

Advanced Utility Mercury-Sorbent Field-Testing Program

Semi-Annual Technical Progress Report

April 1, 2004 – October 31, 2004

(Note: The reporting period was extended 30 days to cover all of the Detroit Edison St. Clair Plant testing.)

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Abstract

This report summarizes the work conducted from April 1, 2004 through October 31, 2004 for the project entitled Advanced Utility Mercury-Sorbent Field-Testing Program. The project activities addressed are primarily the sorbent injection field trials at the Detroit Edison St. Clair Power Plant (Phase IV). The reporting period was expanded by one month in order to include all of the Detroit Edison testing. Specifically, the topics discussed in the report are the mercury control equipment used at the Detroit Edison plant trials and the baseline, parametric, and long-term test results with brominated carbon injection at this site.

The highlight of the document is the presentation of the results from the parametric and long-term tests at the St. Clair Plant. This plant normally fires an 85% subbituminous/15% bituminous coal blend and has only a cold-side ESP for air pollution control, a common U.S. configuration. The parametric testing demonstrated that mercury removal rates, due only to the injected sorbent, of 90% could be achieved at the low injection rate of 3.0 lb/MMacf when using Sorbent Technologies B-PAC sorbents. Even higher mercury removal rates were achieved when 100% subbituminous coal was fired by the plant. Plain PAC could not nearly achieve this level of mercury removal and its performance exhibited a plateau at high injection rates.

The long-term continuous injection test lasted for 30 days. During this time, B-PAC sorbent was injected at a rate of 3.0 lb/MMacf as the plant operated in its usual manner. The average total gas-phase mercury removal for the 30 day period was 94%. Discounting native mercury removal of about 25%, the B-PAC removed about 91.5% of the plant's mercury that it saw. At this rather typical subbituminous-coal site, this equates to mercury emissions of less than 0.5 lb Hg/Trillion Btus, far less than any planned regulatory limits. Sorbent consumption costs for this level of mercury removal were approximately \$12,000/lb Hg removed. This is only about 20% of previous "baseline" mercury control cost estimates. No negative impacts on boiler operation or equipment were observed.

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Introduction

The **Advanced Utility Mercury-Sorbent Field-Testing Program** project is divided into six phases as follows:

- Phase I: Project Plan Development
- Phase II: Equipment Preparation
- Phase III: Qualification Testing & Support Activities
- Phase IV: Field Trial at Detroit Edison's St. Clair Plant
- Phase V: Field Trial at Duke Power's Buck Station
- Phase VI: Reporting & Technology Transfer Activities

This report primarily details the progress made on Phase IV, Field Trial at Detroit Edison's St. Clair Plant, from April 1 through October 31, 2004. Prior to this period, mercury removal of greater than about 70% at coal-fired power plants burning subbituminous coals had never been demonstrated, no matter what rate of activated carbon was injected.

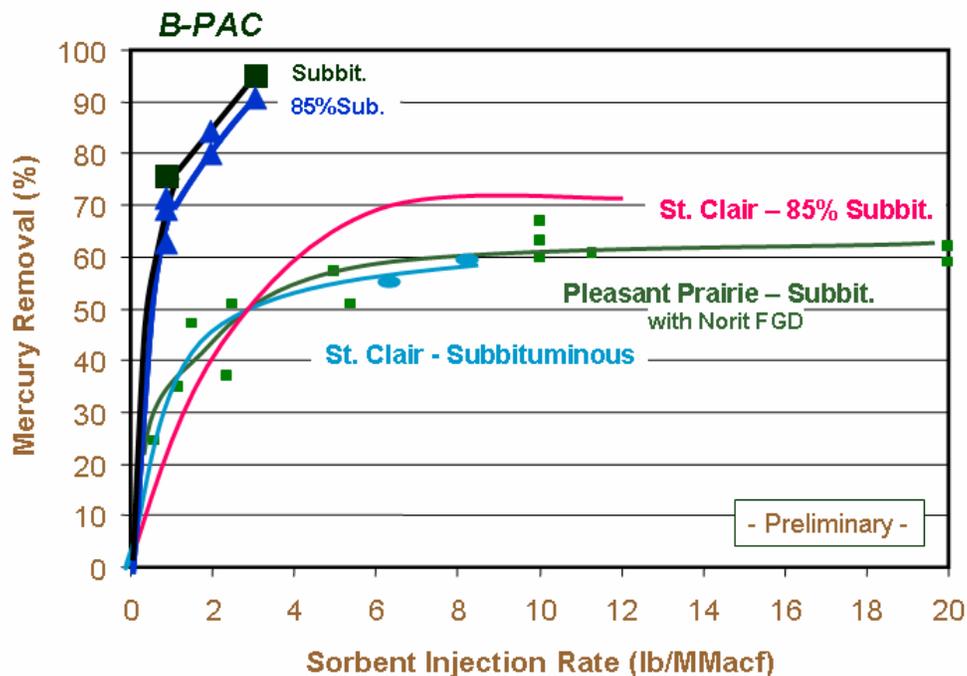
Phase I was completed in the first reporting period and Phase II was well underway. Phases III and VI cover ongoing efforts. Consequently, the activities covered in Phases II, III, and VI needed to support the St. Clair Plant effort are also described in this report.

Executive Summary

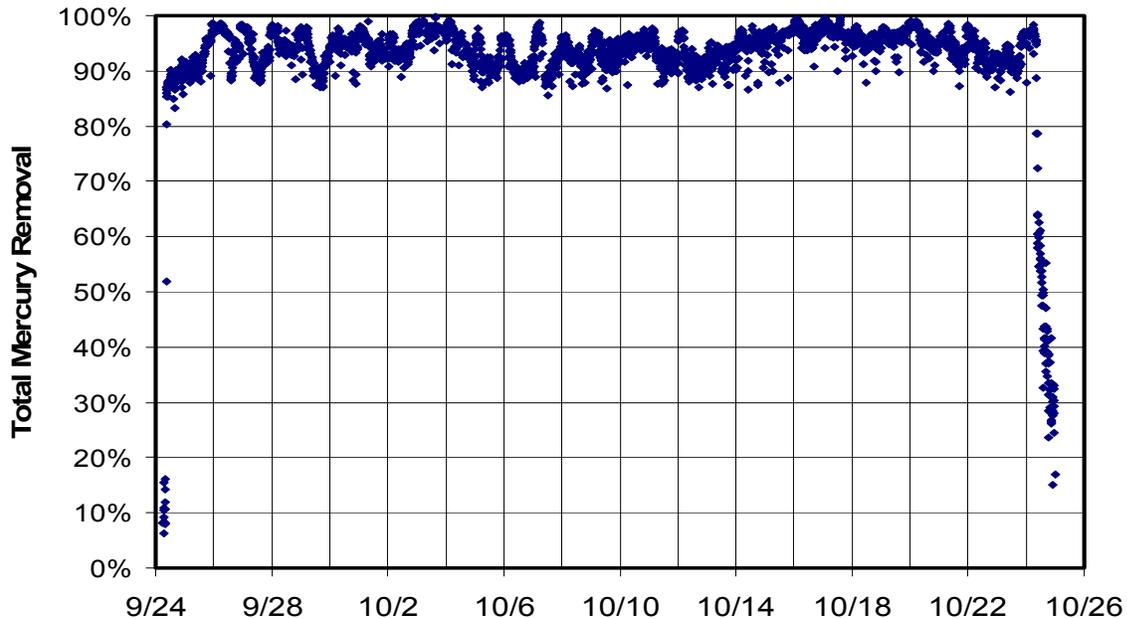
This report summarizes the work conducted in the second half-year plus one month (April 1 through October 31, 2004) of the project entitled Advanced Utility Mercury-Sorbent Field-Testing Program, Cooperative Agreement No. DE-FC26-03NT41990. The extra month was included in this report to capture most of the Phase IV testing effort at the Detroit Edison St. Clair Power Plant.

Detroit Edison's St. Clair Plant is representative of a large number of U.S. coal-fired power plants requiring easily-retrofitted mercury emission control. The plant burns a typical Powder River Basin subbituminous coal, with a small amount of bituminous coal typically blended in, and has only a cold-side electrostatic precipitator for air pollution control. The project work at St. Clair was divided into baseline, parametric, and long-term mercury control testing. Operation of the new mercury S-CEMs was evaluated in the baseline portion of the project as well as the normal operating conditions of Unit 1A, the boiler/ESP system, in which the injection program was conducted.

Norit Darco FGD plain activated carbon was evaluated in the parametric testing to provide a baseline for the comparison with other sorbents evaluated. A number of variations of the Sorbent Technologies' B-PAC brominated carbon mercury sorbent were evaluated at different injection rates in the short-term tests. It was found that 70% mercury removal could be achieved with a B-PAC injection rate of only 1.0 lb/MMacf, while 90% mercury removal could be achieved with an injection rate of 3.0 lb/MMacf. It was also discovered that with brominated carbons a slightly higher mercury removal rate was achieved when the boiler was firing 100% subbituminous coal as compared to the plant's normal 85% subbituminous/15% bituminous coal blend, in contrast to prior expectations. The results for the standard B-PAC sorbent from the parametric testing are presented in the figure below for comparison with the results from plain PAC at St. Clair and at Pleasant Prairie, another full-scale demonstration using low rank coal.



The standard B-PAC brominated carbon sorbent was selected for the long-term testing. This sorbent was injected at a rate of 3.0 lb/MMacf for thirty consecutive days. There were no unplanned injection stoppages. The result was an average 94% total mercury removal rate for the 30 day period as shown in the figure below. About 91% of the Hg removal can be attributed to the B-PAC sorbent. Fly ash mercury analyses and OHM stack tests confirm these results.



There were no observed detrimental impacts on the boiler operation or equipment during these tests. Corrosion coupons installed for the entire long-term test did not exhibit any corrosion.

The mercury control costs associated with this control technology are dominated by the cost of the sorbent consumed. These costs were estimated at this site to be about \$3,700/ lb Hg for 70% mercury removal and \$11,500/lb Hg for 94% mercury removal. See the example calculation below for 70% mercury removal for a median subbituminous coal plant with 7 µg/Nm³ of gas-phase mercury at the sorbent injection point.

$$\left(\frac{1 \text{ lb sorbent}}{1,000,000 \text{ acf}}\right) \left(\frac{\text{Nm}^3}{(70\%)7 \mu\text{g Hg}}\right) \left(\frac{\$0.75}{\text{lb sorbent}}\right) \left(\frac{1.5 \text{ acf @ } 300\text{F}}{1 \text{ scf}}\right) \left(\frac{35.3 \text{ scf}}{\text{Nm}^3}\right) \left(\frac{10^9 \mu\text{g Hg}}{2.2 \text{ lb Hg removed}}\right) = \$3,700/\text{lb Hg}.$$

Note that DOE “baseline” costs for mercury control were set at \$50,000 to \$70,000/lb of Hg removed. Clearly, the B-PAC sorbent provided much higher mercury removal at a much lower cost than has been previously estimated.

This first extended full-scale test of B-PAC injection upsets a long-held industry view that retrofit mercury control at plants burning subbituminous coals will be difficult and expensive.

Experimental

Host Site - Detroit Edison St. Clair Power Plant

The Detroit Edison St. Clair Power Plant is located in East China Township, Michigan on the banks of the St. Clair River northeast of Detroit and directly across from Canada. The power plant consists of six active boilers with a gross generating capacity of 1390 MW. There are four identical boilers (Units 1 - 4) with a capacity of 160 MW, each of which were built in the 1950's, and two larger boilers (300 MW and 450 MW) which were built in the 1960's. The mercury testing program at the St. Clair Power Plant was conducted in Unit 1.

Unit 1 was originally designed to burn bituminous coal but was converted to a blend of subbituminous and bituminous coals in 1975 in order to reduce sulfur emissions. Currently, the blend is composed of 85% subbituminous coal from Montana and 15% bituminous coal from the eastern United States. Sustained 100% subbituminous operation is not currently possible due to the build up of deposits within the boiler. The conversion to the coal blend reduced the full coal generating capacity of Unit 1 from 160 MW to 145 MW, due to limitations in coal grinding and drying capacity. Oil over-firing is used to reach the full 160 MW capacity when it is needed.

At the same time as the coal switch, new electrostatic precipitators (ESPs) were installed on Unit 1. The flue gas from Unit 1 is split in half and directed through two identical, but separate, cold-side ESPs. The flue gas is recombined after the induced draft fans and directed up a common stack.

Photograph 1. Detroit Edison St. Clair Power Plant ESPs



In Photograph 1, the flue gas exits the building on the left after having already passed through the air preheaters. The two gas streams are conveyed over, up and into separate EPS. The mercury sorbent injection trials were conducted on the ESP 1A gas stream thus making the effective capacity treated about 80 MW.

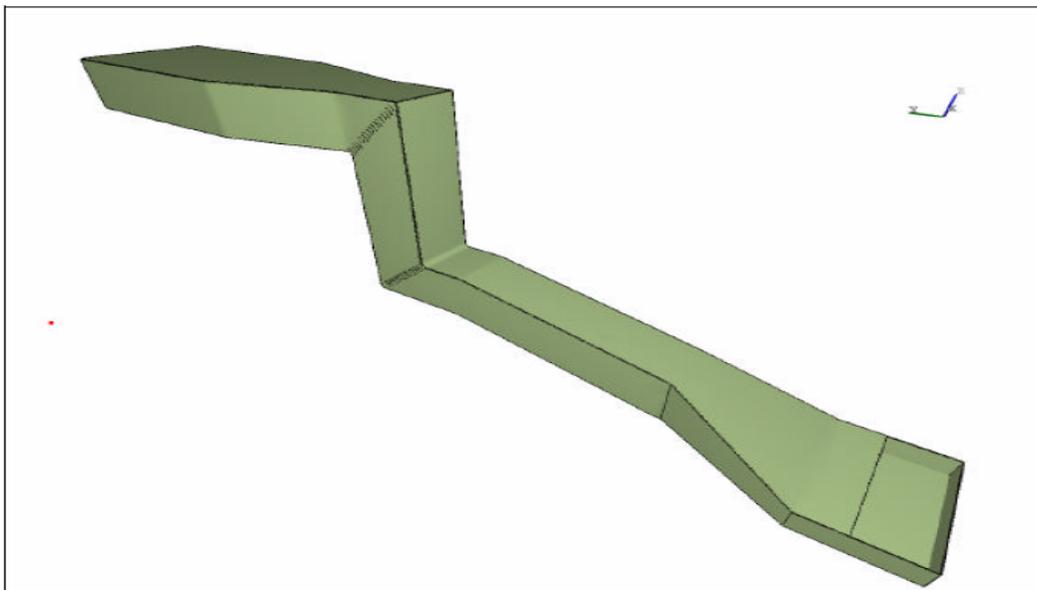
The ESPs are large by design to handle wide variations in coal selection. Each ESP has a design SCA of 700 ft²/Kacfm, when all fields are operable. ESP 1A had fields 1 and 3 down during the mercury testing program, reducing the effective SCA to a still relatively large 467 ft²/Kacfm. The ESP operates at approximately 300°F while collecting about 3.5 tons of fly ash per hour. Some of the fly ash is sold for flowable fill applications while some is used as landfill.

CFD Modeling

Fuel Tech is a partner in this DOE mercury project and they were charged with the computational fluid dynamic (CFD) modeling of the gas flows in the ductwork at the St. Clair Plant. The results were used to assist Sorbent Technologies in placing the injection lances in the optimum location to generate a uniform sorbent distribution within the ductwork. A uniform distribution of sorbent to flue gas should provide the maximum mercury removal.

The St. Clair Plant Unit1 ESP 1A was studied by Fuel Tech personnel. A preliminary visit was made in March 2004. Gas flow and temperature measurements were collected in May 2004 for use in the CFD model. The section of the ductwork modeled is shown in Figure 1.

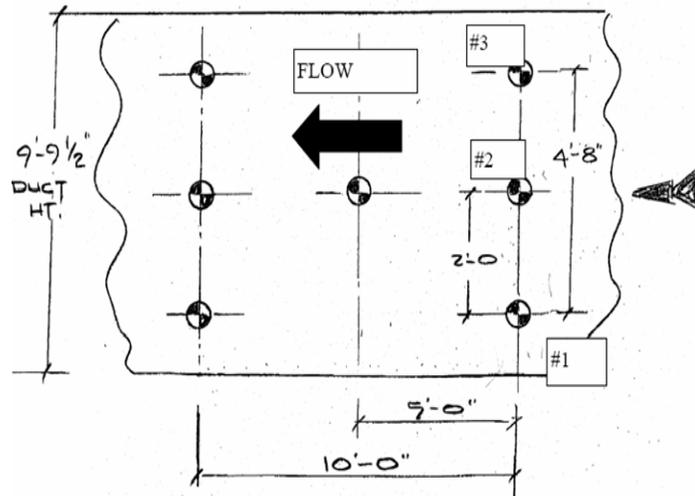
Figure 1. Detroit Edison St. Clair Unit 1 ESP 1A Ductwork Modeled



The gas flow is from right to left in this figure. It starts immediately after the flue gas is split and ends at the ESP plenum. The view above is from the opposite side of the ductwork as shown in Photograph 1. The flue gas first traverses a section of gradually rising ductwork before turning vertical and then horizontal. There are turning vanes in each turn.

A series of 4" ports were installed for the flow and temperature testing and for the mercury trials. These ports are located in the gradually rising section of ductwork and are shown in Figure 2.

Figure 2. Ports Installed in the Unit 1 ESP 1A Ductwork

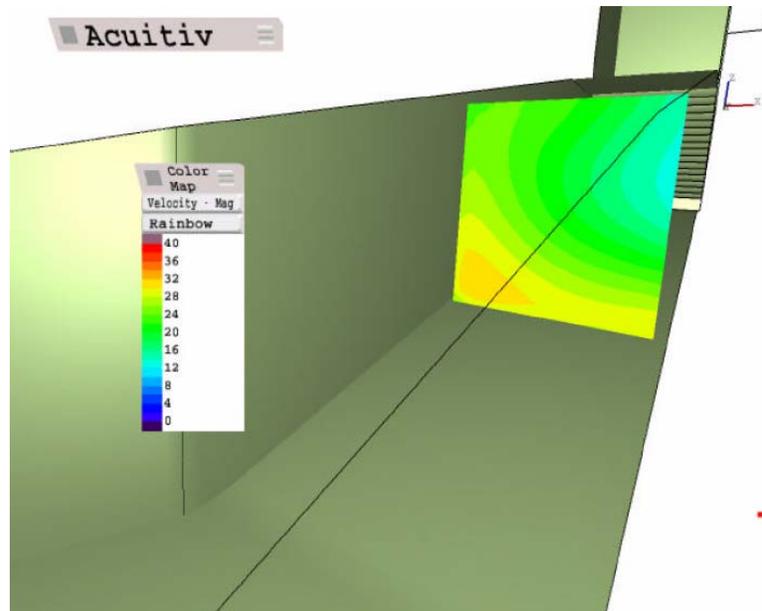


TEST PORTS 4" SCH #40 PIPE
x 15" O.A.L W/ STD. N.P.T

All of the ports in Figure 2 plus more in the vertical section of the ductwork were used for the temperature and flow testing conducted by Fuel Tech. Ports 1-3 were later used for the OHM mercury testing, while the three ports on the left (4-6) were used for sorbent injection. Port 4 is the lowest port. The middle port (not numbered) was for the continuous flow and temperature measurement instruments used in controlling the sorbent injection rate.

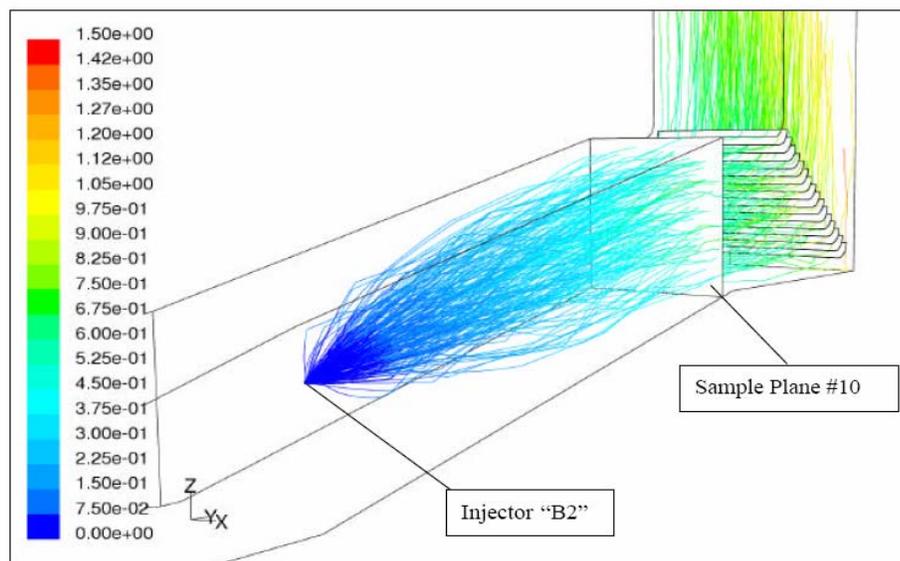
The flow in the ductwork was found to be biased, with highest flow in the lower left hand corner of the duct (near Port 4) and the lowest in the opposite corner. This flow is depicted in Figure 3 below for the plane of Ports 4-6, which is the plane of sorbent injection. Orange represents high flow and blue, low flow. The pattern becomes more uniform as the flue gas passes downstream but never fully becomes uniform. This biased flow pattern would play a key role in the recommended placement of the injection lances.

Figure 3. Flue Gas Flow in Unit 1 ESP 1A Ductwork



The gas stream, as expected, is very turbulent and rapidly distributes any material injected into it. This is clearly shown in Figure 4 for a single point of injection. Note the "Sample Plane" used in this figure. Sample planes were used for determining the distribution of the sorbent at different locations downstream of the injection point.

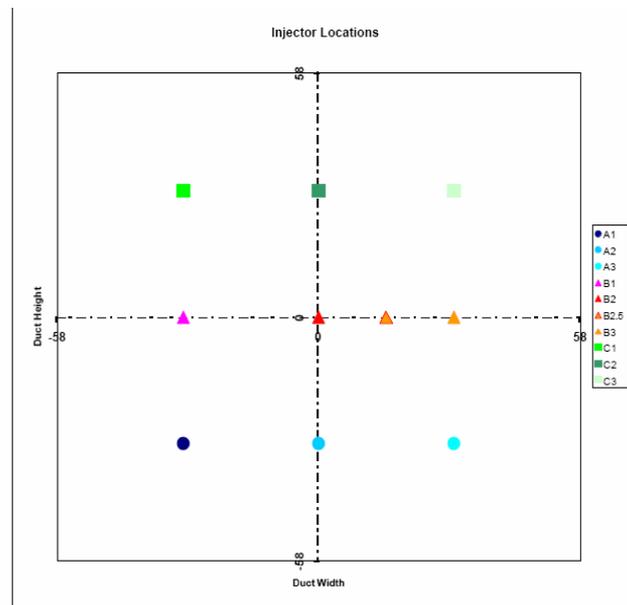
Figure 4. Single Point Injection in Unit 1 ESP 1A Ductwork



Fuel Tech modeled a variety of sorbent injection velocities from 1 m/s to 25 m/s and found that there was very little penetration of the injection stream into the gas stream even at the highest injection velocity. The injection velocity used at the Detroit Edison St. Clair power plant was about 20 m/s through each lance.

Fuel Tech next modeled a variety of injection locations and the number of injection lances in operation. The injection locations are shown in the Figure 5 below.

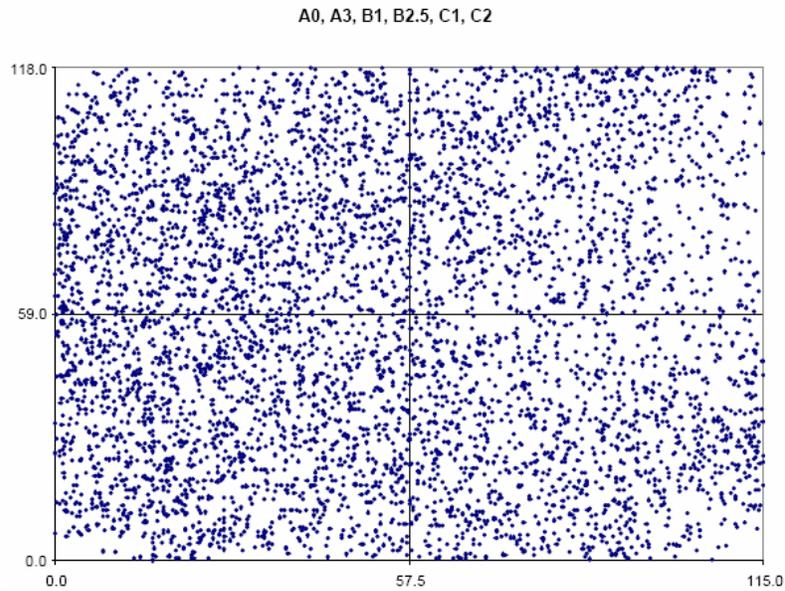
Figure 5. Potential Lance Locations Evaluated in Unit 1 ESP 1A Ductwork



The orientation of the duct is the same as in Figure 3 with the lower left hand corner of the duct near Port 4 having the highest gas velocities. The height of the locations was fixed by the existing ports. The lower level are the A locations; A1 being closest to Port 4 and A3 the farthest away. The middle levels are the B locations and the top level the C locations. Later, the use of an A0 location was evaluated. The A0 location was 12" below location A1.

The distribution of the sorbent in the ductwork was evaluated with between 3 to 9 injection lances in operation. The CFD model predicted the number of sorbent particles in each of 100 grid boxes at several sample planes downstream of the injection plane. The distribution values were converted into a sorbent density number by dividing by the volume of the flue gas passing through each grid. The object was to obtain the most uniform sorbent distribution on a mass flow basis at the nearest sample plane. It was discovered that the best distribution was achieved with six lances located at points A0, A3, B1, B2.5, C1 and C2. The sorbent concentration distribution at the Sample Plane is shown in Figure 6.

Figure 6. Sorbent Distribution at the First Sample Plane in Unit 1 ESP 1A Ductwork



The sorbent distribution improves the farther downstream the particles proceed. The use of the A0 location proved important in providing a good sorbent distribution in the high flow area. Consequently, Detroit Edison St. Clair personnel hot-tapped the port below Port 4 so that a lance could be installed at location A0.

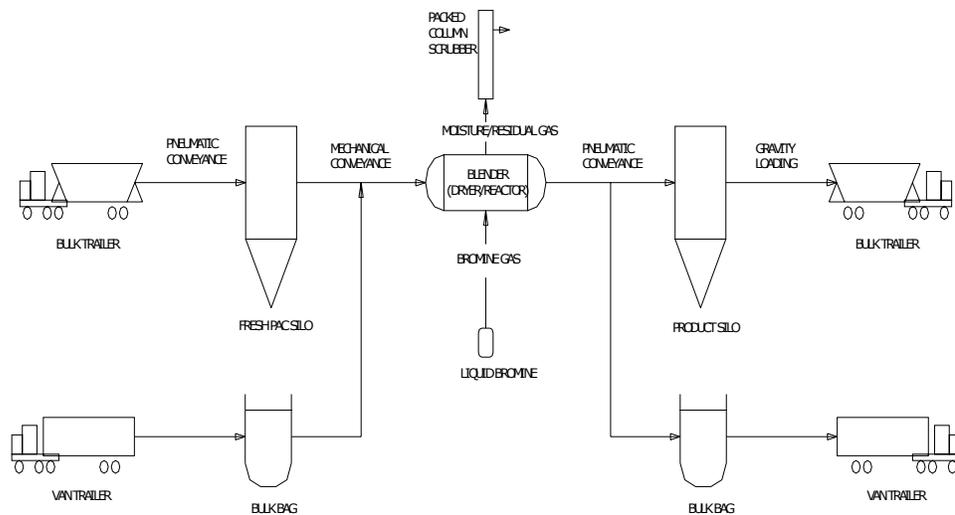
Finally, Fuel Tech modeled the system with the injection lances in place. There was little difference in the flow patterns, so the lances themselves have very little impact upon the flue gas flow pattern or the sorbent distribution.

Sorbent Production Facility

Sorbent Technologies manufactures all of its sorbents in its facility located in Twinsburg, Ohio. The sorbent production facility is in the same building complex as are the main Sorbent Technologies offices and laboratories. A general diagram of the sorbent preparation system is shown in Figure 7.

The sorbent production system was developed by Sorbent Technologies through over seven years of experimentation prior to the DOE demonstration project. The detailed operation of the system is proprietary and is covered by a patent, however, the concept is fairly simple. Sorbent Technologies' sorbents (trademarked B-PAC™) are powdered activated carbons (PACs) which have been processed through a bromine treatment to greatly enhance their mercury performance and cost-effectiveness.

Figure 7. Diagram of the Sorbent Technologies Sorbent Preparation System



The substrate PAC can be received by either super sack or bulk tanker and the processed B-PAC™ can be shipped to the power plant in either super sacks or by bulk tanker. This dual material handling capability is necessary to facilitate the smaller quantities of several sorbents that are required during the parametric variation testing portions of the program and the larger quantities that are required of a single sorbent during the long-term tests.

The PAC from either the fresh storage silo or a super sack is conveyed mechanically to the bromination reactor. The plain PAC is reacted with bromine in this device. The finished sorbent is conveyed pneumatically either to a finished-product silo before loading into a bulk tanker or into super sacks and into a van trailer for shipment to the test sites.

The capacity of this plant can easily be increased when demand warrants. A truckload of PAC is shown being unloaded into the raw material silo in Photograph 3. The elevated product silo used for filling tanker trucks is in the background.

Photograph 2. PAC being Unloaded



Sorbent Injection System

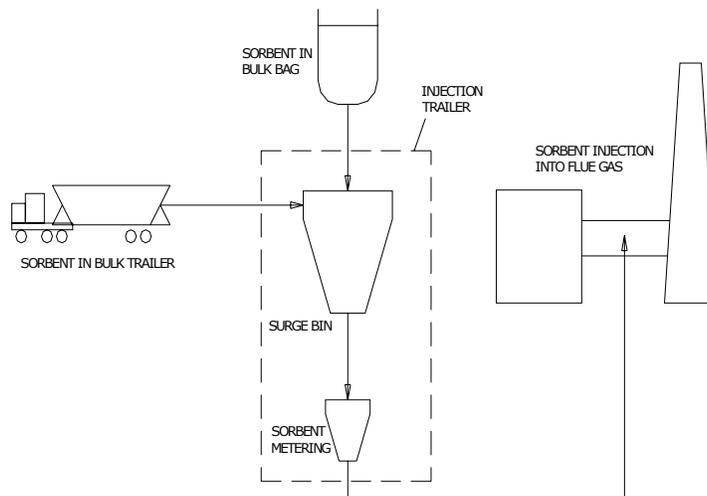
The sorbent injection system design took into consideration both the desires of our host sites and the Sorbent Technologies previous full-scale mercury testing experience. The host sites all had space constraints and were not interested in having a silo erected on their site for the testing. Thus, the design incorporated the use of pneumatic tankers for the storage of large quantities of sorbent. The need for gravimetric control rather than volumetric control had been demonstrated earlier. The injection system was design to fit inside a trailer and be fully mobile.

The functions of the sorbent injection system are as follows:

1. To provide for sorbent loading to a day storage hopper from either super sacks or pneumatic trucks.
2. To deliver the sorbent from the day storage hopper to a feeder system hopper.
3. To gravimetrically feed sorbent at selected rates into an eductor injection system.
4. To provide dilute-phase conveying of the sorbent through the sorbent distributor and to the injection lances.

A diagram of the general sorbent injection system design is shown in Figure 8.

Figure 8. Diagram of the Sorbent Technologies Sorbent Injection System



The general operating principals behind the sorbent injection system are the same as have been used in nearly every other full-scale mercury sorbent injection trial. All of the injection systems are based upon dilute phase injection. The only significant change is that, for the sake of feeding accuracy, gravimetric control was used instead of volumetric control.

The day storage hopper, feeder hopper, gravimetric feeder and eductor are all enclosed in a mobile trailer. A bin vent filter is provided to capture any dust generated by material handling. This filter is located on top of the day hopper. Blowers are used to provide the air flow necessary to convey the sorbent from a tanker to the day storage hopper and to convey the sorbent from the feeder to the injection lances. The first of these blowers is located outside of the trailer while the other is located inside. All controls for the operation of the injection system are in an isolated area within the trailer. The inside of the injection trailer is shown in Photograph 3 and its installation in cramped quarters at the St. Clair Plant.

Photograph 3. Sorbent Technologies Sorbent Injection Trailer



The gravimetric feeder is shown just inside the left corner of the trailer. The screw to refill the hopper is also shown ending at the yellow cap. The bin vent filter can be seen on top of the trailer. The system controls are located in the cabin in front.

The injection system has a PLC based control system which controls all of the injection system operations. The control system monitors the amount of sorbent in the feeder system hopper and activates the screw feed system associated with the day storage hopper to provide refills as necessary. The control system can also refill the day storage hopper from a tanker. The system comes complete with temperature and flow instruments to monitor the flue gas in the injection location. The flow data is used to determine how much sorbent must be injected to meet a fixed injection rate in terms of pounds of sorbent per million actual cubic feet of flue gas. The data from the mercury instruments is also fed to the control system. This data can be used to control the sorbent feed rate such that either a constant outlet mercury level or a steady mercury removal rate is achieved.

The injection system was designed with the ease of installation and disassembly in mind. Only electricity and injection ports are required from the host site to support its operation. The installation can be accomplished in less than a day. The injection system was designed to have a sorbent injection rate range from as low as 15 lb/hr to a high of over 600 lb/hr. This range was selected in order to be able to provide testing at a variety of size boilers.

Photograph 4. Tanker Containing Mercury Sorbent at the Detroit Edison St. Clair Plant



A standard PAC delivery tanker was used in the long-term run. The tanker could hold about 15 tons of mercury sorbent and could be refilled from another tanker. Thus, the need for a silo for these tests was eliminated. See Photograph 4.

From the mobile injection trailer, the sorbent was blown through a single 2-inch ID line to a distributor, which divided the flow approximately equally to six injection lances sticking through three ports into the ductwork, two lances to each port, inserted to two different distances. See the photograph below.



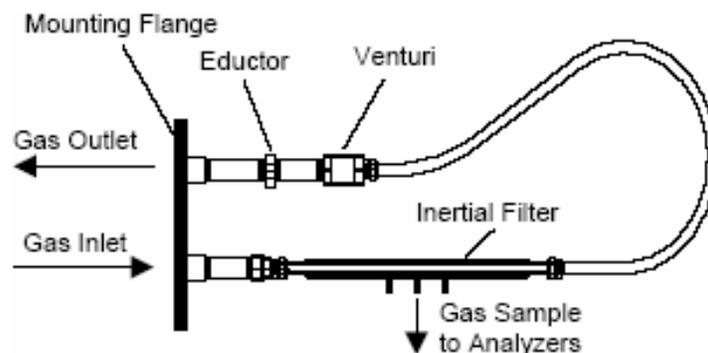
Mercury Monitoring and Measurement Equipment

Mercury measurements in the test program were made by means of four methods. First, mercury S-CEMs were used for semi-continuous analysis. This was the primary mercury performance measurement method utilized. Second, OHM mercury tests were conducted at four times during the test program. Third, QuickSEMs were used for a few days of testing during the long-term trial. Fourth, fly ash and coal samples were regularly analyzed for mercury.

Flue Gas Sampling

A Baldwin Model 3300 inertial separator was used to provide a particulate free gas sample for the S-CEM mercury measurement. A diagram of the device is shown in Figure 9.

Figure 9. Diagram of Baldwin Inertial Separator

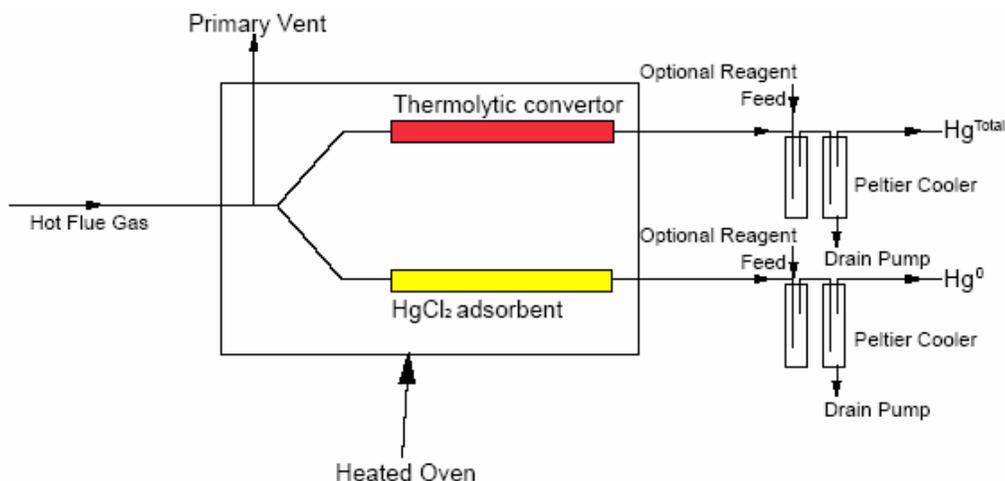


Flue gas is drawn into the system by means of an eductor. The flow rate is measured by a Venturi meter and adjusted to provide an axial gas flow through the inertial separator of 70 to 100 feet per second. A gas sample is extracted at a low inertial filter face velocity of 0.006 feet per second. The particulate matter follows the gas streamline and is thus separated from the gas sample. The gas removed from the duct is returned after use. The entire inertial separator is in an enclosure and maintained at 400^oF to avoid any condensation issues.

Mercury S-CEMs

The latest version of the PS Analytical mercury monitoring equipment was used for this test program. The sample gas was conveyed through a heated line from the inertial separator to the conversion module where the oxidized mercury species were either converted to elemental mercury in order to provide a total gas phase mercury measurement or removed from the gas to allow for the measurement of elemental mercury. The PS Analytical unit oxidized mercury conversion modules, can operate in the traditional wet chemistry method, as well as by a new, parallel dry method. The dry system uses a thermolytic converter to convert the oxidized mercury to elemental. A diagram of the process is shown in Figure 10.

Figure 10. Diagram of the PS Analytical Dry Conversion Process



The conversion modules could be operated in the wet mode, the dry mode or alternating back and forth. The wet/dry mercury conversion modules used in this project were Serial Numbers 001 and 002. One of the wet/ dry conversion modules is shown in Photograph 5.

Photograph 5. PS Analytical Wet/Dry Mercury Conversion Module



The dry conversion process is being developed to eliminate two of the main problems associated with mercury S-CEMs; wet chemicals and their wastes.

The gas from the mercury conversion module was directed to a PS Analytical Sir Galahad II EX mercury analyzer. The gas sample is drawn across a gold trap in which the mercury is collected. After a prescribed sampling time, the trap is heated in order to release the mercury which is measured by atomic fluorescence. The system is calibrated at least once per day using mercury standards. The analyzer provides one mercury measurement every five minutes, thus it is a semi-continuous emission monitor. If both elemental and oxidized mercury are being analyzed, repeat measurements are ten minutes apart.

Two mercury S-CEMs were acquired for these tests. Each analyzer was placed inside a small building in order to provide climate control. The analyzer building at the outlet of Detroit Edison St. Clair Unit 1 ESP 1A system is shown in Photograph 7.

Photograph 6. Outlet Mercury S-CEM Building at the St. Clair Power Plant



Western Kentucky University, a project partner, provided all of the personnel to operate the mercury S-CEMs at the Detroit Edison St. Clair Power Plant. The mercury data collected was all corrected to 3% oxygen before submittal to Sorbent Technologies.

OHM Testing

The Ontario Hydro Method (OHM) mercury testing was contracted to METCO Environmental, which had considerable experience with the Method. The sampling followed the procedures set forth in the Code of Federal Regulations, Title 40, Chapter I, Part 60, Appendix A, Methods 1, 2, 3B, 4 and 5, and the Ontario Hydro Method, revised July 7, 1999. Simultaneous triplicate two-hour tests were performed at the gas “inlet” (before the sorbent Injection) and “outlet” locations at the St. Clair Power Plant Unit 1 ESP 1A. Ports 1-3 shown in Figure 2 were used for the inlet testing. Ports in the ductwork exiting ESP 1A were used for the outlet testing.

A total of four sets of OHM tests were performed. Each test set consisted of six simultaneous sample trains. One set was performed during the baseline testing on July 28, one set during parametric testing on September 9, and two sets during the long-term test: one on October 6 and one on October 21. METCO Environmental also performed separate Methods 26A tests for halogens in the flue gas on each day they performed OHM testing.

QuickSEM™ Testing

Detroit Edison leased a QuickSEM™ instrument from EPRI Solutions for testing throughout their plants. The instrument is shown in Photograph 8.

Photograph 7. QuickSEM Instrument



The instrument pulls a measured amount of flue gas, proportional to the flue gas flow rate, through a mercury trap for a period of 24 hours. The trap is sent for mercury analysis and the result translated into a mercury concentration by dividing by the amount of gas sampled. The instrument was only available for the last two days of the long-term testing program.

Coal and Fly Ash Mercury Analysis

Coal and fly ash samples were taken throughout the baseline, parametric, and long-term testing at the St. Clair Power Plant. The coal samples were analyzed for mercury in the Detroit Edison laboratories using microwave acid digestion followed by ICP-MS analysis. The fly ash samples were analyzed for mercury both by Detroit Edison's laboratory, using digestion-ICP/MS and by Sorbent Technologies, using an OhioLumex Model RA-915+ Mercury Analyzer (Photograph 8).

Photograph 8. OhioLumex Model RA-915+ Mercury Analyzer



The OhioLumex mercury analyzer is an atomic absorption spectrometer with Zeeman background correction. The Zeeman background correction eliminates the need for gold traps to concentrate the mercury. The instrument is calibrated with NIST standards and has a detection limit of 500 ng/Kg.

Results and Discussion

Safety

Detroit Edison St. Clair Power Plant personnel provided safety and environmental awareness training to all of the Sorbent Technologies, Western Kentucky University, METCO Environmental, and Fuel Tech personnel who worked at the site. A pre-job check-in log was maintained by Sorbent Technologies through out the program. As a result of the dedicated effort of all parties concerned, there were no lost-time accidents or environmental events during the entirety of the testing program.

Baseline Testing

The baseline testing at the Detroit Edison St. Clair Power Plant began on June 1, 2004, with the insertion of the corrosion coupons and ended on August 1, 2004, with the completion of the baseline data collection. The baseline testing was divided into three phases. During the first phase, the new mercury S-CEMs were set-up and the dry conversion system was tested for the first time. The instruments are all the latest version of the PS Analytical mercury monitors. The oxidized-Hg conversion systems could operate in either the conventional wet mode or the new dry mode. The second phase of the baseline testing consisted of side-by-side testing of the new mercury S-CEMs using both the wet and dry mode of mercury conversion. The third phase consisted of operating the mercury S-CEMs 24 hours per day to collect baseline mercury data. During this period, the a first set of OHM tests and halogen tests were performed.

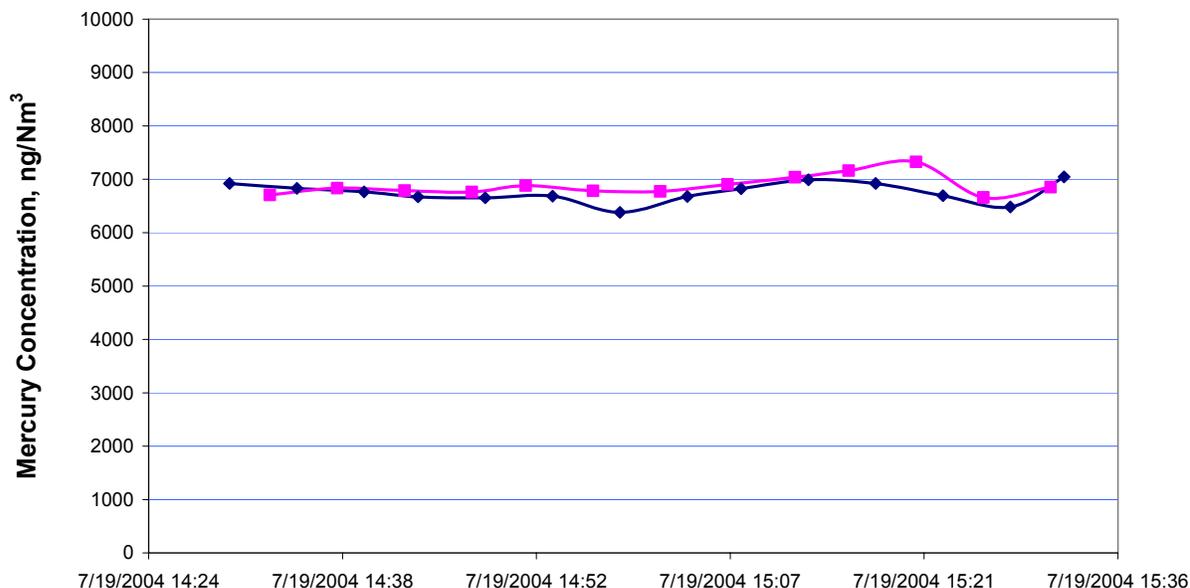
Mercury S-CEM Start-Up

The S-CEM start-up activities began on June 18 and ran through July 2, 2004. The purpose of the effort was to burn in the new S-CEMs, collect preliminary mercury data, and test the dry/wet conversion modules. There were the normal start-up problems associated with new systems, requiring minor repairs and adjustments in order to make the systems operate properly. As expected, there were also issues with the dry conversion systems, which prompted a slight delay in the completion of the side-by-side tests and the baseline testing.

Side-by-Side Testing

The side-by-side mercury S-CEM tests were conducted from July 19 through 23, 2004. During these tests, both mercury monitors and conversion modules were installed in the outlet monitor building so that they could measure the mercury in the same gas stream coming from the inertial separator. The first test conducted was a side-by-side test of the two analyzers measuring the Hg^(T) concentration in the gas from one conversion module being operated in the traditional wet method. The results from this test are presented in Figure 11.

Figure 11. Side-by-Side Test with One Conversion Module Operating in the Wet Mode and Two Mercury Analyzers

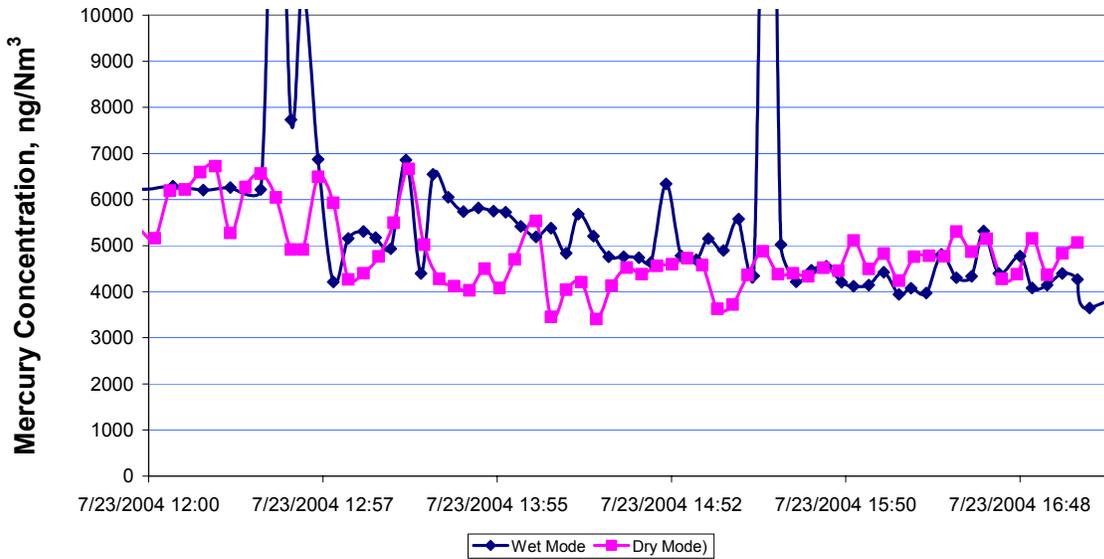


The comparison of the results from the two mercury analyzers was excellent, the averages for the test period being within 2% of each other. This difference is well within the manufacturer's tolerance and may have decreased if the test were performed for a longer period of time.

A second test was to compare the operation of the two systems when one conversion module was operating in the dry mode and the other in the wet mode. Any difference beyond that demonstrated in the test above would be as a result of differences in the performance of the conversion modules. The results from this test are presented in Figure 12.

The mercury data from the two conversion methods tracked each other well. The dry conversion appeared to produce fewer spikes, which are always present when using PSA's standard wet conversion method. The average mercury concentration over the test period using the dry conversion method was 4852 ng/Nm³ as compared to 5056 ng/Nm³ using the wet conversion method, or only 4% apart. The spikes from the wet conversion method were removed from the data in order to make these calculations. Thus, the dry conversion method appears to have potential for replacing the wet conversion method. The only concern about this method is long-term system reliability, which has not yet been tested. Sorbent Technologies decided to operate the S-CEMs in the wet conversion mode for these trials to insure that the data could be directly compared to that generated in previous tests. The dry conversion mode will be used more fully in upcoming test programs. Once the dry conversion method is fully developed, it will be a large step forward for mercury monitoring technology as two major sources of problems, chemicals and their wastes, will be eliminated.

Figure 12. Side-by-Side Test with Two Conversion Modules, One Operating in the Wet Mode and One in the Dry Mode with Two Mercury Analyzers



Baseline Data Collection

The baseline mercury data collection was conducted from July 25 through August 1, 2004. The OHM and halogen tests were performed on July 28th. The coal data for this period is presented in Table 1 along with samples from 9 random days during the baseline period when the plant’s standard coal blend was in use. A coal sample was taken in the morning of each day from each of five storage coal feed silos and a composite sample made for analysis. All of the coal analyses were performed by the Detroit Edison laboratories.

Table 1. Coal Data from the Baseline Period at the St. Clair Power Plant

Date	Mercury hg(ppm)	Total Moist	Dry Basis				
			Ash	Vol	FC	Sulfur	Btu
7/25/2004	0.042	25.89	5.78	41.27	52.95	0.55	12,474
7/26/2004	0.049	23.05	5.79	40.74	53.47	0.57	12,611
7/27/2004	0.051	23.05	6.05	40.83	53.12	0.67	12,662
7/28/2004	0.054	24.47	6.39	40.32	53.29	0.62	12,617
7/29/2004	0.068	22.37	6.51	40.38	53.11	0.79	12,690
Average 9 Days Previous	0.059	22.89	6.42	40.34	53.24	0.75	12,560

Unit 1 fired 100% subbituminous coal on the weekend of July 24-25. This can be clearly seen in the low mercury, ash, and sulfur values, plus the elevated moisture and volatile matter content of the coal sampled on July 25th. The transition back to the 85%/15% coal blend was completed sometime on Monday July 26. The coal mercury level increased from 0.042 ppm on July 25th to 0.068 ppm on July 29th. The low mercury level on July 25th was due to the use of 100% subbituminous coal, but the increase thereafter must be due to an increase in mercury in the coal blend. The average mercury content of the previous samples averaged 0.059 ppm, in the middle of the data for these days.

Unit 1 is equipped with two ESPs; ESP 1A and ESP 1B. This program was conducted in the ESP 1A ductwork. ESP 1A has six fields with two hoppers under each field to collect the fly ash. Field 1 of ESP 1A, the first field, was not operational throughout the program. It served as a drop-out chamber for any large particles in the flue gas and little fine sorbent was collected by it. The majority of the fly ash, and injected sorbent, is collected in Field 2, with lesser amounts being collected in the downstream fields 3 and 4. The two ESPs serving Unit 1 have a common fly ash removal system which continuously operates. It takes less than 20 minutes to circulate through all of the hoppers in both ESPs. The fly ash in Fields 5 and 6 are removed only once per day due to the tiny amount collected there. Samples were always taken from Fields 1 through 4, since the vast majority of the fly ash was collected in these fields during the baseline period. Occasionally, samples were also taken from the back hoppers for completeness sake.

For example, fly ash samples were taken from the ESP 1A fields on ten days between June 23rd and July 29th. The average composition of the fly ash by field is presented in Table 2. This fly ash data came from the Detroit Edison laboratories.

Table 2. Fly Ash Data from the Baseline Period at the St. Clair Power Plant

ESP	Unburned	Dry										
Field	Carbon	LOI	SiO2	Al2O3	TiO2	Fe2O3	CaO	MgO	K2O	Na2O	SO3	P2O5
1	0.53	0.48	46.5	16.9	1.1	9.7	10.4	2.4	0.9	4.5	2.8	0.6
2	0.78	1.10	40.5	20.6	1.3	7.4	13.3	3.3	1.0	5.8	3.1	1.0
3	0.72	1.35	34.6	21.6	1.4	7.2	16.3	4.0	1.0	6.4	4.5	1.1
4	0.34	1.04	26.3	20.7	1.4	6.7	19.7	4.8	0.9	7.4	7.6	1.2
5	0.21	1.20	24.8	20.0	1.4	6.6	18.4	4.6	1.1	7.7	10.1	1.3
6	0.19	1.45	23.8	19.6	1.4	6.9	18.3	4.5	1.1	7.5	11.1	1.3

The fly ash in Field 1 resembles sand in size and composition. The fly ash is primarily composed of SiO₂, Al₂O₃, CaO, and Fe₂O₃. The SiO₂ and Fe₂O₃ content of the ash decreases as you proceed back in the ESP while the CaO content increases. The Al₂O₃ content of the ash is fairly constant across all ESP fields. The fly ash is high in Na₂O which increases farther back in the ESP. The unburned carbon content of the fly ash peaks in Fields 2 and 3 and declines the farther back in the ESP you proceed. The fly ash LOI (loss on ignition) is high in Fields 2 and 3 due to the unburned carbon but is the highest in Fields 5 and 6 due to high levels of carbonates and sulfates in the last two fields. Most of the compositional differences from field to field are probably due to the size separating ability of ESPs. The size of the fly ash decreases with field. Sulfates are generally of a very small size and thus are concentrated in the last ESP fields.

Sorbent Technologies performed the fly ash mercury analyses using an OhioLumex RA-915+. The mercury data for the baseline samples, sorted by field, are presented in Table 3.

Table 3. Fly Ash Hg Data (ppb) from the Baseline Period at the St. Clair Plant

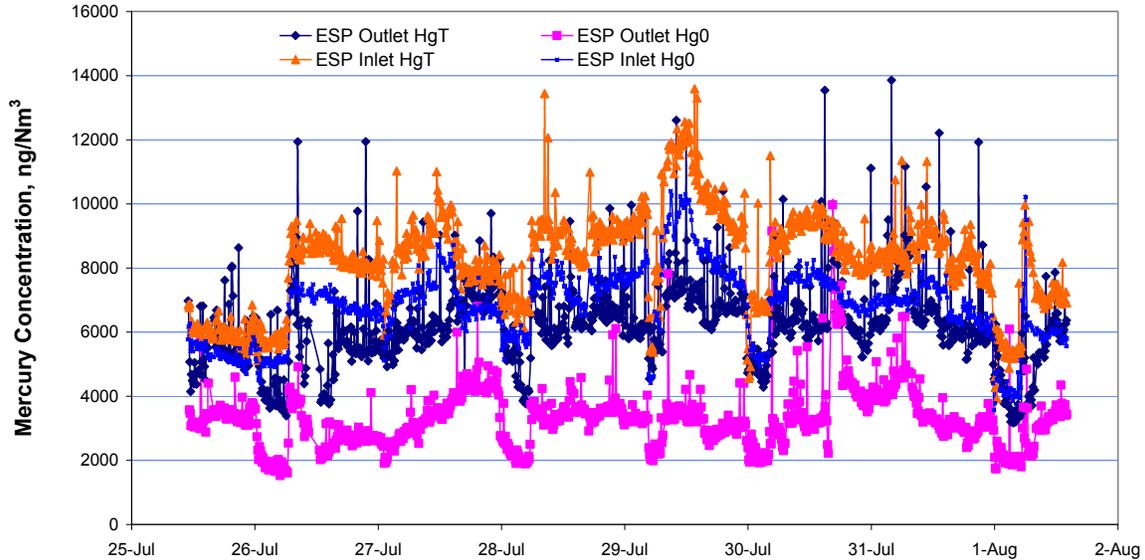
ESP Field	Average of 12 days	7/24/2004	7/25/2004	7/26/2004	7/27/2004	7/28/2004	7/29/2004
1	103	90	27	109	62	15	110
2	302	78	65	369	206	221	460
3	323	161	78	233	203	211	422
4	107						
5	50						
6	40						

The averages for samples taken on 12 days between June 22 and July 23, 2004, are provided for comparison with the data for baseline period. All of these samples were taken when the standard coal blend was in use. The mercury distribution in the fly ash closely matches the distribution of the unburned carbon content shown in Table 2. Fields 2 and 3 had the highest unburned carbon content and also the highest mercury content. Fields 1 and 4 had the next highest unburned carbon content and the next highest mercury content. The fly ash mercury content, however, was highly variable with one standard deviation of the average values being at least 40% for the first three fields.

Unit 1 fired 100% subbituminous coal on the weekend of July 24-25. The fly ash unburned carbon content is usually very low when operating in this mode and low mercury levels were observed in the fly ash during these days. The fly ash mercury level was higher on the next days reflecting the higher mercury content in the coal and the higher unburned carbon in the fly ash. It should be noted that the mercury content of the fly ash on 7/29/04 was much higher than the rest of the samples reflecting the high mercury level observed in the coal on that date (see Table 1).

The mercury data from the S-CEMs for the baseline period is presented in the Figure 13. Data is shown for the inlet and outlet locations for elemental mercury, Hg⁽⁰⁾, and for total gas phase mercury, Hg^(T). The data is corrected to 3% oxygen content so that the inlet and outlet data can be directly compared. The outlet gas stream is about 2 to 3% higher in oxygen than the inlet due to air leakage into the ESP.

Figure 13. Baseline Hg S-CEM Data (Corrected to 3% O₂) from the Detroit Edison St. Clair Power Plant from 7/25-8/1/04



It can be observed from the figure that the mercury levels varied over the baseline period, as would be expected from the variation in coal mercury content. In addition, the inlet mercury concentrations were higher than the outlet level indicating that there was some native capture of mercury by the fly ash being produced.

In order to better analyze the data, the baseline data was broken in to periods of similar boiler load. Unit 1 usually drops load in the evenings when demand is lower. During most of the time, the boiler load is automatically varied to meet the demand of the power grid. The operating data from the baseline test period, broken into the periods of similar load, is shown in the Table 4.

Table 4. Baseline Period Operating Data for St. Clair Unit 1

<u>Date</u>	<u>Time EDST</u>	<u>GMW</u>	<u>Opacity</u>	<u>SO₂, ppm</u>	<u>NO_x, ppm</u>	<u>CO₂, %</u>	<u>Preheater Inlet O₂, %</u>
7/25/04	11:00 - 23:55	124	2.8	167	297	8.7	5.6
7/26/04	1:00 - 06:19	49	2.7	145	193	5.0	10+
7/26-27/04	06:40 - 00:48	141	2.4	289	260	9.4	4.2
7/27/04	01:05 - 02:29	56	2.7	177	197	5.5	9.7
7/27/04	02:46 - 06:03	80	2.5	240	218	7.1	7.7
7/27/04	09:02 - 23:04	142	2.6	292	323	8.9	5.5
7/28/04	00:06 - 05:22	48	2.7	160	188	5.1	10+
7/28/04	05:40 - 07:38	132	2.6	286	286	8.7	5.2
7/28/04	07:40 - 23:59	142	3.1	310	298	9.0	5.2
7/29/04	00:30 - 5:20	127	3.1	291	285	9.0	5.2
7/29/04	08:09 - 17:56	145	3.1	319	235	9.4	4.5
7/29/04	18:14 - 23:59	128	3.2	324	230	9.1	4.6
7/30-31/04	05:14 - 15:33	140	3.0	306	239	9.1	5.2
7/31/04	15:50 - 18:38	162	3.9	350	217	9.2	5.4
7/31/04	18:43 - 23:59	140	3.7	352	261	8.9	4.7
8/1/04	01:13 - 6:11	50	3.5	197	180	5.1	10+
8/1/04	07:03 - 14:00	142	3.6	360	282	9.1	4.8

The baseline test period was broken into 17 periods of fairly stable load. The load varied from the minimum load of 48 gross megawatts (GMW) to the full coal load of about 145 GMW to the maximum load with additional oil firing of 160 GMW. The opacity level was low for all of these periods, as it was throughout all of the testing including that with sorbent injection. This will be demonstrated with further data from the parametric and long-term mercury sorbent injection tests. The low opacity of the emissions can be attributed to the large size of the ESP and the favorable resistivity of the fly ash.

The oxygen level of the flue gas leaving the boiler varied with load. At high loads, the oxygen level was about 5% while it more than doubled at low loads. The CO₂, NO_x and SO₂ levels demonstrated the impact of dilution with load. The SO₂ levels were no higher than 360 ppm even at high loads, reflecting the impact of using low sulfur subbituminous coal.

The mercury data for the 17 periods of stable boiler load is presented in Table 5. The mercury data is only from the 1A ESP system.

Table 5. Mercury S-CEM Data from the Baseline Period at St. Clair Unit 1A (Hg in ng/Nm³)

<u>Date</u>	<u>Time Period, EDST</u>	<u>HgT</u>	<u>Inlet</u>		<u>HgT</u>	<u>Outlet</u>		<u>Native HgT Removal, %</u>
			<u>Hg0</u>	<u>% Hg0</u>		<u>Hg0</u>	<u>% Hg0</u>	
7/25/04	11:00 - 23:55	6044	5342	88.4%	5574	3434	61.6%	7.8%
7/26/04	1:00 - 06:19	5806	5089	87.7%	4154	1847	44.5%	28.5%
7/26/04	06:40 - 00:48	8224	6942	84.4%	5802	2878	49.6%	29.5%
7/27/04	01:05 - 02:29	6939	5961	85.9%	5472	2224	40.6%	21.1%
7/27/04	02:46 - 06:03	8561	7113	83.1%	5817	2674	46.0%	32.1%
7/27/04	09:02 - 23:04	8581	7187	83.8%	6840	4059	59.3%	20.3%
7/28/04	00:06 - 05:22	6966	5825	83.6%	4937	2235	45.3%	29.1%
7/28/04	05:40 - 07:38	8977	7573	84.4%	6677	3585	53.7%	25.6%
7/28/04	07:40 - 23:59	9063	7466	82.4%	6679	3565	53.4%	26.3%
7/29/04	00:30 - 5:20	9513	7888	82.9%	6225	3145	50.5%	34.6%
7/29/04	08:09 - 17:56	11211	9119	81.3%	7362	3391	46.1%	34.3%
7/29/04	18:14 - 23:59	9454	7673	81.2%	6910	3085	44.6%	26.9%
7/30/04	05:14 - 15:33	8820	7242	82.1%	6833	3962	58.0%	22.5%
7/31/04	15:50 - 18:38	8135	6519	80.1%	5930	3052	51.5%	27.1%
7/31/04	18:43 - 23:59	7884	6376	80.9%	6188	3015	48.7%	21.5%
8/1/04	01:13 - 6:11	6015	4873	81.0%	3964	2323	58.6%	34.1%
8/1/04	07:03 - 14:00	7193	5936	82.5%	5807	3219	55.4%	19.3%

The inlet Hg^(T) concentration varied by nearly a factor of two over the baseline test period. The low inlet mercury concentrations were all at low loads. However, the inlet mercury concentration, even in periods with similar loads, varied by as much as 50%. Presumably, this variation is due to the variation in the inlet coal mercury content. The inlet gas was composed of more than 80% Hg⁽⁰⁾ of the total gaseous mercury. In fact, the Hg⁽⁰⁾ composed nearly 90% of the total gaseous mercury for the first period during which 100% subbituminous coal was being used.

The outlet Hg^(T) concentrations exhibited a percentage variation similar to the inlet concentrations but there was a loss across the ESP of about 25% when burning the standard 85%/15% coal blend. This loss is the plant's native mercury removal from capture by the unburned carbon in the fly ash. The native removal for the first period, when burning 100% subbituminous coal, was less than 10%.

Typically, the fraction of Hg⁽⁰⁾ present in the outlet flue gas was reduced from about 80% to about 50% between the inlet and outlet measurements. This indicates that elemental mercury entering the ESP was being partially oxidized during the passage through the ESP.

A set of OHM mercury sample trains, three in the inlet and three in the outlet, were taken on July 28, 2004. The OHM mercury tests were all performed simultaneously. The averaged results from these tests are presented in Table 6.

**Table 6. Mercury OHM and S-CEM data for 7/28/04 at St. Clair Unit 1A
(ng Hg/Nm³, corrected to 3% O₂)**

<u>Inlet HgT</u>		<u>Inlet Hg0</u>		<u>Outlet HgT</u>		<u>Outlet Hg0</u>	
<u>SCEM</u>	<u>OHM</u>	<u>SCEM</u>	<u>OHM</u>	<u>SCEM</u>	<u>OHM</u>	<u>SCEM</u>	<u>OHM</u>
9,043	8,903	7,634	7,183	6,142	1,1234	3,354	6,991
					(A)		(A)
Native Hg Removal by SCEM data				32.1%			
Native Hg Removal by OHM data				-26.2%			

(A) One Outlet OHM data point discarded

The mercury S-CEM data is only for the hours of the OHM testing. All of the data is corrected to 3% O₂ to allow for comparison of inlet and outlet data. One of the outlet OHM data points was spurious, very high, and was not used in the calculations. The inlet mercury concentrations, both Hg^(T) and Hg⁽⁰⁾, measured by the two techniques appear comparable.

This could not be said for the outlet mercury data, however. The S-CEM data indicated a 32% native removal of mercury across ESP 1A. The OHM data, on the other hand, indicated a 26% *increase* in mercury across this ESP. METCO Environmental could not explain the results. Sorbent Technologies strongly believes that these OHM results are in error. This highlights the problem with using OHM tests for S-CEM calibration. First, the results were not obtained until the program was well into parametric testing. Second, the OHM measurements showed high variability and a net Hg gain. Sorbent Technologies chose not to correct the S-CEM data based upon the OHM data.

(In the ICR testing performed on St. Clair Unit 4 in 1999, which is identical to Unit 1, the native mercury removal across the ESP that was observed was over 20%, although technically, the coals, sampling locations and operating conditions used in 1999 were different from those used today.)

The baseline OHM mercury data indicated that, for the sampling locations used, there was not a significant concentration of particulate mercury in either the inlet or outlet flue gas of ESP 1A. The inlet particulate mercury concentration was about 1% of the total and the outlet was essentially 0%.

Parametric Testing

The purpose of the parametric testing program was to evaluate the mercury removal performance as a function of injection rate and coal fired, and to evaluate several different versions of the Sorbent Technologies B-PAC mercury sorbents. Based on these results, the mercury sorbent to be used in the long-term testing and its injection rate would be determined. Standard Norit Darco FGD PAC was used as a baseline sorbent for comparative purposes, as it has been in most previous full-scale tests.

The parametric testing began on August 5 and ran through September 23, 2004. A total of 46 tests were performed over 26 days. Unit 1 was operated on each testing day at a stable load, as close to full coal load as possible, for a period of 6 to 8 hours. This required a considerable amount of scheduling and adjustment on the part of Detroit Edison, for which Sorbent Technologies is very grateful. All of the tests were conducted using the 85% subbituminous/15% bituminous coal blend, except for those conducted on the weekends of 8/21-22/04 and 9/11-12/04, when 100% subbituminous coal was utilized. A typical test lasted about two hours at one injection rate, although some were longer. The outlet Hg S-CEM data before the test was compared to the mercury data after it stabilized during an injection test in order to define the mercury removal due to the sorbent, separating out the native removal for that day.

It was quickly discovered that it was impossible to obtain representative fly ash samples from the ESP hoppers during the couple-hour parametric tests. The injected sorbent, mixed with the plant fly ash, was not uniformly moving through the system with “plug” flow, as evidenced by significantly lower marginal increases in carbon in collected fly ash. Thus, fly ash analyses were abandoned during the parametric part of the program. Clearly, the mercury content of the fly ash jumped during periods of injection, but the degree could not be accurately determined. Fly ash analyses and mercury mass balances were a focus of the long-term program during which the problem of obtaining representative fly ash samples was eliminated by steady, continuous sorbent injection.

Coal samples were taken each day of parametric testing. The results of the mercury tests are summarized in Table 7.

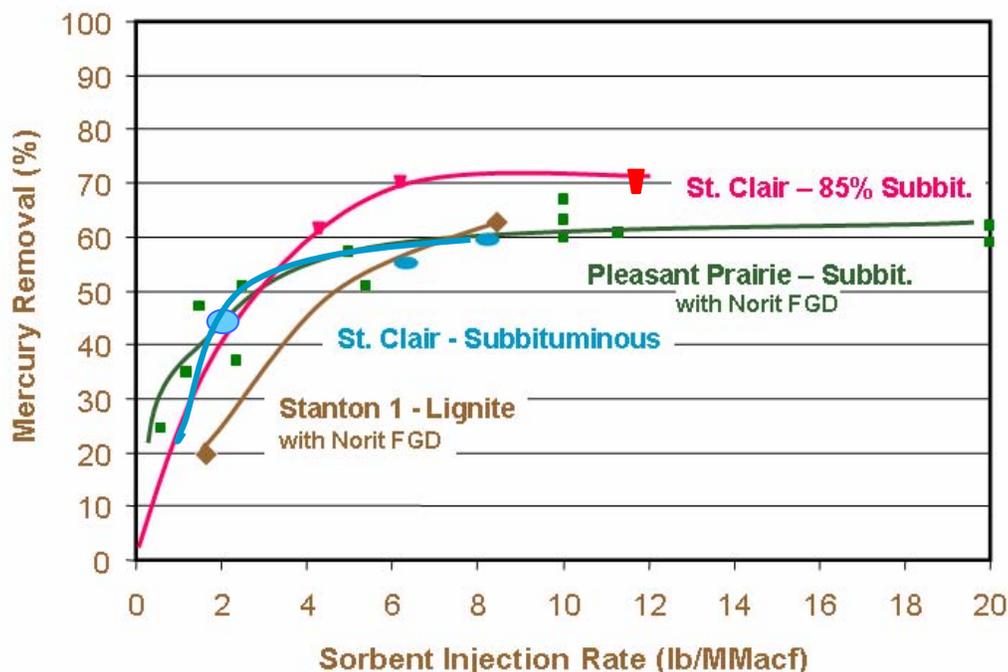
Table 7. Coal Mercury during Parametric Testing

<u>Coal</u>	<u>Avg.Hg, ppm</u>	<u>Range, ppm</u>
Blend	0.053	0.032 to 0.074
Subbituminous	0.041	NA

The mercury content of the blended coal averaged close to that identified in the baseline testing, but had a wider range. The 100% subbituminous coal was only used on four days during the parametric testing and averaged about the same mercury content as that found on the first day of the baseline test (July 25th).

The Norit Darco FGD plain activated sorbent was injected on 6 different days during 9 tests at rates from 2.0 to 12.0 lb/MMacf. The results are presented in Figure 14. The results from the Wisconsin Electric Pleasant Prairie full-scale test with 100% subbituminous coal and from the Stanton Station 1 full-scale test with 100% lignite are also presented for comparison. Note that the mercury removal results are due to sorbent only; i.e. native removal is not included in these mercury removal results.

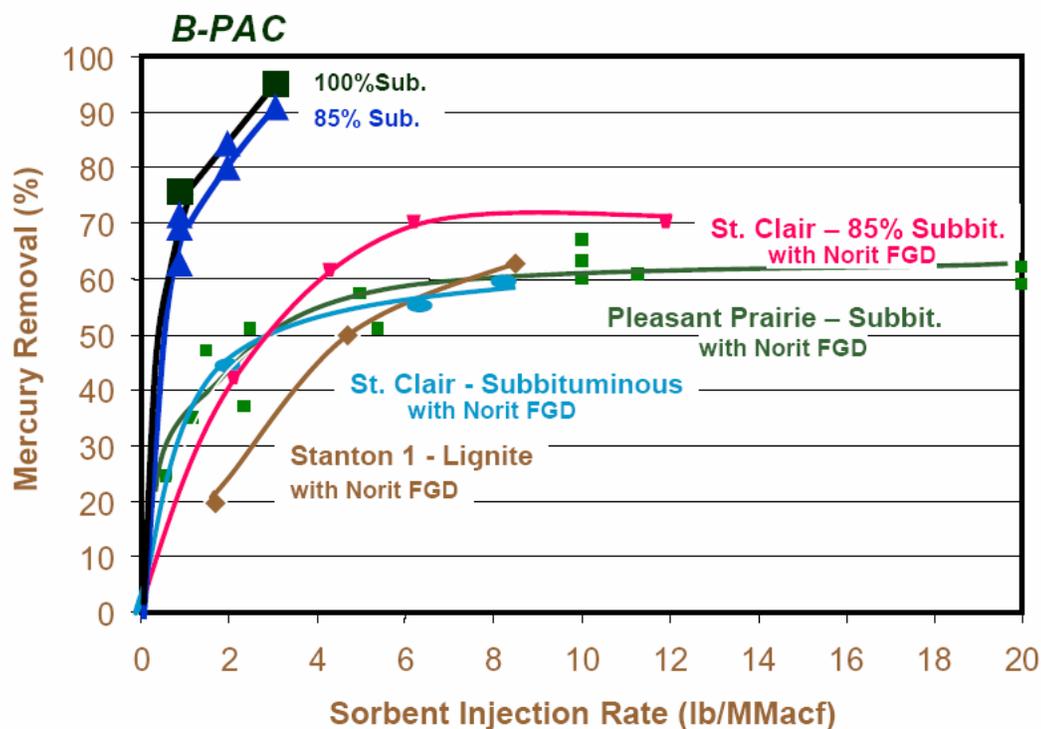
Figure 14. Detroit Edison St. Clair Parametric Testing Mercury Removal Results Using Norit Darco FGD Sorbent



The results for mercury removal tests at the St. Clair Power Plant using the Norit sorbent and utilizing 100% subbituminous coal fall on the mercury removal curve from the Pleasant Prairie test and are slightly better than the Stanton Station 1 test results. The mercury removal plateaus at about 60% mercury removal at an injection rate of approximately 6.0 lb/MMacf and does not increase at higher injection rates. The mercury removal results at the St. Clair Power Plant when firing the coal blend were slightly better, achieving 70% mercury removal at an injection rate of about 6.0 lb/MMacf. Again, this mercury removal rate did not increase even when the injection rate was increased to 12.0 lb/MMacf. This finding has been observed in other tests.

The standard Sorbent Technologies B-PAC™ mercury sorbent is internally denoted “A-5B.” The parametric mercury removal results from the testing with this sorbent are presented in Figure 15. Mercury removal results can be contrasted with that of standard Norit Darco FGD.

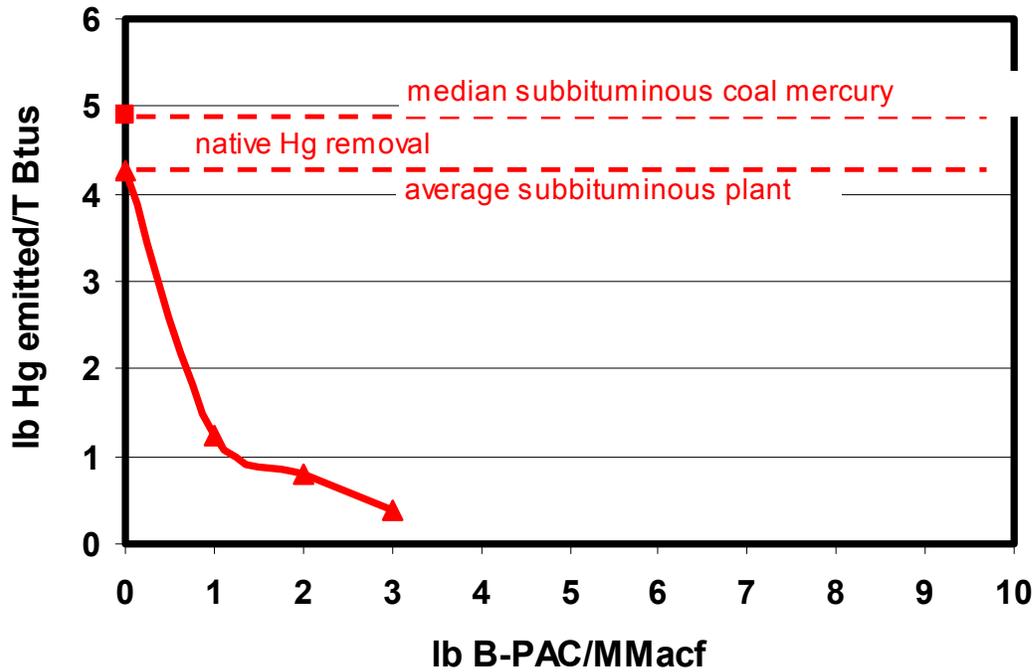
Figure 15. Detroit Edison St. Clair Parametric Testing Mercury Removal Results Using Sorbent Technologies A-5B and Norit Darco FGD Sorbents



The A-5B sorbent provided about 70% mercury removal at an injection rate of 1.0 lb/MMacf and 90% mercury removal at 3.0 lb/MMacf with the standard 85% subbituminous coal blend. Slightly higher mercury removals were achieved when 100% subbituminous coal was being utilized. These results are a major accomplishment in that 90% mercury removal was achieved at injection rates only a small fraction of what the plain PAC needed to achieve 60% to 70% mercury removal.

The parametric test results can be converted to pounds of mercury per trillion BTU heat input using the coal data. The results are presented in Figure 16. In this case, the results are presented for the median 100% subbituminous coal. An emission rate of just over 1.0 lb Hg/TBtus was accomplished with a B-PAC injection rate of 1.0 lb/MMacf. Mercury emissions below 1.0 and 0.5 lb Hg/TBtus were reached with injection rates of 2.0 and 3.0 lb/MMacf, respectively.

Figure 16. Mercury Emissions in Pounds per Trillion BTUs



Sorbent Technologies evaluated a number of different versions of the B-PAC sorbents using, for example, activated carbon substrates from different manufacturers. The results for from the tests with the different sorbents under normal boiler operating conditions are presented in Table 8. While the individual sorbent characterizations remain confidential, all were different variations of Sorbent Technologies standard brominated carbons.

Table 8. Parametric Mercury Sorbent Tests at St. Clair Unit 1A

<u>Date</u>	<u>Start Time</u>	<u>End Time</u>	<u>Sorbent</u>	<u>Injection Rate, lb/MMacf</u>	<u>Hg Removal Due to Sorbent, %</u>	<u>Coal Utilized</u>
8/26/2004	7:20	9:20	A-5B	1.0	71	85%/15% Blend
8/26/2004	9:20	11:33	A-5B	3.0	91	85%/15% Blend
8/27/2004	7:07	9:26	A-5B	1.0	70	85%/15% Blend
8/27/2004	10:26	12:20	A-5B	2.0	81	85%/15% Blend
9/13/2004	8:15	11:00	A-5B	1.0	70	85%/15% Blend
9/13/2004	12:35	2:34	A-5B	3.0	89	85%/15% Blend
9/23/2004	7:13	10:36	A-5B	1.0	69	85%/15% Blend
9/12/2004	8:12	10:22	A-5B	1.0	71	100% Subbituminous
9/12/2004	10:22	12:54	A-5B	3.0	84	100% Subbituminous
9/9/2004	6:46	1:59	A-5C	3.0	92	85%/15% Blend
9/10/2004	7:50	10:30	A-5C	1.0	73	85%/15% Blend
9/10/2004	10:30	1:00	A-5C	2.0	85	85%/15% Blend
9/11/2004	10:18	12:48	A-5C	1.0	77	100% Subbituminous
9/11/2004	12:48	2:58	A-5C	3.0	93	100% Subbituminous
8/30/2004	3:48	6:00	B	1.0	72	85%/15% Blend
9/14/2004	7:09	9:56	C	1.0	61	85%/15% Blend
9/14/2004	9:56	12:30	C	3.0	78	85%/15% Blend
9/15/2004	8:00	10:26	D	1.0	47	85%/15% Blend
9/15/2004	10:26	12:30	D	3.0	71	85%/15% Blend
9/16/2004	6:57	9:17	E	1.0	68	85%/15% Blend
9/16/2004	9:17	11:38	E	3.0	87	85%/15% Blend
9/17/2004	6:47	8:17	F	1.0	53	85%/15% Blend
9/17/2004	8:17	9:17	F	3.0	73	85%/15% Blend
9/23/2004	10:49	1:22	F	3.0	83	85%/15% Blend
9/22/2004	8:13	11:11	G	1.0	65	85%/15% Blend
9/22/2004	11:11	1:55	G	3.0	83	85%/15% Blend

During the parametric testing program, there was a week during which the native mercury removal across ESP 1A was as high as 67%. Attempts were made to discover the cause of this event, without result. The high native removal appeared to have the effect of reducing the performance of the B-PAC sorbents, although the total mercury removal was nearly as it was under normal operating conditions. The results for the tests performed under abnormal operating conditions are presented in Table 9.

Table 9. Parametric Mercury Sorbent Tests Under Abnormal Conditions

<u>Date</u>	<u>Start Time</u>	<u>End Time</u>	<u>Sorbent</u>	<u>Injection Rate, lb/MMacf</u>	<u>Hg Removal Due to Sorbent, %</u>	<u>Total Hg Removal, %</u>	<u>Coal Utilized</u>
9/3/2004	10:45	1:56	A-5B	3.0	76	90	85%/15% Blend
9/7/2004	12:49	4:01	A-5B	1.0	57	82	85%/15% Blend
8/31/2004	8:18	12:57	G	3.0	75	88	85%/15% Blend
9/2/2004	8:27	11:00	G	1.0	33	69	85%/15% Blend
9/1/2004	9:00	11:19	H	1.0	32	64	85%/15% Blend
9/1/2004	11:19	2:59	H	3.0	71	85	85%/15% Blend
9/2/2004	11:19	1:48	I	1.0	38	71	85%/15% Blend
9/3/2004	7:40	9:48	I	1.0	38	74	85%/15% Blend
9/8/2004	9:07	11:47	J	1.0	57	70	85%/15% Blend
9/8/2004	11:47	2:05	J	3.0	79	85	85%/15% Blend

A set of Ontario Hydro Method (OHM) tests was conducted on September 9, 2004. Mercury sorbent was being injected during the entire OHM test period in an effort to confirm the mercury removal being achieved by the sorbent. The data from this test is compared with that from the S-CEM during the same period in Table 10. All of the mercury data is corrected to 3% oxygen to allow for direct comparison of inlet and outlet data.

Table 10. Mercury OHM and S-CEM data for 9/9/04 (Corrected to 3% O₂)

<u>Inlet HgT</u>		<u>Inlet Hg0</u>		<u>Outlet HgT</u>		<u>Outlet Hg0</u>	
<u>SCEM</u>	<u>OHM</u>	<u>SCEM</u>	<u>OHM</u>	<u>SCEM</u>	<u>OHM</u>	<u>SCEM</u>	<u>OHM</u>
5794	4296	3840	3452	458	499	216	144
	(A)		(A)				

Total Hg Removal by SCEM data 92.1%

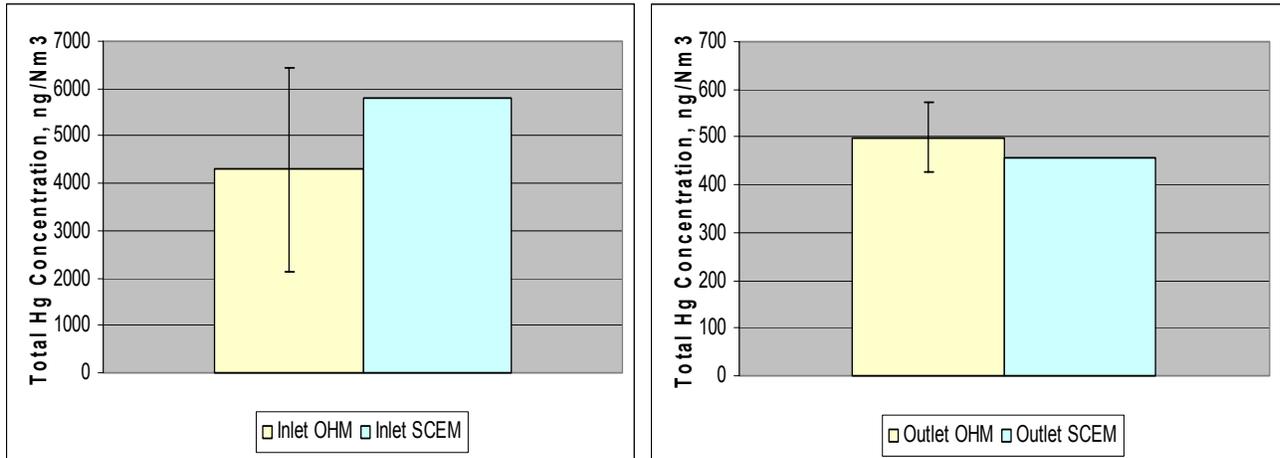
Total Hg Removal by OHM data 88.4%

(A) One spurious OHM data point omitted

The OHM and S-CEM data for the inlet Hg^(T) concentrations were significantly different in these tests, but the rest of the data compared favorably. The S-CEM data indicated that the mercury removal on this date was 92% while the OHM data indicated it was 4% lower at 88%. The OHM data thus confirms the high mercury removal of the B-PAC sorbent being injected.

One concern with the OHM testing is the high variability of the average results. The OHM data and S-CEM data is presented in Figure 17 along with two standard deviation error bars on the OHM data.

Figure 17. Inlet and Outlet Hg OHM and S-CEM Data for 9/9/04



The inlet OHM mercury average is lower than the inlet S-CEM data, but the S-CEM data is within the two sigma error bars, which were large for this test. The outlet OHM data appears to be what should be expected with a fairly small absolute error.

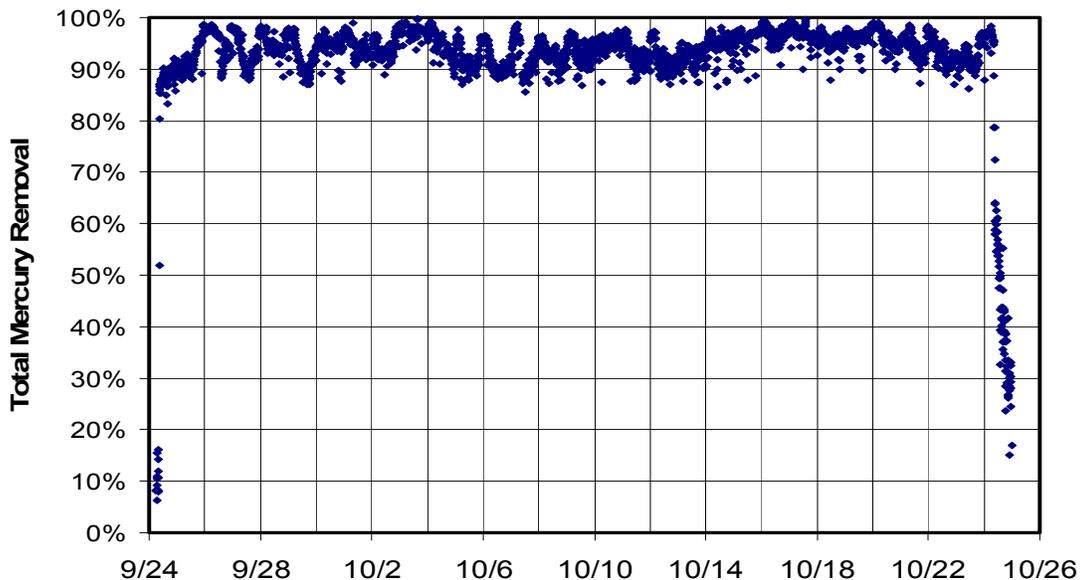
The standard A-5B B-PAC sorbent performed very well in the parametric testing and was chosen for use in the long-term test. A constant injection rate of 3.0 lb/MMacf was selected. A mercury removal rate due to sorbent of about 90% was expected based upon the parametric testing. The total mercury removal rate (sorbent and native) was expected to be about 92.5% based upon the average 25% native removal identified in the baseline testing.

Long-Term Testing

The long-term testing at the Detroit Edison St. Clair Power Plant Unit 1 ESP 1A began at 8:30 a.m. EST on September 24 and ran 30 days until 8:30 a.m. EST on October 24, 2004. The injection system was operated in the manner to automatically follow the flue gas flow rate and maintain a sorbent injection rate of 3.0 lb/MMacf. The sorbent injection system operated around the clock for the 30 days without any problems.

With B-PAC injected at 3 lb/MMacf, over the 30-day period, the instantaneous total vapor-phase mercury removal varied between about 88% and 98%, depending on the plant's operating conditions. Based upon the Hg S-CEMs measurements, the long-term average mercury removal was 94%. The data is presented in Figure 18. This is total mercury removal since native and sorbent mercury removal cannot be distinguished once the long-term testing began. Native mercury removal was about 10% before the test began and about 30% when it ended.

Figure 18. Detroit Edison St. Clair Long-term Testing Mercury Removal Results Using Sorbent Technologies A-5B Sorbent at an Injection Rate of 3.0 lb/MMacf



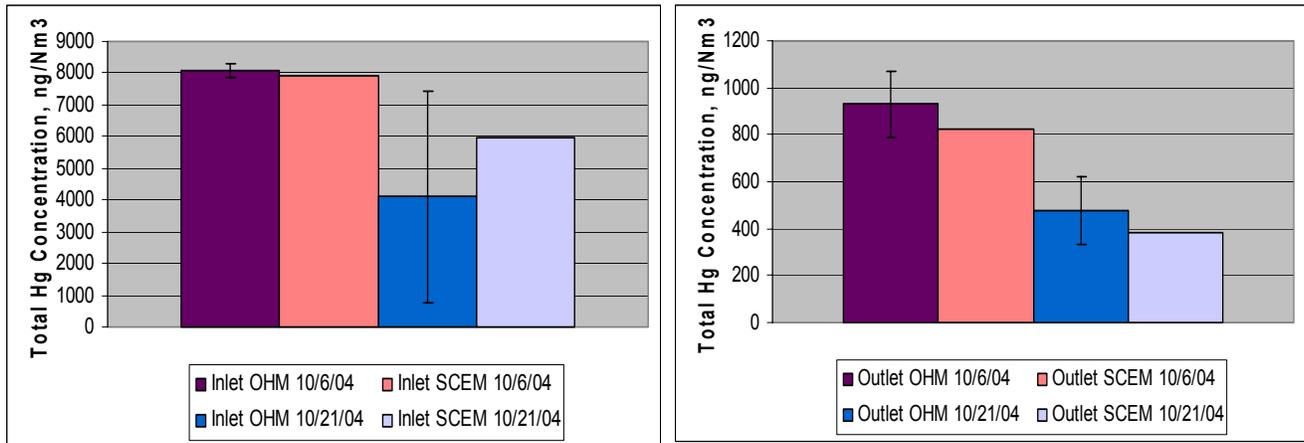
Two sets of OHM tests were conducted during the long-term testing. The results of these tests are presented in Table 11.

Table 11. Mercury OHM and S-CEM data for 10/6/04 & 10/21/04 at St. Clair Unit 1A (Corrected to 3% O₂)

Date	Inlet HgT		Inlet Hg0		Outlet HgT		Outlet Hg0	
	SCEM	OHM	SCEM	OHM	SCEM	OHM	SCEM	OHM
10/6/04	7907	8077	6382	7108	827	929	371	378
10/21/04	5984	4097	4580	2954	384	477	156	143
				<u>10/6/04</u>	<u>10/21/04</u>			
				Total Hg Removal by SCEM data	89.5%	93.6%		
				Total Hg Removal by OHM data	88.5%	88.4%		

The results from the test on October 6 were very similar for both the S-CEM and OHM data. The inlet data for the test on October 21 were different from the S-CEM and the OHM. The inlet OHM data was lower than the inlet S-CEM data, similar to that observed in the parametric testing. In any case, the calculated mercury removal rates were all very high. The inlet and outlet OHM data (with error bars) and the inlet and outlet S-CEM data are presented below.

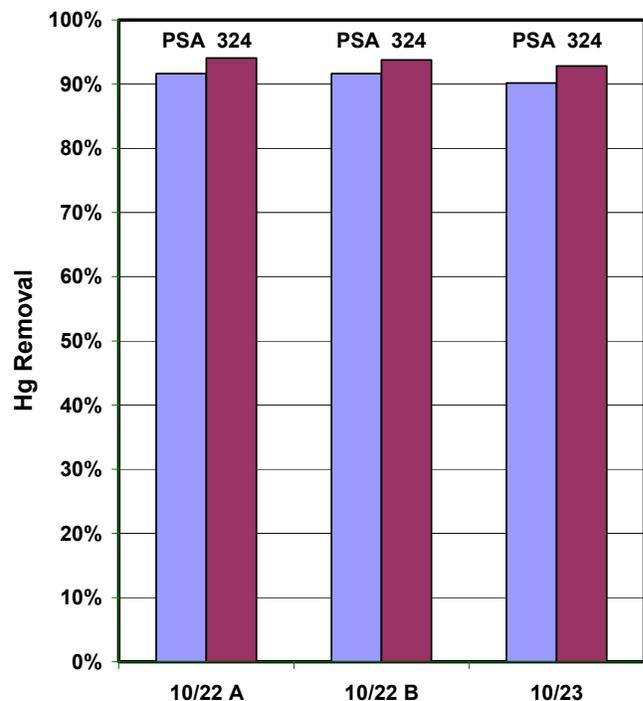
Figure 19. Inlet and Outlet Hg OHM and S-CEM Data for 10/6/04 and 10/21/04



The inlet data provides the most striking comparison. The OHM and S-CEM inlet mercury values for 10/6/04 are very close and the two-sigma error bar on the OHM data is very small. The inlet OHM and S-CEM mercury data on 10/21/04, however, are not very close and the two-sigma error bar on the OHM data was huge. The S-CEM data, of course, fall well within the error bar. The outlet mercury OHM and S-CEM data is close for both test dates and the error bars on the OHM data is modest. Due to the high variability of the individual sample train measurements, the OHM results were not used to correct the S-CEM data throughout the program.

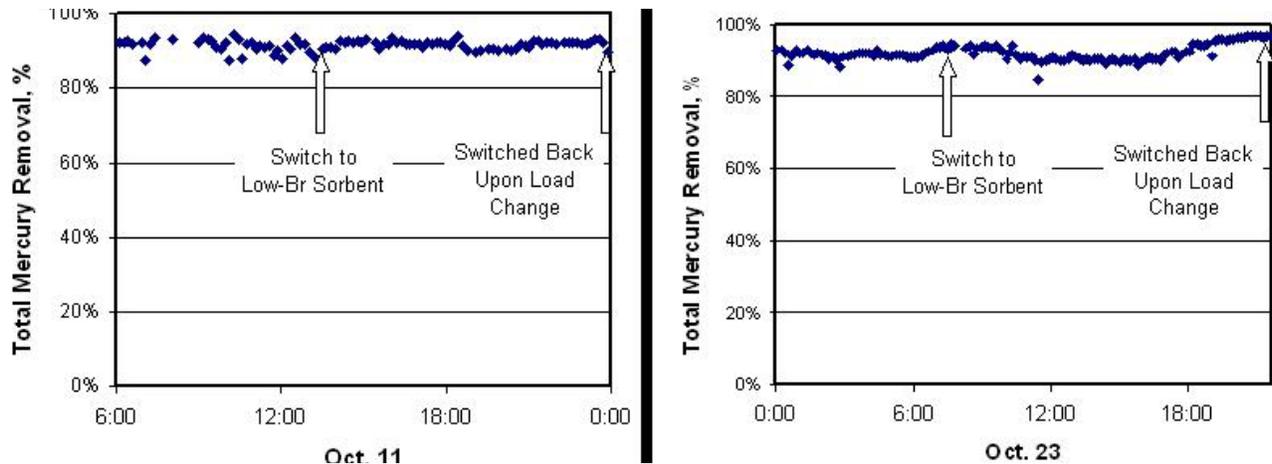
Detroit Edison took three Method 324 QuickSEM sorbent sampling-tube inlet and outlet measurements near the end of the 30-day test as an extra S-CEM check. The results from those measurements appear in Figure 20. The Method 324 analyses indicated slightly better mercury removal performance than the PSA semi-continuous analyzers.

Figure 20. Mercury QuickSEM Data from St. Clair Unit 1A



During the long-term testing, a number of brief coincident tests were performed. Two involved the evaluation of low-cost versions of the standard A-5B sorbent. These variations contain less bromine than standard B-PAC. To perform these tests, the day storage hopper was emptied and the lower-cost sorbent was added. There was no interruption of sorbent injection. The tests were performed on October 11 and 23. The data for these two days are presented in Figures 21 and 22.

Figures 21 & 22. Lower-Cost B-PAC Mercury Removal Test on 10/11/04 & 10/23/04



The switchover to the lower-cost B-PAC began at 13:30 on October 11 and at 7:30 on October 23 and ran through the end of the day when the plant load significantly changed. The total mercury removal on October 11 averaged 91.3% while the standard A-5B was being injected and 91.8% when the lower-cost B-PAC was in use. On October 23, the total mercury removal during the A-5B use was 91.3% and it was 91.8% during use of the lower-cost B-PAC. Clearly, there was no major difference in these two sorbents in this application. The mercury removal for both sorbents was included in the long-term mercury removal data presented in Figure 18 since there was not a significant difference in the two sorbents.

Another experiment was carried out during the long-term run to evaluate the intermittent operation of the sorbent injection system as a potential means of reducing the effective injection rate. It is known that the impact of the sorbent does not end immediately upon the termination of injection. Thus, a high mercury removal might be achieved at a lower sorbent injection rate if the rate of recovery, after injection is ceased, is slower than the rate of removal increase when the injection is begun. In this test, the injection system was switched on and off every minute for a period of 64 minutes. Before and after the test, the mercury removal was 92%. During the test, it decreased to 81%. Effectively, the injection rate had been cut to 1.5 lb/MMacf from 3.0 lb/MMacf by switching the injection system on and off. A mercury removal of 81% is approximately what would be expected at a B-PAC injection rate of 1.5 lb/MMacf. Thus, it appears that, for this application, the rate of mercury recovery was similar to the rate of mercury capture increase and this intermittent method of injection provided no benefit. The data for the 64 minutes of the test was not included in Figure 18 because of the significant impact on mercury removal during the test.

Daily coal samples were taken during the long-term test for analysis. The average composition of the coal samples is presented in Table 12 along with the value standard deviation. These analyses were performed by Detroit Edison in their laboratories.

Table 12. Coal Data from St. Clair Unit 1A during the Long-Term Test

	Total	Hg	Dry Basis				
	Moisture	ppm	Ash	Volatile Matter	F/C	Sulfur	Btu
Average	22.83	0.055	6.60	40.01	53.38	0.78	12592
St. Dev.	1.02	0.012	0.62	0.70	0.56	0.18	89
St. Dev., %	4.5%	21.1%	9.3%	1.8%	1.0%	23.6%	0.7%

The coal data is very representative of what is expected when using a blend of 85% subbituminous coal and 15% bituminous coal. The moisture level is high, averaging nearly 23%, while the ash (6.6% dry basis) and sulfur (0.78% dry basis) are low. The coal Btu content was about 12,500 per pound on a dry basis. These values and their variability compare very well with those of the baseline period.

The coal mercury content averaged 0.055 ppm on an as received basis, but was fairly variable with a standard deviation of 21%. The coal mercury data from the long-term test also compares favorably with the baseline coal mercury data.

Fly ash samples were taken daily from the various ESP field hoppers during the long-term test program. Selected samples were analyzed for their major components by Detroit Edison and analyzed for mercury by Sorbent Technologies. Compositional analysis of the fly ash samples collected during the long-term testing is presented in Table 13.

Table 13. Fly Ash Data from St. Clair Unit 1A during the Long-Term Test

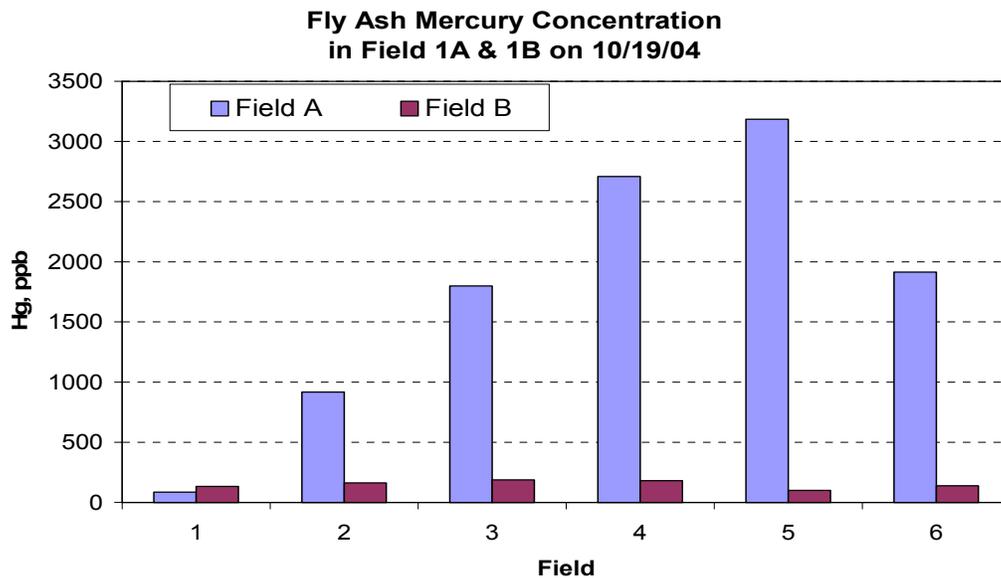
ESP Field	SiO2	Al2O3	TiO2	Fe2O3	CaO	MgO	K2O	Na2O	SO3	P2O5
1	48.5	17.1	1.1	9.8	9.3	2.2	1.0	3.4	1.9	0.7
2	40.2	19.5	1.3	7.7	15.3	3.8	0.9	5.7	2.7	0.9
3	35.0	19.9	1.4	7.1	17.2	4.3	0.9	6.4	4.6	1.0
4	30.4	20.5	1.5	6.9	19.1	4.8	0.9	7.0	6.6	1.1
5	28.9	19.9	1.5	7.0	19.4	4.8	0.9	6.5	8.0	1.2
6	26.6	20.1	1.5	6.7	20.1	5.1	0.9	7.1	8.4	1.4

The fly ash composition during the long-term test, independent of the increased carbon and mercury content due to the sorbent, was very similar to that measured during the baseline testing (as shown in Table 2). The compositional differences of the fly ash, from field to field, are probably due to segregation by size and are not impacted by sorbent injection.

Mercury Mass Balance

The fly ash mercury data is important in that it can be used to create a mercury mass balance to confirm the mercury removal results of other measuring techniques. During the long-term testing, an opportunity arose to sample not only the fly ash from the six fields of ESP 1A, but also from the six fields of ESP 1B, which did not see injected sorbent and could provide baseline (i.e. native Hg removal) comparisons. The fly ash mercury data for both ESP 1A and ESP 1B are presented in Figure 23.

Figure 23. Fly Ash Mercury Data for ESPs 1A and 1B



The impact of sorbent injection can be clearly seen. The fly ash mercury level in ESP 1B does not exceed 250 ppb in any field but does so in all fields except Field 1 in ESP 1A.

In order to convert the fly ash mercury data into a mercury mass balance, the mass distribution of the fly ash in the fields must be known. Sorbent Technologies personnel, with the assistance of Detroit Edison personnel, conducted several tests to estimate the distribution of the fly ash by field in ESP 1A. Fields 1 and 3 were inoperable during the long-term test program. Field 1 acted as a drop out chamber with the material collected there resembling sand with a bulk density twice that of the fly ash collected in the other fields. Field 3 was not powered during the trial, but the rapper system remained in operation and a significant amount of fly ash, charged in Field 2, was collected in Field 3. It was estimated that based upon hopper evacuation times that the mass distribution of the fly ash in ESP 1A was 10% in Field 1, 70% in Field 2, approximately 10% in Field 3 and 10% in Field 4. The back two fields collected very little fly ash and, unlike the first four fields, the hoppers serving back fields were emptied only once per day. This distribution of fly ash by field for ESP 1A was used in mass balance calculations.

A carbon mass balance was determined using the unburned carbon content of the fly ash and the fly ash distribution in the hoppers. The carbon mass balance provides a method of evaluating the mass balance assumptions and factors which will also be used in the mercury mass balance. The data for the carbon mass balance analysis is presented in Table 14.

Table 14. Long-Term Test Carbon Mass Balance

Unburned Carbon in Fly Ash (%)								
Field	1	2	3	4	Average Due to Sorbent	Daytime MW	Fly Ash, t/h	Sorbent Injected, t/h
9/28	0.52	2.13	4.59	5.64	1.72	133	1.605	0.032
9/30	0.84	2.62	5.77	5.34	2.18	111	1.340	0.033
10/2	6.19	0.72	3.01	4.95	1.07	117	1.412	0.017
10/4	0.28	2.10	5.27	5.55	1.73	141	1.702	0.034
10/11		2.88	6.86	6.62	2.52	138	1.666	0.048
10/12	0.46	2.61	6.40	5.08	2.17	129	1.557	0.039
10/15	0.71	4.02	8.00	6.04	3.44	126	1.521	0.060
10/21		2.86	7.28	7.55	2.64	111	1.340	0.040
10/23		1.56	5.70	4.29	1.24	118	1.424	0.020
Average								0.036

The fly ash unburned carbon content and the fly ash distribution by field was used to determine an average unburned carbon content of the fly ash. The average unburned carbon content was reduced by the amount normally present without sorbent injection (0.85%) to define the increased unburned carbon only due to sorbent. ESP 1A collects approximately 3500 pounds of fly ash per hour when St. Clair Unit 1 is operating at the full coal load of 145 MW. The power generation rate during the daytime hours (since this is when the samples were collected) was used to determine how much fly ash was generated on each day based upon a ratio compared with full coal load. Finally, the amount of sorbent injected was predicted based upon the average unburned carbon content of the fly ash. The B-PAC sorbent used in this test program contains only 88% carbon (with the majority of the remainder being ash). This factor was considered in calculating the amount of carbon injected. In this case, the calculation predicts that the injection rate was 0.036 tons per hour or 72 pounds per hour. The actual injection rate according to the gravimetric feeder data was 67 pounds per hour, providing a carbon mass balance of 107%. This is a very good carbon mass balance considering all of the assumptions.

A mercury mass balance was determined in a similar manner. In this case, the mercury content of the fly ash in the first four fields was used to calculate an average fly ash mercury concentration. The baseline fly ash mercury content was not subtracted from the calculated average fly ash mercury content since a total mercury mass balance is being calculated. Again, the ratio of the daytime power generation rate and the full coal generation rate is used to convert the full coal usage rate (70 tons per hour) into a coal usage rate on a given day. Similarly, the daytime power generation rate is used to calculate a fly ash production rate for each day. It should be noted that the mercury content of the grinding rejects is higher than the coal but the amount of rejects (approximately 150 pounds per day) is insignificant in comparison to the amount of coal used. The data for the mercury mass balance is presented in Table 15.

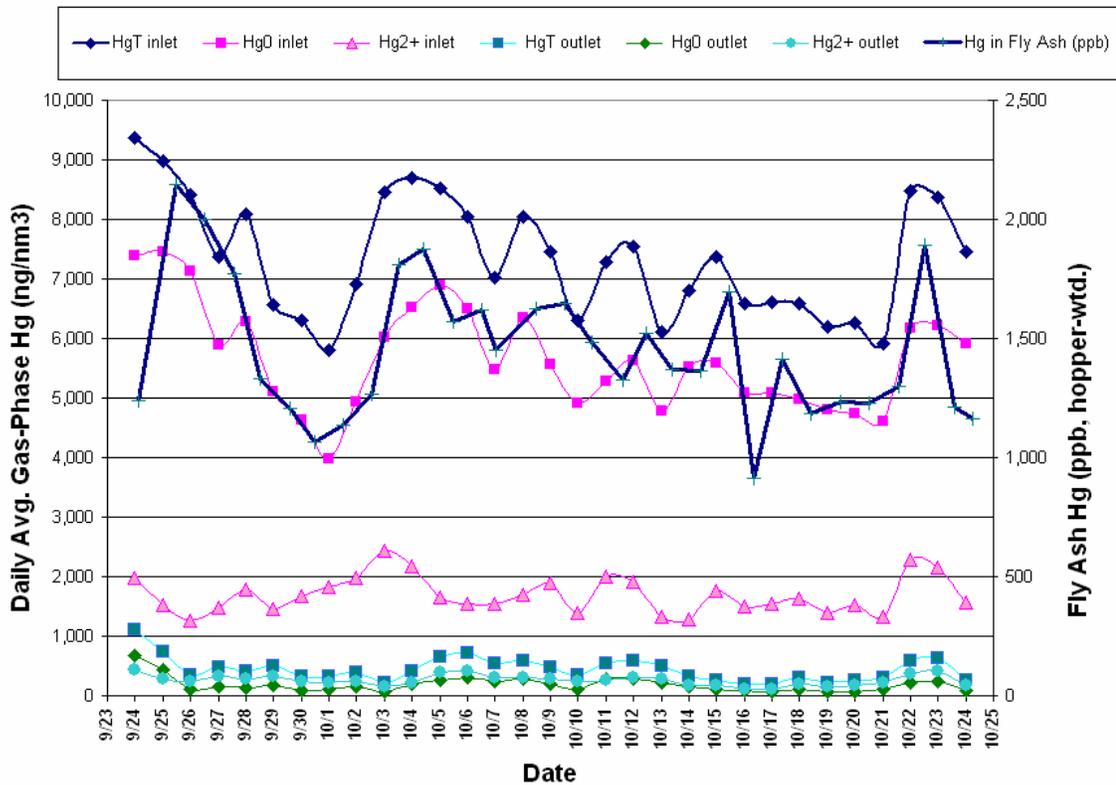
Table 15. Long-Term Test Mercury Mass Balance

Field	Hg in Fly Ash (ppb)					Hg/coal, ppb	Daytime Load, MW	Fly Ash, t/h	Hg in ash, 10 ⁻⁶ t/hr	Hg in coal, 10 ⁻⁶ t/hr
	1	2	3	4	average					
9/24						60	135			1.955
9/26	34	1557	1737	2260	1493	50	75	0.905	1.351	0.905
9/27						65	125			1.961
9/28	70	781	1671	2751	996		133	1.605	1.598	
9/29						35	134			1.132
9/30	78	687	1214	1840	794		111	1.34	1.064	
10/1						48	111			1.286
10/2	1192	81	883	2228	487	59	117	1.412	0.687	1.666
10/3						65	129			2.024
10/4	64	1347	2914	1374	1378	66	141	1.702	2.346	2.246
10/7						51	135			1.662
10/9						45	132			1.434
10/11		916	1679	2590	1068	69	138	1.666	1.779	2.298
10/12	96	1072	1577	2861	1204		129		1.874	
10/13						50	123			1.484
10/15	57	1372	1422	2978	1406	67	126	1.521	2.139	2.038
10/17						50	130			1.569
10/19						41	120			1.188
10/21		825	1607	2652	1003	41	111	1.34	1.344	1.099
10/22						76	135			2.477
10/23		522	2042	2895	859		118	1.424	1.223	
					1069	55		1.499	1.541	1.672

Some days with only coal analysis and some days with only fly ash analysis were included to provide better averages for the test program. The calculated average mercury input to the boiler through coal during the long-term test program was 1.67×10^{-6} tons per hour as compared to the mercury captured in the fly ash of 1.54×10^{-6} tons per hour. Thus, the mercury mass balance predicts that the 92.2% of the mercury entering St. Clair Unit 1 was captured. The mercury S-CEM data determined that the mercury capture rate was 94.2%. Thus, the mercury mass balance provides a very good confirmation of the mercury removal rates determined by the mercury S-CEMs.

Another correlation of the mercury in the fly ash can be seen in Figure 24. In this figure, the average daily inlet Hg S-CEM mercury measurements is plotted on the same graph as the average daily fly ash mercury content. The fly ash mercury content followed the trend of the inlet Hg S-CEM data with higher levels observed when higher inlet mercury levels were observed. The outlet Hg S-CEM data is also presented for completeness. As would be expected from the high mercury removal rate achieved in the long-term test, the outlet mercury concentrations were very low throughout the test.

Figure 24. Fly Ash and S-CEM Hg Data during the Long-Term Test at St. Clair



It has been noted in other test programs that the sorbent injected into an ESP can remain for weeks if not months in the system before it is removed. Detroit Edison personnel collected fly ash samples from the six fields of ESP 1A on three different days in the three weeks after sorbent injection was terminated. The long-term test ended on October 24, 2004. Sorbent Technologies analyzed these fly ash samples for mercury. Results are presented in Table 16.

Table 16. Post Long-Term Test Fly Ash Mercury Content

Fly Ash Hg content(ppb)						
Date	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6
11/5/2004	9	42	42	453	924	2258
11/12/2004	2	31	80	298	370	909
11/17/2004	7	ND	49	36	80	484

Note: the long-Term test ended 10/24/2004

The first set of samples was collected on November 5, 2004, twelve days after sorbent injection was ended. The mercury levels in Fields 1-3 had recovered to their pre-injection level but not those in Fields 4-6. In fact, the mercury content of the fly ash in Field 6 was still near that observed during the injection trial. The fly ash samples collected on November 12 and 17 (18 days and 23 days, respectively, after injection was stopped) show a continued decline in the fly ash mercury content. It is assumed that the main reason for the continued high mercury levels in the fly ash is inefficient ash removal from the hoppers. It was discovered during the parametric test that it was impossible to obtain a truly representative fly ash sample when only injecting for a few hours since any sample contained an unknown percentage of fly ash generated when sorbent was not being injected. Fields 5 and 6 are only evacuated daily, instead of continuously as are the hoppers in the other fields, and this probably increased the longevity of fly ash generated from the long-term test in these fields.

One additional calculation was made in order to evaluate the mercury data from this test program. The coal data for the day of each OHM test was used to determine the pounds of mercury per trillion Btu input. The OHM and S-CEM data was converted to these units using an F-factor method. The results of these calculations are presented in Table 17.

Table 17. Coal, OHM and S-CEM Data in lb/T Btu

Test Period	Date	Coal Btu/lb	Coal	Coal	Coal	Inlet OHM	Inlet S-CEM
		as Received	lb/T Btu	Hg, ppm	lb Hg/T Btu	lb Hg/T Btu	lb Hg/T Btu
Baseline	07/29/04	9513	1.05E+08	0.054	5.7	6.3	6.4
Parametric	09/09/04	9857	1.01E+08	0.044	4.5	3.1	4.2
Long-Term	10/06/04	9896	1.01E+08	0.051	5.2	5.8	5.7
Long-Term	10/21/04	9546	1.05E+08	0.041	4.3	2.7	3.9

The coal and inlet S-CEM data compare favorably on all four days of testing while the coal and inlet OHM data compare well only on the two days when the OHM data is close to the S-CEM data. On two days, the inlet OHM was substantially below the coal and S-CEM mercury data. These are also the days when the OHM data had the highest variability. This data is another argument for the OHM data being incorrect on the two days in question. It should also be noted that the outlet OHM measurement for the baseline test was about 8.0 lb Hg/T Btu, far above any of the inlet data. Due to the inaccuracy of the OHM mercury data, it was not used to correct the S-CEM data throughout the program.

Bromine Off-Gassing

In addition to the OHM testing, METCO Environmental performed Method 26A halogen testing at St. Clair on four occasions. The halogen testing was only performed at the outlet location on three of the four tests. For one test during the long-term injection run, the halogen testing was performed at both the inlet and outlet locations. The halogen test data is presented in Table 18.

Table 18. Halogen Data from the Testing at St. Clair Unit 1A

Method 26A Results – All data in ppm.

Without Sorbent	Baseline 07/28/04	Inlet – Long-Term 10/21/04	
HF	1.0	0.4	
HCl	8.1	3.6	
Cl ₂	<0.1	0.3	
HBr	0.1	<0.1	

With B-PAC @ 3 lb/MMacf	Parametric 09/09/04	Long-Term 10/06/04	Long-Term 10/21/04
HF	2.2	0.1	0.4
HCl	5.9	6.0	4.3
Cl ₂	0.1	0.2	0.4
HBr	1.0	0.3	0.2

No Br₂ detected.

Though the error bars for this data are probably relatively great, there did not appear to be significant hydrogen bromide evolution, at least during the long-term run. Without sorbent injection, baseline HBr was measured at 0.1 ppm and an inlet sample during the long-term run resulted in a <0.1 ppm reading. HBr measurements at the ESP outlet during long-term injection were only 0.3 and 0.2 ppm. Note that bromine was not detected in any of the measurements.

Possible HBr Corrosion Issues

If significant HBr was released from B-PAC, duct and ESP corrosion is possible. Barry Dooley, a corrosion expert at EPRI, had indicated that, even if 100% of the bromine were to leave the activated carbon and enter the gas stream, there would be no impact on corrosion because SO₃ was the driving force behind such corrosion. Nevertheless, four carbon steel corrosion coupons were installed as per EPRI recommendations for 30 days during the baseline testing period and four more for 30 days during the long-term test. After removal, the coupons were cleaned and reweighed, per ASTM methods. The average weight change results are in Table 19.

Table 19. Corrosion Coupon Data from the Testing at St. Clair Unit 1A
(4 each, 30 days)

	<u>Average Δ Weight</u>
Baseline Period	+ 0.13%
Continuous B-PAC Injection	+ 0.13%

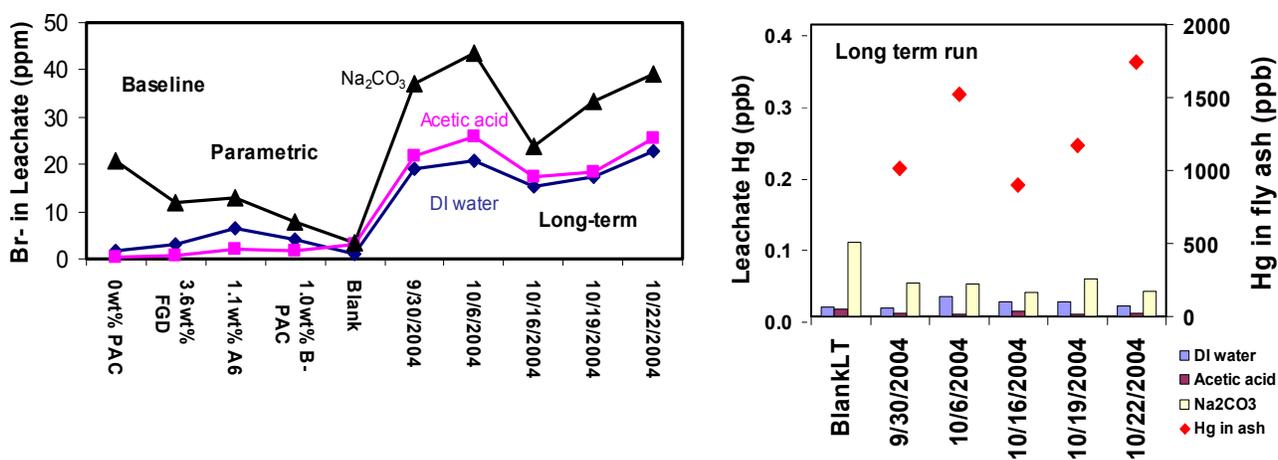
The average weight gain from both sets of coupons was the same, 0.13%. Of the eight samples, only one coupon experienced any weight loss at all and the loss was very slight. Based on weight loss for the time period tested, there was no corrosion evident due to the use of brominated sorbents.

Bromine in Leachates from St. Clair Fly Ash Containing B-PAC

Fly ashes containing some of the sorbents that were tested in the parametric runs and the long-term B-PAC run were leached with deionized water (DI), an acetic acid solution (Toxic Characteristic Leaching Procedure, TCLP), and an alkaline Na_2CO_3 solution (Synthetic Groundwater leaching Procedure, SGLP) and the leachates were examined for bromide. The results appear in Figure 25 below. In the SGLP tests, leachates of the fly ash without sorbents contained about 20 ppm Br^- and that of the fly ash containing plain carbon contained about 10 ppm Br^- , but little Br^- was found in the DI and TCLP leachates of either sample. About 20 to 30 ppm Br^- was found in the SGLP B-PAC leachates and from 10 to 20 ppm in the DI and TCLP leachates of these fly ashes.

None of these concentrations are significant for a halide. For perspective, the Earth's oceans contain an average about 70 ppm Br^- .

Figures 25 & 26. Bromine and Mercury in Fly Ash Leachates



Mercury in Leachates from St. Clair Fly Ash Containing B-PAC

Project fly ashes were also tested for released mercury in the various leachates. Data from the long-term run fly ashes containing B-PAC appear above in Figure 26. Mercury did not appear to leach from the sorbents in the fly ash: the detected mercury levels were all extremely low, despite relatively high Hg in the fly ash samples. In fact, from comparisons with the blank samples, with the deionized water and alkaline samples it appeared that the mercury flux was from the leaching solution to the solids. The sorbents appeared to still have unutilized mercury adsorption capacity and were adsorbing the trace mercury that came in with the leaching solutions.

Operation of the St. Clair Boiler 1 During the Long-Term Test Period

Detroit Edison St. Clair Unit 1 operated normally for the entire period of the long-term test. The boiler operation was under AGC (Automatic Governance Control) for most of the long-term test period. In this manner, the boiler load could be automatically varied, within limits, by a remote computer system matching production to the needs of the power grid. The boiler was under the control of the site operators when not in AGC. There were no requirements made on boiler operation during the long-term test. The injection system was to adjust to the boiler load to maintain the desired 3.0 lb/MMacf injection rate. This will be the standard method of operation once mercury control technology is commercially used. The control technology should be transparent to generating power. The boiler load in gross MW is presented in Figure 27.

The boiler load during the long-term test had its normal pattern generally varying between 120 MW and 145 MW, as needed, during the day and dropping to between 40 MW and 50 MW at night. The oil was over-fired along with coal on October 18 in order to achieve the maximum load of 160 MW, which was maintained for about four hours. The mercury removal on this day was the same as for the others during the long-term test indicating that the oil injection had no impact upon mercury sorbent injection.

The flue gas oxygen content follows the opposite trend to load, since air flow is not decreased in proportion to boiler load in order to avoid depositing fly ash in the ductwork at low loads. The flue gas oxygen content measured at the preheater outlet is presented in Figure 28.

The flue gas oxygen content as measured at the preheater outlet is about 6% at the higher loads and at least 10% at the lower loads. The oxygen monitor at this location has a high span of 10%.

Sorbent Technologies provided the instrumentation to measure the temperature and flow of the flue gas at the point of sorbent injection. The instrument location is the center port of the seven shown in Figure 2. The flue gas temperature at the injection location is presented in Figure 29.

The flue gas temperature has the same pattern as the boiler load in that the highest temperatures are recorded at the highest load. The flue gas temperature has the opposite pattern of the flue gas oxygen content. The net result of these opposite trends is that the flue gas flow rate does not exhibit the pattern of high flows during the daytime and low flow during the night but is rather stable as can be seen in Figure 30.

Figure 27. Boiler Load during the Long-Term Test

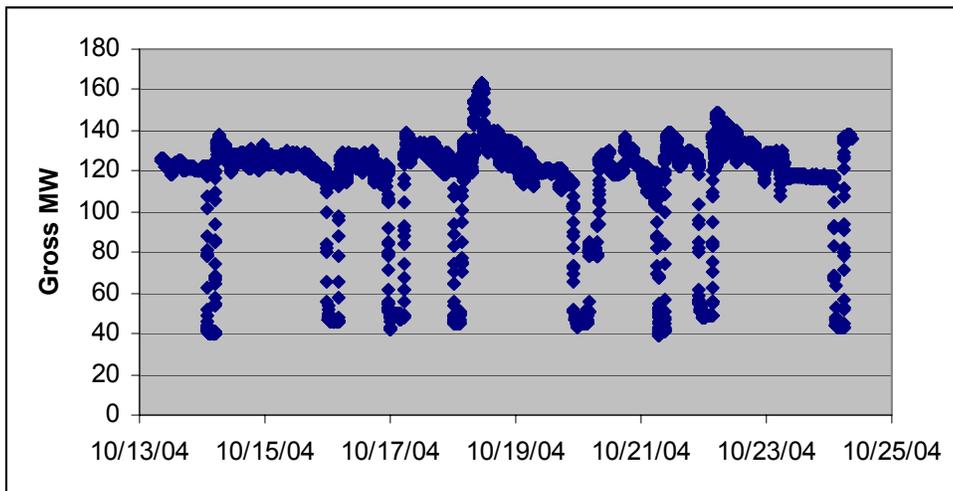
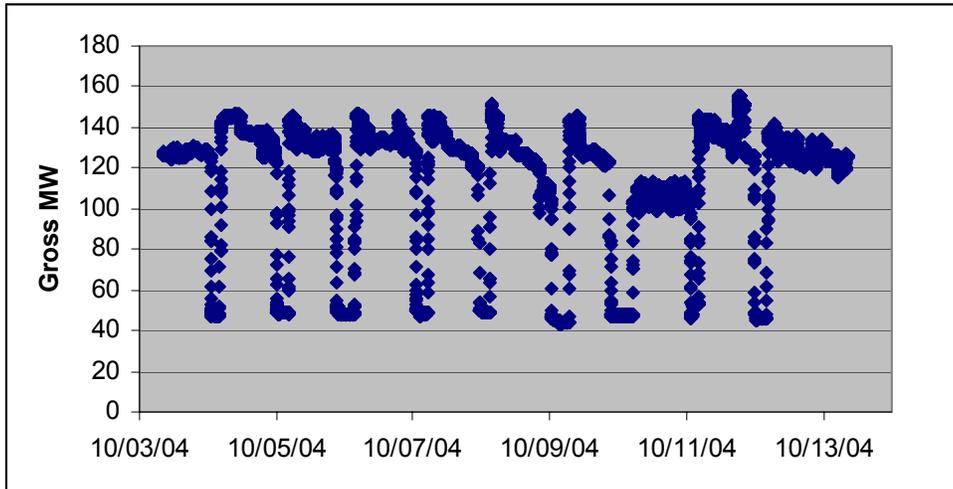
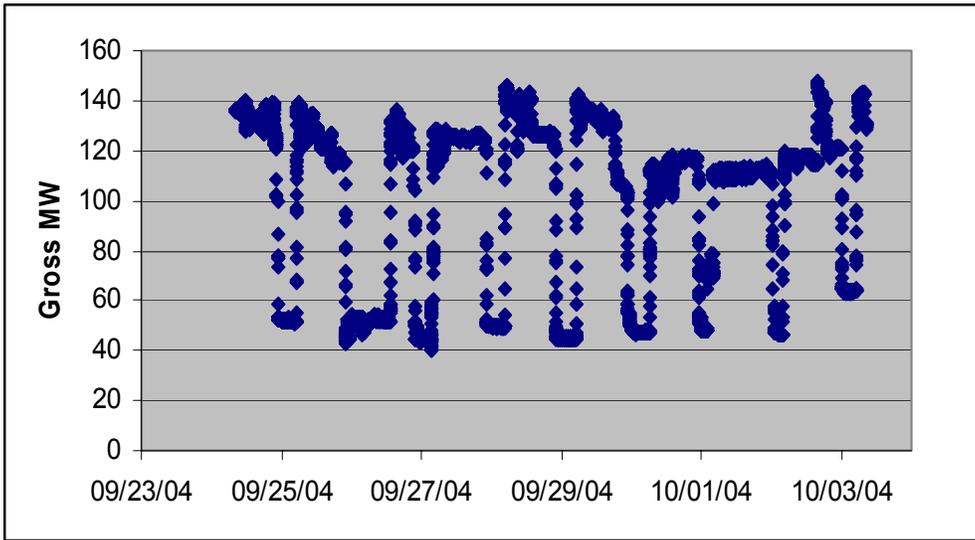


Figure 28. Preheater Outlet O₂ during the Long-Term Test

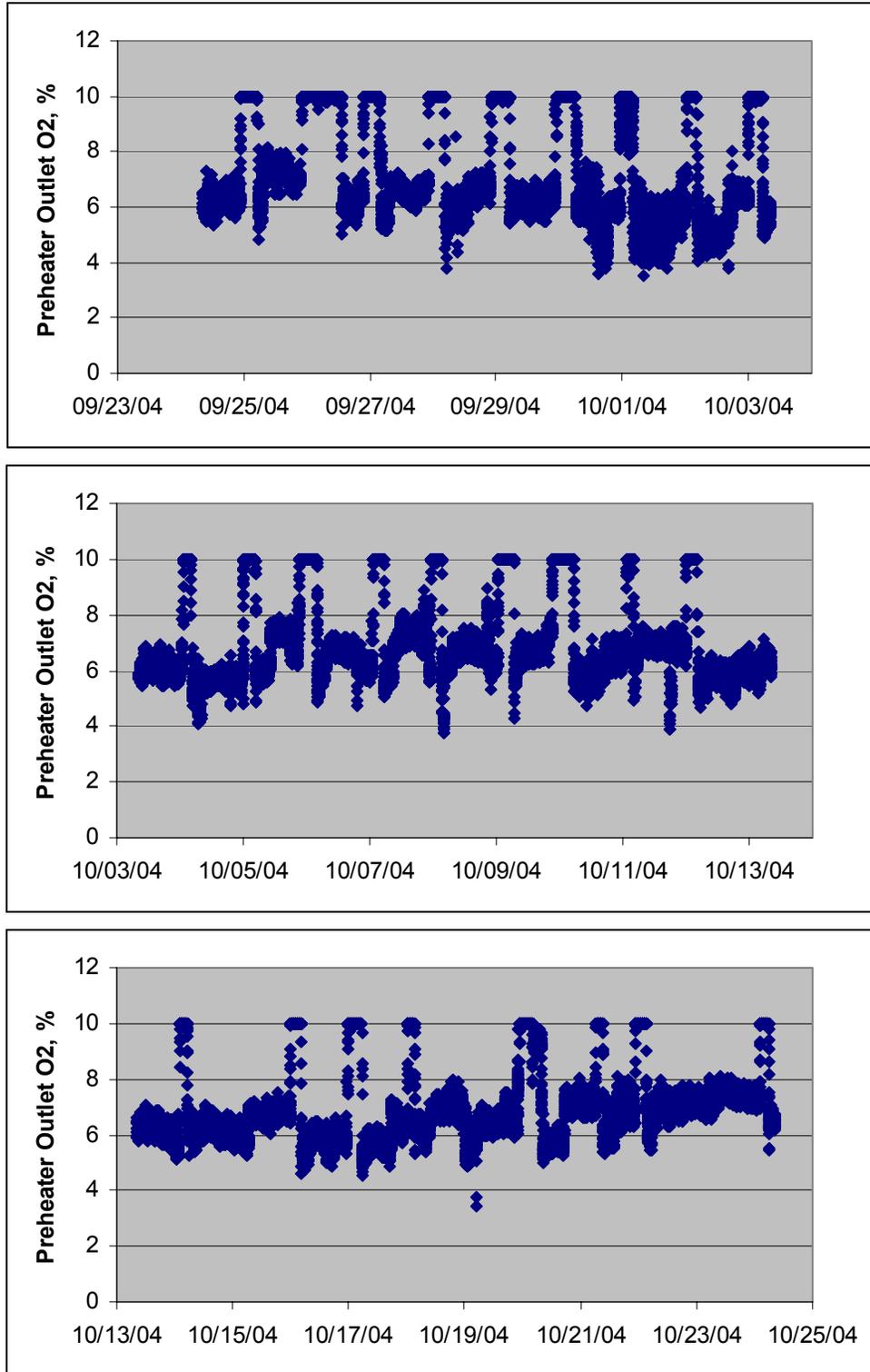


Figure 29. Flue Gas Temperature at Injection during the Long-Term Test

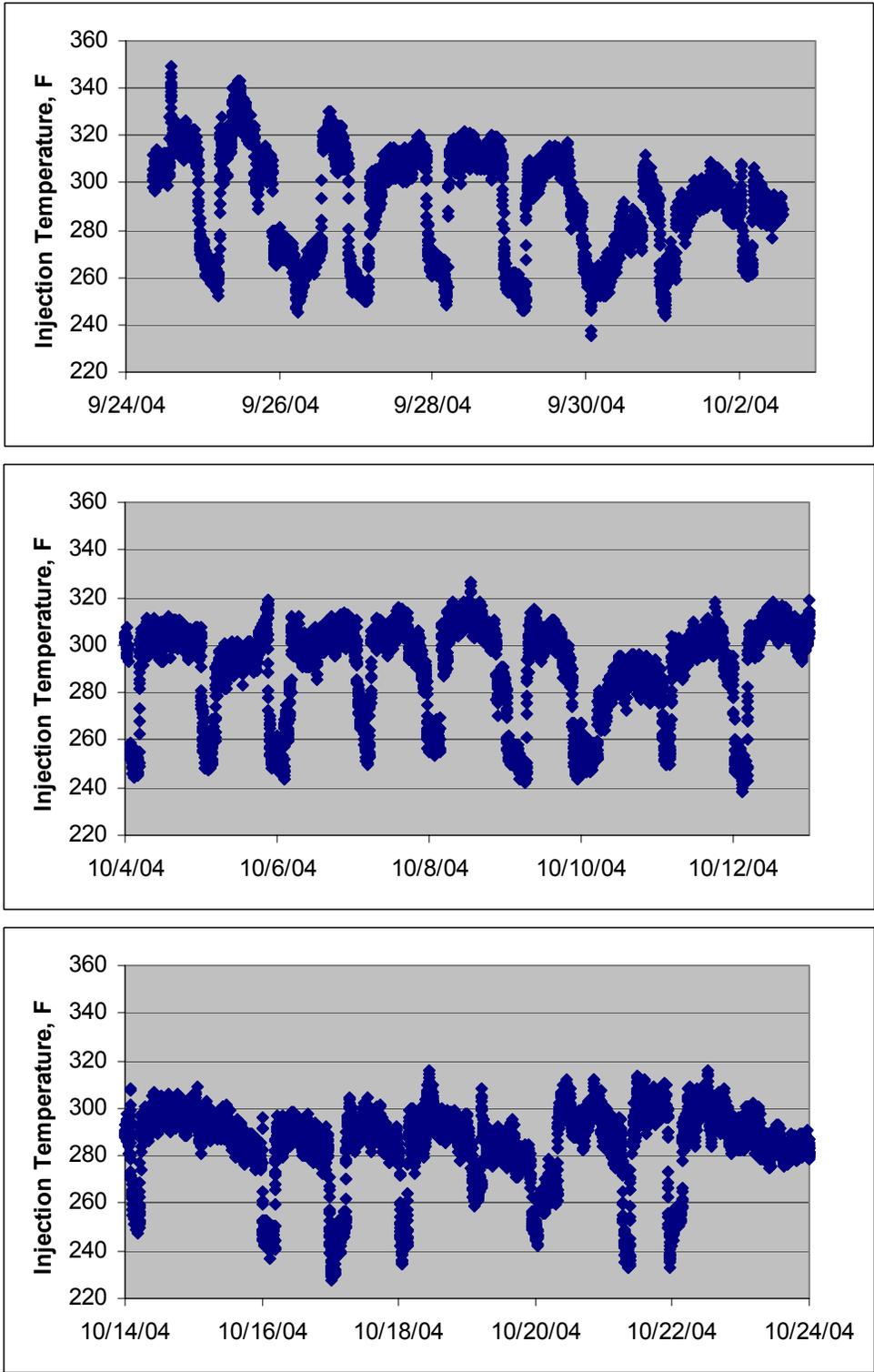
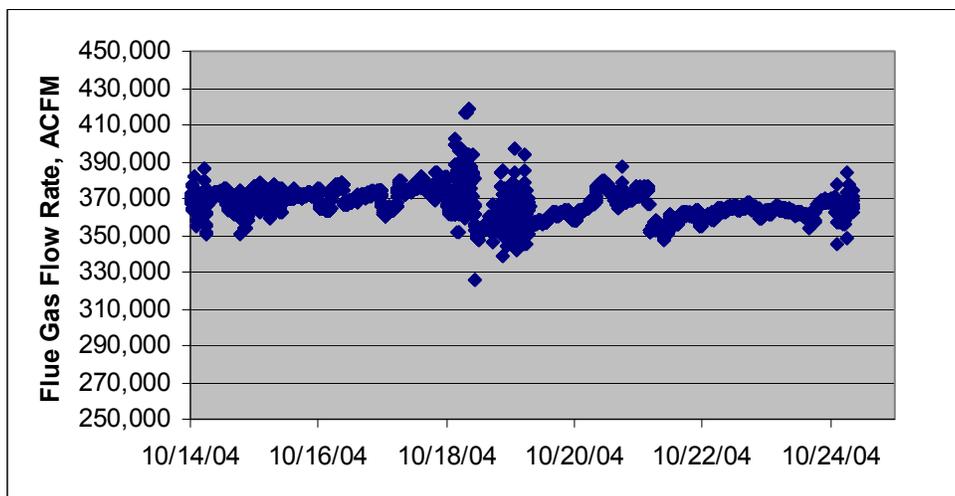
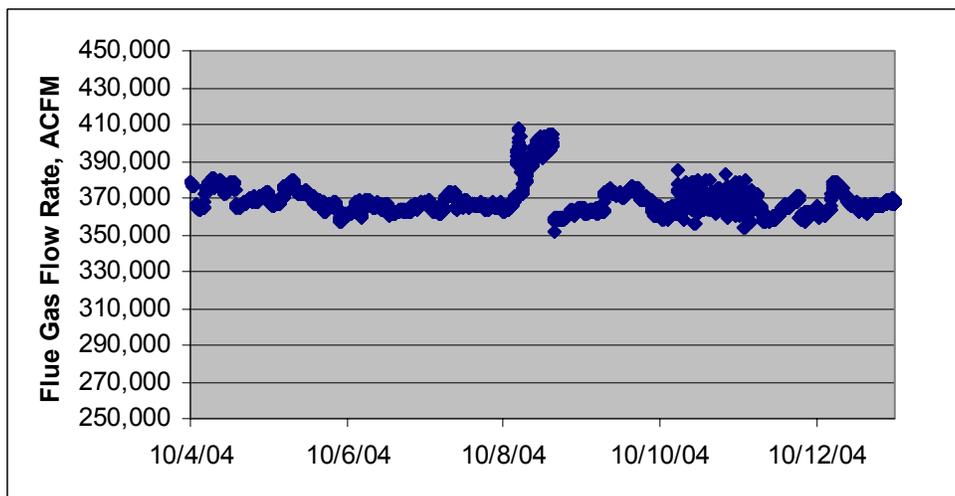
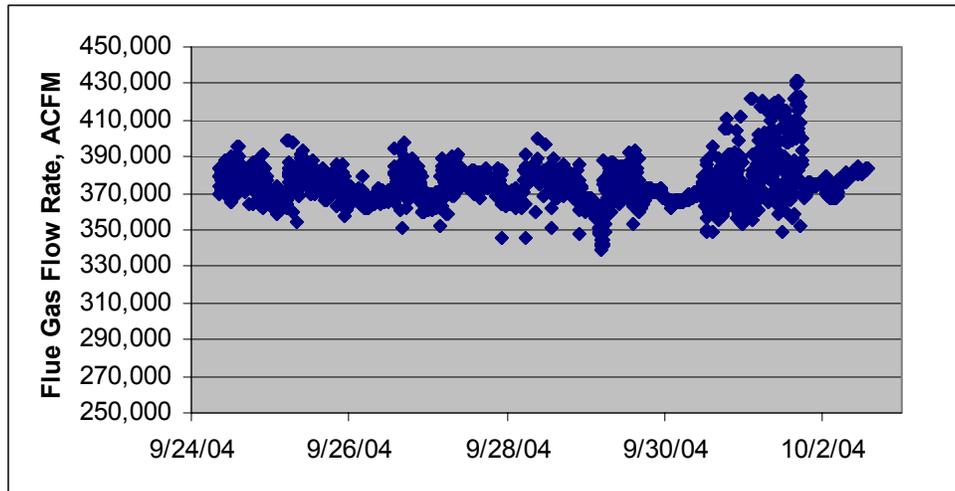


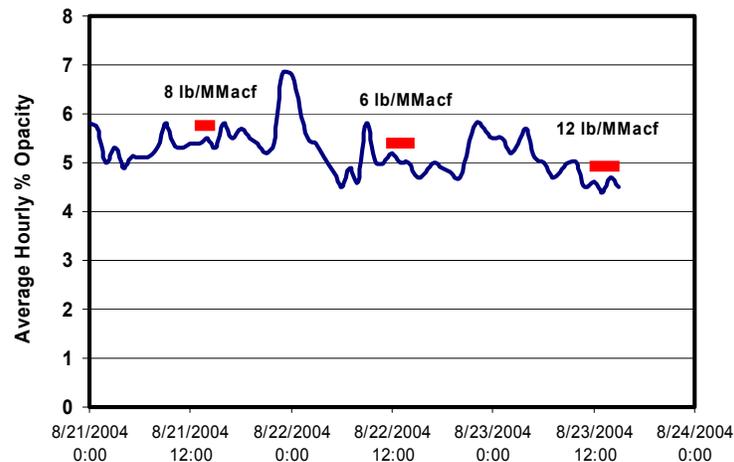
Figure 30. Flue Gas Flow Rate at the Point of Injection during the Long-Term Test



Possible ESP Effects

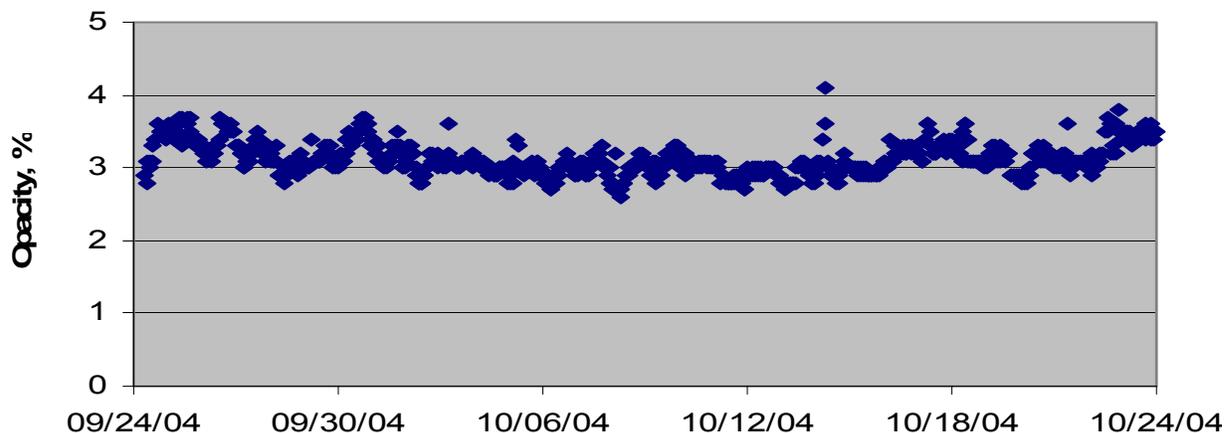
The cold-side ESP at the Detroit Edison St. Clair Power Plant Unit 1A was only fully operating four of the six available fields. Field 1 was acting essentially as a dropout chamber while Field 3 collected fly ash which had been charged in Field 2. The rappers on Field 3 were maintained in operation. Even with two fields out of service, the SCA of ESP 1A was still large and it was expected that there would be no impact of sorbent injection, amounting to only about a 2% increase in particulate load, on the flue gas opacity. None was observed in the parametric program in August, even when injecting Norit Darco FGD PAC at an injection rate of 12 lb/MMacf. See the opacity plot below.

Figure 31. Flue Gas Opacity during Some Parametric Testing



During the September long-term run, the plant background opacity was even lower. Plant opacity measured during the long-term test is presented in Figure 32. There was no evidence of increased particulate emissions due to the sorbent injection.

Figure 32. Flue Gas Opacity during the Long-Term Test at St. Clair



Mercury Control Cost Analysis

Capital Costs

The capital equipment and installation effort at St. Clair was relatively minimal and do not conflict with estimates of \$1.5/kW or less for retrofitted activated carbon systems, including mercury measurement.

Operating & Maintenance Costs

Because so little capital equipment was necessary at St. Clair, operating and maintenance costs were, and will be, the dominant costs in control systems such as this. By far the dominant O&M cost for mercury control using sorbent injection will be the cost of the sorbent.

In these tests at the Detroit Edison's St. Clair Power Plant, a mercury removal rate of 70% could be achieved at a B-PAC injection rate of 1.0 lb/MMacf and a long-term mercury removal rate of over 90% was observed with an injection rate of 3.0 lb/MMacf. These results are when the boiler was firing a 85% subbituminous/15% bituminous coal blend. Slightly higher results were achieved when 100% subbituminous coal was in use.

For these calculations, the data for the coal blend is utilized. A mercury concentration at the point of injection of $5 \mu\text{g}/\text{Nm}^3$, under actual gas conditions, is also assumed in the calculation, and it is assumed that the B-PAC cost is \$0.75/lb.

The cost calculation for 70% mercury removal would be as follows:

$$\left(\frac{1 \text{ lb sorbent}}{1,000,000 \text{ acf}} \right) \left(\frac{\text{Nm}^3}{(70\%) 5 \mu\text{g Hg}} \right) \left(\frac{\$0.75}{\text{lb sorbent}} \right) \left(\frac{1.5 \text{ acf @ } 300\text{F}}{1 \text{ scf}} \right) \left(\frac{35.3 \text{ scf}}{\text{Nm}^3} \right) \left(\frac{10^9 \mu\text{gHg}}{2.2 \text{ lb Hg removed}} \right) = \$5,200/\text{lbHg}.$$

94% mercury removal would similarly cost:

$$\left(\frac{3 \text{ lb sorbent}}{1,000,000 \text{ acf}} \right) \left(\frac{\text{Nm}^3}{(94\%) 5 \mu\text{g Hg}} \right) \left(\frac{\$0.75}{\text{lb sorbent}} \right) \left(\frac{1.5 \text{ acf @ } 300\text{F}}{1 \text{ scf}} \right) \left(\frac{35.3 \text{ scf}}{\text{Nm}^3} \right) \left(\frac{10^9 \mu\text{gHg}}{2.2 \text{ lb Hg removed}} \right) = \$11,500/\text{lbHg}.$$

These sorbent consumption costs are for St. Clair, whose coal-Hg, and consequent $5 \mu\text{g}/\text{Nm}^3$ of gas-phase Hg at injection, are slightly lower than the median and average for subbituminous coal-burning plants. Costs would be even lower for the median and average subbituminous plants.

These costs are only a fraction of what has been previously predicted for the cost of retrofit mercury control with plain powdered activated carbon. See, for example, the historic "baseline" cost estimate of the Department of Energy of \$50,000 to \$70,000 per pound of Hg removed (Bajura, 2003.)

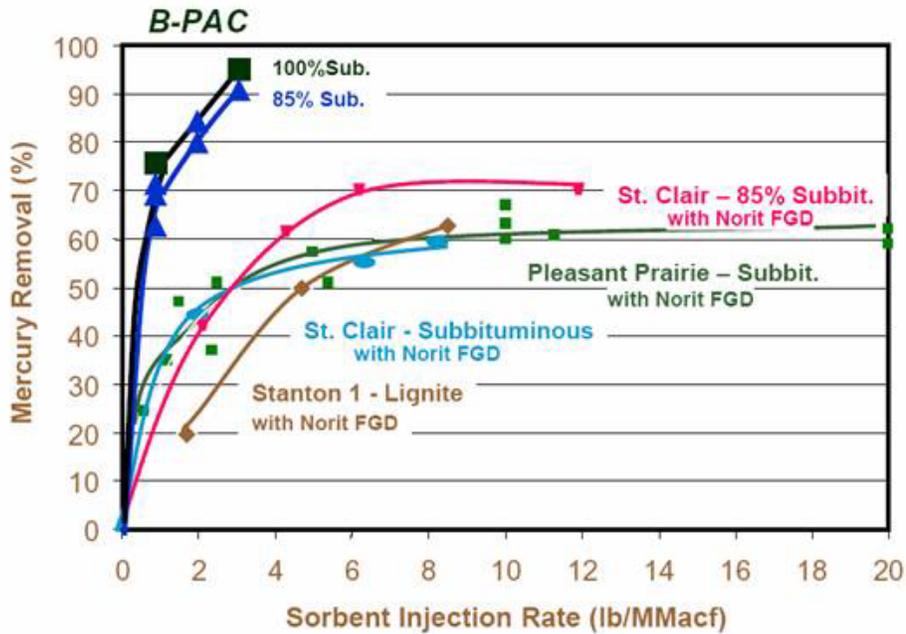
Conclusions

For the testing conducted at the Detroit Edison St. Clair Power Plant, the following conclusions can be made:

1. The Sorbent Technologies B-PAC sorbent production facility came on-line without a problem and reached its design capacity.
2. The Sorbent Technologies mobile sorbent injection system was proven to be both accurate and dependable, having not had a problem during the trials.
3. Initial tests of the PS Analytical dry mercury conversion system suggest the potential for eliminating two of the major problems associated with mercury S-CEMs, chemicals and their wastes. However, the more traditional wet system was used in the long-term run.
4. CFD modeling was valuable in obtaining a uniform distribution of sorbent after injection. Such modeling increases in value if high, 90+% mercury removal is being targeted.
5. The use of bituminous coal in a blend with subbituminous coal enhanced native mercury removal at this plant. Native mercury removal when firing 100% subbituminous coal was 15% or less. This removal increased to 25% to 35% when the coal blend was in use.
6. The B-PAC sorbent was able to achieve 70% mercury removal due to sorbent at an injection rate of 1.0 lb/MMacf and 90% mercury removal with an injection rate of 3.0 lb/MMacf. At this plant and at the average subbituminous plant these levels translate to slightly more than 1 lb Hg/TBtu at the lower injection rate and less than 0.5 lb Hg/TBtu at the higher injection rate.
7. A total mercury removal rate of over 94% was achieved at a B-PAC injection rate of 3.0 lb/MMacf during the long-term test over a 30 day period. This is an unprecedented result, especially considering that a low rank coal was being used with just a cold-side ESP. The B-PAC itself removed an average of about 91% of the mercury over this period.
8. Mercury mass balances using the coal and fly ash mercury data confirmed the high mercury removal rates recorded by the mercury S-CEMs. Both Method 324 sorbent-tube measurements and Ontario Hydro Method sampling confirmed the S-CEM measurements, but the standard deviation of triplicate Ontario Hydro Method measurements were very high on several tests and the OHM results came too late to be of much use in any case.
9. At some plants the use of B-PAC sorbents with smaller amounts of bromine appears to have the potential to provide the same high mercury removal rates at even lower costs.
10. There were no observed impacts upon boiler operation. The opacity for the test periods was no different than for the baseline periods. Corrosion testing did not identify any corrosion due to the sorbent and the HBr content of the flue gas was found to be minimal. Detroit Edison could operate the boiler as they saw fit during the long-term test and the injection system adjusted to their operation. Mercury control was transparent to their operation.
11. The control costs for this technology, which are nearly all sorbent costs, were found to be about \$5,000/lb Hg for 70% mercury removal and about \$12,000/lb Hg for 90% control due to the sorbent. These costs are much lower than with those with plain PACs in previous full-scale tests.

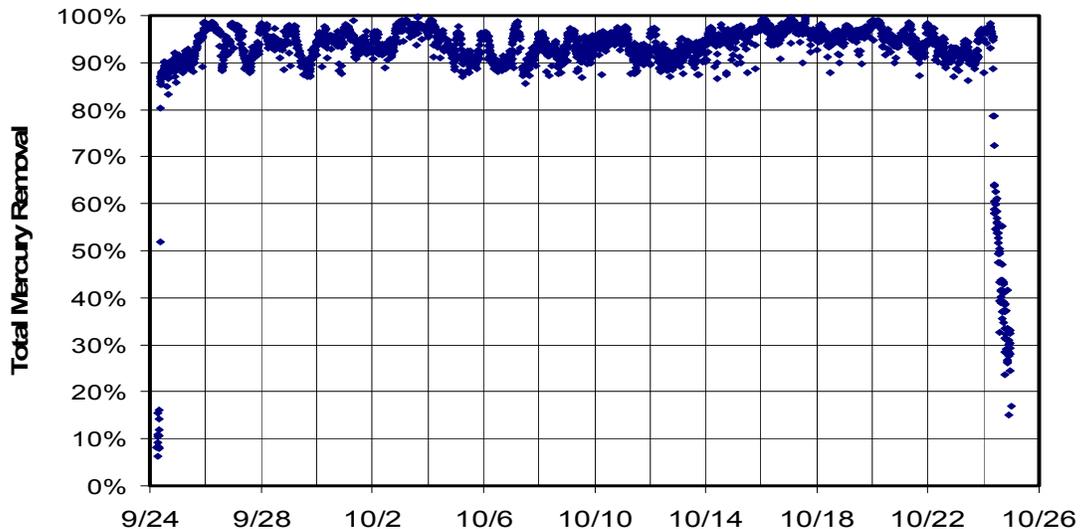
Significant Accomplishments

Two figures summarize the accomplishments of the St. Clair plant demonstration. The B-PAC results from the parametric testing at the St. Clair Power Plant are presented in the first figure.



Clearly, the B-PAC sorbent provided much higher mercury removal at a much lower sorbent usage rate than did the plain Norit Darco FGD PAC. Further, mercury removal results were better when 100% subbituminous coal was burned, compared to the normal 85% subbituminous/15% bituminous coal blend.

The results from the long-term 30 day test with B-PAC are presented in the figure below.



The average mercury removal rate for the 30 day period was 94%. The cost for this level performance is estimated at less than \$12,000/lb of Hg removed.

Problems Encountered

A continuing problem of note was the Ontario Hydro Method stack mercury testing. While the S-CEM data was always within the error-bars of the OHM results, these error-bars were usually so large as to make the OHM exercise of little value. First, the OHM test provides only a two hour average snapshot of the mercury levels. Second, the results are not received for many weeks, making any corrective action problematic. Third, despite using an experienced outside stack-testing team, the standard deviations of the triplicate measurements were large in several measurements and no explanation for this could be found.

While the Ontario Hydro method proved extremely valuable as a standardization tool for speciating mercury in the early years of power plant mercury research, its value, particularly in light of its high costs, in future programs may be limited.

Plans For The Next Reporting Period

The work in the next reporting period (November 1, 2004 through March 31, 2005) will be focused on the work at Duke Power. The report will cover the brief second qualification test at the Cliffside Steam Station conducted in December 2004, as well as all of the preparation work for the testing at the Buck Power Plant. Testing at the Buck Power Plant is scheduled to begin in March 2005 with the installation of equipment and to run into June 2005.

References

Bajura, R., "New Horizons in Coal RD&D," Low-Rank Fuels Symposium, Billings, Mont., June 2003.