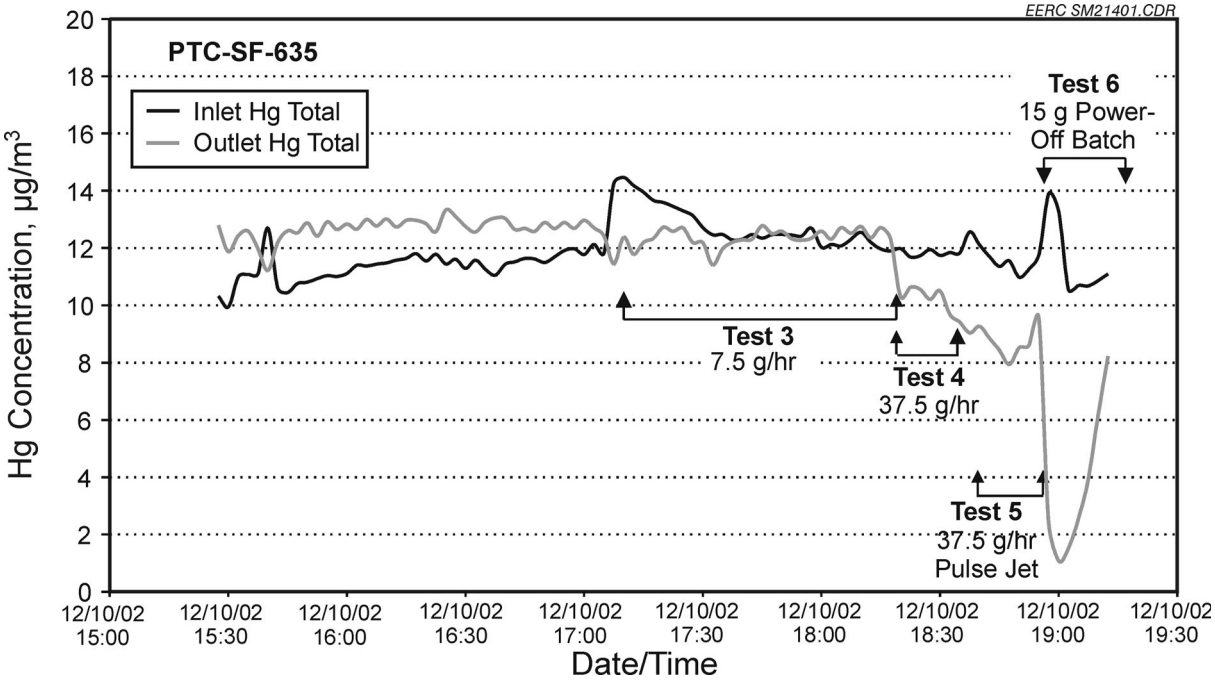


Figure 11. Tests 3–6 – CMM mercury concentration in the flue gas at the AHPC inlet and outlet with FGD injection at 275°F (PTC-SF-635).

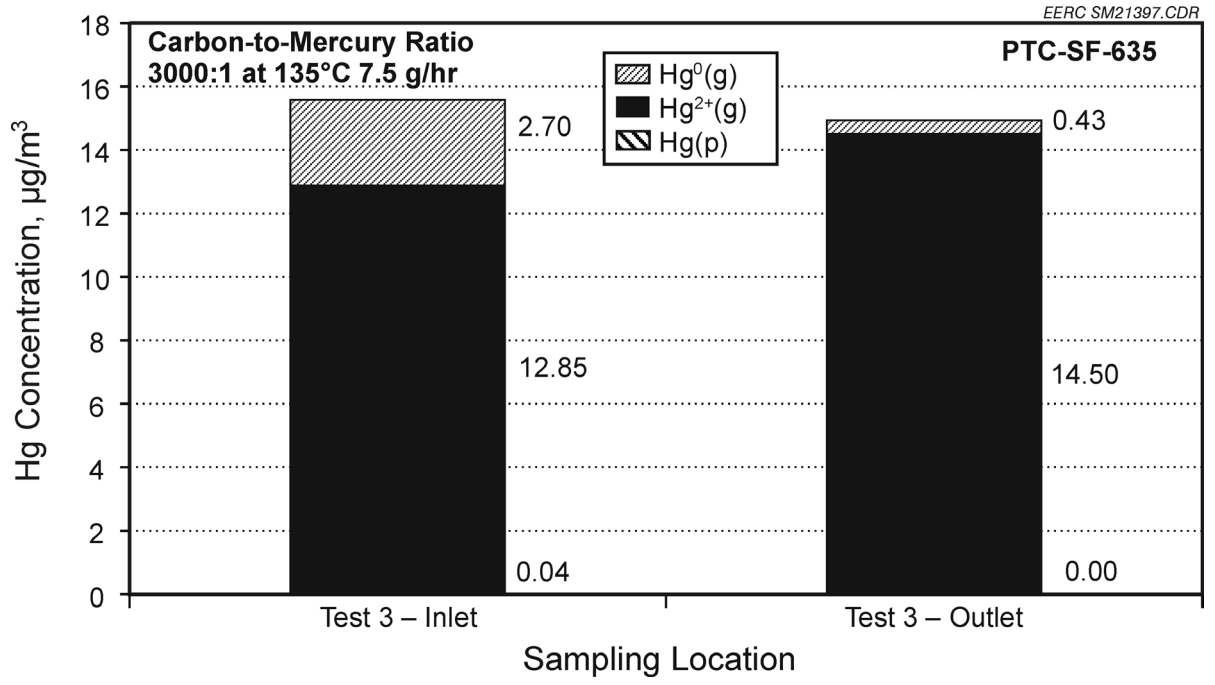


Figure 12. Test 3 – OH mercury concentration in the flue gas at the AHPC inlet and outlet with FGD injection at 275°F (PTC-SF-635).

After an hour, the carbon feed rate was increased to 37.5 g/hr to see if better mercury capture would occur. At the higher feed rate, only 15% mercury removal was noted, so the decision was made to shut off high-voltage power to the AHPC to see if mercury capture would improve if all of the carbon reached the bags. Mercury removal was still marginal, so 15 g of an additional batch of carbon was added to see if the mercury level would drop. The additional batch of carbon did briefly result in mercury dropping down to 1 $\mu g/m^3$, but it quickly climbed again. These tests all indicated that the FGD carbon was not effective at removing mercury under these conditions. The carbon injection rate was then set back to the Test 3 condition of 7.5 g/hr and operated overnight until noon the next day. The CMM data during this time (Figure 13) show no mercury removal, which provides further proof of the ineffectiveness of the FGD carbon. One additional power-off batch, Test 7, was completed by injecting a batch of 22.5 g of carbon within a minute. This resulted in a brief drop in mercury, but after only 15 minutes, the mercury rapidly started increasing again. Figure 14 is a more detailed graph of this batch injection test. Since the outlet mercury rises above the inlet level after breakthrough, this may indicate desorption of some of the previously captured mercury. In previous bench-scale breakthrough tests with a thin fixed bed of carbon, desorption was commonly seen for cases where the flue gas was high in both $NO_x$ and $SO_2$.

The poor mercury capture by the activated carbon is consistent with previous bench-scale tests, but those tests were completed without $SO_3$. These tests were all conducted at a temperature of 135°C (275°F), which is below the acid dew point for the measured $SO_3$ level of 31.7 ppm. The possibility was raised that $SO_3$ condensation on the activated carbon might impair mercury capture. To address this concern, further testing was completed after increasing the AHPC temperature to 160°C (320°F).

#### *3.2.4 Tests 8–11 (carbon injection tests at 160°C)*

After adjusting the upstream heat exchangers to raise the AHPC temperature to 160°C (320°F), injection of carbon at a rate of 7.5 g/hr was started. Since no mercury removal was seen at that rate, the carbon injection was increased to a rate of 30 g/hr, but less than 10% mercury removal was seen (Figure 15). The carbon injection was then scaled back to the Test 8 conditions of 7.5 g/hr for a longer-term test overnight. The inlet and outlet CMM data in Figure 15 and the OH measurements (Figure 16) show no mercury removal during this time. To provide final proof that the poor mercury removal was due to the carbon sorbent rather than a limitation of the AHPC, the high-voltage power was again shut off and short-term tests were completed, first at 7.5 g/hr and then at 30 g/hr. Data in Figure 16 show that even with no high-voltage power and the high carbon addition rate, mercury removal was in the range of 0% to 10%. Since very poor mercury capture was seen at 160°C (320°F) as well as 135°C (275°F), the reason appears to be something other than an acid dew point problem. Apparently, in the temperature range from 135°–160°C (275°–320°F) with these flue gas concentrations, the FGD sorbent is ineffective at mercury capture.

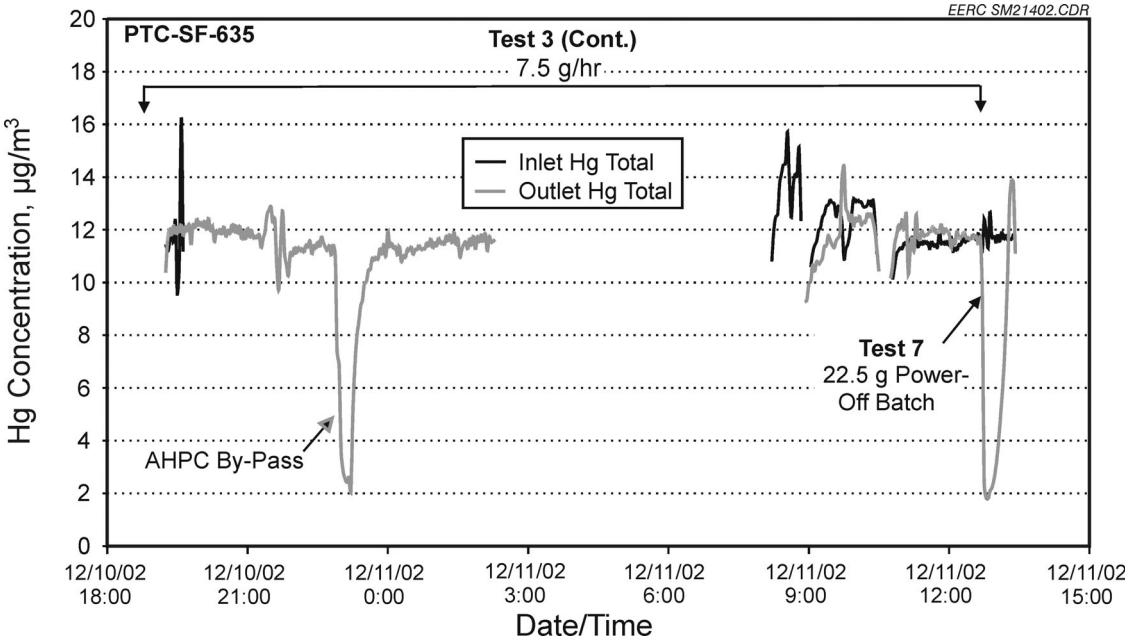


Figure 13. Tests 3 and 7 – CMM mercury concentration in the flue gas at the AHPC inlet and outlet with FGD injection at 275°F (PTC-SF-635).

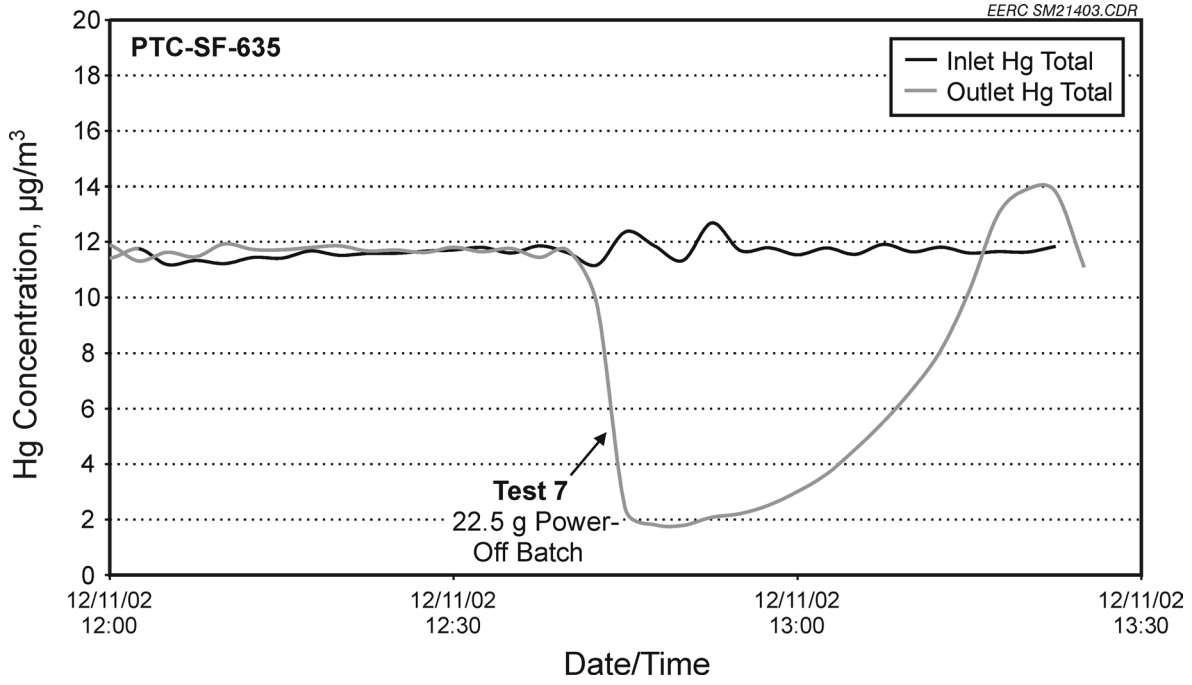


Figure 14. Test 7 – CMM mercury concentration in the flue gas at the AHPC inlet and outlet with FGD injection at 275°F (PTC-SF-635).

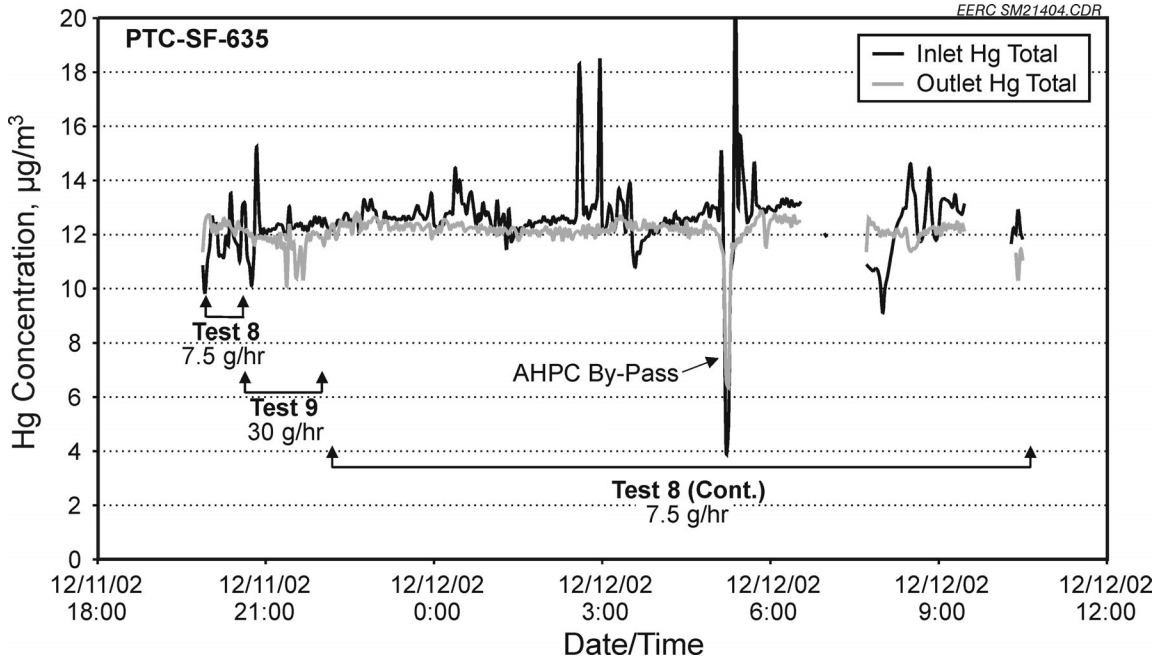


Figure 15. Tests 8 and 9 – CMM mercury concentration in the flue gas at the AHPC inlet and outlet with FGD injection at 320°F (PTC-SF-635).

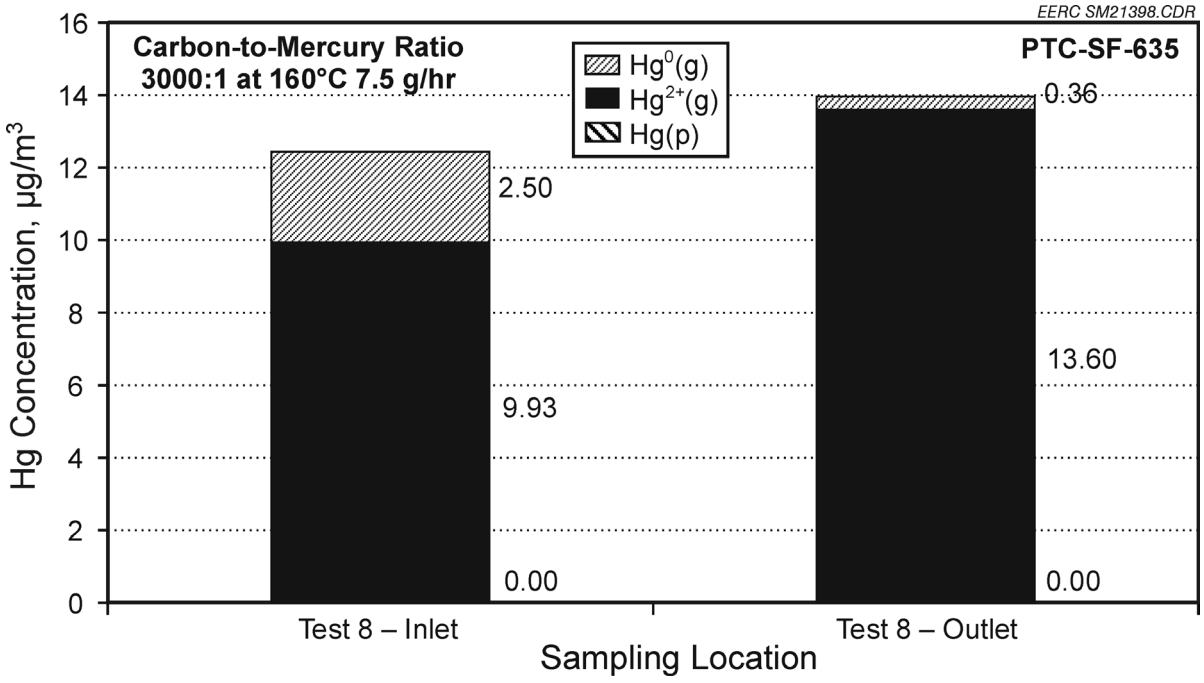


Figure 16. Test 8 – OH mercury concentration in the flue gas at the AHPC inlet and outlet with FGD injection at 320°F (PTC-SF-635).

### *3.2.5 Tests 12–15 (alternative sorbent tests at 160°C)*

The carbon feed was then stopped, all of the carbon-laden ash was removed from the AHPC, and the system was allowed to return to baseline conditions. Next, a non-carbon-based alternative sorbent was injected first continuously at 15 g/hr and then in a power-off batch mode. This sorbent also was ineffective at mercury capture (Figure 17). Two additional short-term batch injection tests were completed, first with straight limestone powder followed by a combination of 15 g of limestone and 15 g of the FGD carbon. As seen in the Figure 17 data, these tests were marginal in mercury removal effectiveness and the combination of limestone and FGD carbon was no better than the previous batch FGD carbon injection tests.

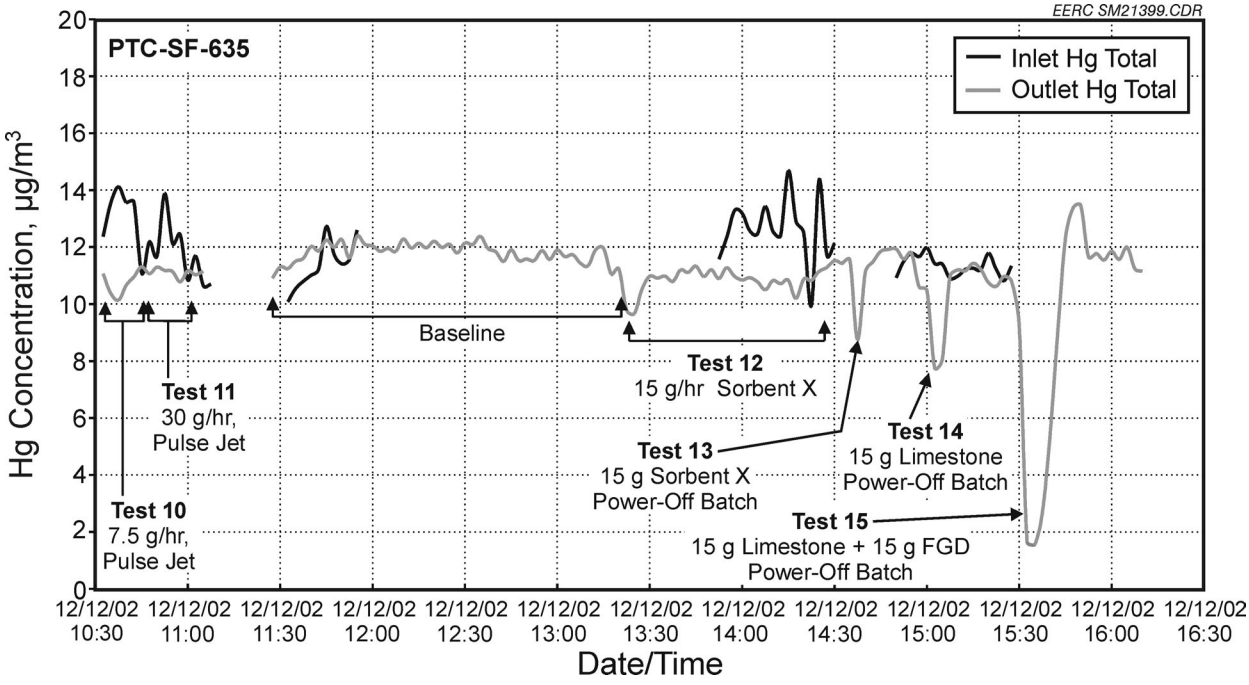


Figure 17. Tests 10–15 – CMM mercury concentration in the flue gas at the AHPC inlet and outlet with FGD injection at 320°F (PTC-SF-635).

## 4.0 CONCLUSIONS AND DISCUSSION

- The data from the 2.5-MW AHPC tests show that without supplemental HCl injection and a low carbon injection rate of 0.30 kg/hr (1.5 lb/million acf), from 65% to over 90% total mercury removal was achieved. Other than the initial 2-hr test for which removal was 65%, longer-term tests all demonstrated a minimum of 80% and up to 92% removal. 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 recent November 2002 tests. These results indicate that the exact level of mercury control that can be achieved with a low carbon addition rate is dependent on many factors and is difficult to predict. However, it is encouraging to see that very excellent mercury control can be achieved

with the AHPC at very low carbon addition rates. High mercury removal was seen both for the 8-in. W.C. (2.0-kPa) pulse trigger tests, which resulted in a 3-hour pulse interval, and for the 20-min timed pulse interval tests. This indicates that a long pulse interval is not necessary to achieve good mercury removal.

- The small effect (if any) seen with the supplemental HCl injection 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). Previous work has also demonstrated that the addition of chlorine compounds into the combustion zone will result in a higher fraction of oxidized mercury. 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.

- The Springfield bituminous coal produced a flue gas that was high in all of the acid gases, and most of the inlet mercury was in oxidized form. A number of short- and longer-term tests with the NORIT FGD carbon at both 135° and 160°C (275° and 320°F) showed that this sorbent is completely ineffective at mercury control under these conditions. This is in contrast to the extensive previous testing 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 level of mercury control that can be achieved for bituminous coals with activated carbon in the AHPC will likely be much better if the concentrations of the acid gases are lower than those seen in these tests.

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