

# ICAC Forum '03

## Multi-Pollutant Emission Controls & Strategies

### Full-Scale Results of Mercury Control by Injecting Activated Carbon Upstream of ESPs and Fabric Filters

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#### ABSTRACT

Injecting sorbents upstream of particulate control equipment represent the most mature and versatile technology to reduce mercury emissions from coal-fired boilers. This paper will provide operating data from five different full-scale field test programs. The data covers a range of coals and operating conditions and includes performance with both ESPs and fabric filters.

Results from three programs with ESPs were conducted under a cooperative agreement with the Department of Energy National Technology Laboratory (NETL). Host site configurations included units burning both Powder River Basin and low sulfur bituminous coals and sites that had high and low natural mercury removal. Results from this test program have shown the capabilities and limitations of using ACI for mercury control with ESPs. This paper will include results from Wisconsin Electric Pleasant Prairie, PG&E NEG Brayton Point, and the recently completed results from PG&E National Energy Groups Salem Harbor Station. This site provided key information on the impact of an SNCR system and documented the importance of temperature and LOI in mercury removal with and without ACI. In addition, results from an EPRI program on a high-sulfur bituminous coal are referenced.

This paper will also provide results on performance with a fabric filter at the Alabama Power Gaston Station including short-term tests completed in 2001 and the most recent results from a yearlong test that began in March 2003. Results from the short-term tests showed high mercury removal efficiencies were possible, but operational restraints prevented running these conditions for extended periods and could not provide information on long-term impact on fabric filter performance. The current program will evaluate the long-term (~1 year) performance of activated carbon for mercury control and its affect on bag life, pressure drop and balance-of-plant equipment. The paper will also present progress on a new \$50M five-year demonstration program of TOXECON that will take place at the We Energies Presque Isle Power Plant. This project was recently selected for contract negotiations under the Clean Coal Power Initiative.

## **INTRODUCTION**

The power industry in the US is faced with meeting new regulations to reduce the emissions of mercury compounds from coal-fired plants. These regulations are directed at the existing fleet of nearly 1100 existing boilers. These plants are relatively old with an average age of over 40 years. Although most of these units are capable of operating for many additional years, there is a desire to minimize large capital expenditures because of the reduced (and unknown) remaining life of the plant to amortize the project.

In addition, utilities are being faced with operating in an unregulated competitive environment in which they must strive to be the low cost provider. Since the cost of fuel represents approximately 70% of the incremental cost of generating electricity, it is critical that the plant be able to purchase the cheapest fuels available. It is also critical that these plants are operating reliably, especially during peak demand periods.

Therefore, the industry needs environmental control technologies that will have the following fundamental characteristics:

- Will take advantage as much as possible of existing equipment and minimize the need for installing new major capital equipment;
- Can effectively meet regulations on a wide variety of coal characteristics;
- Will not require additional manpower or specialized technical expertise; and
- Can be installed and operated without jeopardizing the reliability of the generating facility.

This paper provides a summary of the latest information on sorbent-based mercury control technology on coal-fired boilers. New operating and performance data from full-scale installations have proven the effectiveness of sorbent injection for reducing mercury emissions. The paper describes how different coal characteristic, operating conditions, and equipment configurations impact mercury removal.

## **DESCRIPTION OF TEST PROGRAMS**

Injecting a sorbent such as powdered activated carbon (PAC) into the flue gas represents one of the simplest and most mature approaches to controlling mercury emissions from coal-fired boilers. The gas phase mercury in the flue gas contacts the sorbent and attaches to its surface. The sorbent with the mercury attached is then collected by the existing particle control device, either an electrostatic precipitator (ESP) or fabric filter. This combined material consisting of about 99% fly ash and 1% sorbent is then either disposed of or beneficially used.

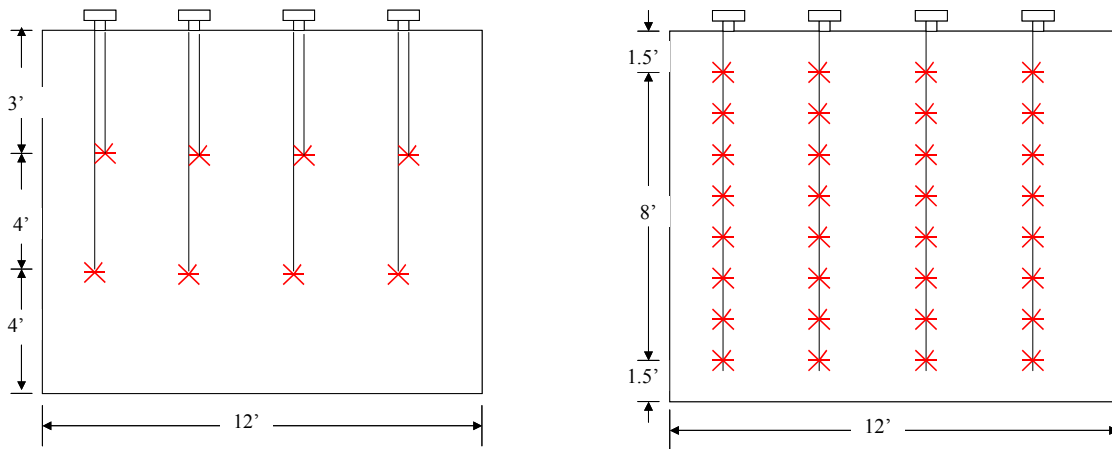
Under a cooperative agreement from the Department of Energy National Energy Technology Laboratory (DOE/NETL), ADA-ES is working in partnership with PG&E National Energy Group (NEG), Wisconsin Energy Corp., Alabama Power Company, Ontario Power, TVA, First Energy, Hamon Research-Cottrell, Arch Coal, Kennecott Energy and EPRI on a field test program of sorbent injection technology for mercury control. The test program, which took place at four different sites during 2001 and 2002, is described in detail elsewhere (Durham et al., 2001).

Four full-scale demonstrations were conducted during 2001 and one in 2002 with additional tests proposed for 2003. The first program was completed in the spring of 2001 at the Alabama Power E.C. Gaston Station (Bustard et al. 2002). This unit burns a low-sulfur bituminous coal and uses a hot-side ESP followed by a COHPAC<sup>TM</sup> fabric filter as secondary collector for remaining fly ash and injected carbon. The second program was conducted during the fall of 2001 at the We Energies Pleasant Prairie Power Plant (Starns et al., 2002). This unit burns a subbituminous Powder River Basin (PRB) coal and uses an ESP to collect the carbon and fly ash. The third program was completed in the summer of 2002 at PG&E National Energy Group's Brayton Point Station (Durham et al., 2002). This unit burns low-sulfur bituminous coals and use ESP for particulate control. The fourth program was completed in the fall of 2002 at PG&E National Energy Group's Salem Harbor Station. Salem Harbor fires bituminous coals with an ESP for particulate control and a SNCR system for NO<sub>x</sub> control. EPRI conducted full-scale sorbent injection tests at the Abbott Power Plant. This 11 MW unit a high-sulfur Illinois coal.

## **ACTIVATED CARBON INJECTION EQUIPMENT**

Activated carbon injection equipment used with an ESP is designed to feed from 5 to 20 lb/MMacf. A typical carbon injection system consists of a bulk-storage silo and twin blower/feeder trains each rated at 750 lb/hr. PAC is delivered in bulk pneumatic trucks and loaded into the silo, which is equipped with a bin vent bag filter. From the two discharge legs of the silo, the reagent is metered by variable speed screw feeders into eductors that provide the motive force to carry the reagent to the injection point. Regenerative blowers provide the conveying air. A PLC system is used to control system operation and adjust injection rates. Hard piping carries the reagent from the feeders to distribution manifolds located on the ESP inlet duct, feeding the injection probes. Each manifold can supply up to six injectors.

Figure 1 shows two injection lance and nozzle arrays tested at Brayton Point. Tests were conducted to determine if the increased number of nozzles in the second array improved distribution of the sorbent resulting in improved mercury capture. Tests were also conducted to document the effect of co-current and counter-current injection. The results indicated that both lance configurations provided essentially comparable distribution of the sorbent resulting in reductions in mercury emissions by up to 90%.



**Figure 1. Distribution Lance Arrays Tested at the Brayton Point Station**

## **DESIGN AND OPERATING CONSIDERATIONS FOR ACTIVATED CARBON INJECTION UPSTREAM OF ESPS**

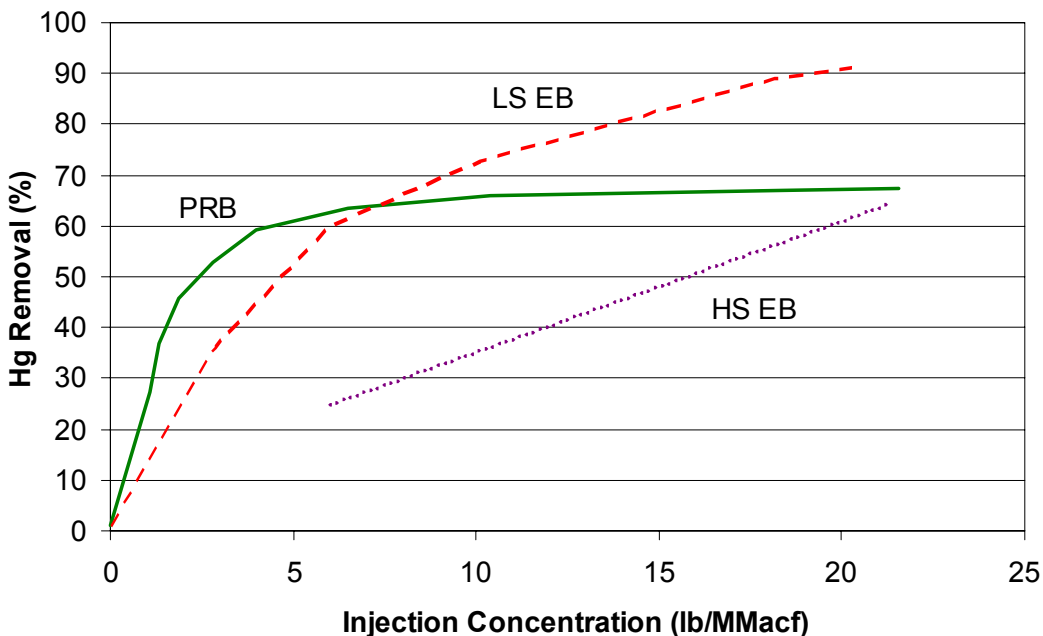
Figure 2 presents full-scale data from Brayton Point, burning a low-sulfur bituminous coal, Pleasant Prairie, burning a Powder River Basin (PRB) coal, and a power plant tested with funding from Illinois Clean Coal Power Initiative and EPRI that burns a high-sulfur bituminous coal. For all cases, mercury removal increases with increased rates of carbon injection. For the PRB coal, mercury removal was limited to 70% across the ESP. A similar limited removal trend was observed during EPRI slipstream tests on sites burning PRB coals (Sjostrom, 2002). This behavior is likely a function of the coal and resulting mercury speciation and flue gas constituents. This limitation is most likely due to the trace amounts (<1 ppm) of HCl available in the gas stream.

Researchers have observed that very low concentrations of HCl in the flue gas is required for standard activated carbon to effectively remove elemental mercury (Sjostrom et al., 2002). The activated carbon sorbent is designed to adsorb contaminants in the flue gas whether they be vapor phase mercury, sulfur dioxides, or gaseous HCl. At Pleasant Prairie, where gaseous HCl concentrations are less than 1ppm, once all of the HCl in the flue gas was adsorbed by the activated carbon, the effectiveness of activated carbon to capture elemental mercury was greatly reduced. This could help explain the apparent ceiling phenomenon observed at Pleasant Prairie where the mercury removal efficiencies did not increase when sorbent injection concentrations increased above 10 lbs/MMacf.

In contrast to the Pleasant Prairie results, at Brayton Point burning the low-sulfur bituminous coal, mercury removal exceeded 90% at the highest carbon injection rate. This coal has a high-chloride level that results in high concentrations of HCl. Theory suggests that oxidized mercury adsorption is not as sensitive to the presence of HCl in the flue gas. At Brayton Point the predominant species of mercury is in the oxidized and there is approximately 150 ppm of HCl present in the flue gas form, whereas at Pleasant Prairie where the majority of vapor phase mercury was in the elemental form. These two factors create an environment in the flue gas for activated carbon to capture both forms of mercury; oxidized and elemental, at all injection concentrations. Thus, as can be seen in Figure 2, increasing activated carbon injection for bituminous coal results in continuing increases in the amount of mercury capture.

The lowest results were obtained on the high-sulfur bituminous coal. This may be due to competition of SO<sub>3</sub> for the active sites on the carbon. Slipstream tests using a packed bed have shown that acid gases such as SO<sub>3</sub> reduce the capacity of the activated carbons for mercury. These full-scale tests confirm that the presence of trace gases can impact the performance of sorbent injection for mercury control.

Ontario Hydro measurements were made at both these locations. Table 1 present results from the PRB test site. These tests show that the overall removal was 73% even though the majority of the mercury was in the elemental form. In fact, the collection efficiency was nearly identical for both elemental and oxidized mercury. This test is typical of results from other sites, showing the capability of powdered activated carbon to capture all forms of mercury from both bituminous and subbituminous coals.



**Figure 2. Comparison of Mercury Removal Performance with PAC**

**Table 1. Speciated Mercury Measured by Ontario Hydro Method, Long-Term Tests at PAC Injection Concentration = 11 lbs/MMacf**

	Particulate ( $\mu\text{g}/\text{dncm}^{\text{a}}$ )	Elemental ( $\mu\text{g}/\text{dncm}^{\text{a}}$ )	Oxidized ( $\mu\text{g}/\text{dncm}^{\text{a}}$ )	Total ( $\mu\text{g}/\text{dncm}^{\text{a}}$ )
ESP Inlet	1.0	14.7	1.7	17.4
ESP Outlet	0	4.3	0.4	4.7
Removal Efficiency (%)	100	70.7	74.5	72.9

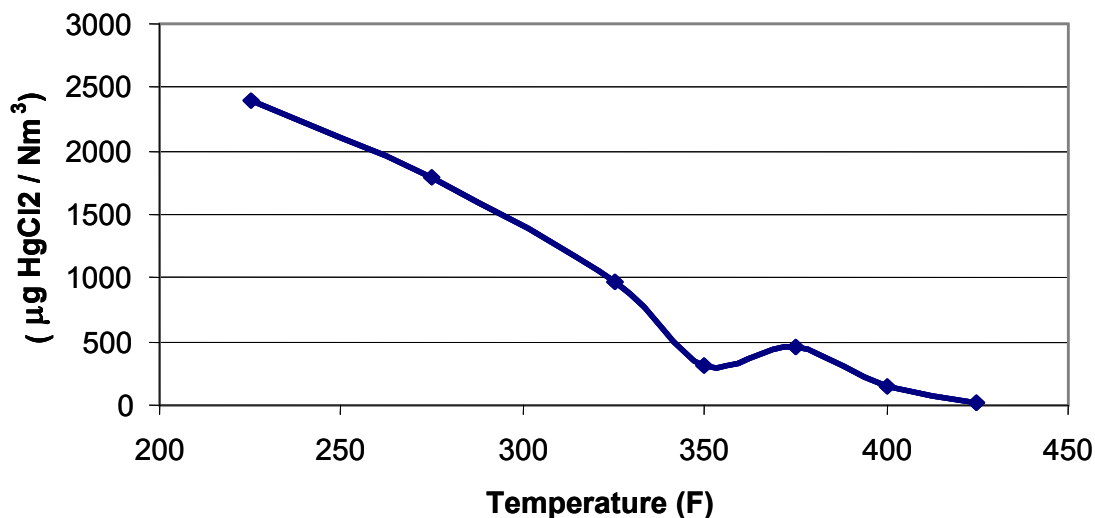
<sup>a</sup> Normal: T = 32°F

### Impact of Gas Temperature on Mercury Removal

Analysis of the ICR data showed that mercury capture across ESPs and fabric filters was strongly dependent upon flue gas temperature and unburned carbon levels. It was believed that this phenomenon was due to the fact that while unburned carbon has very low capacity to hold on to mercury, this capacity significantly increases at lower temperatures. For example decreasing the temperature from 300°F to 250°F could result in a factor of ten increase in capacity. For this reason, plants with high carbon levels and low temperatures showed the highest mercury capture.

The importance of temperature was expected to diminish somewhat when activated carbon was injected to capture mercury. As shown in Figure 3, activated carbon has a very high capacity to hold onto the captured mercury, in excess of a thousand micrograms of mercury per gram of carbon at temperatures below 300 °F. This represents excess capacity as the carbon is only exposed to the flue gas long enough to capture about one hundred micrograms of mercury per gram of carbon. Since much of the capacity of PAC is underutilized, cooling the gas to enhance the carbon to even higher capacity would be wasted and should not result in better performance.

### Equilibrium Adsorption Capacity - Darco FGD

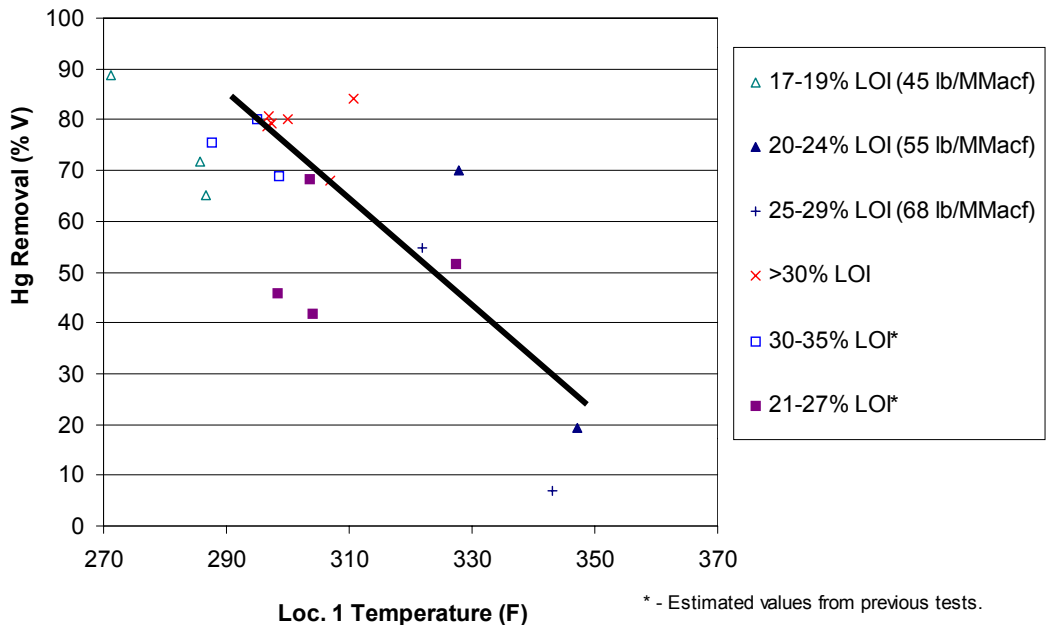


**Figure 3. Sorbent Adsorption Capacity vs. Temperature**

The NETL full-scale field tests provided the means to evaluate the role of temperature in mercury removal. A spray cooling system was installed and operated during the Pleasant Prairie tests. The equipment was installed upstream of carbon injection and provided the capabilities of cooling the gas by up to 50 °F. Mercury measurements were made while injecting activated carbon at the normal operating temperature of 300 °F and with the spray cooling system operating to cool the gas to 250 °F. There was no impact on mercury removal with activated carbon from spray cooling. As expected, since the sorbents had a significant amount of excess capacity, increases in capacity at the lower temperature did not result in a change in overall mercury removal.

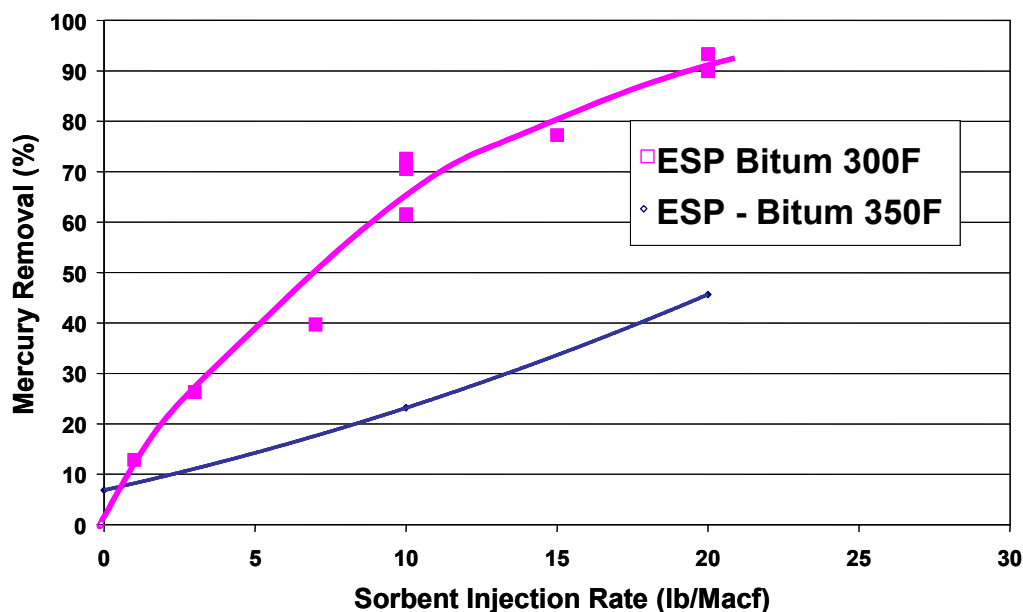
There was also interest in the impact of higher operating temperatures on both native mercury removal and the performance of activated carbon. At the Salem Harbor Station, placing the steam coils in service could increase temperature by up to 50°F. Under normal operating conditions, ESP inlet temperatures averaged approximately 300°F. Placing the steam coils in service, the average ESP inlet temperature increased to 350°F. These tests were important because the ash produced at Salem Harbor had very high-unburned carbon levels, in excess of 30%. This resulted in natural mercury removal levels as high as 90%.

During the parametric test series, the steam coils were placed into service while Unit 1 was held steady at full load (~ 86 MW). ESP inlet temperatures were increased from 300°F to 350°F. The data plotted in Figure 4 show that without injecting activated carbon, the mercury removal by the unburned carbon was extremely sensitive to the gas temperature. For all operating conditions, increasing the flue gas temperature decreased the overall removal efficiency for the vapor phase mercury from ~ 90% to the 10-20% range.



**Figure 4. Hg Removal Efficiency vs. Temperature (no Sorbent Injection)**

Temperature can also be important even with activated carbon at very high temperatures. Figure 5 shows a comparison of performance with activated carbon injection at Brayton Point and Salem Harbor. At Brayton Point, removal levels exceeding 90% were achieved with activated carbon at average temperatures of 300 °F. However, at Salem Harbor, at the hotter temperature range of 343-350°F, activated carbon performance was severely impacted and maximum mercury removal efficiency was nominally only 45%. Therefore, some form of cooling may be required for applications where the flue gas temperature exceeds 340°F. Since both of these test sites had predominantly oxidized mercury in the flue gas, it is not known whether the performance of activated carbon on gas streams with predominantly elemental mercury will be as sensitive to temperature. Additional testing on a site burning a Western coal will be required to determine the maximum temperature for effective mercury capture.



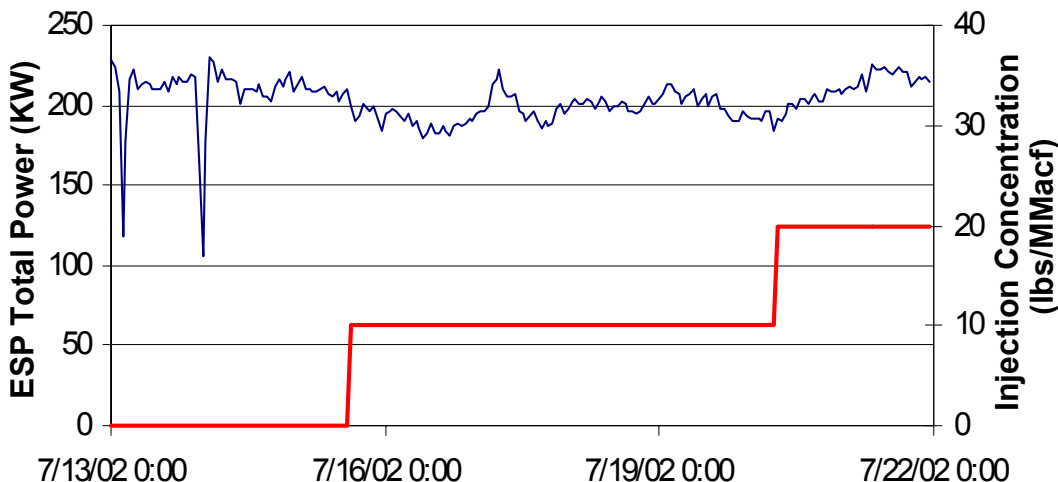
**Figure 5. Temperature Impacts on the Performance of Activated Carbon on Gas Streams Containing Predominantly Oxidized Mercury**

### Impact on ESP Performance

There are two issues related to the impact of activated carbon injection on the downstream ESP. The first is the impact on the bulk properties of the ash collected on the plates. A change in the overall resistivity of the material could result in a significant degradation of the performance of the ESP. However, at all three test sites with ESPs, there was no change observed in the fundamental operation of the ESP. As an example, Figure 6 shows a plot of the ESP power before and during the injection of activated carbon at Brayton Point. Even at injection rates up to 20 lb/MMacf, there was no observable change in ESP operation. Similar results were also experienced at Pleasant Prairie and Salem Harbor.

The second issue is whether the easily reentrainable carbon can be effectively captured in the ESP. Measurements of both particulate emissions and opacity were made at all three test sites. These measurements indicated that there was no increase in emissions during any of the test

programs. This would not be unexpected in that the activated carbon represented an increase of only 1-2% in the inlet particulate loading. In addition, the activated carbon had a mass median diameter of 17 micrometers so the particles would not be difficult to capture. One caveat is that all three ESPs were relatively large with specific collection areas in excess of 450 ft<sup>2</sup>/kacfm. Additional testing will be required to document capture in smaller ESPs.

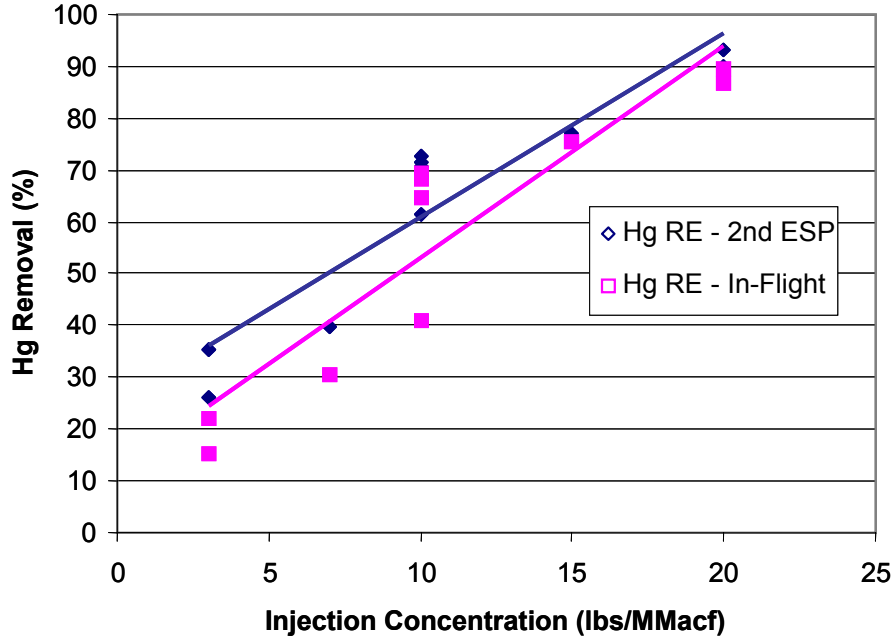


**Figure 6. ESP Power During Injection of Activated Carbon at Brayton Point**

### **Residence Time Required for Mercury Removal**

One key issue to be considered in the retrofit application of activated carbon injection to a large number of plants is whether there will be sufficient residence time available upstream of the ESP for the sorbent to react with the mercury. This question has two components with the first dealing with the amount of time required for the reaction. During the Brayton Point test program, an additional CEM measurement location was added to be able to determine how much of the mercury reacted with the sorbent before entering the ESP. The distance between the sorbent injection location and the CEM location in front of the ESP was approximately 24 feet. This allowed for a residence time of < 0.5 seconds for reaction between the activated carbon particle and the gaseous mercury.

Figure 7 shows a comparison of the removal of mercury as measured across the entire system (i.e. inlet ducting and ESP) with that measured in the ducting alone. As can be seen, it appears from this data that a majority of the capture occurs in-flight upstream of the ESP. The capture of up to 90% of the mercury in-flight is less than a half of a second was much faster than the model predicted. To insure that this was not a measurement artifact, testing of the extraction probe under different conditions is being conducted. It is believed, however, that an artifact could not entirely contribute to the immediate drop in mercury concentration seen upon initiation of carbon injection, and the immediate return when injection was ceased. Similar tests on a stream containing predominantly elemental mercury will be needed to determine the time necessary for acceptable performance.



**Figure 7. Comparison of Mercury Removal Measured “In-Flight” and Across the ESP**

The second component of the residence time issue is the total amount of time available for carbon and mercury interaction in the system. One key point is that the in-duct residence time represents the smallest of the three components of residence time available for a reaction between an injected sorbent and mercury in the flue gas. In addition to the ducting upstream of the ESP, additional residence time is available in the ESP inlet cone and the ESP chamber.

Table 2 shows a comparison of the residence time available in these three areas for the three test sites in this program. As can be seen, the ESP cone provides time for reaction that is two to three times as long as that available in the ducting. Greater time is available in the ESP, but much of this cannot be considered because a significant amount of carbon is removed in the front fields of the ESP. However, because of the apparent fast reaction between the mercury and the activated carbon, and the time available in the ducting and the ESP cone, there should be sufficient time for the process to perform in a large number of plants.

**Table 2. Total Residence Time for Interaction Between Activated Carbon and Mercury**

Plant	In-Duct (Sec.)	ESP Cone (Sec.)	ESP Box (Sec.)
Brayton Point	0.54	1.5	12
Salem Harbor	0.9	1.6	18
Pleasant Prairie	0.75	3.1	14.7

## **Impact of Selective Non-Catalytic Reduction (SNCR)**

Minimal data are available to assess the affect of SNCR on mercury capture, and there is some debate in the industry as to its potential effectiveness. Salem Harbor's Unit 1 utilizes a urea based SNCR system to help reduce NO<sub>x</sub> emissions. With permission from Massachusetts Department of Environmental Protection (MADEP) along with plant personnel, Salem Harbor's Unit 1 operated at full load (~ 86 MW) without the SNCR system upon start-up from a week long outage. This would ensure the system was free of any residual ammonia and help quantify the impacts of SNCR on mercury capture.

During the period in which Unit 1 operated without the SNCR system, vapor phase mercury measurements were made throughout the system with the S-CEM. With the SNCR system out of service, vapor phase mercury removal efficiencies ranged from 80-95%. Mercury removal efficiencies were consistently high throughout this particular test and there was no decrease in mercury removal when SNCR was turned on.

## **PERFORMANCE OF SORBENT INJECTION WITH FABRIC FILTERS IN TOXECON™ CONFIGURATION**

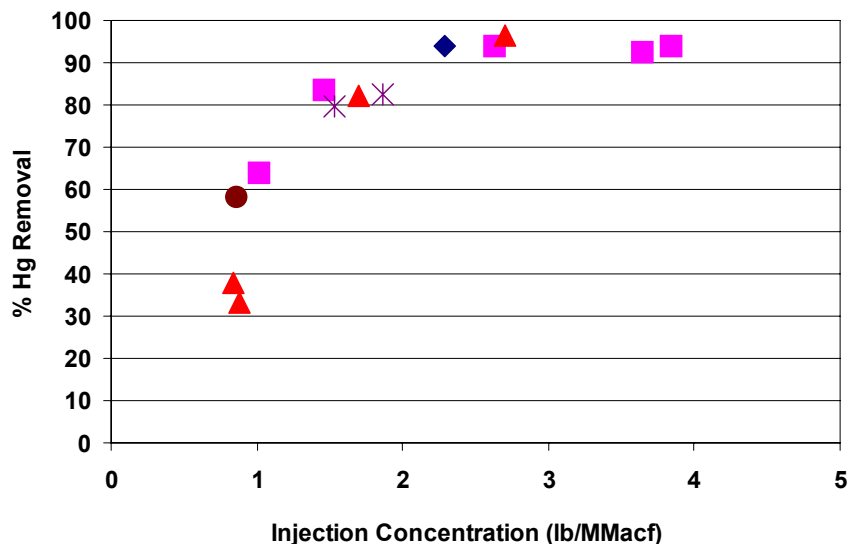
One of the disadvantages of injecting activated carbon is its impact on the salability or reuse of ash. One straightforward, cost-effective approach to reducing mercury emissions without contaminating the fly ash is the use of the EPRI COHPAC™ (COHPAC) and TOXECON™ (TOXECON) processes that are currently commercially available. COHPAC is an EPRI patented concept that places a high air-to-cloth ratio baghouse downstream of an existing ESP to improve overall particulate collection efficiency. The process becomes TOXECON when a sorbent such as activated carbon is injected upstream of the COHPAC baghouse located downstream of an ESP. With this configuration, the ash is collected upstream of the carbon injection and remains acceptable for sale. The downstream baghouse provides an effective control device for the activated carbon resulting in high levels of mercury control at relatively low sorbent injection rates.

### **COHPAC Short-Term Filter Field Tests, 2001**

Short-term full-scale carbon injection tests were conducted at Alabama Power's Plant Gaston Unit 3B COHPAC baghouse in spring 2001 (Bustard, 2002). A summary of the parametric test results, Figure 8, shows a rapid increase in mercury removal, up to 95%, as carbon injection concentration increases.

One important consideration in the COHPAC configuration is that carbon represents a significant increase in the particle loading to the baghouse. Because of the strong relationship between pressure drop and particle loading, carbon injection at Gaston showed a linear increase in cleaning frequency with increased carbon injection rates. At this site (with a rotating arm pulse jet type of filter) a pulse cleaning frequency of 1.5 p/b/h was considered to be the highest acceptable rate without significantly impacting bag life.

During a ten-day test period, carbon was injected continuously 24 hours. Based on results from the parametric tests, injection rate was determined taking into consideration both mercury removal and the projected increase in COHPAC cleaning frequency. An injection concentration of 1.5 lbs/MMacf was chosen to maintain COHPAC cleaning frequency below 1.5 p/b/h.



**Figure 8. Parametric Test Results Showing Mercury Removal Trend with Activated Carbon Injection. Testing Conducted at Alabama Power’s Plant Gaston, 2001**

Ontario Hydro measurements were conducted near the end of the 10-day test period. As can be seen in Table 3, the activated carbon is effective for both vapor-phase species, even the more difficult to capture elemental mercury.

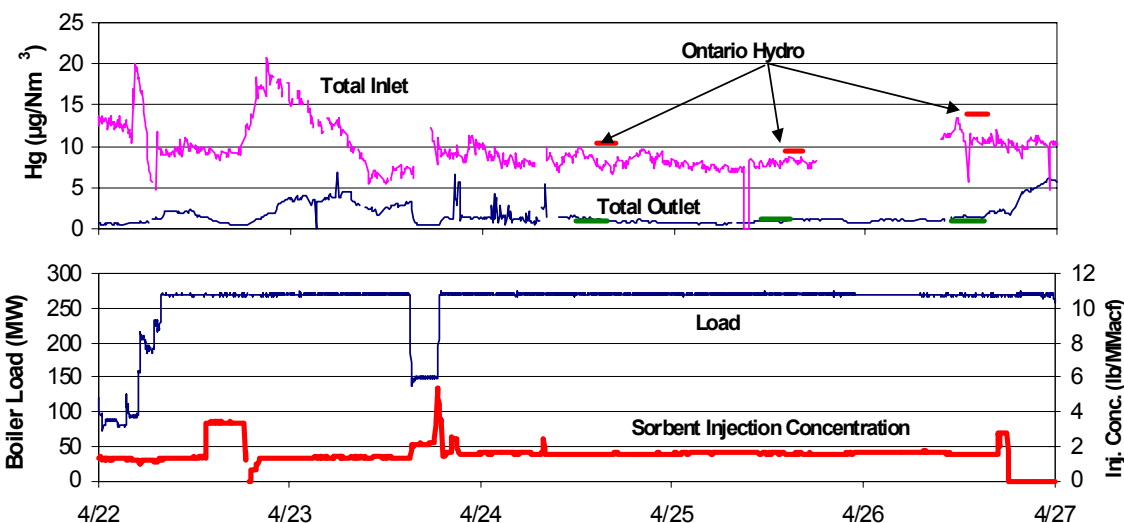
**Table 3. Average Mercury Removal Efficiencies Across COHPAC as Measured with Ontario Hydro Method**

Sampling Location	Particulate ( $\mu\text{g}/\text{dncm}^1$ )	Oxidized ( $\mu\text{g}/\text{dncm}^1$ )	Elemental ( $\mu\text{g}/\text{dncm}^1$ )	Total ( $\mu\text{g}/\text{dncm}^1$ )
COHPAC Inlet	0.2	6.4	4.6	11.2
COHPAC Outlet	0.1	0.9	0.0	1.1
Removal Efficiency (%)	50	86	99	90

<sup>1</sup> Normal: T = 32°F

Figure 9 presents inlet and outlet mercury concentrations as measured by the S-CEMs, boiler load, and activated carbon injection concentration during the last 5 days of the continuous injection test. Periods when Ontario Hydro measurements were made are also identified. The S-CEMs indicate that mercury removal was nominally 87, 90, and 88% during the Ontario Hydro tests. This correlates well with the manual measurements that showed an average mercury

removal of 90%. However, it is important to note that the S-CEMs showed that the average mercury removal efficiency over the multi-day time period was 78%, with variations between 36% to over 90%. This difference is probably due to varying coal and operating conditions over time. Figure 9 also shows that during this 5-day period, inlet mercury concentration varied by nearly a factor of five. Outlet concentrations can be seen to follow the inlet and there are times during these transitional periods when removal efficiencies are fairly low. During the period when the Ontario Hydro tests were run, inlet mercury levels were fairly steady. These tests were conducted under ideal conditions and may show the best-case condition for mercury control at this injection rate.



**Figure 9. Inlet and Outlet COHPAC Mercury Concentrations, Boiler Load and Activated Carbon**

### Long-Term TOXECON Field Test at E. C. Gaston Station

As with all other air pollution control technologies, sorbent-based mercury control is a developing technology that needs to go through a phased approach as it matures to become accepted as commercially viable. The results of the first field test program at Gaston provided a good indication of the capabilities and limitations of the TOXECON technology for controlling mercury. However, the tests were performed for a limited amount of time (< 200 hours of continuous operation) and did not allow for a thorough operational analysis of the use of this technology for mercury control. In the fall of 2002, ADA-ES was selected by the DOE to continue to mature the technology and conduct a long-term test program at the Gaston Station.

This program provides the first opportunity to evaluate activated carbon in the TOXECON configuration for a year of operation. Although new TOXECON units may be designed more conservatively than COHPAC units, important long-term operating data will be obtained through this test. Technical and financial support on this program will be provided by Southern Company and Alabama Power, the EPRI, Allegheny Energy, Arch Coal, Inc., First Energy, Hamon Research-Cottrell, Ontario Power Generation, Duke Power and TVA.

## Test Program

The objective of this program is to conduct a longer-term (approximately one year) demonstration of TOXECON (sorbent injection into COHPAC) for power plant mercury control that will yield data on operability, maintainability, reliability, balance-of-plant impacts, and costs.

The yearlong test program has four major tasks:

1. Design and install an activated carbon injection system capable of continuous operation for up to one year.
2. Install a mercury analyzer capable of long-term, continuous operation. This analyzer is referred to as semi-Continuous Emissions Monitor (S-CEM).
3. Evaluate the long-term performance of carbon injection upstream of COHPAC for mercury control. The first test (up to six months) will be conducted using the existing set of bags. In the second phase (up to six months), a set of new bags made from high permeability fabrics will be tested.
4. Perform short-term tests of alternative sorbents.

Prior to the start of carbon injection, baseline testing will be conducted. This will be followed by optimizations tests to integrate carbon injection with COHPAC. Feedback control may be required in order to vary the injection concentration to maintain an acceptable cleaning frequency. This will be followed by up to 6 months of continuous injection and mercury removal monitoring. This first six-month test will be conducted using the existing 2.7-denier bags.

A key parameter to be evaluated during the test program is fabric used to make the filter bags. The OEM fabric for the four COHPAC baghouses in the U.S. (Gaston Units 2 and 3 and Big Brown Units 1 and 2) was a 2.7 denier Ryton™ (now sold as Torcon) felt. Denier is a measure of the linear density of a fiber and provides an indication of the cross section or thickness of the fibers.

EPRI has invested significant resources to develop a fabric that has inherently higher permeability and therefore lower pressure drop. This fabric is of interest at Gaston because the major impact on COHPAC from earlier short-term sorbent injection testing was an increase in cleaning frequency, or equivalent pressure drop. This high-permeability fabric may reduce the impact of the increased mass loading on pressure drop and allow for either higher injection rates or less performance degradation over time.

A second six-month test is planned with a set of the new, high-perm 7-denier Ryton™ bags. All of the 2.7-denier bags in the B-Side baghouse will be replaced with high-perm bags. Baseline measurements will be made for up to a period of one month to fully understand COHPAC performance with the new, high-perm bags. Carbon injection concentration will again be optimized followed by continuous carbon injection for up to 6 months.

Time is also included to evaluate other mercury control sorbents that may have advantages in cost and/or performance.

### **Baseline Results**

Baseline tests, no activated carbon injection, were conducted in April and May 2003. During these periods, operating performance data of the COHPAC baghouse and mercury at the inlet and outlet of COHPAC were measured under normal operating conditions. Coal and ash samples were also collected during this period.

### **COHPAC Performance**

At Gaston, the primary variable used to track COHPAC performance is cleaning frequency. The cleaning logic is set to begin a clean at a specified pressure drop/drag set-point. During the Phase I testing in 2001, it was possible to add carbon at a rate of 1.5 per Macf and stay below a cleaning frequency of 1.5 p/b/h. During baseline tests in April of 2003, it was learned that there was an increased particle loading to the baghouse due to an unexplained change in the performance of the ESP. As a direct result of the increased loading, the average baseline cleaning frequency was about 1.8 p/b/h, with periods of continuous cleaning at 4.3 p/b/h, even without carbon injection.

Inlet loading to COHPAC is measured with a BHA Particulate Monitor, located upstream of the carbon injection lances. Particulate loading on the 3B side during baseline varied from a low near 0.025 gr/acf to nearly 0.2 gr/acf, with an average loading of 0.054 gr/acf. As would be expected, inlet loading has a direct impact on cleaning frequency and is the cause of the higher baseline cleaning frequency seen in this second round of tests.

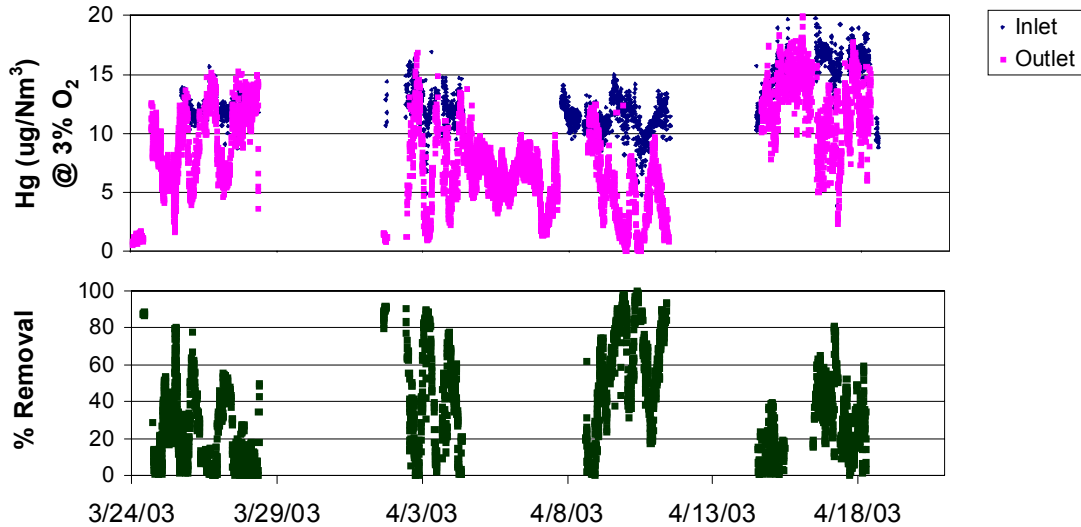
### **Mercury Measurements**

Continuous total vapor-phase mercury was measured at the inlet and outlet of Unit 3B COHPAC with the on-site S-CEM on working days, Monday through Friday. A set of Ontario Hydro measurements for total mercury was also conducted.

Data from the first baseline period are shown in Figure 10. The top graph presents inlet and outlet mercury concentrations; the second graph presents calculated mercury removal efficiency. Figure 10 shows:

- Over the nearly 5-week baseline period, inlet mercury varied between nominally 7 and 18  $\mu\text{g}/\text{Nm}^3$ . This is similar to variations seen during the Phase I tests.
- Outlet mercury varied between nominally 1 and 18  $\mu\text{g}/\text{Nm}^3$ , with mercury removal efficiencies varying between 0 and 90%. The average baseline mercury removal was 26%. This was certainly not what was seen in Phase I, where baseline S-CEM measurements showed very little, if any, mercury removal.

- Periods of high mercury removal can be correlated to periods of high inlet loading and cleaning frequency. An analysis of the particulate matter exiting the ESP shows a significant increase in the carbon content. The combination of the higher particle loading and the increased carbon levels are the most likely cause of the increase in baseline mercury removal from the 2001 tests.

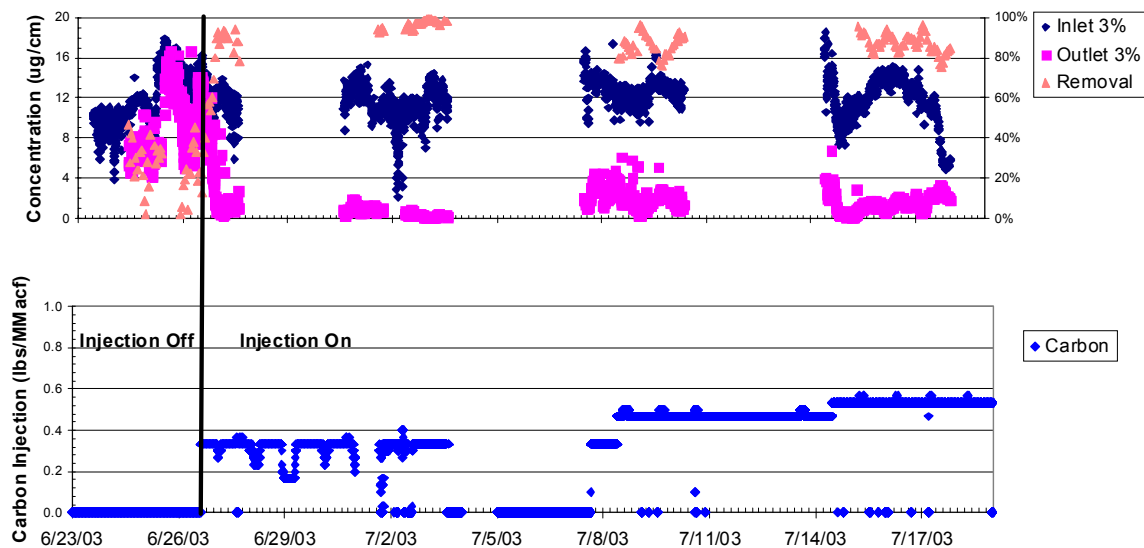


**Figure 10. Baseline Inlet and Outlet Mercury Concentrations and Calculated Mercury Removal Efficiencies Across COHPAC 2003**

### Long-Term Tests

The high baseline cleaning frequency presented a challenge to the test plan because adding carbon to the baghouse would further increase cleaning frequency. To minimize the impact of activated carbon, a new carbon injection feedback control program was installed that sets carbon feedrate based on inlet mass loading. During periods of high inlet loading and naturally high mercury removal, carbon injection is turned off; so overall mercury removal is not significantly impacted during these non-injection periods. An example of this can be seen in Figure 11, which shows inlet and outlet mercury concentration, calculated mercury removal, and carbon injection concentration for a portion of the first six-month test period. During periods when mercury measurements were made, removal efficiency was almost always maintained above 80%.

Nearly four months of continuous injection have been completed. It is expected that operation will continue in this mode until mid-September.



**Figure 11. Mercury Removal Across COHPAC During Long-Term Injection Test with Activated Carbon Injection, 2003**

### **We Energies Presque Isle Power Plant TOXECON Project**

A We Energies proposal was selected for contract negotiations under the DOE Clean Coal Power Initiative (CCPI) to design, install, evaluate and operate an integrated emissions control system for mercury and particulate matter that will treat the flue gases of three 90 MW subbituminous coal-fired units. This will be the nation’s first application of TOXECON technology designed for activated carbon injection and mercury control on a coal-fired utility boiler. It also represents the first COHPAC or TOXECON technology on a unit firing a PRB coal.

Once the contract is finalized, this \$50M project, of which We Energies will provide 50% of the funds, will take place at their Presque Isle Power Plant located in Marquette, Michigan. 0Units 7, 8, and 9 are each 90 MW with individual hot-side ESPs as the primary particulate control device. The proposed project involves controlling the emissions from the three units using a single, TOXECON baghouse island.

Operating and performance data from the Gaston long-term evaluation will be incorporated into the design of the new TOXECON system at Presque Isle, especially performance data from the high-perm bag test.

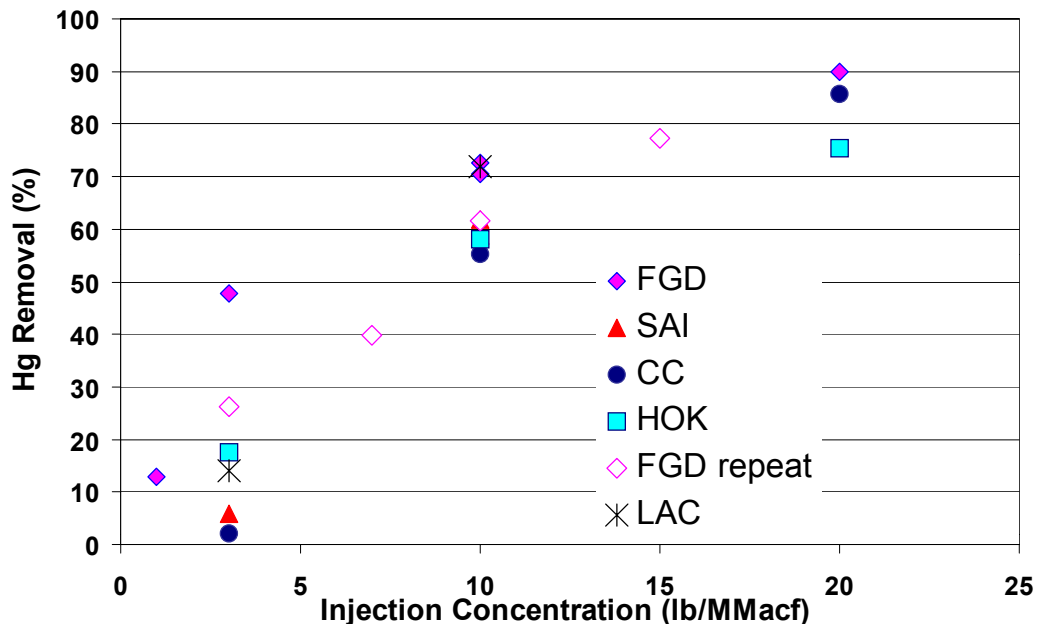
### **SORBENT CHARACTERISTICS**

The most commonly used sorbent for mercury control has been activated carbon. For the past two decades, activated carbon injection upstream of a baghouse has been successfully used for removing mercury from flue gases from municipal and hazardous waste combustors. Activated carbon is carbon that has been “treated” to produce certain properties such as surface area, pore

volume, and pore size. Activated carbon can be manufactured from a variety of sources, (e.g. lignite, peat, coal, wood, etc.). More commonly, steam is used for activation, which requires carbonization at high temperatures in an oxygen-lean environment. As some carbon atoms are vaporized, the desired highly porous activated carbon is produced. Commercially, activated carbons are available in a range of particle sizes, as well as other characteristics that are needed for a specific application.

At Brayton Point, mercury sorbents from other suppliers were evaluated. A set of parametric tests was conducted on each sorbent to determine mercury removal at different injection concentrations. Each condition was tested for a minimum of six hours.

A summary of results from all the parametric tests, five different sorbents, is presented in Figure 12. This graph shows that all sorbents showed the same trends, which included a direct relationship between mercury removal efficiency and sorbent injection concentration. Because of the short duration of the tests, we can only conclude that there are several high capacity activated carbons capable of effective capture of mercury from coal-fired flue gases.



**Figure 12. Performance of Activated Carbons from Different Suppliers at Brayton Point**

Tests have been conducted by EPRI to evaluate the performance of chemically treated sorbents, such as iodated carbon, in an HCl deficient flue gas (Sjostrom, 2002). In this flue gas, the results from the iodine-impregnated carbon injection were significantly better than the results with untreated carbons. This improved performance with a chemically treated sorbent is further indication that the presence of trace amounts of HCl are a critical to the effective performance of untreated activated carbon.

It should be noted that the iodated carbon costs ten times that of standard activated carbons and therefore may be prohibitively expensive. However, these promising results indicate that it may be possible to enhance performance in low HCl environments by chemically modifying the sorbent.

## **MERCURY IN COAL COMBUSTIONS BYPRODUCTS**

Since the purpose of controlling emissions from coal-fired boilers is to reduce potential buildup of mercury compounds in lakes and streams, the stability of the captured mercury in the ash and other coal combustion byproducts (CCBs) is a critical component of the overall control scheme. The ICR program showed that currently approximately 30 tons per year of mercury is contained in CCBs. Pending mercury control regulations could result in an additional 20 to 40 tons per year of mercury in CCBs. Also, there is a concern over the impact of powdered activated carbon in ash being sold for use in concrete.

In the US, approximately 67% of all fly ash produced from utility coal combustion is disposed of in landfills or surface impoundments. The remaining 33% is used for a variety of commercial applications. There are approximately 600 waste disposal sites for CCBs in the US, half are landfills and half are surface impoundments. Note that here CCBs include other streams such as bottom ash and scrubber sludge. A 1999 EPA study estimated that about half of the CCB landfills and a little less than a third of the surface impoundments have some type of liner, the most common type being compacted clay (Senior et al., 2002).

Volatilization of mercury from landfills was estimated by EPA to be small. To date, there has been no evidence based on laboratory leaching studies for leaching of large amounts of mercury from fly ash under landfill conditions. Leaching appears to be the most likely pathway for liberation of mercury from fly ash. Volatilization may be important for certain applications of fly ash as filler in concrete applications. Volatilization is, of course, the primary pathway for mercury if fly ash is used as a raw material in cement kilns. However, volatilization will be complete in this case.

PAC-injection applied to coal-fired boilers will result in the fly ash being mixed with a certain amount of mercury-containing sorbent. This material will be sent to land disposal or used in specific applications (assuming that the presence of the sorbent is compatible with the application). Since the mercury on the spent sorbent may be present in a different form than on fly ash, it is necessary to consider what might be the most likely routes for release of mercury in sorbent-fly ash mixtures and how sorbent-containing coal utilization byproducts (CUBs) should be tested.

Senior et al. (2002) evaluated samples of ash with PAC from two ADA-ES field demonstration programs. The Gaston sample (the product of a bituminous coal) had a high LOI and mercury content, in spite of the low sorbent injection rate, because most of the ash was removed upstream of the COHPAC baghouse by a hot-side ESP. Thus the sample had a relatively high proportion of sorbent. The Pleasant Prairie sample (the product of a subbituminous coal) had a low LOI and mercury content. Sorbent was injected upstream of an ESP and was combined with the full ash

stream. The LOI and mercury content were much lower than the Gaston sample. Little or no detectable Hg leached by ASTM water leach, TCLP, SGLP (including 30- and 60-day leaching), sulfuric acid leach (bituminous ash). Samples were also analyzed by CONSOL as part of a DOE program. They also found no leaching of mercury from PAC (Withum et al., 2002).

Although the ash with PAC appears to be highly stable, initial testing with a PRB ash determined that the presence of even trace amounts of activated carbon in the ash rendered the material unacceptable for use in concrete. Even though the Pleasant Prairie (PRB) ash conformed to the ASTM C-618 standard for Class C fly ash, it did not pass the Foam Index test that is also required for sale of this ash for use in concrete formulation. These are field tests used to determine the amount of Air Entrainment Additives needed to meet freeze thaw requirements. This means that with PAC injection, the plant would not only lose revenues from ash sales, it would incur additional expenses to land fill the material.

## CONCLUSIONS

The power industry in the US is faced with meeting new regulations to reduce the emissions of mercury compounds for coal-fired plants. These regulations are directed at the existing fleet of nearly 1100 existing boilers. A reliable retrofit technology is needed for these plants that minimizes the amount of new capital equipment while providing continued flexibility in fuel selection.

Recent full-scale field tests have proven the effectiveness of activated carbon injection for reducing mercury emissions. This technology is ideally suited for use on existing coal-fired boilers as it provides the following advantages:

- Minimal capital cost of equipment (<\$3/kW);
- Can be retrofit with little or no downtime of the operating unit;
- Effective for both bituminous and subbituminous coals;
- Can achieve 90% removal when used with a fabric filter that has been designed properly for carbon injection; and
- It can be integrated to enhance mercury capture with virtually every configuration of air pollution control equipment including ESPs, fabric filters, wet and dry scrubbers.

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