

# **FULL-SCALE EVALUATION OF MERCURY CONTROL BY INJECTING ACTIVATED CARBON UPSTREAM OF ESPS**

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## **ABSTRACT**

Under a cooperative agreement with the Department of Energy National Technology Laboratory (NETL), ADA-ES has conducted a series of tests evaluating the performance of activated carbon injected upstream of electrostatic precipitators (ESPs) for mercury control and the effect of changing operating conditions such as temperature and LOI on natural mercury control. 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 viability and limitations of using activated carbon for mercury control with ESPs. This paper includes 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 importance of temperature and LOI in mercury removal with and without activated carbon injection.

## **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.

## **PROGRAM DESCRIPTION**

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.

## **ESP TEST SITE DESCRIPTION**

### **We Energies Pleasant Prairie Power Plant**

Pleasant Prairie Power Plant is located near Kenosha, Wisconsin. Tests were conducted on ¼ of the 600MW Unit 2 that fires a variety of Powder River Basin, low-sulfur subbituminous coals. The primary particulate control equipment consists of Research-Cottrell weighted wire cold-side ESPs with sulfur trioxide (SO<sub>3</sub>) flue gas conditioning. The specific collection area (SCA) is 468 ft<sup>2</sup>/kacfm.

Hopper ash is combined from all four precipitators in the dry ash-pull system. The ash is sold as a cement powder substitute in concrete and is considered a valuable byproduct. Sorbent for mercury control was injected into the ductwork downstream of the SO<sub>3</sub> injection grid. The sorbent had approximately 0.75 seconds of residence time in the duct before entering the ESP. A spray cooling system provided by EnviroCare International was installed upstream of sorbent injection to adjust flue gas temperature.

### **PG&E NEG Brayton Point Site Description**

Brayton Point Station is located in Somerset, Massachusetts. Unit 1 has a tangentially fired boiler rated at 245 MW firing a low sulfur, bituminous coal.

The primary particulate control equipment consists of two cold-side ESPs in series, with an EPRICON flue gas conditioning system that provides SO<sub>3</sub> for fly ash resistivity control. The EPRICON system is not used continuously, but on an as-needed basis. The first ESP (Old ESP) in this particular configuration was designed and manufactured by Koppers. The Koppers ESP has a weighted wire design and a specific collection area (SCA) of 156 ft<sup>2</sup>/1000 acfm. The second ESP (New ESP) in the series configuration was designed and manufactured by Research-Cottrell. The second ESP has a rigid electrode design and an SCA of 403 ft<sup>2</sup>/1000 acfm. Total

SCA for the unit is 559 ft<sup>2</sup>/1000 acfm. The precipitator inlet gas temperature is nominally about 280°F at full load.

Hopper ash is combined between both precipitators in the dry ash-pull system. The ash is processed by an on-site carbon separation system, to reduce the carbon content to approximately 2%. This processed ash is sold as base for concrete and is considered a valuable product for the Brayton Point Station. The remainder of the higher carbon ash is a disposable waste.

### **PG&E NEG Salem Harbor Site Description**

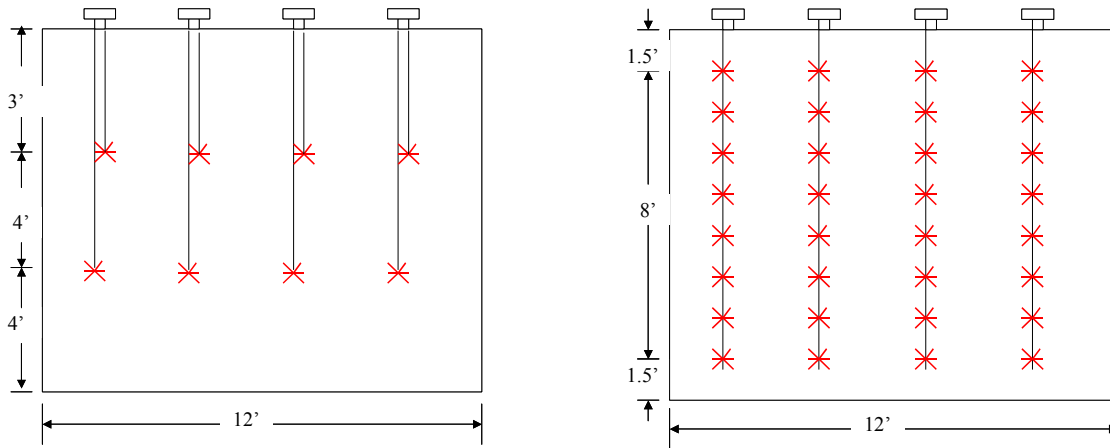
Salem Harbor Station is located in Salem, Massachusetts. Units 1-3 fire and use oil for startup. Unit 1 is a 88 gross MW B&W single-wall-fired unit with twelve DB Riley CCV-90 burners firing a low sulfur, bituminous coal from South America.

The particulate control equipment consists of a two-chamber, cold-side ESP, which provides two separate gas flow paths from the outlet of the tubular air heaters to the ID fan inlets. This Environmental Elements ESP has a rigid electrode design and a specific collection area (SCA) of 474 ft<sup>2</sup>/1000 acfm. The precipitator inlet gas temperature is nominally 295°F at full load. There are eight electrical fields in the direction of flow, and two across. The discharge electrodes are 44.5 feet in length and are spaced 18" apart in the direction of gas flow.

### **ACTIVATED CARBON INJECTION EQUIPMENT**

Activated carbon injection equipment used with an ESP will be 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

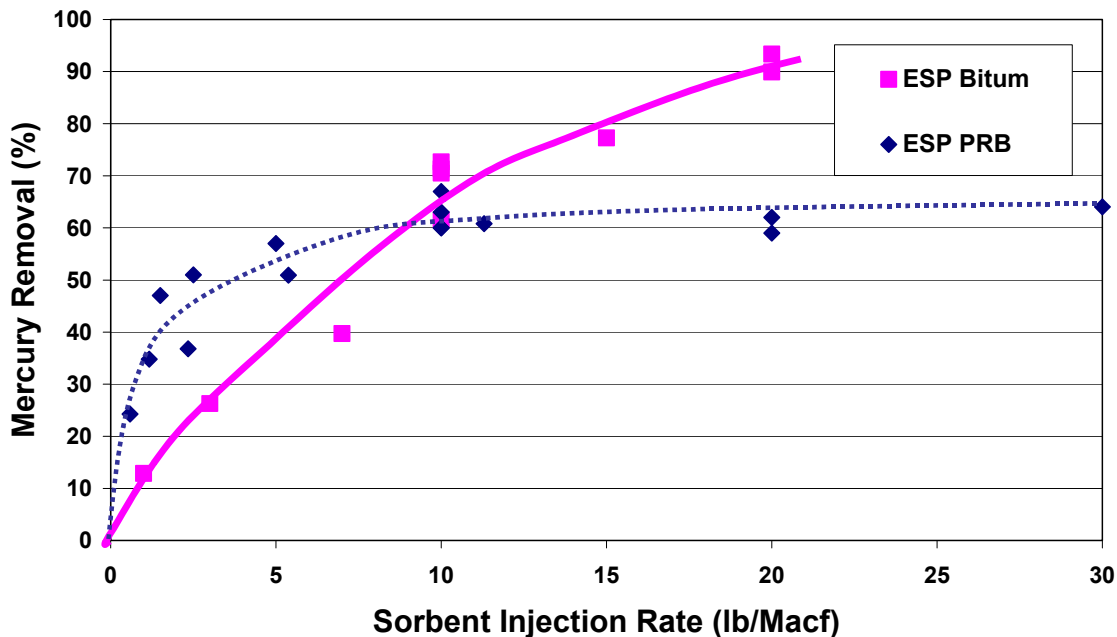
## DESIGN AND OPERATING CONSIDERATIONS FOR ACTIVATED CARBON INJECTION

Figure 2 presents full-scale data from Brayton Point, burning a bituminous coal, and Pleasant Prairie, burning a Powder River Basin (PRB) coal. For both cases, mercury removal increases with increased rates of carbon injection. For the PRB coal, mercury removal was limited to 70% across the ESP. This limitation is most likely due to the trace amounts (<1 ppm) of HCl available in the gas stream. For the bituminous coal, mercury removal exceeded 90% at the highest carbon injection rate. This coal has a high-chloride content that resulted in approximately 150 ppm of HCl.

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.

Theory also 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 form, in contrast to Pleasant Prairie where the majority of vapor phase mercury was in the elemental form, and there is a significant amount of HCl present in the flue gas. 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.

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.** Mercury Removal with Activated Carbon Injection Upstream of an ESP

**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

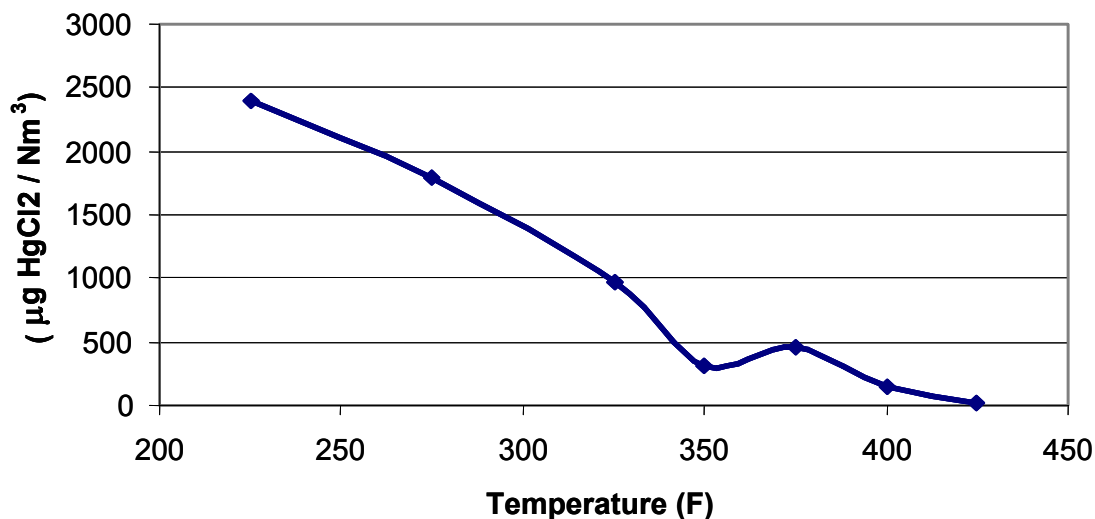
### Impact of Gas Temperature on Mercury Removal

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



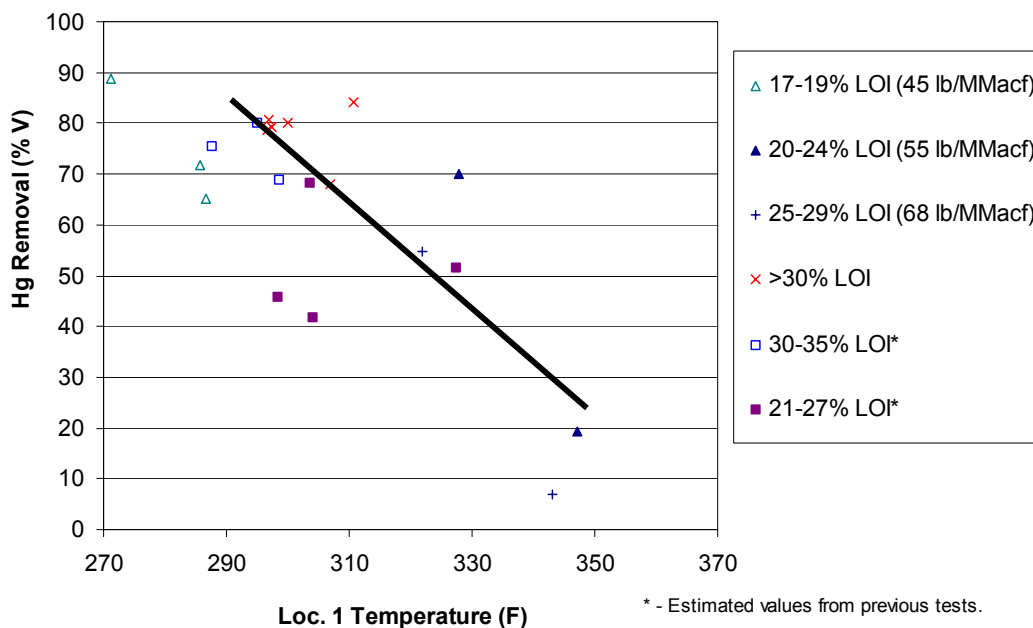
**Figure 3.** Sorbent Adsorption Capacity vs. Temperature

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

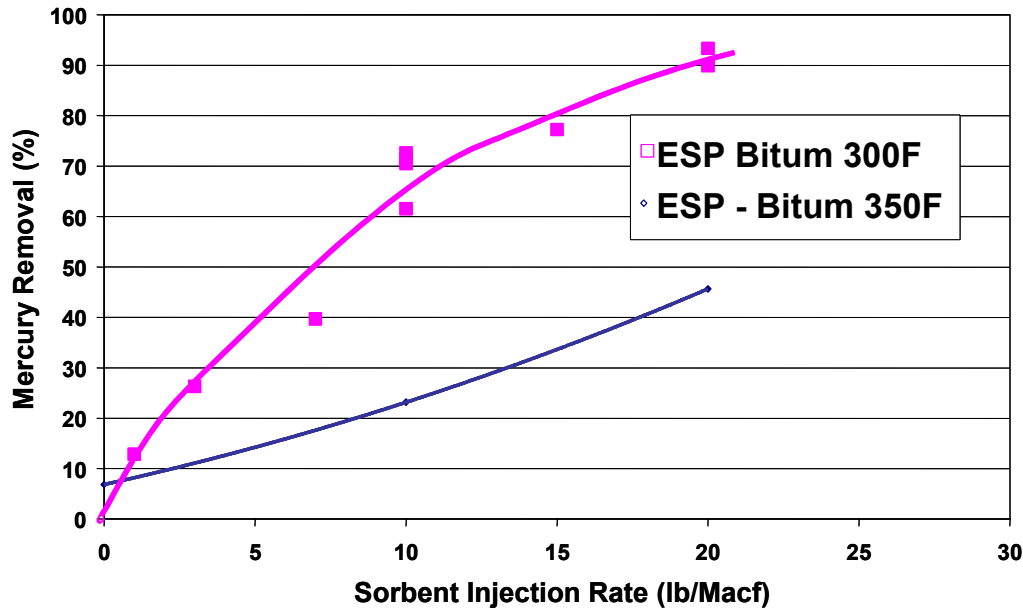
conditions, ESP inlet temperatures averaged approximately 300°F. Placing the steam coils in service, the average ESP inlet temperature increased to 350°F. These tests were important because the ash produced at Salem Harbor had very high unburned carbon levels, in excess of 30%. This resulted in natural 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

### 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 several suppliers were evaluated. The first phase of the sorbent screening process was conducted by URS Corporation using a fixed bed of carbon to measure the sorbents mercury adsorption capacity. The mercury adsorption tests were carried out on a slipstream of flue gas extracted from upstream of the first precipitator, with and without SO<sub>3</sub> injection. Eight coal derived sorbents, two fly ash, one tire derived sorbent, and one zeolite based sorbent were each tested at a temperature of 275°F. The major conclusions from the fixed-bed tests were:

- Carbons are capable of achieving high mercury capacities in Brayton Point Unit 1 flue gas;
- SO<sub>3</sub> appears to inhibit carbon adsorption and with certain sorbents decreased the adsorption capacity to zero. With the activated carbon products, the presence of SO<sub>3</sub> in

the flue gas decreased the adsorption capacity in some cases by a factor of six, however the measured adsorption capacity was still above the threshold capacity (nominally 150 µg/g for an ESP). Therefore performance of these sorbents should not be impacted;

- Only one of the fly ash based sorbents tested showed an adsorption capacity greater than 150 µg/g; and
- The zeolite based sorbent showed a low adsorption capacity in the Brayton Point flue gas, thus, this particular sorbent was not chosen for full-scale testing.

Using the results from the fixed-bed tests as one of the selection criteria, five activated carbon sorbents were selected for the full-scale test. A series of parametric tests was conducted to determine the optimum operating conditions for several levels of mercury control. During this particular series, the primary variables that were tested included injection concentration, sorbent type, and SO<sub>3</sub> flue gas conditioning on/off. Standard testing conditions were with Unit 1 boiler at full load operation and the EPRICON flue gas conditioning system on. Each condition was tested for a minimum of six hours, or until a state of equilibrium had been reached.

A summary of results from all the parametric tests is presented in Figure 6. It is important to emphasize that this graph represents the mercury capture across the second ESP. This is incremental mercury capture that is being measured independent of the baseline mercury capture that is happening across the first ESP. The different symbols represent different sorbents. This graph shows that all sorbents showed the same trends, which included a direct relationship between the Hg removal efficiency and sorbent injection concentration. Because of the short duration of the tests and the difficulty of the mercury measurements, we can only conclude that there are several high capacity activated carbons capable of effective capture of mercury from coal-fired flue gases.

### **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 7 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.

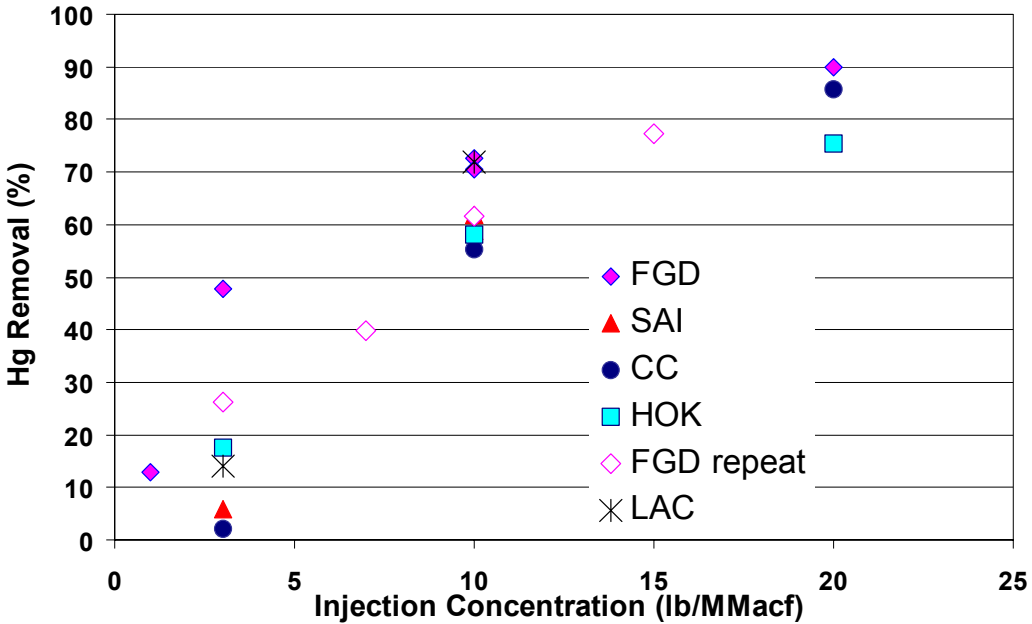


Figure 6. Performance of Activated Carbons from Different Suppliers at Brayton Point

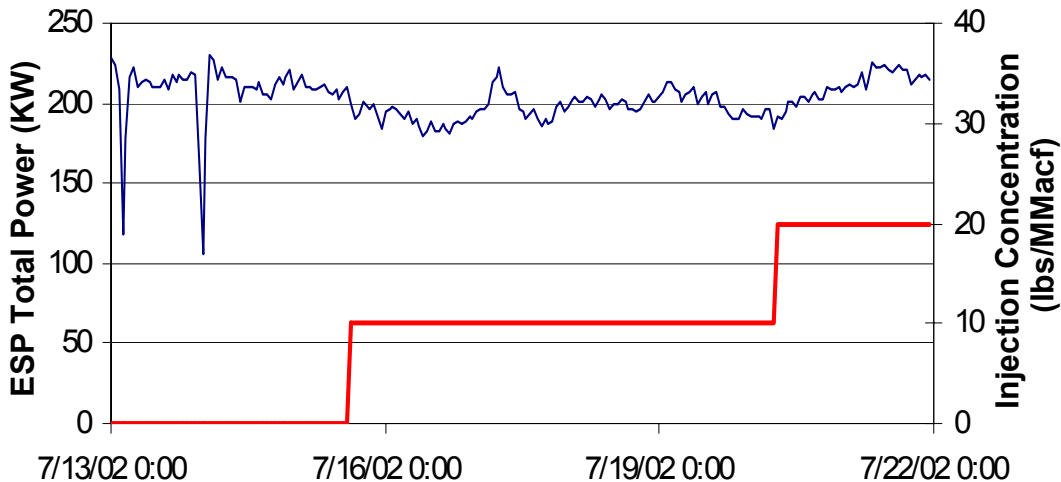


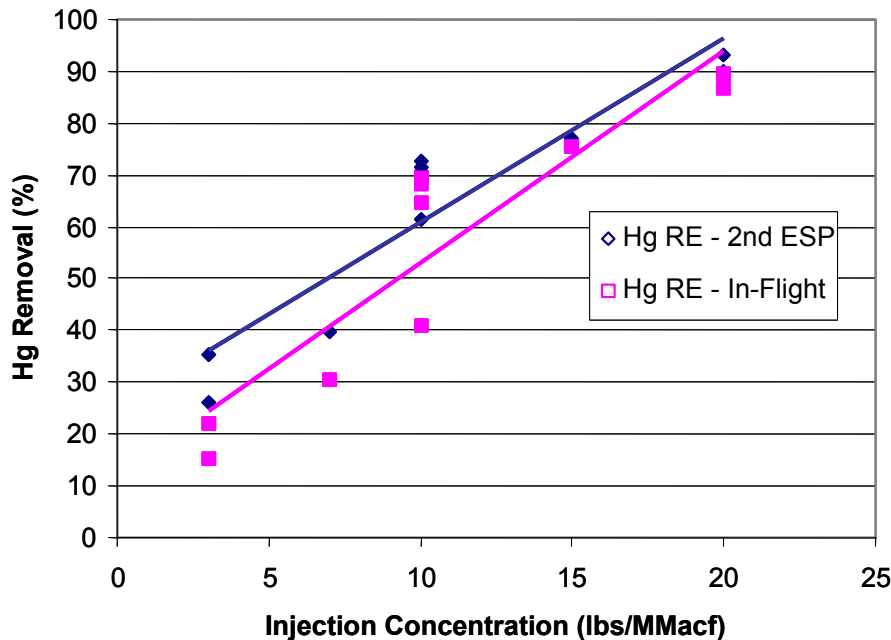
Figure 7. ESP Power During Injection of Activated Carbon at Brayton Point

### 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 8 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, the data was analyzed to determine if the results could be explained by a build up of carbon in the inlet probe. However, it could be seen that the mercury concentration dropped almost immediately upon initiation of carbon injection, and returned when injection was ceased. This confirmed the speed of the reaction with activated carbon, at least for oxidized mercury. Similar tests on a stream containing predominantly elemental mercury will be needed to determine the time necessary for acceptable performance.



**Figure 8.** 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 injection 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 of the removal of the carbon in the front fields of the ESP. However, because of the 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

<b>Plant</b>	<b>In-Duct (Sec.)</b>	<b>ESP Cone (Sec.)</b>	<b>ESP Box (Sec.)</b>
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.

## **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 mercury captured is a critical component of the overall control scheme. This includes the 30 tons/yr that is currently leaving the plant with coal-combustion byproducts (CUBs) as well as the additional 20 to 40 tons/yr that would be added as a result of mercury control regulations. In addition, 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 CUBs in the US, half are landfills and half are surface impoundments. Note that here CUBs include other streams such as bottom ash and scrubber sludge. A 1999 EPA study estimated that about half of the CUB 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 (ACI) 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; 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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