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) 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 will include 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 Power Plant operated by Otter Tail Power Company, which will host 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 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 emission 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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AHPC	advanced hybrid particulate collector
CEM	continuous emission monitor
DOE	Department of Energy
EERC	Energy & Environmental Research Center
EPA	Environmental Protection Agency
ESP	electrostatic precipitator
FGD	flue gas desulfurization
IAC	iodine-impregnated activated carbon
PRB	Powder River Basin
PTC	particulate test combustor

MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

EXECUTIVE SUMMARY

Since 1995, the U.S. Department of Energy (DOE) has supported development of a new concept in particulate control, called the advanced hybrid particulate collector (AHPC). 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.

During the first quarter of the project, initial bench-scale testing was completed and plans were made for an initial field test earlier than planned in the original schedule.

The bench-scale results completed this quarter were in good agreement with data. This means that the planned work based on the previous results is still valid and that no changes to the overall experimental approach are necessary at this time.

Results show 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.

Results with two temperatures indicate that, while somewhat better sorbent capacity was seen at the lower temperature, the same additive concentration effects with SO_2 and NO_2 were seen at both temperatures. This confirms that the approach logic is valid for a wide temperature window.

Testing with the 2.5-MW AHPC at Big Stone was not scheduled to begin until early 2002 after completing the first pilot-scale tests. However, the project team decided to plan an initial field test the first week of November 2001 prior to the pilot-scale tests at the EERC. By doing initial testing in November, mercury sampling in the worst part of the winter can be avoided. Mercury control testing at Big Stone will then resume in the spring of 2002, and the completion of the field testing within the planned schedule is expected.

A full-scale retrofit of an AHPC at the Big Stone Power Plant was recently announced by DOE as one of the projects selected under the DOE Power Plant Improvement Initiative. Because design of this project must begin immediately, it is imperative to have as much information available as possible. By completing this initial field test early, additional information on AHPC performance with carbon injection should facilitate final design of the full-scale Big Stone AHPC.

In addition to the initial field test, plans for next quarter include completion of additional bench-scale tests and the first pilot-scale tests.

MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

1.0 INTRODUCTION

This project was awarded under U.S. Department of Energy (DOE) 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 Power Plant operated by Otter Tail Power Company, which will host 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 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 emission 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 Power Plant. For Phase III, further testing of an improved version of the 2.5-MW scale AHPC at the Big Stone Power 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.

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.

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 will encompass 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 purpose of verifying previous results, expanding on the SO_2 and NO_2 concentrations effect, and linking the synthetic gas results to the results with real flue gas.

The 30 tests planned with the bench-scale unit are divided into three series that follow a logical progression. The first series of tests is being done 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. These results are expected to show whether the SO_2 and NO_2 concentration effects are additive and, once verified with real flue gas, serve as a basis to predict the sorbent capacity if the SO_2 and NO_2 concentrations are known. In all of these tests, an inlet Hg^0 concentration of 15 $\mu g/m^3$ will be used.

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

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

* Norit Americas flue gas desulfurization (FGD) activated carbon.

Each test will be for a duration of approximately 4 hr. The 150 mg of Norit Americas 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, which will be verified for approximately one-third of the tests.

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. These comparisons will be made for both a western subbituminous and an eastern bituminous coal. The simulated flue gas concentrations will be matched to actual concentrations measured in the combustion tests. Since these results are critical, both the real flue gas and simulated flue gas tests will be duplicated. 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 will be completed as part of the first two pilot-scale tests in Task 3. These bench-scale tests will be conducted using a slipstream bench-scale system sampling flue gas from the particulate test combustor (PTC).

After the Series 2 tests, the data will be evaluated to determine if the simulated gas tests provide comparable results to the tests with real flue gas, in terms of initial breakthrough capacity and desorption after 100% breakthrough. If the results are comparable, it will provide confidence in proceeding with the pilot-scale mercury capture tests.

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

Test No.	Sorbent Type	Temp., °C	Sorbent Concentration, mg	Flue Gas	SO_2, ppm	HCl, ppm	NO, ppm	NO_2, ppm
11	FGD	135	150	Real	Flue gas from western coal			
12	FGD	135	150	Real	Duplicate test western coal			
13	FGD	135	150	Simulated*	400	4	300	5
14	FGD	135	150	Simulated Duplicate*	400	4	300	5
15	FGD	135	50	Simulated*	400	4	300	5
16	FGD	135	150	Real	Flue gas from eastern coal			
17	FGD	135	150	Real	Duplicate test eastern coal			
18	FGD	135	150	Simulated*	1000	50	400	10
19	FGD	135	150	Simulated Duplicate*	1000	50	400	10
20	FGD	135	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) 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). The IAC also appears to be better at capturing Hg^0 than the FGD. However, since the IAC is more costly than FGD, it must be effective at lower concentrations than the FGD. The IAC will be evaluated with flue gas concentrations for both a subbituminous and a bituminous coal at two concentration levels and at 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 the FGD. The most promising sorbent would then be further evaluated in pilot-scale testing in Task 3.

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 will be 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 will be 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

Table 3. Bench-Scale Series 3 – Sorbent Type

Test No.	Sorbent Type	Temp., °C	Sorbent Concentration, mg	Flue Gas	SO_2, ppm	HCl, ppm	NO, ppm	NO_2, ppm
21	IAC	135	150	Simulated*	400	4	300	5
22	IAC	135	50	Simulated*	400	4	300	5
23	IAC	135	150	Simulated*	1000	50	400	10
24	IAC	135	50	Simulated*	1000	50	400	10
25	IAC	163	150	Simulated*	400	4	300	5
26	IAC	163	150	Simulated*	1000	50	400	10
27	New No. 1**	135	150	Simulated*	400	4	300	5
28	New No. 2**	135	150	Simulated*	400	4	300	5
29	New No. 3**	135	150	Simulated*	400	4	300	5
30	New No. 4**	135	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 would be selected based on background data and availability.

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.

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 the purpose of 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.

For all of the pilot-scale tests, extensive mercury sampling with both the Ontario Hydro method and mercury CEMs will be completed. The Ontario Hydro measurements will also provide a measure of the particulate collection efficiency of the AHPC. During each week, a total of two to three inlet and six to eight outlet Ontario Hydro samples will be completed. In addition, continuous outlet measurements will be completed with at least one mercury continuous emission monitor (CEM) (Semtech, Tekran, or PS Analytical). The exact instruments will be selected at a later time based on the most current information from other continuing mercury work at the EERC. Several shorter tests will also be completed at the inlet with the mercury

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.

CEMs. All other flue gases such as O_2, CO, CO_2, SO_2, NO, and NO_2 will be monitored by CEMs on the PTC. Chloride concentration in the flue gas will be determined by Method 26A. The feed coals and fly ash samples (which will include the spent sorbent) will also be analyzed for mercury for each test. Approximately three ash samples will be submitted for leaching analysis for each coal type. These samples will also be made available for an air desorption test method that is being developed under U.S. Environmental Protection Agency (EPA) funding at the EERC. The specific subbituminous and bituminous coals to be tested will be selected at a later date. A logical choice for the subbituminous coal would be the coal burned at the Big Stone Power Plant; however, since several different subbituminous Powder River Basin (PRB) coals have been used at this plant during the last year, the exact coal that would be used during the field testing is uncertain. A logical selection for the bituminous coal would be Blacksville since significant mercury test data for this coal already exist (both at the EERC and elsewhere); however, new information may point to a different coal as a better selection.

2.2.4 Task 4 – Field Demonstration Pilot Testing

Big Stone Power Plant was commissioned for service in 1975. The unit is jointly owned by three partners: NorthWestern, Montana–Dakota Utilities, and Otter Tail Power Company. The unit is a 450-MW-rated, Babcock and Wilcox cyclone-fired boiler. The primary fuel for the first 20 years of operation was North Dakota lignite, but 4 years ago, the primary fuel was switched to PRB subbituminous coal. This fuel has approximately one-half of the moisture and one-third more heat than North Dakota lignite. Almost all of the effects of this new fuel have been positive. However, one challenge that has occurred is the decreased efficiency of the ESP because of an increase in resistivity of the fly ash. The combinations of a very fine particle size produced from the cyclone-fired boiler and high ash resistivity make this a challenging test for the AHPC.

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. Since the field AHPC is still on location at the Big Stone Power Plant, having just completed the Phase III demonstration testing, the system is ready for mercury testing. The only modification required is the addition of a sorbent injection system. A total of 5 months of field tests are planned. The first month will be for baseline testing without sorbent injection to establish the mercury concentration, speciation, and amount of fly ash capture. A comparison will also be made of the mercury emissions at the plant stack with the AHPC outlet to determine if the amount of fly ash capture of mercury and possible change in mercury speciation across the plant ESP and AHPC are different.

The second month of field tests will be for the purpose of establishing the sorbent addition rate to achieve 90% mercury control. Following the second month of field testing will be a project decision point. The field data will be reviewed to determine if an acceptable level of mercury control has been achieved, and the results will be compared with the 55-kW pilot-scale tests. If results are acceptable, field testing will continue. If expectations have not been met and no alternatives such as testing another sorbent or altering the process are obvious, the decision may be made to end the project. 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 will be for the purpose of evaluating alternative sorbents. If alternative sorbent testing is not necessary, 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 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.

For the field testing at Big Stone, 4 weeks of intensive mercury sampling are planned. For the baseline testing, a total of 12 Ontario Hydro samples will include the inlet and outlet of the AHPC, the plant inlet to the ESP, and the plant stack. NO and NO_2 will be measured with a portable CEM; SO_2 and NO_x will be obtained from the plant CEMs; and HCl will be determined with Method 26A. A mercury CEM will also be installed at the AHPC outlet for continuous measurements during the day. Coal and fly ash samples from both the plant ESP and AHPC will be analyzed for mercury. The second week of mercury testing will occur during the first month of carbon injection tests. Approximately, three inlet and eight outlet samples will be completed as

well as mercury CEM measurements during the day. An additional 2 weeks of mercury sampling are planned during the third and fifth months of longer-term demonstration. In each of these weeks, two inlet and four outlet Ontario Hydro samples will be taken as well as outlet mercury CEM sampling during the day. Plant coal and AHPC ash samples will also be analyzed for mercury during the longer-term testing.

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 Power 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 Power Plant will be responsible for removing the 24-in. ductwork that breeches the plant ductwork, the electrical power lines, air supply lines, and communication lines once the project is complete.

2.3 Initial Field Test Scheduled with a 2.5-MW AHPC at the Big Stone Power Plant

According to the planned work, testing with the 2.5-MW AHPC at Big Stone was not scheduled to begin until early 2002 after completing the first pilot-scale tests. However, the project team decided to plan an initial field test the first week of November 2001 prior to the pilot-scale tests at the EERC. Several reasons for performing an initial early test include the following:

- Delay in implementing the overall program by five months resulted in moving the whole schedule back by five months. With the original proposed work, the field testing would have begun in the summer. This would have prevented some of the weather problems associated with mercury sampling outside in the winter. By doing initial testing in November, we will avoid having to begin the mercury sampling in the worst part of the winter. It is expected that the mercury control testing at Big Stone will then resume in the spring of 2002, and the completion of the field testing within the planned schedule should still be possible.

- A full-scale retrofit of an AHPC at Big Stone was recently announced by DOE as one of the projects selected under the DOE Power Plant Improvement Initiative. Because design of this project must begin immediately, it is imperative to have as much information available as possible. By completing this initial field test early, additional information on AHPC performance with carbon injection should facilitate final design of the full-scale Big Stone AHPC.

- Since no mercury sampling has previously been completed at the Big Stone plant, early baseline data on the actual inlet mercury concentration and speciation should help in finalizing the EERC pilot plant testing. For example, if higher-than-expected fly ash capture of mercury were seen at Big Stone, that would have to be considered in planning the pilot plant tests.

For the week of testing from November 5 to 9, baseline testing is planned for the first day, followed by carbon injection in both AHPC and pulse-jet operational modes for the remainder of the week. The planned starting carbon addition rate is 24 kg/million m^3 (1.5 lb of FGD carbon sorbent/million acf) of flue gas.

A total of four Ontario Hydro samples are planned for each day, including both inlet and outlet. In addition two mercury CEMs will provide continuous information on the outlet mercury emissions.

This initial field testing should not impact the overall completion schedule of the field testing, but it may delay completion of the first pilot-scale tests. The first test was scheduled to be completed by the end of November. This test will now likely be delayed by several weeks, but there is adequate time in the schedule to make that time up later, so completion of the pilot-scale tests is still expected to be on schedule.

3.0 RESULTS AND DISCUSSIONS

During the last quarter, the EERC bench-scale system was set up for completing the first series of fixed-bed tests. Since the system had not been operated recently, a number of shakedown and repeatability tests were completed prior to starting the formal tests. For these tests, a new shipment of the FGD carbon was obtained from Norit Americas. Another purpose of the shakedown tests was to confirm similar results with the new carbon batch compared to the previous results.

A schematic of the system is shown in Figure 1, and Figure 2 shows the system in the EERC mercury testing laboratory. The gas-mixing system is shown in Figure 3.

The fixed-bed contactor consists of a Teflon-coated, 2.5-in.-diameter dust-loading filter holder (Figure 4). A quartz filter loaded with sorbent makes up the actual fixed bed (Figure 5). The filters are uniformly coated with the sorbents by pulling a vacuum on the outlet side of the filter holder and feeding the sorbent at the inlet side. The process is very repeatable for mass loadings down to 10 mg. The fixed-bed assembly is maintained at the desired temperature inside an oven (Figure 6) which can be controlled to ±1°C. A Tekran mercury analyzer continuously measures the elemental mercury concentration (Figure 7). In order to monitor oxidized forms of mercury, a $SnCl_2$ reduction cell is used prior to the analyzer to convert all forms of mercury for analysis. The spent sorbent is analyzed for mercury to determine a mass balance, and typically, good mass balance closures in the range from 80% to 120% are achieved.

The flue gas concentrations for the Series 1 bench-scale tests are given in Table 5. Both SO_2 and NO_2 were varied as part of the tests. The plan was to complete these tests at 135°C, but a number of tests were also completed at 107°C for comparison with previous results.

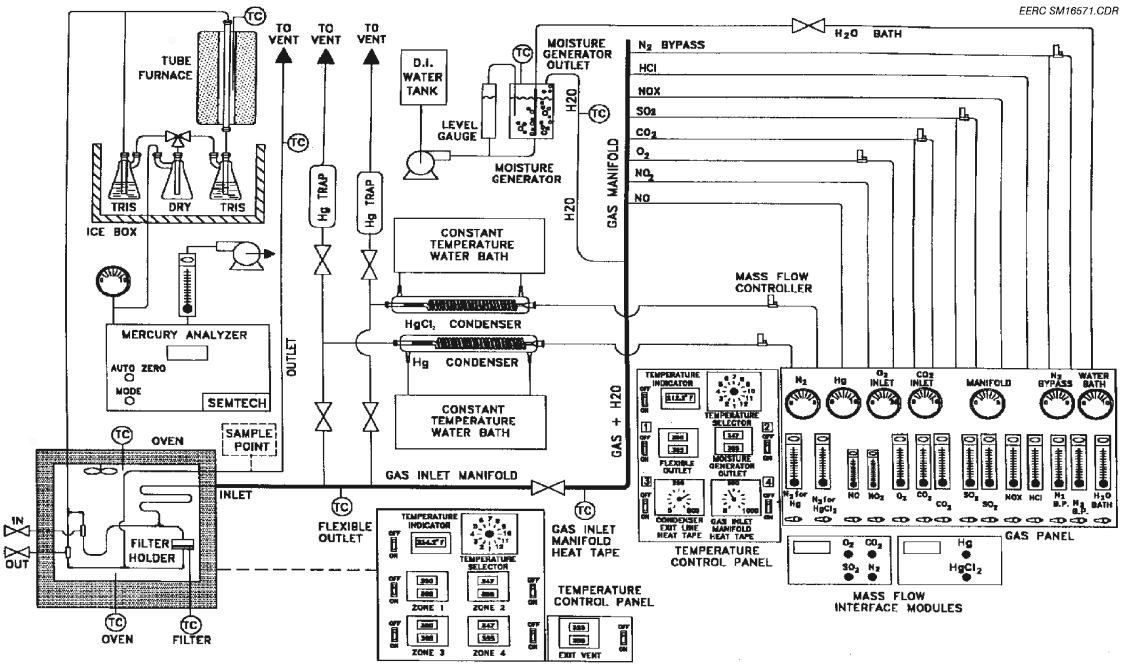

Figure 1. Schematic diagram of the mercury bench-scale system.

Figure 2. EERC mercury bench-scale system.

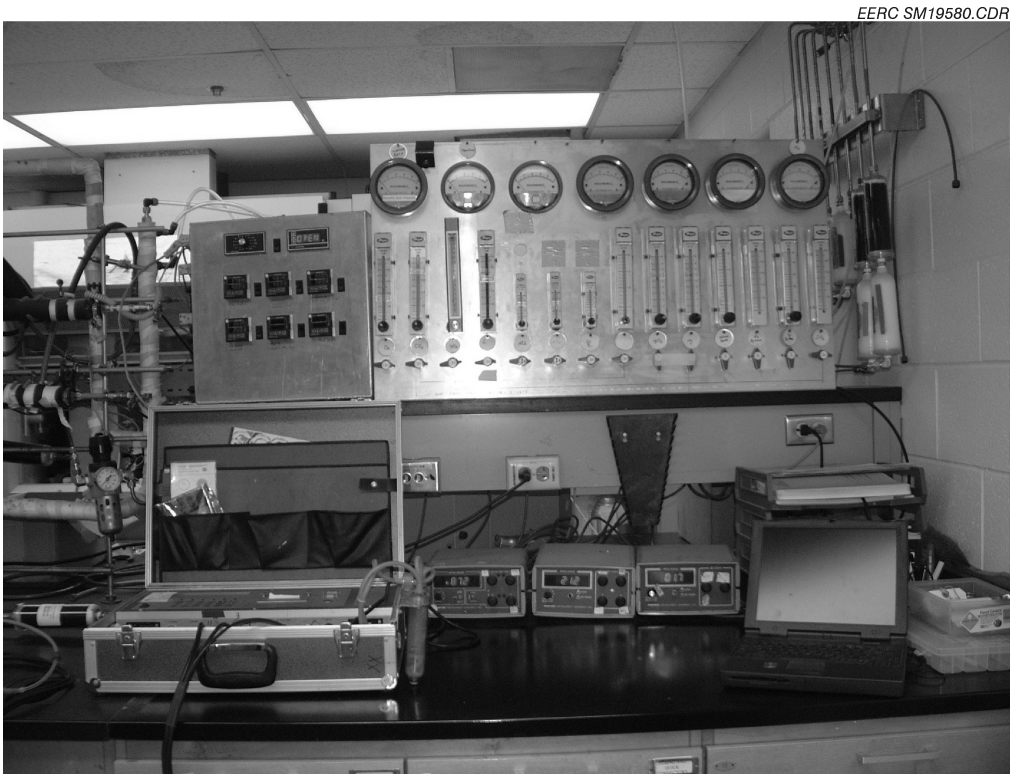

Figure 3. EERC bench-scale gas delivery system.

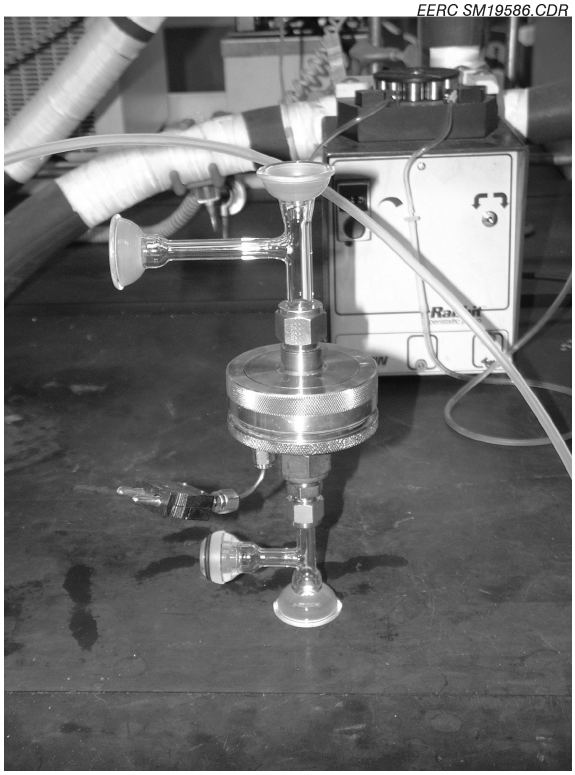

Figure 4. Fixed-bed filter holder.

Figure 5. Carbon fixed bed.

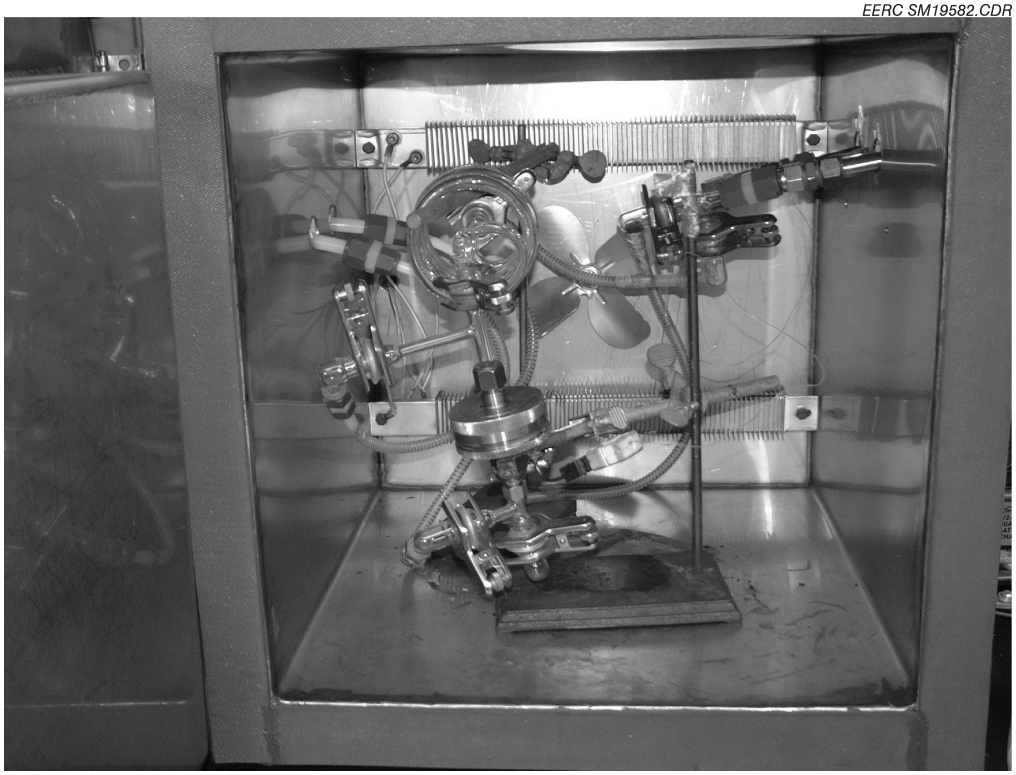

Figure 6. Fixed-bed oven.

Figure 7. Tekran mercury instrument.

TABLE 5. Baseline Flue Gas Concentrations

Hg^0	15 µg/m^3
O_2	6%
CO_2	12%
H_2O	8%
N_2	Balance
HCl	50 ppm
NO	400 ppm
NO_2	Varied
SO_2	Varied

Several initial tests were completed to establish repeatability. From Figure 8 it can be seen that repeat tests for the same conditions are almost identical. All fixed-bed results are presented as breakthrough curves (see Figure 8), where the percent of inlet Hg concentration is plotted as a function of test time. All of these tests show an initial time of 100% capture (near zero percent of inlet) followed by a breakthrough curve that for most tests reached 100% of the inlet (no mercury

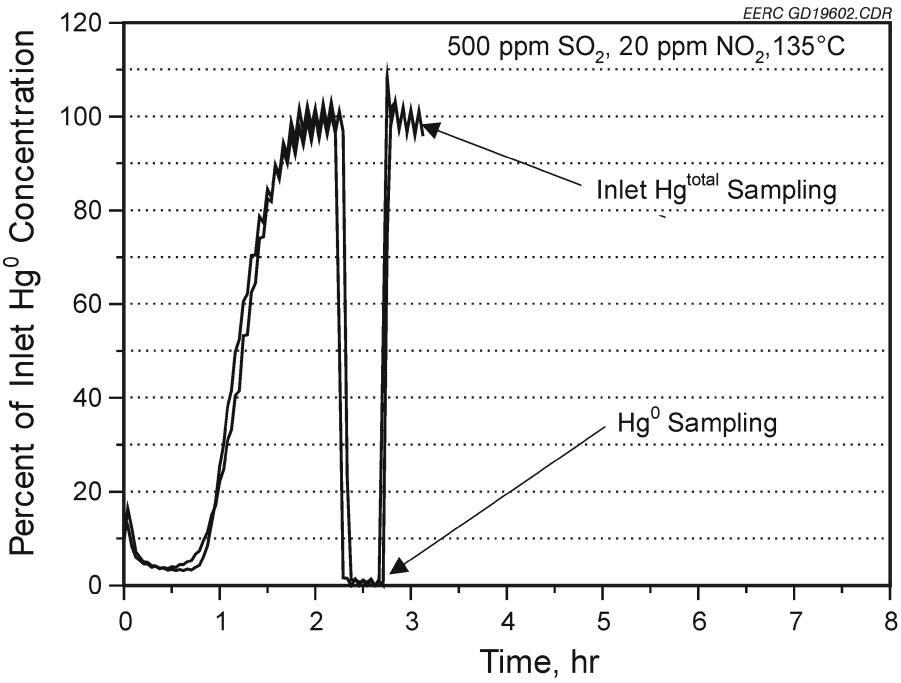

Figure 8. Example of full plot with repeat.

capture). For all of the tests, the mercury conversion system was set to measure total mercury. However, after 100% breakthrough, the system was set to measure only elemental mercury (Hg^0), as shown in Figure 8. A zero reading of Hg^0 means that all of the mercury exiting the fixed bed has been converted to an oxidized form of mercury. At the end of a test, the system was then switched to measure the inlet mercury to verify that the inlet mercury concentration did not change from the start to the end of a test. The Hg^0 and inlet measurements were completed for most of the individual tests, but for comparison, the curves presented in later figures were truncated when they reached nearly 100% breakthrough.

For one of the planned repeat tests, breakthrough did not occur for over 7 hours. Expected results should have been similar to those presented in Figure 8. However, it was discovered well into the test that the moisture source was dry (Figure 9). When moisture was started after 7 hours, very rapid breakthrough was seen above the 100% level (meaning desorption was occurring).

This test verified previous results that showed breakthrough and desorption depend on the presence of moisture as well as other components in the gas.

A comparison was also made of two of the current repeat tests with two repeat tests completed several years ago (Figure 10). For these conditions, breakthrough started at about 1 hour into the test and reached 80% by about 1.5 hours. The curves did appear to deviate somewhat from each other from 80% to 100% breakthrough, with the old data (upper two curves) reaching 100% somewhat earlier than the current tests (lower two curves). Nevertheless, there appeared to be very good general agreement between the old and recent data.

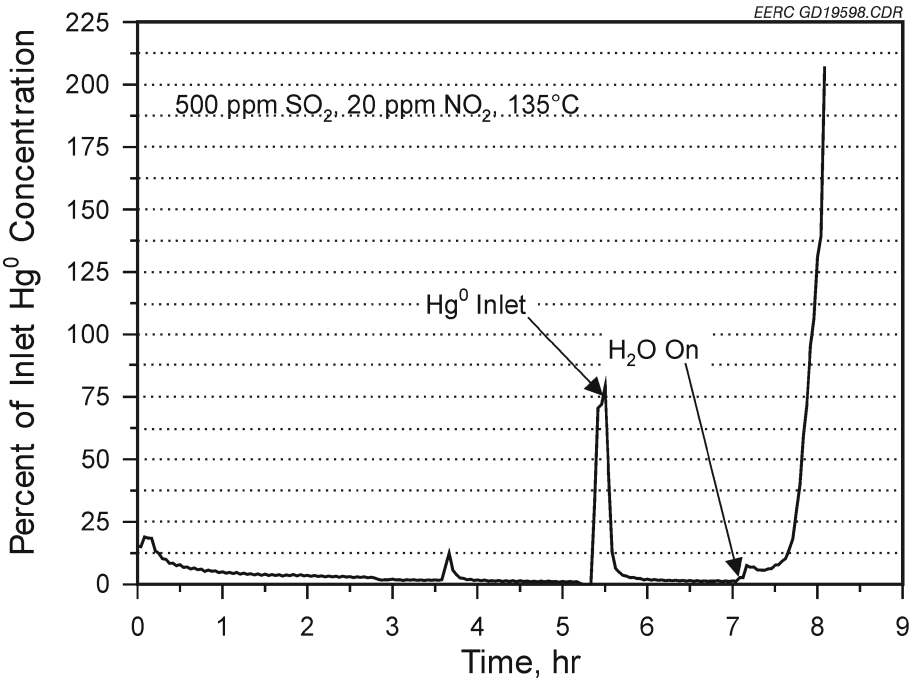

Figure 9. Moisture effect test H_2O started at 7 hours.

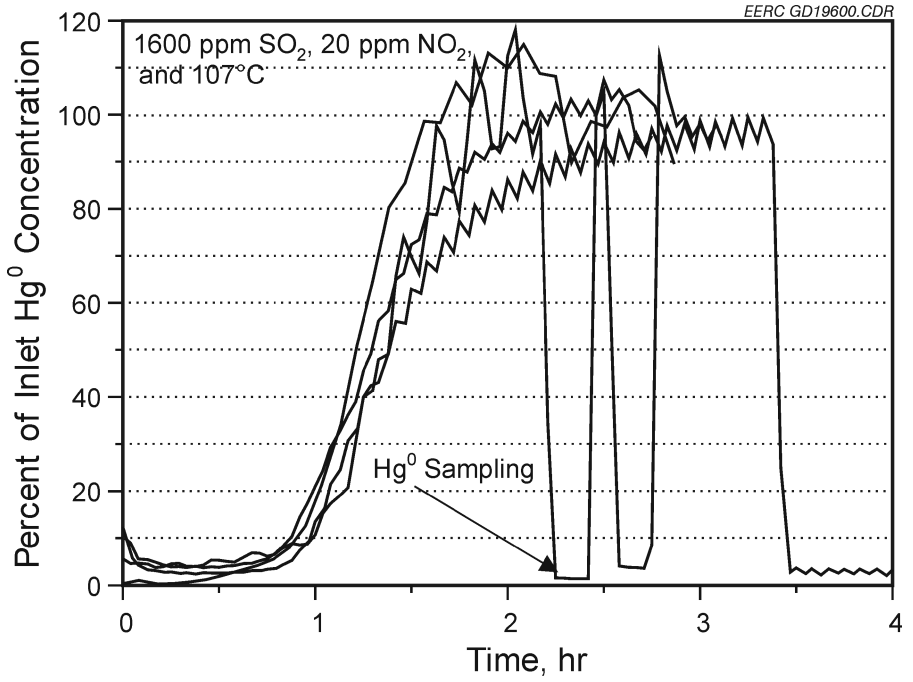

Figure 10. Comparison of bench-scale Series 1 results with previous data.

The effect of NO_2 concentration at 135°C at two different SO_2 levels (200 ppm and 500 ppm) is shown in Figures 11 and 12. For both cases, lower NO_2 concentration results in longer breakthrough times, consistent with previous data. At the higher SO_2 concentration, breakthrough was much faster, suggesting that the SO_2 and NO_2 concentration effects are additive. Furthermore, since the 200 ppm SO_2, 10 ppm NO_2 curve was almost identical to the 500 ppm SO_2, 5 ppm NO_2 curve, the implication is that an additional 5 ppm of NO_2 produces the same effect as an additional 300 ppm of SO_2.

Two NO_2 concentration tests were also conducted at 107°C (Figure 13) for comparison with previous results. The NO_2 concentration effect appears to hold at the lower temperature, but the lower temperature results in a somewhat longer breakthrough time.

The SO_2 concentration data at 5, 10, and 20 ppm of NO_2 are shown in Figures 14–16. Again, results suggest that the SO_2 and NO_2 concentration effects are additive in that an increase in either SO_2 or NO_2 results in a more rapid breakthrough. Interestingly, at the highest NO_2 concentration and the highest SO_2 concentration (Figure 16), the SO_2 effect is not as great. This suggests that there may be an upper limit at which higher SO_2 concentrations no longer result in significantly shorter breakthrough times. This is consistent with previous SO_2 concentration results at 107°C, which showed little difference in breakthrough times between 1600 ppm and 3000 ppm of SO_2.

Three current SO_2 concentration tests at the lower temperature of 107°C show the clear effect of shorter breakthrough with higher SO_2 concentration (Figure 17) and are consistent with previous data.

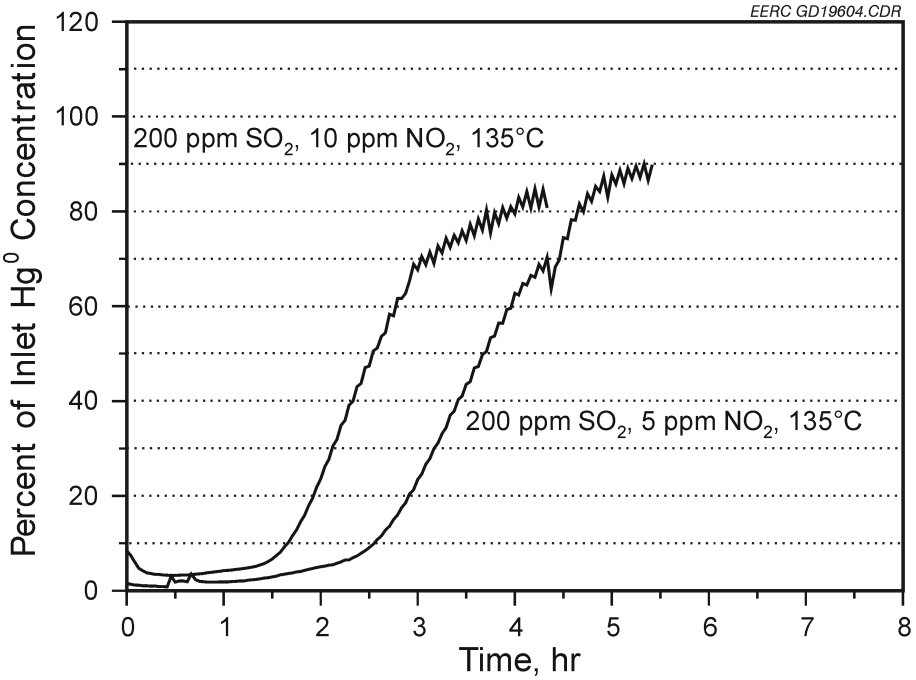

Figure 11. NO_2 concentration effect at 200 ppm SO_2 and 135°C.

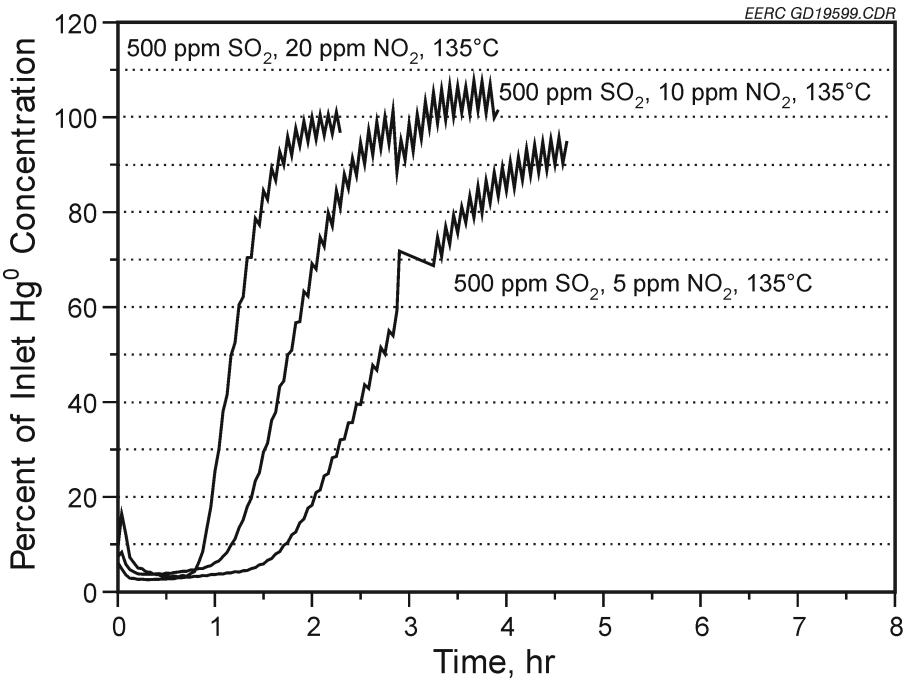

Figure 12. NO_2 concentration effect at 500 ppm SO_2 and 135°C.

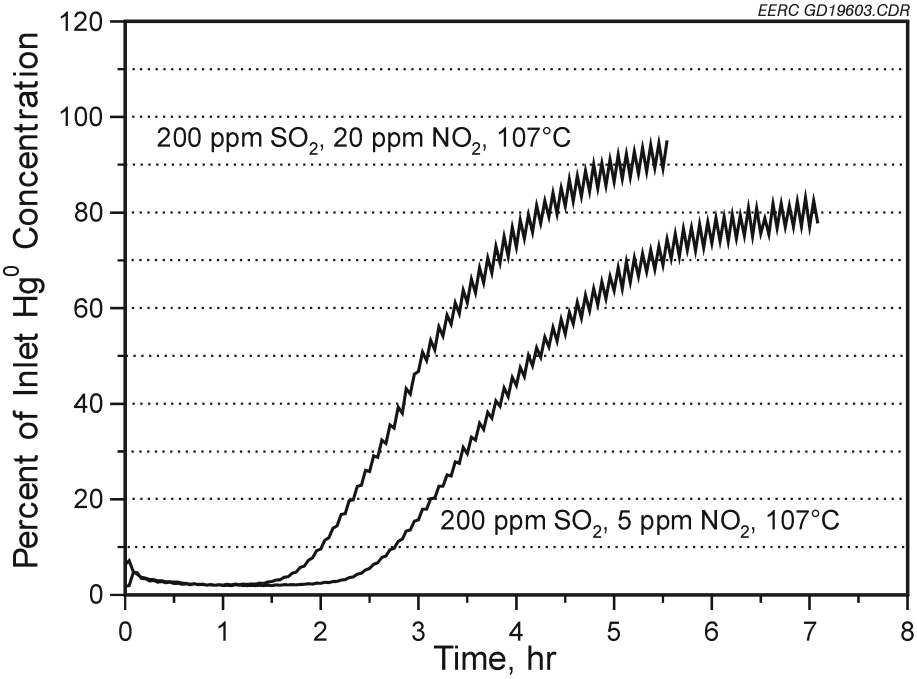

Figure 13. NO_2 concentration effect at 200 ppm SO_2 and 107°C.

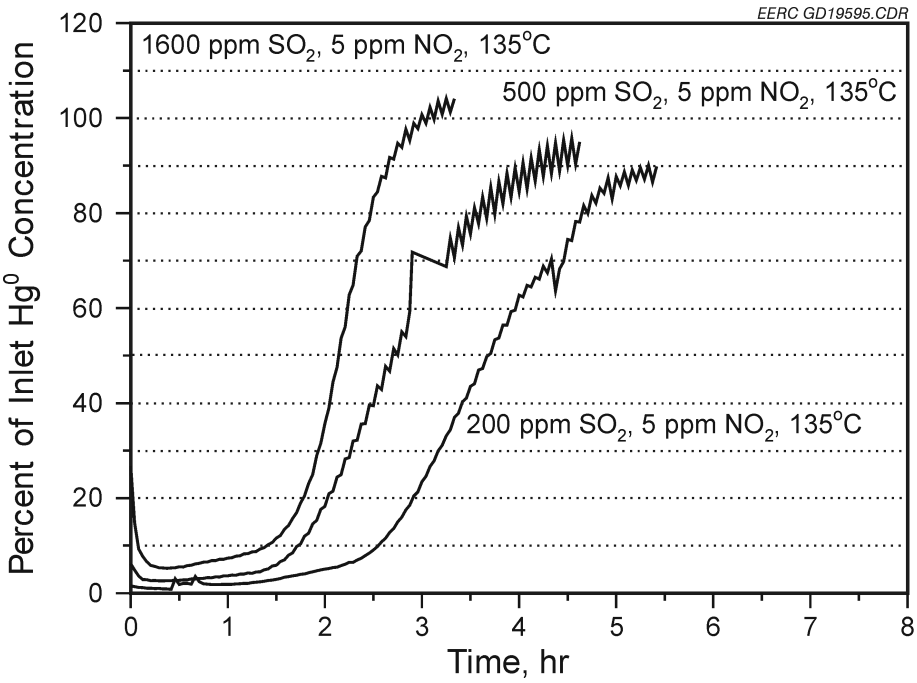

Figure 14. SO_2 concentration effect at 5 ppm NO_2 and 135°C.

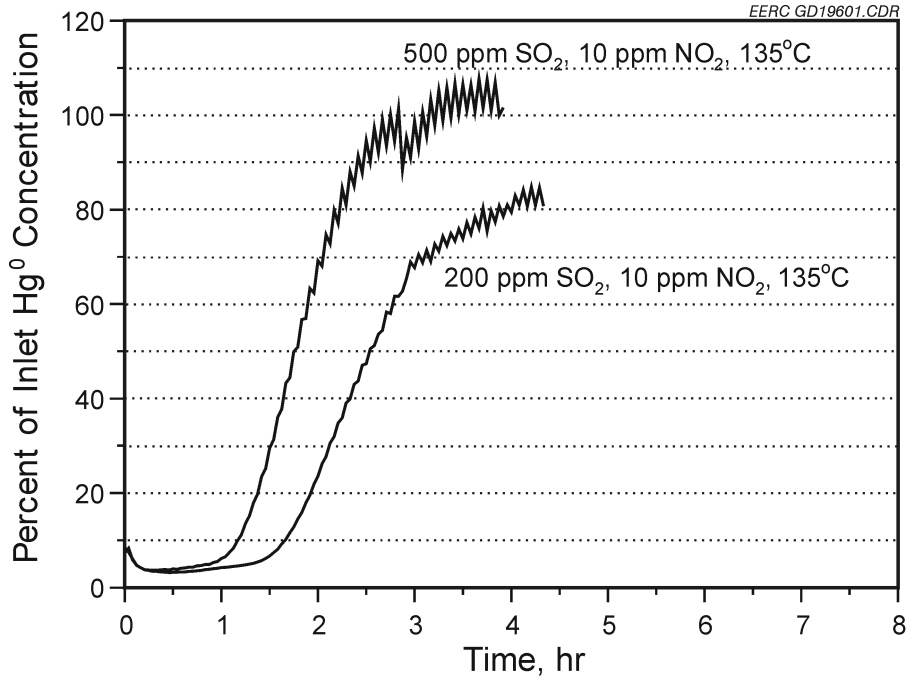

Figure 15. SO_2 concentration effect at 10 ppm NO_2 and 135°C.

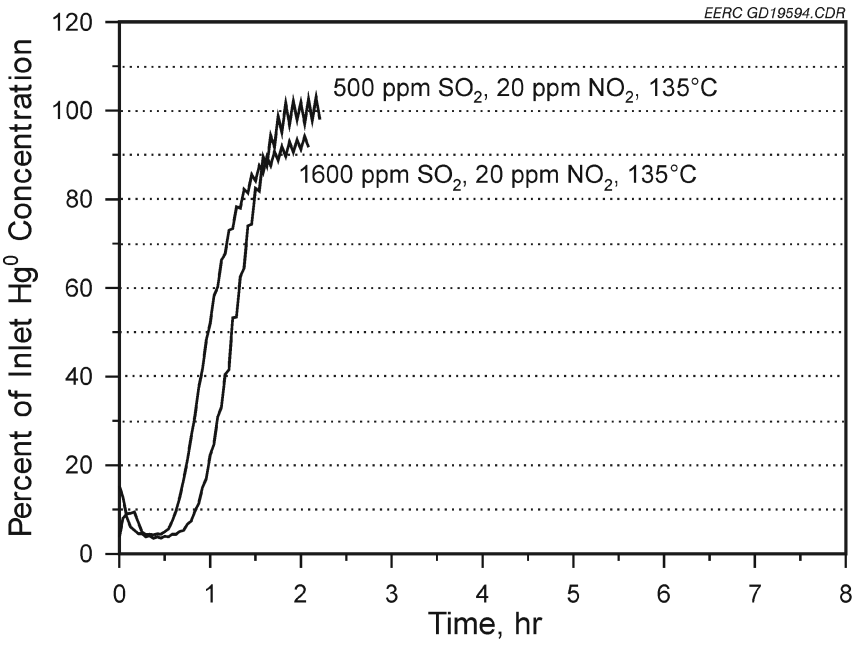

Figure 16. SO_2 concentration effect at 20 ppm NO_2 and 135°C.

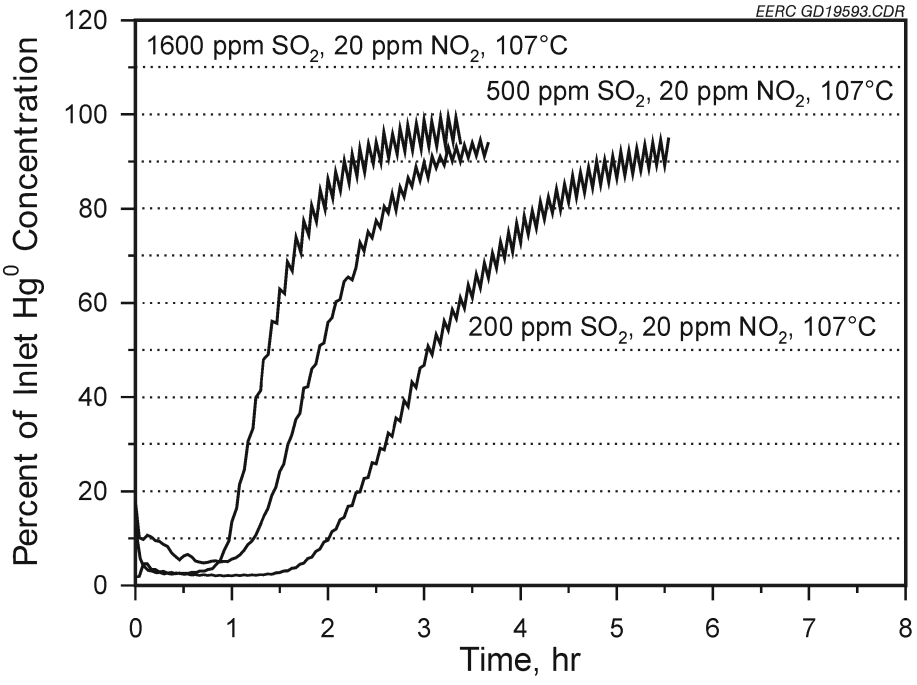

Figure 17. SO_2 concentration effect at 20 ppm NO_2 and 107°C.

The temperature effect is more clearly shown in Figures 18–20, which consistently show somewhat more rapid breakthrough at 135°C compared to 107°C. However, at both temperatures the same additive effects of SO_2 and NO_2 are clear.

Two remaining tests from Series 1 and analysis of the spent sorbent samples for mass balance closure have not been completed yet, but will be discussed in more detail next quarter.

4.0 CONCLUSIONS

- The bench-scale results completed to date are in good agreement with previous data. This means that the planned work based on the previous results is still valid and that no changes to the overall experimental approach are necessary at this time.

- Results also show that the SO_2 and NO_2 concentration effects are additive, which should facilitate predicting sorbent performance in real systems when the SO_2 and NO_2 concentrations are known.

- The results with two temperatures indicate that, while somewhat better sorbent capacity was seen at the lower temperature, the same additive concentration effects with SO_2 and NO_2 were seen at both temperatures. This confirms that the approach logic is valid for a wide temperature window.

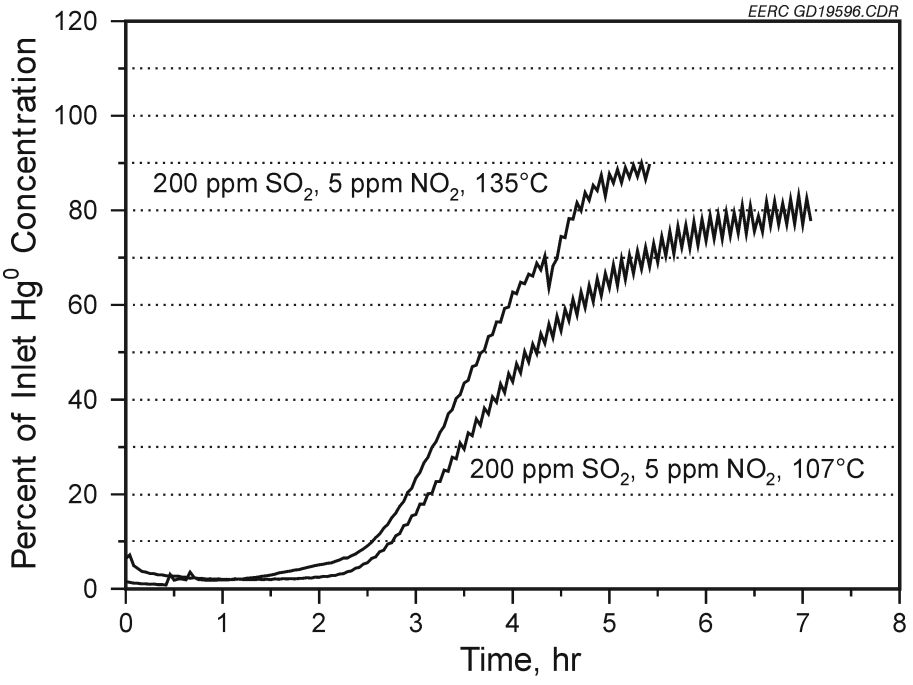

Figure 18. Temperature effect at 200 ppm SO_2 and 5 ppm NO_2.

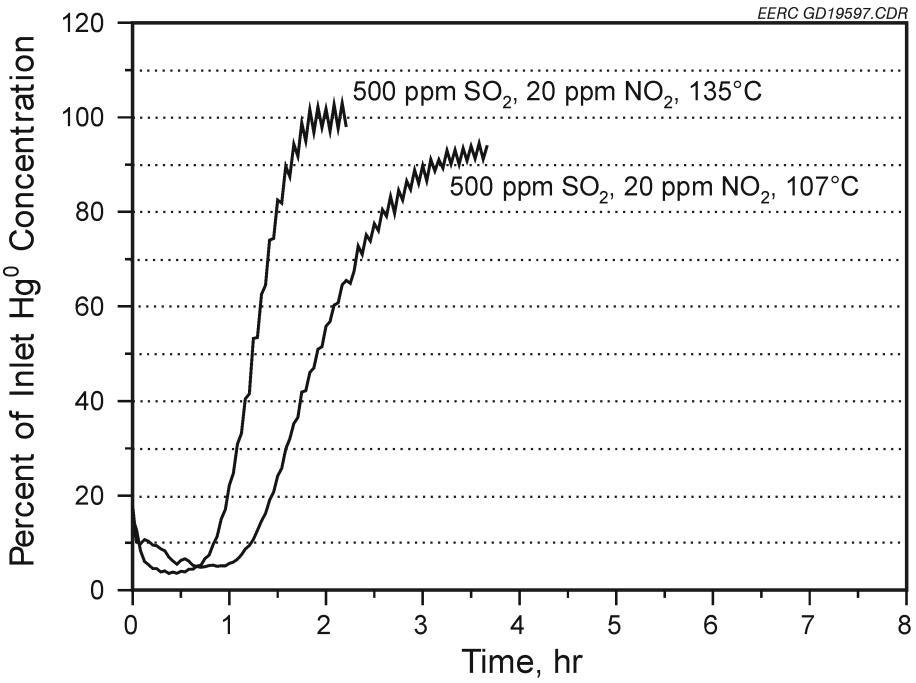

Figure 19. Temperature effect at 500 ppm SO_2 and 20 ppm NO_2.

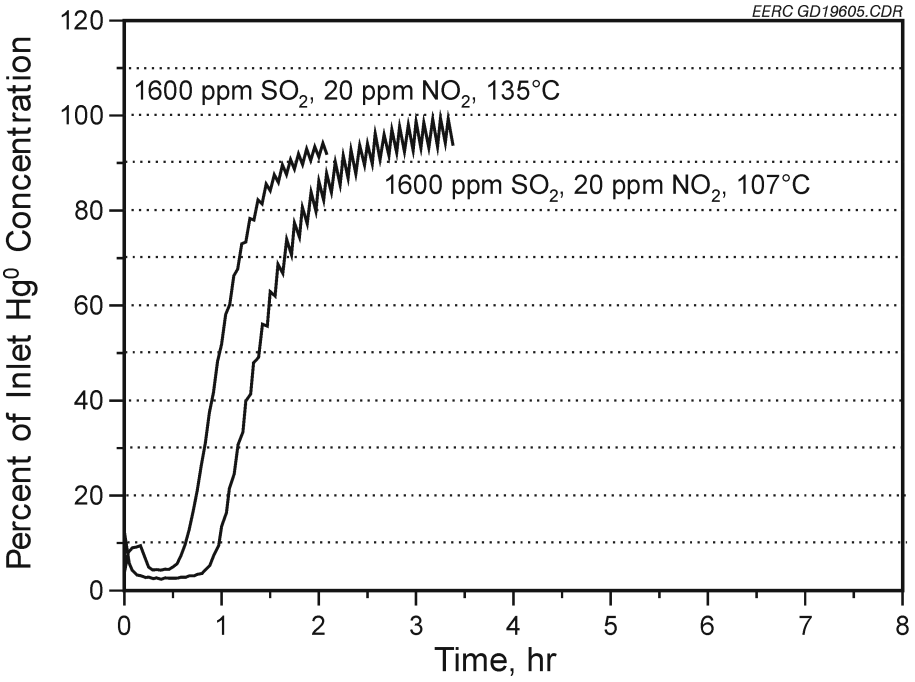

Figure 20. Temperature effect at 1600 ppm SO_2 and 20 ppm NO_2.