# Evaluation of Sorbent Injection for Mercury Control

Quarterly Technical Report
Reporting Period: October 1, 2004–December 31, 2004

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Submitted: February 2, 2005

DOE Cooperative Agreement No.: DE-FC26-03NT41986

Report No. 41986R05

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# ABSTRACT

The power industry in the U.S. is faced with meeting new regulations to reduce the emissions of mercury compounds from coal-fired plants. These regulations are directed at the existing fleet of nearly 1,100 boilers. These plants are relatively old with an average age of over 40 years. Although most of these units are capable of operating for many additional years, there is a desire to minimize large capital expenditures because of the reduced (and unknown) remaining life of the plant to amortize the project. Injecting a sorbent such as powdered activated carbon into the flue gas represents one of the simplest and most mature approaches to controlling mercury emissions from coal-fired boilers.

The overall objective of the test program described in this quarterly report is to evaluate the capabilities of activated carbon injection at five plants with configurations that together represent 78% of the existing coal-fired generation plants. This technology was successfully evaluated in NETL's Phase I tests at scales up to 150 MW, on plants burning subbituminous and bituminous coals and with ESPs and fabric filters. The tests also identified issues that still need to be addressed, such as evaluating performance on other configurations, optimizing sorbent usage (costs), and gathering longer-term operating data to address concerns about the impact of activated carbon on plant equipment and operations. The four sites identified for testing are Sunflower Electric's Holcomb Station, AmerenUE's Meramec Station, AEP's Conesville Station, and Detroit Edison's Monroe Power Plant. In addition to tests identified for the four main sites, parametric testing at Missouri Basin Power Project's Laramie River Station Unit 3 has been scheduled and made possible through additional cost-share participation targeted by team members specifically for tests at Holcomb or a similar plant.

This is the fifth quarterly report for this project. Long-term testing was completed at Meramec during this reporting period. Preliminary results from parametric, baseline and long-term testing at Meramec are included in this report. Planning information for the other three sites is also included. In general, quarterly reports will be used to provide project overviews, project status, and technology transfer information. Topical reports will be prepared to present detailed technical information.

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# INTRODUCTION

The overall objective of this test program is to evaluate the capabilities of activated carbon injection at four plants with configurations that together represent 78% of the existing coal-fired generation plants. A short-term test at a fifth site has been added to the program. This technology was successfully evaluated in NETL's Phase I tests at scales up to 150 MW, on plants burning subbituminous and bituminous coals and with ESPs and fabric filters. The tests also identified issues that still need to be addressed, such as evaluating performance on other configurations, optimizing sorbent usage (costs), and gathering longer-term operating data to address concerns about the impact of activated carbon on plant equipment and operations. A summary of the key descriptive parameters for the host sites can be found in Table 1. Monroe Power Plant was selected as the fourth site during a team meeting on October 27, 2004. Laramie River Station has been added as the fifth site in the program.

The technical approach that will be followed during this program will allow the team to: 1) effectively evaluate activated carbon and other viable sorbents on a variety of coals and plant configurations, and 2) perform long-term testing at the optimum condition for at least one month. These technical objectives will be accomplished by following a series of technical tasks:

Task 1. Design and Fabrication of Sorbent Injection System

Task 2. Site-Specific Activities including Field-Testing

Task 3. Technology Transfer

Task 4. Program Management and Reporting

Tasks 1, 3, and 4 are intended to support the overall direction, implementation, technology transfer, and management of the program. Task 2 will be repeated for each test site with subtasks designed to address the specific configurations, needs, and challenges of that site. Task 2 is the heart of the program and contains subtasks to address each important component of the testing. A summary of the Field-Testing subtasks (Task 2) is presented in Table 3.

**Table 1. Host Site Key Descriptive Information.**

| | Holcomb | Meramec | Laramie River | Monroe | Conesville |
|---|---|---|---|---|---|
| Test Period | 3/04–8/04 | 8/04–11/04 | 2/05–3/05 | 3/05–6/05 | 7/05–10/05 |
| Unit | 1 | 1 or 2 | 3 | 4 | 5 or 6 |
| Size (MW) | 360 | 140 | 550 | 785 | 400 |
| Coal | PRB | PRB | PRB | PRB/Bit blend | Bituminous |
| Particulate Control | Joy Western Fabric Filter | American Air Filter ESP | ESP | ESP | Research-Cottrell ESP |
| SCA ($ft^2$/kacfm) | NA | 320 | 599 | 258 | 301 |
| Sulfur Control | Spray Dryer Niro Joy Western | Compliance Coal | Spray Dryer | Compliance Coal | Wet Lime FGD |
| Ash Reuse | Disposal | Sold for concrete | Disposal | Disposal | FGD Sludge Stabilization |
| Test Portion (MWe) | 180 and 360 | 70 | 140 | 196 | 400 |
| Typical Inlet Mercury (μg/$dNm^3$) | 10–12 | 10–12 | 10–12 | 8–10 | 15.8 |
| Typical Mercury Removal | 0–13% | 15–30% | <20% | ? | 56% |

A detailed topical report will be prepared at the end of the one-year test period. Quarterly reports will be used to provide project overviews, status, and technology transfer information.

# EXECUTIVE SUMMARY

This five-site project is part of an overall program funded by the Department of Energy's National Energy Technology Laboratory (NETL) and industry partners to obtain the necessary information to assess the feasibility and costs of controlling mercury from coal-fired utility plants. Host sites that will be tested as part of this program are shown in Tables 1 and 2. These host sites reflect a combination of coals and existing air pollution control configurations representing 78% of existing coal-fired generating plants and potentially a significant portion of new plants. These host sites will allow documentation of sorbent performance on the following configurations:

**Table 2. Host Sites Participating in the Sorbent Injection Demonstration Project.**

| | Coal / Options | APC | Capacity MW / Test Portion | Current Hg Removal (%)* |
|---|---|---|---|---|
| Sunflower Electric's **Holcomb Station** | PRB & Blend | SDA – Fabric Filter | 360 / 180 and 360 / 360 | 0–13 |
| AmerenUE's **Meramec Station** | PRB | ESP | 140 / 70 | 15–30 |
| American Electric Power's (AEP) **Conesville Station** | Bituminous Blend | ESP + Wet FGD | 400 / 400 | 56 |
| Detroit Edison's **Monroe Power Plant** | PRB/Bit Blend | SCR + ESP | 785/196 | NA |
| Missouri Basin Power Project's **Laramie River Station** | PRB | SDA – ESP | 550/140 | <20 |

* Based upon recent Ontario Hydro measurements, except Meramec.

During the fifth reporting quarter, October through December 2004, progress on the project was made in the following areas:

### Sunflower Electric Power Corporation, Holcomb Station

- Continue sample and data analysis and working on site report
- Presented preliminary results at Western Fuels and PowerGen

### AmerenUE, Meramec

- Completed long-term testing (October 14–November 17, 2004)
- Team Meeting to present results from Meramec (October 27, 2004)
- Conducted sorbent screening tests
- Continue sample and data analysis
- Presented preliminary results at PowerGen
- Continue sample and data analysis and working on site report

**AEP, Conesville**

- Working with AEP to develop plans for installing sampling ports, silo, etc.
- Working with AEP and REI for flow modeling

**Detroit Edison, Monroe**

- Received verbal approval from DOE, EPRI, and funding team to test at Monroe
- Site visit and meeting at Detroit Edison Monroe
- Working on Host Site agreement with Monroe
- Work with DOE to modify contract to test at Monroe
- Planning activities required to start testing in April 2005 (plant installation document, working with plant, test planning, etc.)
- Issue test plan and installation document

**MBPP, Laramie River Station**

- Received verbal approval from DOE, EPRI, and funding team to test at Laramie River Unit 3
- Site kickoff meeting January 20, 2005
- Issued draft test plan and installation document
- Field testing is scheduled to begin February 2005

# EXPERIMENTAL

The overall objective of this test program is to evaluate the capabilities of activated carbon injection at five plants with configurations that together represent 78% of the existing coal-fired generation plants. Following the technical approach summarized in this section, ADA-ES and the project team will evaluate activated carbon and other viable sorbents on a variety of coals and plant configurations, and perform long-term testing at the optimum condition for up to six weeks. The technical approach is outlined in a series of four technical tasks.

## Task 1. Design and Fabrication of Sorbent Injection System

ADA-ES, the primary test contractor, will provide the majority of the process equipment that will travel from site to site. This equipment will be sized and designed to cover the expected range of plant sizes (70–500 MW) and flue gas conditions, and has the flexibility for both baghouse and ESP applications.

## Task 2. Site-Specific Activities Including Field-Testing

This task has seven subtasks that will be repeated for the four host sites. A summary of these subtasks is presented in Table 3. The four sites identified for testing are Sunflower Electric's Holcomb Station, AmerenUE's Meramec Station, AEP's Conesville Station, and Detroit Edison's Monroe Power Plant. A short-term series of parametric tests has also been included for Missouri Basin Power Project's Laramie River Station. Testing during this quarter was conducted at Meramec Station. Descriptions of Holcomb and Meramec were included in the previous quarterly report. Descriptions of other sites will be included when results are presented.

**Table 3. Task 2 Subtasks (to be repeated at each test site).**

| Subtask | Description |
|---|---|
| 2.1 | Host site kickoff meeting, Test Plan, and QA/QC plan |
| 2.2 | Design and install site-specific equipment |
| 2.3<br>2.3.1<br>2.3.2<br>2.3.3<br>2.3.4<br>2.3.5 | Field-tests<br>Sorbent selection<br>Sample and data coordination<br>Baseline tests<br>Parametric tests<br>Long-term tests |
| 2.4 | Data analysis |
| 2.5 | Sample evaluation |
| 2.6 | Economic analysis |
| 2.7 | Site report |

## Subtask 2.1. Host Site Planning and Coordination

Efforts within this subtask include planning the site-specific tests with the host site utility, DOE/NETL, and contributing team members. The planning process includes meeting with plant personnel, corporate, and environmental personnel to discuss and agree upon the overall scope of the program, the potential impact on plant equipment and operation, and to gather preliminary information necessary to develop a detailed draft Test Plan and scope of work. Efforts include identifying any permit requirements, developing a quality assurance/quality control plan, finalizing the site-specific scope for each of the team members, and putting subcontracts in place for manual flue gas measurements, including Ontario Hydro mercury measurement services.

### *Missouri Basin Power Project, Laramie River Station and DTE, Monroe Power Plant*

Field-testing is scheduled for spring 2005 at Laramie River and Monroe. Specific activities during this reporting period are listed below.

- Submitted request to DOE for contract modification to test at Laramie River and Monroe.
- A Host Site Agreement has been finalized with Laramie River. A Host Site Agreement has been sent to DTE for review. It is expected the DTE agreement will be finalized during the next reporting period.
- ADA-ES personnel are working with Laramie River and Monroe personnel to identify site-specific requirements. A plant procurement document will be developed and submitted to the plant during the site kickoff meetings (scheduled for January 11, 2005, at Monroe and January 20, 2005, at Laramie River).

## Subtask 2.2. Design, Fabricate, and Install Equipment

During this subtask, equipment will be identified, designed, fabricated when necessary, and installed at the host site. Some components are site-specific such as the sorbent distribution manifold and sorbent injectors (if possible, these components will be reused at multiple sites). This equipment must be sized, designed, and fabricated for the specific plant arrangements and ductwork configurations. Required site support includes installation of the injection and sampling ports (if not available), installation of required platforms and scaffolding, compressed air, electrical power, wiring plant signals including boiler load to the injection skid and control trailer, and the balance of plant engineering. The host utility will be responsible for all permitting and any variance requirements.

## Subtask 2.3. Field-Testing

The field-tests will be accomplished through a series of five (5) steps. A summary of these steps is presented below.

### *2.3.1 Sorbent Selection*

To assist in the sorbent selection process, a sorbent screening device (SSD) designed by ADA-ES may be used at the site to compare the performance of candidate sorbents. A description of the device was included in the 2Q04 quarterly report. Results from these tests will be included in the next quarterly report.

### *2.3.2 Sample and Data Coordination*

ADA-ES engineers coordinate with plant personnel to retrieve the necessary plant operating data files and determine appropriate samples to collect during baseline, parametric, and long-term testing periods. Samples are collected based upon a Sample and Data Management Plan developed for the sites. An example of the sampling schedule for Meramec and additional descriptions of the sample management protocol were included in the 2Q04 report.

### *2.3.3 Baseline Testing*

Baseline mercury measurements are typically made at each site for at least one week prior to beginning parametric mercury control tests. Ontario Hydro mercury measurements are conducted at each site in conjunction with SCEM measurements during baseline testing. Additional tests, such as EPA M26a or EPA M29 measurements may also be conducted during this step.

### *2.3.4 Parametric Testing*

A series of parametric tests is conducted at each site to determine the optimum operating conditions for several levels of mercury control. Evaluations of NORIT's DARCO Hg (formerly known as FGD) and one other sorbent chosen by the test team are typically included. Additional tests, such as coal blending or the introduction of additives onto the coal, may also be included. A summary of parametric tests conducted or planned at each site is shown below.

**Sorbent Injection**
(descriptions of sorbents tested are included in the previous quarterly reports)

- DARCO Hg (formerly known as FGD): All sites
- DARCO Hg-LH (formerly known as FGD-E3): Holcomb, Meramec, Laramie River
- Calgon 208CP: Holcomb
- Sorbent(s) to be finalized: Monroe, Conesville

**Coal Blending**

- PRB and Western Bituminous: Holcomb, Laramie River
- PRB and Eastern Bituminous: Monroe
- Eastern Bituminous and PRB: Conesville

**Coal Additives**

- ALSTOM's KNX: Holcomb, Meramec, Laramie River
- EERC's SEA2: Meramec (conducted with AmerenUE funds)

### *2.3.5 Long-Term Testing*

Thirty-day "long-term" testing has been completed at Holcomb and Meramec and is planned for Monroe and Conesville. The sorbents used during the long-term test period are chosen by the test team based upon performance during parametric testing and a review of the material costs and availability. During the long-term tests at Holcomb and Meramec, NORIT America's product DARCO Hg-LH was evaluated. The tests at Meramec were divided into two different phases. During the first phase, the target mercury removal was 60–70%, with a goal of minimizing the sorbent injection in an effort to protect the ability to sell the ash from Meramec Unit 2. The target mercury removal efficiency over the 30-day second phase of testing was 85–95%. Testing at Holcomb did not include the initial 5-day test period at a lower target mercury removal.

The goal of the 30-day test phase is to obtain operational data on mercury removal efficiency, the effects on the particulate control device, effects on byproducts, and impacts to the balance of plant equipment to prove viability of the process and determine the economics. During these tests, Ontario Hydro measurements are conducted at the inlet and outlet of the particulate control device at least once.

## Subtask 2.4. Data Analysis

Data collection and analysis for this program are designed to measure the effect of sorbent injection on mercury control and the impact on the existing pollution control equipment. The mercury levels and plant operation will be characterized without sorbent injection, during coal blending or coal additive testing, and with various injection rates and possible combustion modifications as defined by the final Site Test Plan.

## Subtask 2.5. Coal and Byproduct Evaluation

Coal and combustion byproduct samples collected throughout the program are analyzed in this task. During all field test phases, samples of coal and fly ash are collected. At a minimum, ultimate and proximate analyses will be performed and mercury, chlorine, and sulfur levels will be determined in a representative set of the coal samples. Activated carbon injection will result in the fly ash and scrubber materials being mixed with a certain amount of the mercury-containing sorbent. The ash samples will be analyzed at a minimum for mercury and LOI. It is expected that more than 100 samples will be collected at each site. A subset of these samples will be analyzed.

### Subtask 2.6. Economic Analysis

After completion of testing and analysis of the data at each plant, the requirements and costs for full-scale permanent commercial implementation of the selected mercury control technology will be determined. The program team will meet with the host utility plant and engineering personnel to develop plant-specific design criteria. Process equipment will be sized and designed based on test results and the plant-specific requirements (reagent storage capacity, plant arrangement, retrofit issues, winterization, controls interface, etc.). A conceptual design document will be developed. Finally, a budget cost estimate will be developed to implement the control technology.

### Subtask 2.7. Site Report

A site report will be prepared documenting measurements, test procedures, analyses, and results obtained in Task 2. This report is intended to be a stand-alone document providing a comprehensive review of the testing that will be submitted to the host utility.

## Task 3. Technology Transfer

Technology transfer activities include participation in DOE/NETL-sponsored meetings, EPA Hg MACT Stakeholder meetings, presentations at conferences, and publication of technical papers. Abstracts were submitted to several upcoming conferences including the Electric Utility Environmental Conference and Electric Power. Presentation of results from tests conducted at Holcomb and Meramec is planned.

## Task 4. Program Management and Reporting

The final task provides time for overall program management and time to complete DOE's reporting requirements. This task will also support periodic meetings with DOE to discuss progress and obtain overall direction of the program from the DOE project manager. In addition to the standard financial and technical reports, additional deliverables will include topical reports for each site tested. The Project Schedule and Milestones are presented in Table 4.

**Table 4. Project Schedule and Milestones.**

| Activity | Target Date | Actual Date |
|---|---|---|
| **Holcomb** | | |
| Site Kickoff Meeting | 12/16/03 | 12/16/03 |
| Complete Sorbent Screening Tests | 3/4/04 | 3/2/04 |
| Complete Equipment Installation | 5/21/04 | 4/21/04 |
| Complete Baseline Testing | 5/21/04 | 5/20/04 |
| Initiate Parametric Testing | 5/24/04 | 5/22/04 |
| Complete Parametric Testing | 6/11/04 | 6/11/04 |
| Initiate Long-Term Testing | 7/7/04 | 7/7/04 |
| Complete Team Meeting and Site Tour | 7/21/04 | 7/21/04 |
| Complete Long-Term Test | 8/6/04 | 8/6/04 |
| Complete Economic Analysis | 5/31/05 | |
| Complete Byproduct Analysis Evaluations | 5/31/05 | |
| Complete Site Report | 6/30/05 | |
| **Meramec** | | |
| Site Kickoff Meeting | 4/20/04 | 4/20/04 |
| Complete Pre-Baseline Testing | 6/25/04 | 6/23/04 |
| Complete Sorbent Screening Tests | 10/18/04 | 10/08/04 |
| Complete Equipment Installation | 9/5/04 | 8/23/04 |
| Complete Baseline Testing | 9/5/04 | 8/27/04 |
| Initiate Parametric Testing | 9/6/04 | 8/30/04 |
| Complete Parametric Testing | 10/17/04 | 9/27/04 |
| Complete Team Meeting and Site Tour | 12/17/04 | 10/27/04 |
| Initiate Long-Term Testing | 10/18/04 | 10/14/04 |
| Complete Long-Term Test | 12/17/04 | 11/17/04 |
| Complete Economic Analysis | 8/31/05 | |
| Complete Byproduct Analysis Evaluations | 8/31/05 | |
| Complete Site Report | 9/30/05 | |
| **Conesville** | | |
| Site Kickoff Meeting | 2Q05 | |
| Initiate Field-Testing | 4Q05 | |
| Complete Field-Testing | 4Q05 | |
| **Monroe** | | |
| Site Kickoff Meeting | 4Q04 | |
| Initiate Field-Testing | 3Q05 | |
| Complete Field-Testing | 4Q05 | |
| **Laramie River** | | |
| Site Kickoff Meeting | 1Q05 | |
| Initiate Field-Testing | 2Q05 | |
| Complete Field-Testing | 2Q05 | |

There are more than 100 individual team members from 27 organizations participating in this program. Current project co-funders include:

- ADA-ES, Inc.
- ALSTOM
- AmerenUE*
- American Electric Power*
- Arch Coal
- Detroit Edison*
- Dynegy Generation
- EPRI
- MidAmerican
- NORIT Americas
- Ontario Power Generation* and partners
  - EPCOR
  - Babcock & Wilcox
- Southern Company
- Sunflower Electric Power Corporation* and partners
  - Associated Electric Coop
  - Western Fuels Association
  - Kansas City Board of Public Utilities (KCKBPU)
  - Westar Energy
  - Empire District Electric Company
  - Nebraska Public Power District
  - Kansas City Power and Light
  - Tri-State/Missouri Basin Power Project*
  - Wisconsin Public Service
- Tennessee Valley Authority

* indicates host site

Key members of the test team include:

- ADA-ES, Inc.
- ALSTOM
- EPRI
- NORIT Americas
- Reaction Engineering International
- Tetra Tech, Inc.
- Others
  - Stack test firms
  - Analytical laboratories

To facilitate information sharing, a project Web site is maintained for the project. The project Web site is password protected and available only to project participants. Information available through the Web site includes all presentations, papers, reports, planning documents, schedules, and other information related to the project.

A schedule showing field-tests planned and completed at each test site is shown in Table 5.

**Table 5. Field-Testing Schedule.**

| | 2004 | | | | 2005 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Site | May | Jul | Sep | Nov | Jan | Mar | May | Jul | Sep | Nov |
| Holcomb | | | | | | | | | | |
| Meramec | | | | | | | | | | |
| Laramie River | | | | | | | | | | |
| Monroe | | | | | | | | | | |
| Conesville | | | | | | | | | | |

# RESULTS AND DISCUSSION

## Task 1. Design and Fabrication of Sorbent Injection System

Design and fabrication of the sorbent injection system was completed during the second reporting period—January through March 2004.

## Task 2. Site-Specific Activities Including Field-Testing

Long-term testing was completed at Holcomb Station and baseline and parametric tests were completed at Meramec during the last reporting period. Preliminary site-specific activities have begun at Laramie River, Monroe, and Conesville. Results from testing at Meramec are included under this task heading. Key activities at other sites are also presented.

### Subtask 2.3. Field-Testing, Meramec Station

#### *2.3.1 Sorbent Selection*

This task was completed during the previous reporting period—July–September 2004. In support of upcoming tests at Laramie River and Monroe, a short series of sorbent screening tests were also conducted at Meramec. These results will be included in the next quarterly report.

#### *2.3.2 Sample and Data Coordination*

Data analysis, coal, and byproduct evaluation is ongoing. Details will be included in the site reports.

#### *2.3.3 Baseline Testing*

This task was completed at Meramec during the previous reporting period— July–September 2004.

Meramec Unit 2 fires 100% Powder River Basin (PRB) coal, obtained from several different mines, and is equipped with cold-side electrostatic precipitators (CESP) for particulate control. Variations in coal can be identified primarily through variations in $SO_2$ emissions. At full load, the unit operates at sub-stoichiometric oxygen levels in the combustion zone to control $NO_x$ that may affect the amount of unburned carbon in the ash (LOI). During the baseline tests, the unit was maintained at standard full-load conditions, 140 MW, between the hours of 08:00 and 19:00. At night, the load was reduced to as low as 40 MW.

At the beginning of baseline testing, August 24–26, 2004, the full load mercury concentration at the ESP inlet and outlet was relatively steady. However, changes in the average $SO_2$ concentration at the stack indicates that the coal burned during this time probably came from more than one source. The native, daily average mercury removal across the ESP ranged from 15 to 18%. This agrees well with historical data collected on units with a similar configuration (i.e., 100% PRB/CESP).

The mercury concentration in the fly ash collected in the first field ESP hoppers during baseline testing ranged from 0.374 to 0.680 ppm. This is equivalent to a particulate-phase mercury of 2.6 to 4.8 μg/Nm$^3$ at an ash loading of 3.13 gr/dscf (based on a combustion calculation). This is similar to the difference in the inlet and outlet vapor-phase mercury values suggesting that 1) most of the mercury measured by the SCEM at the inlet to the ESP is in the vapor phase, and 2) the mercury removal measured by the SCEMs can be verified by measuring the mercury concentration in the ash.

Pre-baseline mercury measurements were also made at the ESP inlet and outlet on June 22, 2004, using EPA draft Method 324 (in-situ carbon trap). Results showed the average mercury concentrations at the ESP inlet and outlet were 8.5 μg/dNm$^3$ and 6.8 μg/dNm$^3$ respectively, yielding a mercury removal efficiency of about 20%. This agrees well with the baseline results.

### *2.3.4 Parametric Testing*

This task was completed at Meramec during the previous reporting period— July–September 2004.

**Sorbent Injection Testing**

Two sorbents, DARCO Hg and DARCO Hg-LH, were evaluated at Meramec. All tests were conducted at standard, daytime, full-load conditions.

During the first week of testing, DARCO Hg was evaluated. The baseline (no sorbent injection) mercury removal was measured at the beginning of each test day and ranged from 13% at the beginning of the week to a high of 53% in the middle of the test week. Although sorbent injection was stopped by 18:00 every day, residual sorbent in the ESP may have contributed to the variability in the baseline removal the following morning. Changes in combustion conditions may have also contributed to changes in the baseline removal.

The hour-average mercury removal using DARCO Hg peaked at 74% at an injection concentration of 5 lb/MMacf and showed no further increase up to 20 lb/MMacf. Because of the variability in baseline removal discussed above, it is also useful to calculate mercury removal based on the change in the ESP outlet mercury concentration that resulted immediately upon the initiation of sorbent injection. This was calculated to peak at 72% removal at an injection concentration of 5 lb/MMacf.

These results are similar to those achieved with DARCO Hg at other CESP sites burning low-rank coals (PRB and North Dakota lignite)[1]. The reason for this removal plateau is that while halogen species, such as HCl, appear to enhance the performance of activated carbon, halogen concentrations are relatively low in low-rank coals. It is speculated that activated carbon injection rates of 3 to 10 lb/MMacf are sufficient to absorb the available halogens so that subsequent increases in injection rates are ineffective.

During the second week of parametric testing, the performance of DARCO Hg-LH was evaluated at several injection rates. DARCO Hg-LH is a brominated activated carbon chosen for testing at Meramec because of its potential to achieve mercury removal levels higher than possible with non-chemically treated carbons and its relatively low cost.

One change in normal plant operations should be noted. One of the four coal mills, Mill B, was out of service during this week. Meramec Unit 2 is tangentially fired and Mill B feeds one of four burner levels. Because of the mill outage, Unit 2 was operated at reduced load of about 115 MW, and higher variations were observed in the ESP inlet mercury concentration than during previous tests (average hourly standard deviation was 0.9 $\mu g/Nm^3$ compared to 0.6 $\mu g/Nm^3$ during earlier tests). These variations were likely caused by rapid changes in unburned carbon, or LOI. Changes in LOI can result in different fractions of particulate and vapor-phase mercury in the flue gas and may have contributed to higher than normal mercury removal.

At an injection concentration of 0.6 lb/MMacf, the total mercury removal was 78%. This increased to 97% removal at 3.2 lb/MMacf. The maximum mercury removal based on the change in the ESP outlet mercury concentration due to DARCO Hg-LH injection was 91% at 3.2 lb/MMacf. These data clearly demonstrate that enhanced mercury removal performance can be achieved with the right halogenated activated carbon. These data are presented in Figure 1.

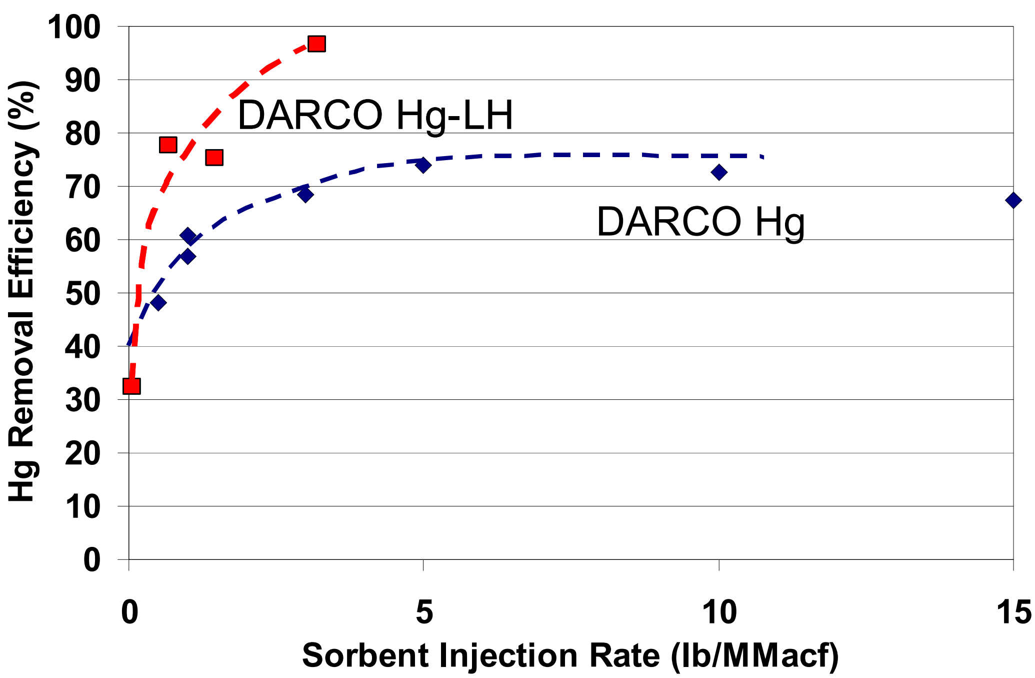


**Figure 1. Parametric Test Results for DARCO Hg and DARCO Hg-LH.**

**Coal Additive Testing**

During the final week of parametric testing, a halogen-based coal additive, ALSTOM's KNX material, was evaluated for enhancements when injecting untreated activated carbon and to native fly ash removal. By the start of this test, Mill B had been returned to service; however, the changes made to Mills A, C, and D during the outage had not been reset for 4-mill operation. This resulted in increased LOI, as verified by LOI measurements. The ESP inlet mercury concentration was more stable than when Mill B was out of service, but the vapor-phase mercury concentration was lower than during previous tests. This was likely due to additional particulate-phase mercury associated with the higher LOI.

Coal treated with KNX reached Unit 2 at around 08:00 on September 20. On September 22 and 23, two ash samples were collected upstream of the ESP using an in-situ cyclone sampling device designed to capture all particulate matter >1 micron. Mercury analysis of these samples yielded 1.59 and 2.27 ppm of mercury in the ash, indicating a large fraction of the incoming mercury is in the particulate phase.

Due to the increased LOI and the resulting decrease in vapor-phase mercury, it is difficult to determine the effectiveness of KNX by itself. The mercury removal and oxidation (indicated by low elemental Hg) was typically higher at the ESP inlet with KNX and high LOI. Data from 9/20–9/23 with KNX addition only can be compared to the data from 9/25 and 9/27 with no KNX or DARCO Hg. With KNX, removal ranged from 57 to 64% compared to 22 to 34% with no KNX. No boiler operational changes were made during this time. These data suggest the KNX alone can enhance the effectiveness of native fly ash containing LOI.

During one day of KNX injection (9/23), DARCO FGD was injected at the ESP inlet. The maximum vapor-phase mercury removal was 87% at an injection concentration of 5 lb/MMacf. The total removal (total mercury = particulate + vapor phase) was likely higher, but the SCEMs do not account for particulate mercury. For example, if we assume based on coal mercury values that the total mercury was actually 10 $\mu g/Nm^3$ when particulate mercury is factored in, then the removal at 5 lb/MMacf would be 95%. For comparison, the change in the vapor-phase mercury at the ESP outlet at a DARCO Hg injection concentration of 5 lb/MMacf was 73% in the absence of KNX.

### *2.3.5 Long-Term Testing*

The 30-day "long-term" test period was divided into two phases. For the first phase, the goal was to determine if the sorbent injection concentration could be minimized to maintain ash sales while achieving 60–70% mercury removal. This test was conducted for five days. During the second phase of testing, the goal was to achieve 85 to 95% mercury removal. This phase of testing was conducted for thirty days. Based upon results from parametric testing, DARCO Hg-LH was chosen for long-term testing.

**Phase I: 60–70% Mercury Removal Target**

Continuous sorbent injection began on October 14, 2004, at an injection concentration of 0.5 lb/MMacf (~8 lb/hr). During this 5-day test, sorbent injection rates were adjusted until mercury removal efficiencies across the ESP were in the range of 60–70%. Results from this portion of long-term testing indicate a sorbent injection concentration of ~1.0 lb/MMacf yielded a vapor-phase mercury capture of 60–70% across the ESP.

Fly ash samples were collected during these tests and are being analyzed. Analyses include mercury content, LOI%, and foam index tests. These data will be used to quantify the impacts of activated carbon injection on fly ash. Results from these tests will be presented in the site report.

**Phase II: 85–95% Mercury Removal Target**

Following the 5-day Phase I test, the sorbent injection concentration was increased to achieve vapor-phase mercury removal efficiencies of 85–95%. The sorbent feeder was configured to adjust feedrate based upon on a feed-forward signal from the plant representing the amount of coal fed into the boiler. An algorithm was developed to correlate coal feed rate to duct flow so that the sorbent injection concentration could be maintained with variation in load.

DARCO Hg-LH was continuously injected over a 30-day period while achieving >90% mercury capture across the ESP. The goal of this task was to prove viability of this technology and determine process economics by measuring the effects of continuous injection on:

- Balance-of-plant impacts
- ESP performance
- Byproducts (i.e., fly ash)

The sorbent injection concentration was increased from 2.5 lb/MMacf to 4.5 lb/MMacf over the first four days of testing in order to achieve 90% vapor-phase mercury capture. Following four days of Phase II testing, the injection concentration was decreased to approximately 3 lb/MMacf with no significant reduction in the mercury removal across the ESP. A trend graph showing mercury concentrations at the inlet and outlet of the ESP during long-term testing is presented in Figure 2. The graph also includes trends of boiler load and $SO_2$ concentrations. The $SO_2$ concentration provides an indication of coal changes at Meramec.

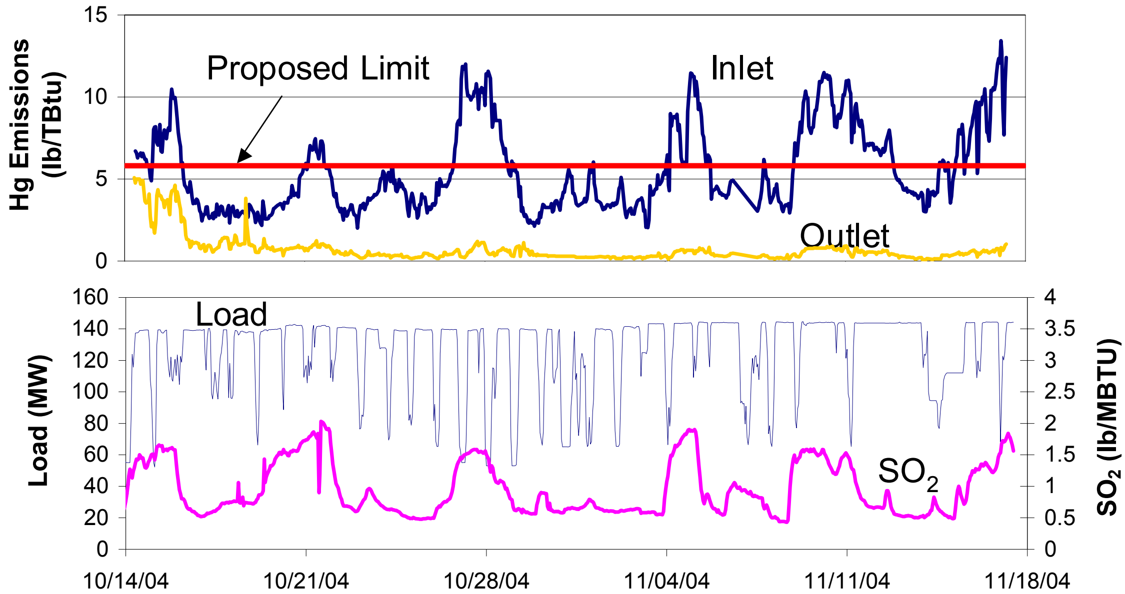


**Figure 2. Mercury and $SO_2$ Trends during Long-Term Testing.**

The average inlet and outlet mercury concentrations were 5.98 and 0.44 lb/Tbtu respectively for the Phase II long-term tests. This yields an average vapor-phase mercury capture of 93% at an average sorbent injection concentration of 3.3 lb/MMacf. This agrees well with the parametric testing results as shown in Figure 3.

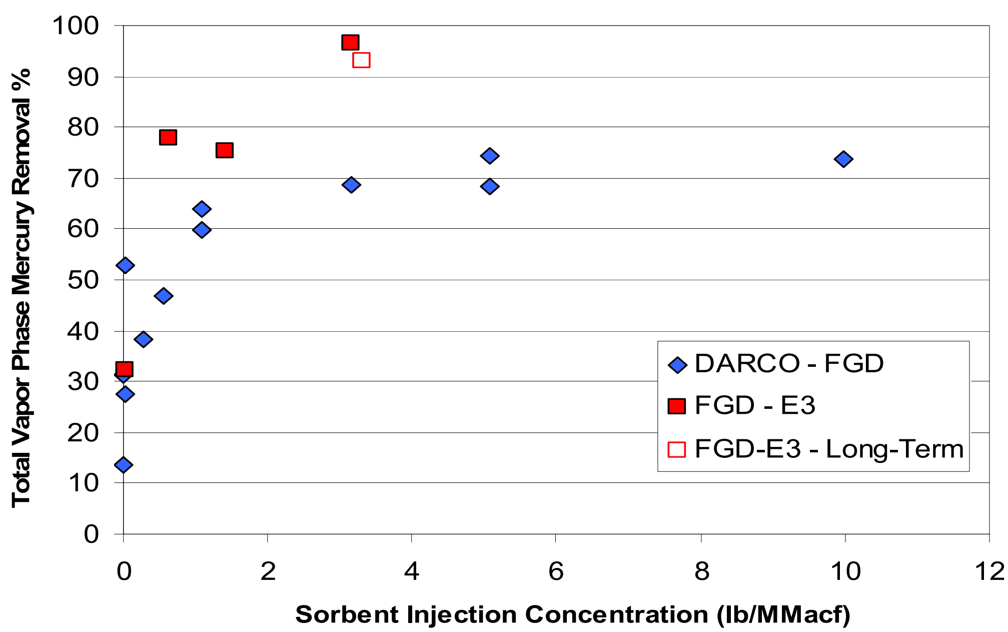


**Figure 3. Comparison of FGD-E3 Results from Parametric and Long-Term Tests.**

To confirm measurements made from the mercury analyzers, Ontario Hydro (i.e., ASTM M6784-02) measurements were conducted at ESP inlet and outlet locations. The Ontario Hydro is recognized by the power industry as the best manual sampling method currently available in determining mercury speciation in coal derived flue gas streams. A series of triplicate runs were conducted between November 2–4 and another set of triplicate runs were conducted on November 9, 2004.

The average total (vapor + particulate) mercury removal efficiency for each series of Ontario Hydro tests completed was 94.6 and 91.2% respectively. Total inlet mercury concentrations from the Ontario Hydro measurements were approximately 40% higher than the concentrations measured by the inlet mercury analyzer. Since the mercury analyzer does not have the ability to measure particulate-phase mercury, in-situ fly ash samples were collected at the ESP inlet and measured for mercury content. Mercury content from these samples suggests 30–40% of the mercury at the ESP inlet was in particulate phase. Total mercury concentrations were calculated by adding the vapor-phase concentration, as measured by the inlet mercury analyzer, and the particulate-phase fraction from the fly ash together. These values were within 10% of the total mercury as measured by both sets of Ontario Hydro tests. These data are presented in Table 6.

**Table 6. Ontario Hydro Results from Long-Term Testing at Meramec.**

| Series 1: Nov. 2 - 4 | | | | | |
|---|---|---|---|---|---|
| **Location** | **Test Method** | **$Hg_{Particulate}$ (µg/dNm3)** | **$Hg^0$ (µg/dNm3)** | **$Hg^{++}$ (µg/dNm3)** | **$Hg_{Total}$ (µg/dNm3)** |
| ESP Inlet | Ontario Hydro | 8.4 | 0.9 | 1.7 | 11.0 |
| | Analyzer/Fly Ash | 3.2 | 3.8 | 3.1 | 10.1 |
| ESP Outlet | Ontario Hydro | 0.0 | 0.4 | 0.2 | 0.6 |
| | Analyzer/Fly Ash | | 0.4 | | 0.4 |
| Removal Efficiency (OH) | | 99.9 | 53.7 | 89.3 | **94.6** |
| Removal Efficiency (A + F) | | | 89.2 | | **95.9** |

| Series 2: Nov. 9 | | | | | |
|---|---|---|---|---|---|
| **Location** | **Test Method** | **$Hg_{Particulate}$ (µg/dNm3)** | **$Hg^0$ (µg/dNm3)** | **$Hg^{++}$ (µg/dNm3)** | **$Hg_{Total}$ (µg/dNm3)** |
| ESP Inlet | Ontario Hydro | 12.4 | 2.4 | 4.6 | 19.4 |
| | Analyzer/Fly Ash | 7.6 | 6.4 | 5.2 | 19.2 |
| ESP Outlet | Ontario Hydro | 0.0 | 1.1 | 0.6 | 1.7 |
| | Analyzer/Fly Ash | n/a | 1.1 | n/a | 1.1 |
| Removal Efficiency (OH) | | 100.0 | 53.0 | 87.4 | **91.2** |
| Removal Efficiency (A + F) | | | 82.9 | | **94.3** |

* - Mercury concentrations are corrected to normal temperature and pressure conditions (i.e., 0° and 760 mm Hg)

The Ontario Hydro sampling train is designed to capture particulate matter on a filter and have it analyzed for mercury content. These data are used to calculate the particulate fraction of mercury in the flue gas. However, if the fly ash is reactive with vapor-phase mercury, this can bias the speciation results. The Ontario Hydro from Table 2 data indicated a significant fraction of mercury collected on the sampling filter. This is likely a measurement artifact due to the reactive nature of the fly ash and not necessarily representative of the actual fraction of mercury on the fly ash at the inlet of the ESP. Nonetheless, the Ontario Hydro is a viable method in determining total mercury concentration in the flue gas.

One of the main objectives during long-term testing was to gather plant-operating data and determine the affects of activated carbon injection on balance of plant issues (e.g., stack emissions, ESP performance). Sorbent was continuously injected into the Unit 2 ESP for 35 days, and there was no measurable increase in stack opacity during the test period. No impacts on ESP performance were noted during testing. However, the plant experienced ESP data acquisition problems at the beginning of long-term testing and it is difficult to quantify the impacts of ACI on ESP performance by analyzing the data collected. It should also be noted that Meramec Unit 2 has a relatively large ESP (SCA = 320 $ft^2$/kacfm). Additional testing is recommended to determine if operational issues would arise on a smaller ESP or during extended testing (>1 month) on a larger unit.

The particulate-phase mercury at the inlet to the ESP at Meramec during the 35-day continuous injection period was nominally 30%. The combustion characteristics present during the test series resulted in higher than expected LOI carbon in the ash. This LOI carbon and the high surface area present in Meramec's tubular air pre-heater likely contributed to a higher fraction of particulate-phase mercury than typically observed for units firing PRB coal with lower LOI and regenerative air pre-heaters, and may have contributed to the high overall mercury removal measured at this site.

It is Ameren's intent to sell the fly ash from Meramec Unit 2 for use in the cement industry. It has been Ameren's experience that when LOI content is less than <0.7%, the fly ash has potential for use as a cement admixture. The increase in carbon due to sorbent injection at an injection concentration of 1 lb/MMacf is estimated to be limited to 0.4%. This concentration was used during the first five days of continuous injection testing. It is well know that even trace amounts of activated carbon can be detrimental to ash quality for cement use because of the characteristics of activated carbon. Therefore, although the injection concentration resulted in a marginal increase in carbon in the ash, it is expected the ash will not be saleable for cement use. In order to maintain ash sales, other options that allow segregating the ash from the injected sorbent, such as TOXECON™ or TOXECON II™, should be considered.

Historical data suggest that no measurable mercury will leach from collected ash. Tests are underway on the ash/sorbent mix collected during the 30-day test at Meramec.

## Subtask 2.4. Data Analysis

Data collected during the baseline, parametric, and long-term test periods are currently being reviewed.

## Subtask 2.5. Coal and Byproduct Evaluation

More than 350 samples were collected from Meramec during the field-testing campaign. Most of the ash samples, several coal samples, and at least one of all other sample types will be analyzed for mercury. Additional analyses, including coal ultimate and proximate analyses, and coal and ash chlorine analyses are being conducted. Results from these tests are being reviewed and will be summarized in the topical report for the site.

# CONCLUSIONS

Field-testing has been completed at Holcomb and Meramec. Preliminary results from Meramec tests were reported in this quarterly report.

Results from Holcomb and Meramec provide information about options for mercury control at plants firing PRB coals. Options evaluated include coal-blending, introduction of additives onto the coal, and sorbent injection. General conclusions and observations from these tests include:

- Coal Blending
  - Up to 80% mercury removal achieved during short-term test at Holcomb
  - Additional tests required to confirm this result
  - *Tests are planned at Laramie River (SDA + ESP) and Monroe (ESP)*
- Coal Additives
  - >80% removal achieved at Meramec without carbon injection *(plant configuration and high LOI may have contributed to removal)*
  - Carbon injection required at Holcomb for high removal
  - *Tests are planned for Laramie River*
- Treated Activated Carbon Injection (DARCO Hg-LH)
  - High removal (>90%) achieved at Holcomb and Meramec during the long-term test periods
  - No adverse balance-of-plant impacts were noted at either site
  - *Treated sorbents will be considered for testing at the remaining test sites*
- Other Balance-of-Plant Concerns
  - Historical data suggest that no measurable mercury will leach from collected ash. Tests are underway on the ash/sorbent mix collected during the 30-day DARCO Hg-LH injection tests at Holcomb and Meramec to determine if either mercury or bromine leach from the samples. DARCO Hg-LH is a bromine-treated activated carbon.
  - Flue-gas bromine measurements were made at Holcomb and Meramec during long-term testing of DARCO Hg-LH. No levels of bromine in excess of those expected for plants firing PRB coals were measured.
  - Trace amounts of activated carbon can be detrimental to ash quality for cement use. Options to protect ash for sales include TOXECON™ and TOXECON II™. TOXECON II™ tests are scheduled to begin this fall on a separate DOE contract.

Specific conclusions and observations from the long-term test period at Meramec include:

- A sorbent injection concentration of approximately 1.0 lb/MMacf was needed to capture 60–70% of the vapor-phase mercury across the ESP during the preliminary 5-day continuous injection test.

- After increasing the sorbent injection rate, the average inlet and outlet mercury concentrations were 5.98 and 0.44 lb/TBtu respectively. This represents an approximate 93% reduction in vapor-phase mercury across the ESP and agrees well with the parametric testing results. The average sorbent injection concentration was 3.3 lb/MMacf.
- No measurable increase in stack opacity, $SO_2$, or $NO_x$ emissions was observed during long-term testing.
- The two sets of Ontario Hydro measurements performed during long-term testing showed average mercury removal efficiencies of 94.6 and 91.2%. These were consistent with measurements made by the inlet mercury analyzer and in-situ fly ash samples.
- The sorbent injection system experienced no material handling problems during long-term testing.
- Data from the second half of long-term testing suggest impacts to ESP operating parameters were minimal. Data from the first half of testing are unavailable.

# REFERENCES

1. Sjostrom, S. (2005). "Full-Scale Evaluations of Mercury Control Technologies with PRB Coals," presented at the 8th Electric Utilities Environmental Conference, Tucson, AZ, January 24–26.

# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ACI | Activated carbon injection |
| APC | Air pollution control |
| B&W | Babcock & Wilcox |
| COC | Chain of Custody |
| DARCO Hg | Sorbent manufactured by NORIT Americas. Formerly known as DARCO FGD |
| DARCO Hg-LH | Sorbent manufactured by NORIT Americas. Formerly known as DARCO FGD-E3 |
| DOE | Department of Energy |
| ESP | Electrostatic precipitator |
| FGD | Flue gas desulfurization |
| ID Fan | Induced draft fan |
| kacfm | Thousand actual cubic feet per minute |
| kW | Kilowatt |
| MW | Megawatt |
| NETL | National Energy Technology Laboratory |
| O&M | Operating and Maintenance |
| PAC | Powdered Activated Carbon |
| PC | Pulverized coal |
| PRB | Powder River Basin |
| SCA | Specific collection area |
| SCEM | Semi-continuous emission monitor |
| SDA | Spray dryer absorber |
| SGLP | Synthetic groundwater leaching procedure |
| SSD | Sorbent Screening Device |
| TCLP | Toxicity characteristic leaching procedure |