

American Electric Power's Experience Testing Full-Scale Activated Carbon Injection for Mercury Mitigation at Three Coal-Fired Power Plants

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ABSTRACT

In response to the Clean Air Mercury Rule (CAMR), which was issued by the United States Environmental Protection Agency (USEPA) in early 2005, it will be necessary to reduce mercury emissions from coal-fired power plants beginning in 2010. Currently, the most well established retrofit technology specifically designed for capturing mercury in the flue gas of coal-fired power plants is the injection of activated carbon (AC) into the flue gas.

From March 2006 through February 2007 American Electric Power (AEP) conducted testing of activated carbon injection (ACI) at three coal-fired power plants to determine activated carbon's effectiveness for mercury removal. Fuels tested included a blend of Powder River Basin (PRB) and eastern bituminous (EB), 100% Texas Lignite (TxL), and 100% PRB. During the testing at each power plant, multiple AC sorbents were tested parametrically to determine which sorbent was most effective at capturing mercury in the cold-side electrostatic precipitator (ESP), and after parametric tests the most effective sorbent was injected continuously for 30 days at each plant. During each test, continuous mercury monitors (CMMs) and carbon traps (QSEMS) were used to measure flue gas mercury concentrations on a daily basis. Intermittent flue gas testing was also performed using the Ontario-Hydro method to measure mercury concentration and speciation, and EPA Method 29 to measure metal concentrations.

This paper discusses the results of ACI testing at the three power plants in question.

INTRODUCTION

Background

The USEPA issued CAMR on March 15th, 2005, but vacated on February 8th, 2008???? This rule required that the U.S. fleet of coal-fired utility boilers reduce its annual mercury (Hg) emissions from an estimated current emission rate of 48 tons per year to 38 tons per year by 2010 (Phase I), with further reductions to 15 tons per year in 2018 (Phase II). The rule also required that continuous mercury monitors (CMMs) be installed and certified on every utility stack by January 1st, 2009. For the time being, ... under CAIR ... > 90 % mercury removal expected for all utilities

The original intent of CAMR (???, to be actualized) was that Phase I be met through the co-benefit of mercury removal on those plants that are retrofitted with selective catalytic reduction (SCR) and wet flue gas desulfurization (WFGD) technologies. In this pollution control equipment configuration mercury is oxidized across the SCR catalyst, and subsequently absorbed in the WFGD downstream. However, it may be necessary to use mercury specific controls such as ACI as a trim to ensure that allowances allocated under CAMR are met by each operating fleet of power plants.

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Calculations

The amount of mercury that is captured in the ESP during normal operation, or the native capture, is calculated by the following equation:

$$C_N = 100 * \left(1 - \frac{Hg_{out,N}}{Hg_{in}} \right) \quad \text{Equation 1}$$

Where C_N is the native mercury capture expressed as a percent, Hg_{in} is the ESP inlet concentration of mercury, and $Hg_{out,N}$ is the ESP outlet concentration of mercury with no activated carbon injection (where both concentrations are given in $\mu g/m^3$).

The incremental capture ΔC_{INC} , ((or the increase in mercury capture compared to the native capture- but this is something completely different ????????) can be calculated by the following equation:

$$\Delta C_{INC} = 100 * \left\{ \frac{Hg_{out,N} - Hg_{out}}{Hg_{in}} \right\} \quad \text{Equation 2}$$

??????????

$$C_{INC} = 100 * \left(1 - \frac{Hg_{out}}{Hg_{out,N}} \right) \quad \text{Equation 2}$$

????????????

Where Hg_{out} is the ESP outlet concentration of mercury with ACI, and ΔC_{INC} is the incremental capture. The total mercury capture can be calculated by the following equation:

$$C_T = 100 * \left(1 - \frac{Hg_{out}}{Hg_{in}} \right) \quad \text{Equation 3}$$

Where Hg_{out} is the ESP outlet concentration of mercury, and $C_T = C_N + \Delta C_{INC}$ is the total mercury capture when activated carbon is being injected.

The incremental capture ΔC_{INC} of mercury is important for economic analysis to calculate a cost per pound of Hg removed (since there is currently no defined cost associated with native

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capture). However, both the total and native capture can fluctuate, thus the total removal is important for fleet emission calculations.

For the purposes of this report, the total mercury capture across the ESP is used as the percent removal, since this is the amount of mercury that is removed from the flue gas stream from the fuel to the stack. As the EPA rule considers only the amount of mercury exiting the stack, the primary focus of this report is the total capture, and not the increase over the native capture. The total capture is the only necessary calculation to predict the total mercury emissions from the plant, given knowledge of the fuel mercury content.

When considering the removal of metals across the ESP, the relative deviation is used to compare results from the ACI condition to baseline results. The relative deviation is calculated as shown in Eq. 3.

$$RD(\%) = 100 * \left(\frac{R_{ACI} - R_B}{R_{ACI} + R_B} \right) \quad \text{Equation 4}$$

Where R_{ACI} is the percentage removal of the metal in question while injecting activated carbon, R_B is the baseline percentage removal of the same metal, and RD is the relative deviation expressed as a percentage.

Equation 4 must be corrected. As it is, it makes no sense; besides: RD(%) is always 100 % = 1.

I would propose to apply the same mode of subscripts as you started with in the equations 1 to 3.

My proposal:

RT as the removal rate of the metal in case of ACI.

RN as the removal rate of the metal in case of baseline (no ACI).

Thus an equation 4 which might make sense could be

$$RD(\%) = 100 \{ (RT - RN) / RN \}$$

"Relative Deviation" is a big word, seems to be "science", but isn't. Why not simply speak of Increment of the Removal Rate as compared with baseline??

Fuel Impacts and Activated Carbon Selection

Mercury occurs naturally in varying amounts in coal, and when coal is combusted mercury is volatilized and is present in a combination of three forms in the flue gas: Particulate (Hg^P), oxidized (Hg^{+2}), or elemental (Hg^0). Hg^P is mercury that is adsorbed onto the surface of a solid particle and collected in the ESP, whereas Hg^0 and Hg^{+2} are present in the vapor phase and may exit the stack unless collected in the ESP or in another collection device. E.g., Hg^{+2} may be collected in the ESP with help of injected activated carbon. Hg^0 isn't easy to collect and may exit the stack anyhow. The fraction of the various forms is known as the speciation of the mercury in the flue gas. The speciation of mercury is determined by the unit configuration and type of pollution control equipment at the particular plant. The speciation is also heavily dependent on the type of fuel burned, and more importantly, on the halogen and sulphur concentration (Cl, Br, S, etc.) in the specific fuel.

Eastern Bituminous (EB) coals, which have relatively high halogen concentrations (as high as 2000 ppm) and low alkalinity, will produce a greater fraction of mercury as Hg^{+2} in the flue gas. PRB coals, which have relatively low halogen concentrations (usually less than 200 ppm) and high alkalinity, typically exhibit much lower fractions of Hg^{+2} as compared to Hg^0 . Calcium can react

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with existing halogens, making even small amounts unavailable for Hg oxidation. TxL fuels typically exhibit low concentrations of halogens, but TxL has a high variability in nearly every constituent of the fuel, including halogen concentration.

When blending fuels, the blend can exhibit characteristics of either fuel type, depending on the ratio of the fuels. Based on the results of Site 1 testing coal blends of EB and PRB that are greater than 15% EB are expected to have sufficient halogen concentrations to behave more like EB coals.

The pore structure of activated carbon is conducive to adsorbing mercury onto the surface. Carbon particles, with adsorbed mercury, are then collected in the particulate control device, thus removing the mercury from the gas stream. However, the presence of halogens is necessary for conditioning of the sorbent such that it is suitable for the capture of Hg species on to the surface of the carbon particle. ((I doubt: As shown by myself, the halogenation of the gaseous Hg⁰ vapor to gaseous Hg₂⁺ is already good for mercury adsorption at PAC: the rest is EERC speculation and phantasy. See the good results with KNX + SAC. But: This hint does not change your ongoing discussion ->)) This makes the combination of fuel type and ACI type very important when considering the amount of mercury that can be removed using ACI.

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The two most common, and commercially proven, forms of activated carbon for mercury capture are standard activated carbon (SAC), and halogenated activated carbon (typically halogenated through the addition of bromine compound, and referred to here as brominated activated carbon, or BAC).

While SAC is effective at capturing Hg in flue gas streams with sufficient halogens, Hg is not efficiently captured with SAC where there is a lack of halogens in the flue gas and the predominant form is Hg⁰. With BAC, it is possible to increase the amount of halogen present, and thus increase the rate of adsorption of Hg onto the surface of the activated carbon. This increase in the halogen concentration is necessary to achieve high capture rates where the halogen concentration is normally low, such as with PRB-fueled plants.

Within this report, SAC1 and BAC1 are products from one company, while BAC2 is produced by a second company.

Sulfur trioxide (SO₃) is known to interfere with activated carbon's ability to capture mercury, as SO₃ competes with mercury to adsorb onto the pore structure of the activated carbon [1]. However, PRB and TxL fuels contain significant amounts of calcium (Ca), which reacts with SO₃ in the flue gas, so that the concentration of SO₃ in the gas phase is extremely low.

BAC is typically 70% more expensive than SAC (50 cents per pound for SAC and 85 cents per pound for BAC were typical industry prices in 2006). Therefore, it is preferable to use SAC where possible (plants with relatively high halogen concentrations in the flue gas), and to use BAC only where the increased amount of halogen is necessary to increase the capture of mercury. A further alternative might be to add a bromine compound as CaBr₂ to the coal (see KNXTM technology of ALSTOM Power) and use only SAC.

Test Methods

For the three tests covered in this report, the Ontario Hydro (OH) Method, carbon trap or QSEMS Method, EPA Method 29, and CMMs were all used to measure mercury in the flue gas.

The Ontario Hydro (OH) Method of mercury testing is conducted by drawing a gas sample through an impinger train. As the gas sample is drawn through the impingers, mercury species are captured separately in their native Hg⁺² and the Hg⁰ forms. The mercury from each impinger is then measured, and the concentration of each species of mercury in the flue gas can be

determined. The OH Method also uses a heated filter, which allows for the capture and measurement of Hg^P.

Mercury measurement via the QSEMS method is achieved by drawing a gas sample through a tube containing iodated granular activated carbon. Mercury adsorbs onto the surface of the carbon in the trap as a known amount of flue gas is drawn through the carbon trap. At each of the plant sites the carbon samples were then analyzed using an Ohio Lumex thermal desorption system that uses Zeeman atomic absorption to analyze Hg. The test method provides a measurement of the total mass of mercury contained in the carbon. Because the volume of flue gas drawn across the trap is measured, the concentration of mercury in the gas can be determined. QSEMS measurement of Hg in flue gas only allows for a measurement of total Hg concentration, and cannot determine the speciation of mercury as with the OH Method. The QSEMS method used is similar to the proposed EPA Appendix K method. The Appendix K is a more rigorous method that requires mercury-spiked carbon sections in the trap. The QSEMS performed at each site was not Appendix K testing.

Mercury measurement using EPA Method 29 is achieved by drawing a gas sample through an impinger train. Method 29 measures multiple metal concentrations in the flue gas, one of which is mercury. Method 29 allows for measurement of particulate and total gas phase mercury, but does not allow measurement of the gas phase speciation of the mercury in the flue gas.

The CMMs used at each site are Nippon mercury monitors, used in conjunction with PS Analytical flue gas conditioners. These monitors are capable of measuring both Hg⁰ and total gas phase mercury, with the difference being Hg⁺². The CMMs do not measure Hg^P.

Opacity Monitoring

While AEP was testing ACI at the three sites, PM testing via EPA Method 5 could not be completed due to the unit configurations (i.e. common stacks, ducts that were too large to be traversed). The only way to determine the effect of the ACI was to monitor the ESP outlet opacity on the units that were tested.

An opacity monitor passes a beam of light across the flue gas, typically in the stack, and measures the percentage loss of light as it passes through the gas. Opacity is often dominated by sub-micron particles, which are well dispersed in the flue gas.

SITE 1

Site Description

Site 1 consists of two 1300 MWn [\(\(sorry: What is qthe meaning of this index n??\)\)](#), supercritical, pulverized coal (PC) units. The two B&W wall-fired boilers are fired with pulverized coal, and typically burn a blend of 85% PRB and 15% EB coals. Each unit is equipped with three vertical shaft Ljungstrom air heaters. The flue gas from the air heaters travels through three separate air heater outlet ducts and into a large chevron, where the flue gas mixes before feeding 8 separate chambers in four ESPs boxes. The ESPs are a Wheelabrator-Frye Incorporation design with a specific collecting area (SCA) of 861 ft²/1000acfm. The layout for unit 2, where all testing was performed, of Site 1 is shown in Fig. 1.

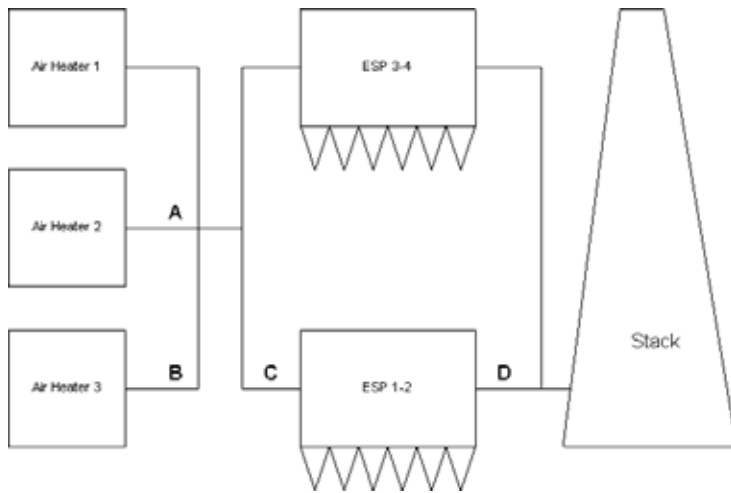


Figure 1: Site 1 Test Layout

Where the locations in Fig. 1 are defined as: A is the middle inlet test location, B is the north inlet test location, C is the ACI location, and D is the outlet test location.

Baseline Test Results

From March 22nd through April 9th 2006, AEP employees performed baseline testing at Site 1 to determine the speciation and native capture of mercury in the flue gas. Although the majority of the fuel burned at Site 1 is PRB coal, the mercury in the flue gas is predominantly found in the form of Hg⁺². This is due to the presence of halogens introduced by the EB portion of the fuel blend. Baseline testing showed that 40% to over 90% of the mercury in the flue gas was of Hg⁺² form at any given time. It was also seen during baseline testing that anywhere from 40-65% of the mercury was removed in the ESP during normal operation.

Parametric Test Results

For the parametric testing at Site 1 one standard activated carbon (SAC1) and two brominated activated carbons (BAC1 and BAC2) were injected at varying rates to determine which carbon was the most effective at removing mercury from the power plant flue gas. Because Site 1 burns a blend of EB and PRB fuels, it was not clear before the test whether there were sufficient halogens present in the flue gas to allow the use of a standard carbon, or whether a brominated sorbent would be necessary to achieve a high percentage removal of mercury across the ESP.

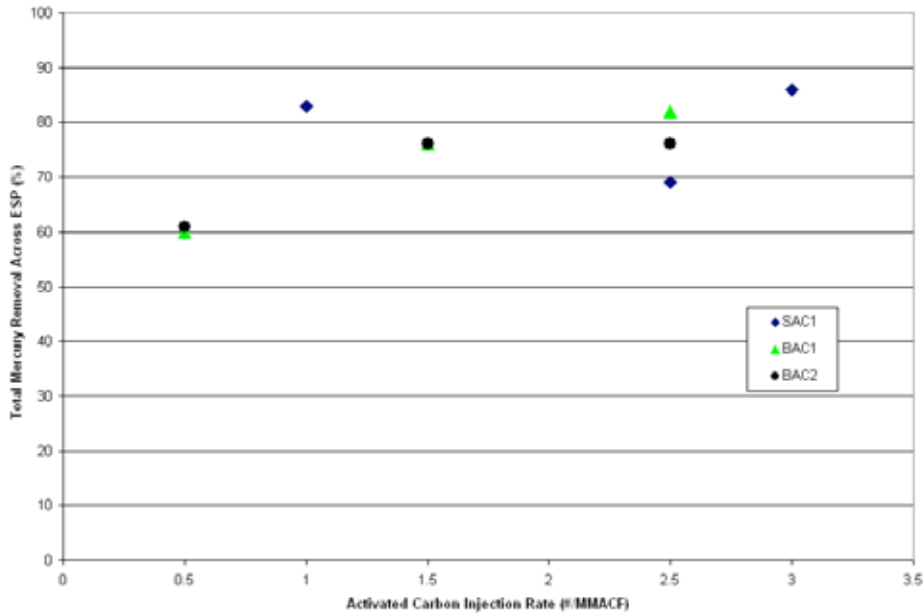


Figure 2: Results form Parametric Testing at Site 1

It should be noted that there were feeder issues when SAC1 was injected at 5 #/MMACF, and during the testing of both types of BAC. It was originally planned to test all carbons at 1, 3, and 5 #/MMACF. However, after the testing it was determined that the feeder had been improperly calibrated, and the actual feed rates represented 0.5, 1.5, and 2.5 #/MMACF (Except during injection rates of 1 and 3 #/MMACF for SAC1). Figure 2 above reflects corrected values, which are representative of actual carbon injection rates during the parametric testing. After correcting the feed rates, it can be seen in Figure 2 that the SAC1 is at least as effective as the BAC1 and BAC2. Since SAC1 cost is significantly less that BAC1 or BAC2, SAC1 was chosen for the long-term test.

Long-Term Test Results

During the long term testing the carbon feed rate was varied between ACI rates from 3 to 8 #/MMACF. Figure 3 shows the mercury removal, as measured by different test methods, over the long-term test.

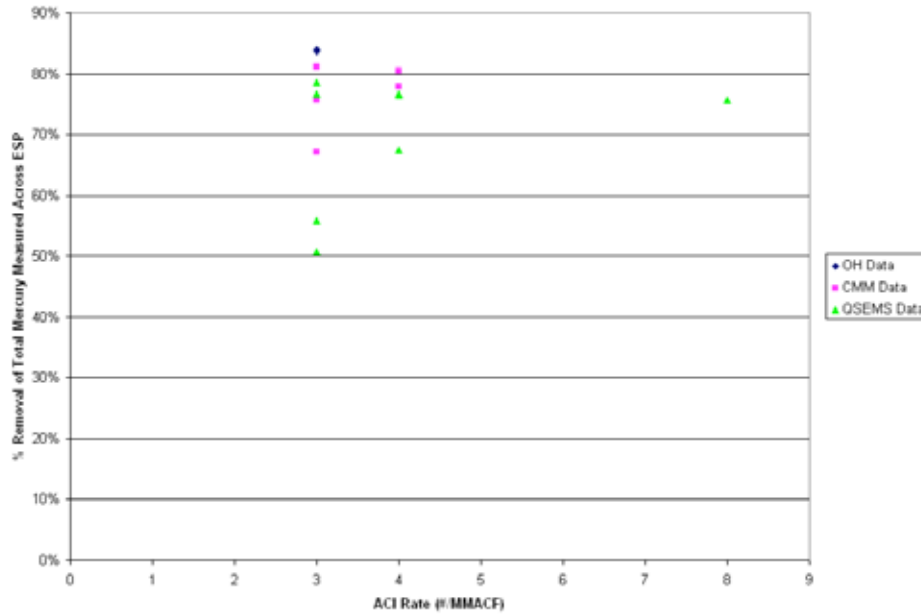


Figure 3: Mercury Removal as a Function of ACI Rate During the Long-Term Testing at Site 1

Figure 3 shows that while there was some variation in the amount of mercury that was removed from the flue gas stream across the ESP, removals of 80% are achievable. It can also be seen that increasing the ACI rate above 3 #/MMACF had little effect on the removal of mercury, indicating that running the system at greater ACI rates than 3#/MMACF does not result in a greater reduction of mercury emissions. (You should explain the low removal rates at 3 #/MMACF, as well. I think SAAC1 is not sufficient in cases with very low halogen content, e.g. more PRB in the blend ?? What about the variations of the blend during this long time test??)

Effect of ACI on Ash Collected in the ESP

Flyash is a byproduct of the combustion process, and is a result of the fact that all coals contain some mineral material. Flyash from Site 1 is either sold for use in concrete or landfilled. As the carbon content of flyash increases by ACI, it becomes less suitable for concrete production because the AC scavenges air bubbles in the mixture of water and ash used for producing concrete. These air bubbles are necessary for the concrete to be able to freeze and thaw without fracturing. (I am not sure that this is totally correct. ACI has a direct influence on the frost stability, and the air bubbles have another ??)

In order to determine the increase in carbon content of the ash due to ACI, ash samples were collected at Site 1. Figure 4 shows the carbon and mercury content in the ash samples as a function of injection rate.

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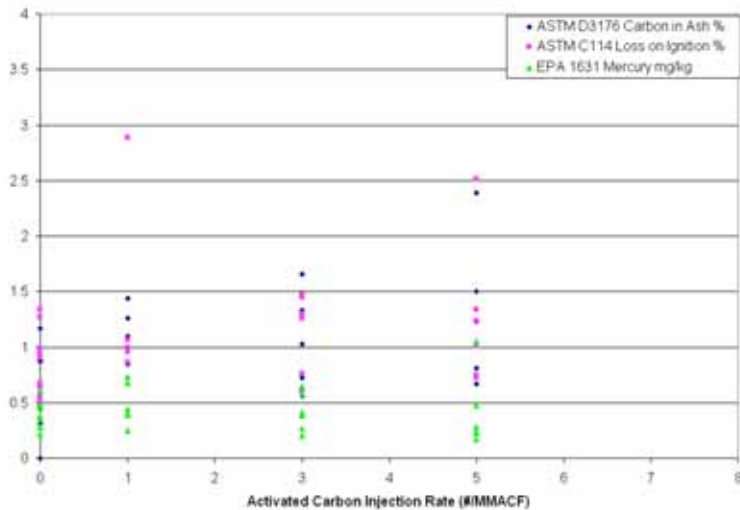


Figure 4: Carbon and Mercury Content of Flyash as a Function of Activated Carbon Injection at Site 1

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As it is, the diagram does not make much sense.

Further: The readability of the diagram must be improved.

Figure 4 shows that while the carbon content of the flyash generally trended upward with increased ACI rate, there was a great deal of variation in the carbon and mercury content of the flyash at all injection rates. This variation can be explained by the lag in ash collection in the ESP and ash collection from the silo where the sample was taken. At Site 1 ash samples cannot be taken directly from the ESP hoppers. As ash is collected on plates in the ESP and rapped off the plates, it fills hoppers below those plates. Periodically, the hoppers are emptied via the ash handling system piping that transports the ash from the ESP hoppers to an ash storage silo. The ash sample is then taken from a sampling line near the ash storage silo. This delay in collection means that each sample, although taken at the same time as a given injection rate was occurring, may not be truly representative of the ash that is being collected in the ESP at that exact time.

((Why don't you show the time-dependency as measured. You might see a here was the ACI change -> there is the effect in mercury))

In order to determine the stability of Hg captured in the collected ash, Toxicity Characteristic Leachate Procedure (TCLP) testing was performed on the ash collected at Site 1. In this testing, ash samples are put in solution to determine if any of the constituents will leach out of the fly ash while in a landfill. The results from the TCLP testing show that, while more mercury is captured during carbon injection and collected in the ESP, the mercury that is captured is not more likely to leach out of the ash. For every TCLP test performed, mercury was below the detectable limit of 0.0001 mg/L.

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The results demonstrate that while more mercury will be collected in the ESP, the increase of mercury in the ash presents no problems for disposal of the material.

Ability of ACI to Capture Metals Other than Mercury

Table 1 shows the results of EPA Method 29 tests for various heavy metals. The EPA Method 29 tests show that many metals are removed at a high rate, whether activated carbon is being injected or not. As is well known in coal and waste combustion, with exception of mercury (Hg) and partially selenium and thallium (Tl), as well, all other heavy metals are desblimating at the fly ash by cool down during boiler passage. Therefor, these metalsd are removed with the fly ash, independent of ACI. There was a slight increase in the removal of Hg, selenium (Se), thallium (Tl), and zinc (Zn). However, other than the increase in removal of Hg, the changes in removal across the ESP are very small, and there is not sufficient data to prove that the differences are statistically significant, and not just variations in the test itself. What can be noted is that there was not a measurable increase in the emission of any heavy metals due to ACI seen during the testing performed at Site 1. ((Anyboddy did expect that? Me not))

Date Description	Parameter	Average ESP Inlet Conc. (ug/dscm)	Average ESP Outlet Conc. (ug/dscm)	Average Removal Rate (%)
05-31-06 to 06-01-06 Baseline No Carbon	P	28546.0	0.0	100.0%
	Mn	1289.2	11.0	99.1%
	Sb	0.0	0.0	BDL
	As	571.0	2.8	99.5%
	Ba	35298.8	202.7	99.4%
	Be	87.1	0.6	99.3%
	Cd	16.0	0.3	98.4%
	Cr	819.9	6.3	99.2%
	Co	364.5	2.0	99.4%
	Cu	3008.9	23.4	99.2%
	Pb	511.7	9.8	98.1%
	Hg	17.5	4.2	76.0%
	Ni	566.4	3.8	99.3%
	Se	354.7	88.4	75.1%
	Ag	0.0	0.4	BDL
	Tl	38.6	6.2	84.0%
Zn	1796.4	57.1	96.8%	
Date Description	Parameter	Average ESP Inlet Conc. (ug/dscm)	Average ESP Outlet Conc. (ug/dscm)	Average Removal Rate (%)
06-07-06 to 06-08-06 Br Carbon 3 lb/Mmacf	P	21727.4	0.0	100.0%
	Mn	959.6	9.6	99.0%
	Sb	0.3	1.2	BDL
	As	513.9	3.4	99.3%
	Ba	26638.6	141.2	99.5%
	Be	78.9	0.6	99.3%
	Cd	16.8	0.3	98.2%
	Cr	769.7	7.6	99.0%
	Co	335.0	2.5	99.3%
	Cu	2245.4	18.5	99.2%
	Pb	434.6	6.6	98.5%
	Hg	9.3	1.5	84.1%
	Ni	516.3	5.7	98.9%
	Se	280.1	49.8	82.2%
	Ag	0.0	0.1	BDL
	Tl	118.4	4.4	96.3%
Zn	2390.7	63.3	97.4%	

Table 1: Results of EPA Method 29 Flue Gas Testing at Site 1

Change ug/dscm to ug/dscm

It should be noted that Table 1 shows a relatively high percentage of baseline mercury capture of mercury, at 76.0%. This removal includes particulate mercury, which was anomalously high during the test (Particulate mercury constituted 82% of the mercury entering the ESP). The Hg^P was removed with an efficiency of 100% (none was detected at the ESP outlet), and due to the high inlet reading, the mercury removal was skewed high. The calculated removal of gas phase mercury during the same test was 0%. However, because the Hg^P concentration was so high during this test the overall removal was calculated as 76.0%. This high level of removal of total mercury across the ESP is not in agreement with the typical 40 to 65% removal of mercury across the ESP for normal operation at Site 1.

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((I have problems: Where did you measure? If behind C (i.e. with ACI, PAV already is injected) it must be like described: Hg₂₊ is already/ at least partially adsorbed in flight, before entering the ESP. ?))

Although Table 1 shows a large removal of mercury for a time when there was no carbon injection ((???), the calculated removals of other metals do not differ greatly whether there is carbon injection or not. Therefore, it is not known whether this high concentration of Hg^P was the result of a flawed test or whether it was truly representative of an anomalous condition.

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Impact of ACI on Stack Opacity

As activated carbon is injected upstream of the ESP, the particulate properties change and the loading to the ESP is increased. Due to this fact it is necessary to closely monitor opacity at the ESP outlet to ensure that the opacity does not increase due to ACI. Each unit at Site 1 is equipped with separate opacity monitors downstream of each set of ESP boxes, so it was possible to monitor the opacity directly downstream of the ESP subjected to ACI.

Figure 5 shows opacity data with no ACI (corresponding to 0 #/MMACF), as well as at various ACI rates during the testing at Site 1.

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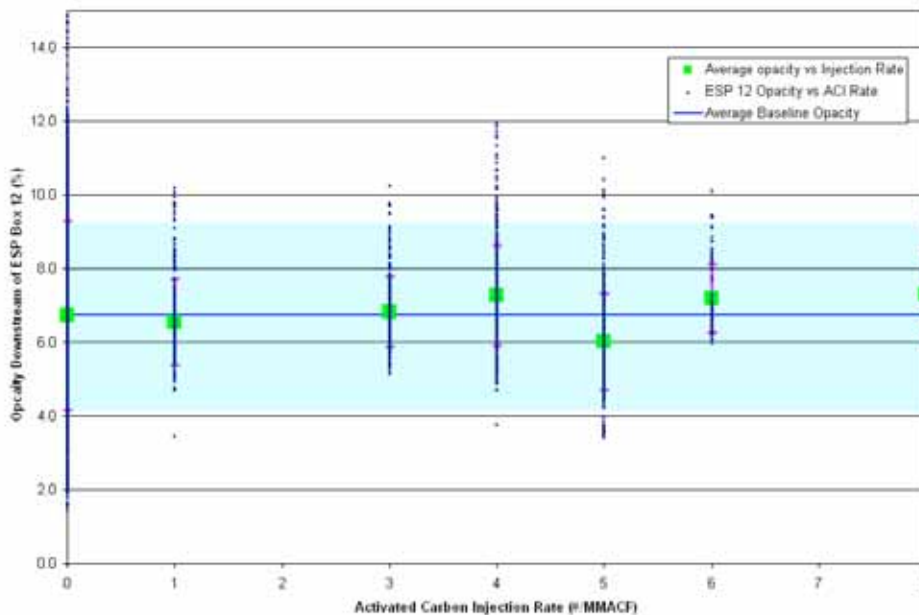


Figure 5: Opacity at the 1-2 ESP Outlet as a Function of ACI Rate at Site 1

Explain what is opacity in %?? ((100 % = darkest night all day long))

The lightly shaded region of the graph indicates the baseline average opacity, plus and minus one standard deviation. ((Explain what means one standard deviation, or better: omit this term)) From the graph, it can be seen that at ACI rates of 1 and 5 #/MMACF the average opacity was lower than the average for baseline, while ACI rates of 3, 4, 6, and 8 #/MMACF had higher average opacities than baseline.

Due to the fact that there was no clear correlation between ACI rate and opacity, it is assumed that ACI had no direct effect on opacity, and that the increase or decrease at any injection rate can be attributed to normal operational variations in the ESP, boiler, or fuel.

Historical data from the transformer/rectifier (T/R) sets in the ESP was analyzed by the ESP specialists within AEP. Their analysis found no evidence of deteriorated ESP performance due to ACI.

SITE 2

Site Description

Site 2 consists of one 650 MWn sub-critical boiler. The B&W Carolina-style boiler is fired with 100% TxL fuel. The unit is equipped with three Rothemühle-type regenerative air heaters, one primary and two secondary. Gas from the air heaters is split into two ducts, which feed the inlets of two cold-side ESP's with a specific collecting area (SCA) of 544 ft²/1000 acfm. Site 2 uses an SO₃ injection system for flue gas conditioning (FGC) at the ESP inlet, and the typical SO₃ injection rate is 4 ppm. The unit is also equipped with a WFGD system. The WFGD system underwent improvements in 2006 to be capable of removing 98% of the SO₂ from the flue gas stream.

The tests in this report were carried out on the ESP 1A (South) inlet and outlet ducts, with one half of the plant's flue gas being treated with activated carbon. Limited QSEMS testing was also performed downstream of the WFGD system associated with the 1A ESP. No testing was performed on the stack at Site 2. Figure 6 shows the test layout for Site 2.

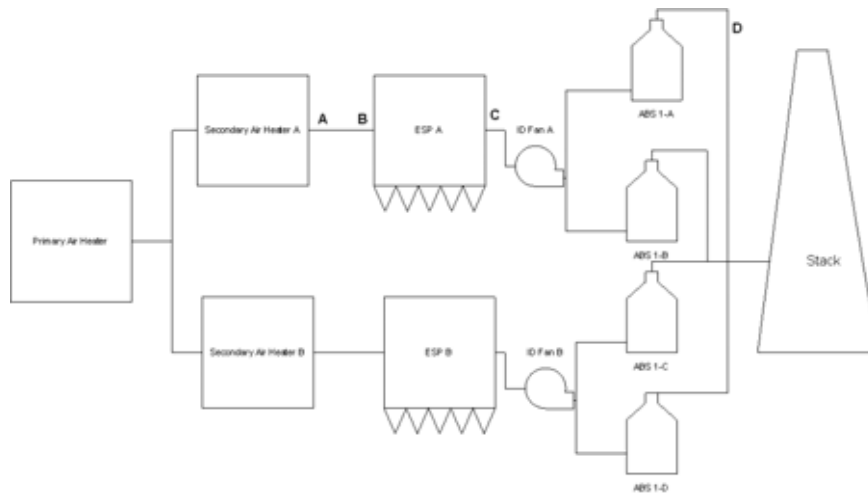


Figure 6: Site 2 Plant Test Layout

Where the locations in Fig. 6 are defined as: A is the inlet test location which is very near the SO₃ injection location for FGC, B is the ACI location, C is the ESP outlet test location, and D is the FGD outlet test location.

Site 2 was specifically targeted for mercury testing because TxL fuel exhibits a relatively high mercury concentration. Due to the high mercury concentration, understanding the effectiveness

of ACI on this type of fuel could offer large mercury reductions by retrofitting a [single](#) plant with an ACI system. [\(\(←> see coming regulation: cap and trade is cancelled\)\)](#)

Baseline Test Results

During normal operation, baseline removal of mercury across the ESP ranged from 11% to 24%, with an average native capture of 18%. This range is due to variability in the fuel that Site 2 receives as well as small variations in the testing methods. Over the course of testing at Site 2 the sulfur content of the fuel varied from 1.5 to 3.0 pounds of sulfur dioxide per million British thermal units (# SO₂/MMBTU) in the flue gas, based on plant historian data. [\(\(Why not mg SO₂/dscm ?? Anybody knows the TxL HHV ??\)\)](#) During that same time period, the calcium content of the ash varied between 7.9% and 12.7% and the chlorine content of the fuel varied from 26 ppm to 355 ppm on a dry basis. Changes in constituents such as calcium, sulfur, and chlorine can lead to slight differences in the flue gas chemistry that can affect the native capture in the ESP.

Parametric Test Results

During the parametric testing at Site 2 two types of activated carbon were tested, SAC1 and BAC1. These carbons were injected at flow rates of 1, 3, and 5 #/MMACF. Parametric testing showed that the most effective carbon was the BAC1. Figure 7 shows the percentage removal of mercury, based on the ACI rate, which was achieved during the parametric testing at Site 2.

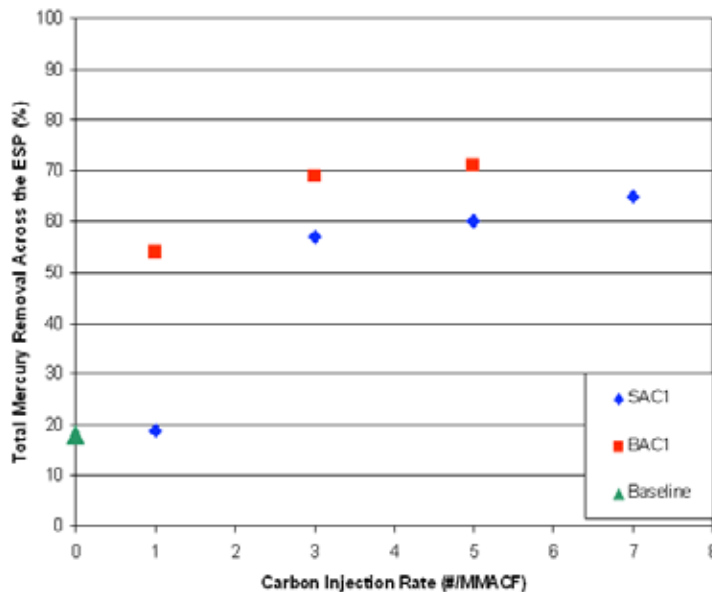


Figure 7: Results from Parametric Testing at Site 2

It should be noted that during the testing at Site 2 it was possible to feed 7 #/MMACF of the SAC, but flow rates that high were not possible with the BAC because the BAC was slightly more dense than the SAC and the blower was not capable of delivering more than 5 #/MMACF of the BAC. However, because the BAC achieved a higher removal of mercury at lower flow rates, the BAC was chosen for the long-term test.

Long-Term Test Results

During the long-term test the ACI rate was varied between 3 and 5 #/MMACF. Figure 8 shows the mercury removal across the ESP as measured by different test methods for the long-term test.

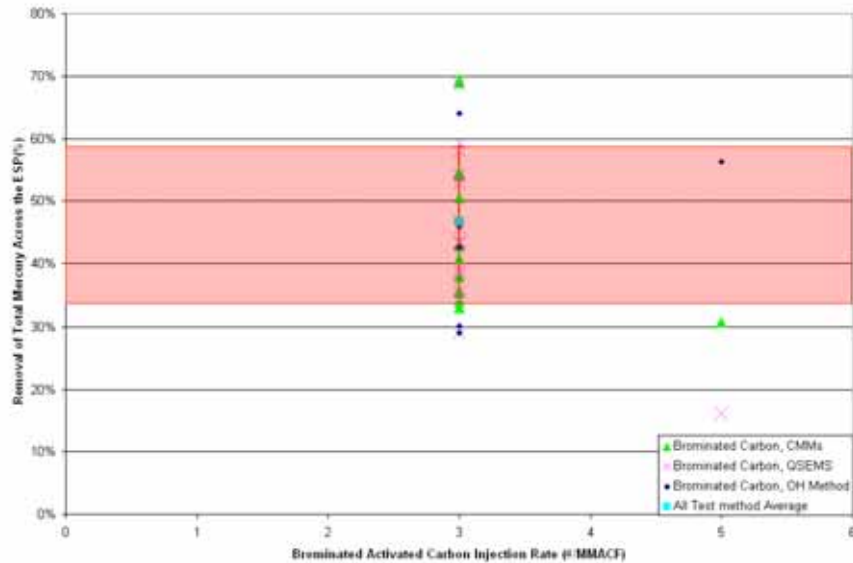


Figure 8: Mercury Removal as a Function of ACI Rate for the Long-Term Test at Site 2

“Explain what the ordinate Removal of Total mercury across the ESP is meanin, i.e. ref. to the equaitons))

Figure 8 shows that there was a great amount of variation in the removal of mercury over the long-term test and that this variation was measured by every test method. A maximum total mercury removal of 69% was achieved, with the average removal obtained with all testing methods found to be 48%. The red-shaded region shows the average removal by all test methods plus and minus one standard deviation.

The data indicates that the highest removals achieved were similar in proportion to the results from the parametric testing at the beginning of the project. However, while removals close to 70% were achieved at ACI rates of 3 #/MMACF, the average removal was closer to 50%. Data analysis was performed to attempt to determine the cause for the fluctuations in removal rate at a constant ACI rate. Figure 9 shows the mercury removal achieved at Site 2 as a function of time.

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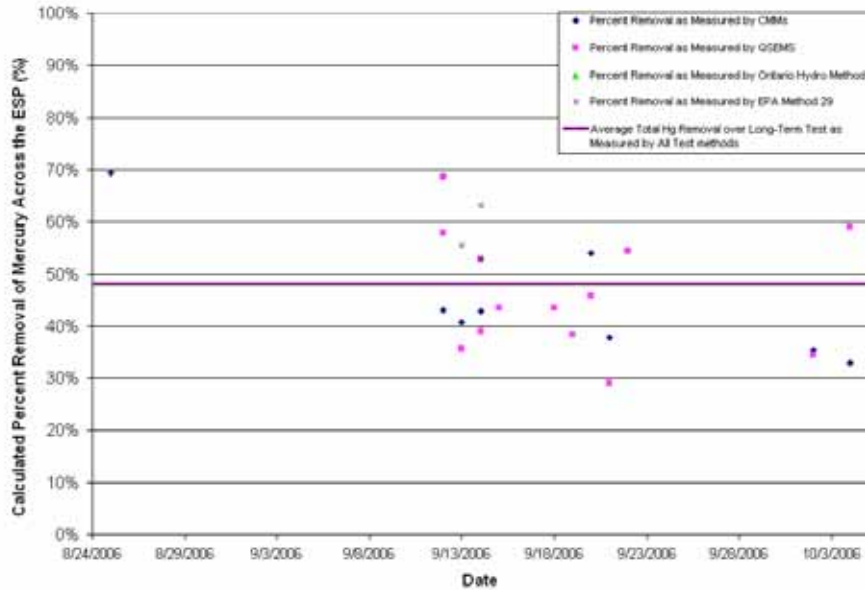


Figure 9: Total Removal of Mercury Across the ESP During the Long-Term Test as a Function of Date at Site 2

The data shown in Fig. 9 applies only to a BAC injection rate of 3#/MMACF, an SO₃ injection rate of 4 ppm, and full load.

Figure 9 shows that removal rates close to 70% were measured at the aforementioned conditions during the parametric testing and at the beginning of the long-term test, but that as the long-term test continued the total removal decreased. Plant operational data was analyzed for the entire test, and a clear correlation between removal rate was not found with ash constituent concentration, fuel constituent concentration, or SO₃ injection rate. Carbon quality is not suspected to be an issue since the removal continued to decline predictably over the course of the test. It is believed that carbon quality would have caused increases and decreases as new shipments arrived, but that a continuous decline in carbon quality over the course of a test would not be likely. There were also no large changes in carbon distribution in the ESP hoppers, which would be an indication of plugged ACI lances. Silo fill indication was also monitored closely, and there was no evidence of problems with the AC feed rate.

The reason for the pronounced decrease in capture of Hg at Site 2 is still being investigated. [\(\(Proposal: Do you have probes of the fired coal? Look at its varying Br- und Cl-content, please\)\)](#)

Those possibilities still being considered are affects of AC on the bulk ash properties, poor control of the SO₃ injection rate, and possible problems with distribution in a very tall and narrow duct with a short residence time.

Effect of ACI on Ash Collected in the ESP

In order to determine the increase in carbon content of the ash due to ACI, ash samples were taken from the ESP hoppers from Site 2. Figure 10 shows the carbon and mercury content in the ash samples as a function of injection rate.

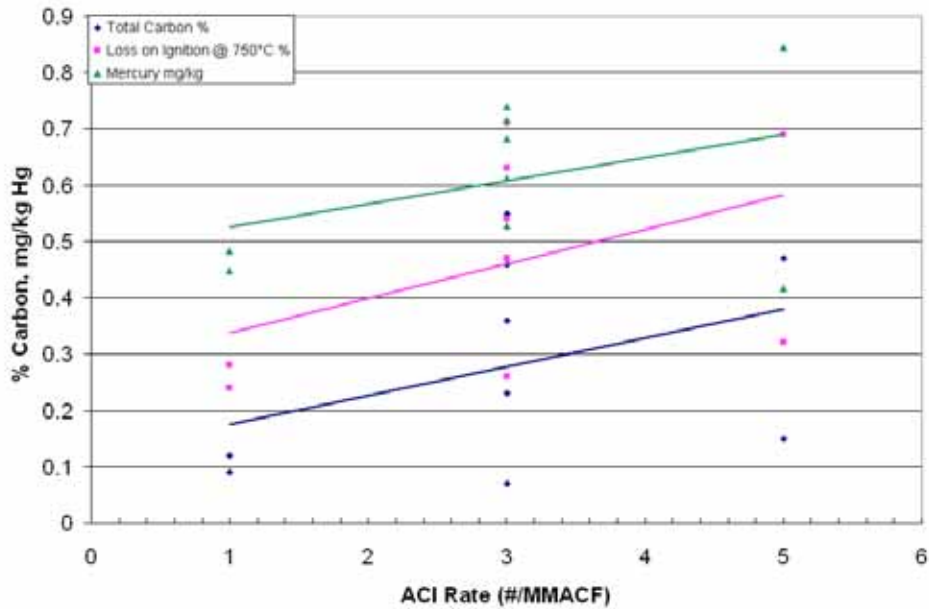


Figure 10: Carbon and Mercury Concentration in Flyash Taken from the A-1 Hopper as a Function of Brominated Activated Carbon Injection at Site 2

Bad readability of Figure 10, should be improved.

Figure 10 shows the carbon in ash (%), the loss on ignition (LOI, %), and the mercury concentration (mg/kg) for all of the ash samples pulled from the A-1 hopper on the ESP. From Fig. 10 it can be clearly seen that as the ACI rate is increased the amount of carbon, LOI, and mercury in the fly ash increases.

Figure 10 demonstrates that the LOI, carbon, and mercury increase as the ACI rate increases for a constant sample point (a specific hopper). However, over the precipitator as a whole it is much more difficult to determine such a relationship. Figure 11 shows the LOI, carbon and mercury concentrations for all of the ash samples taken from the 1 ESP.

((Once again: Please explain, why you are looking at the same time on total carbon and UBC?))

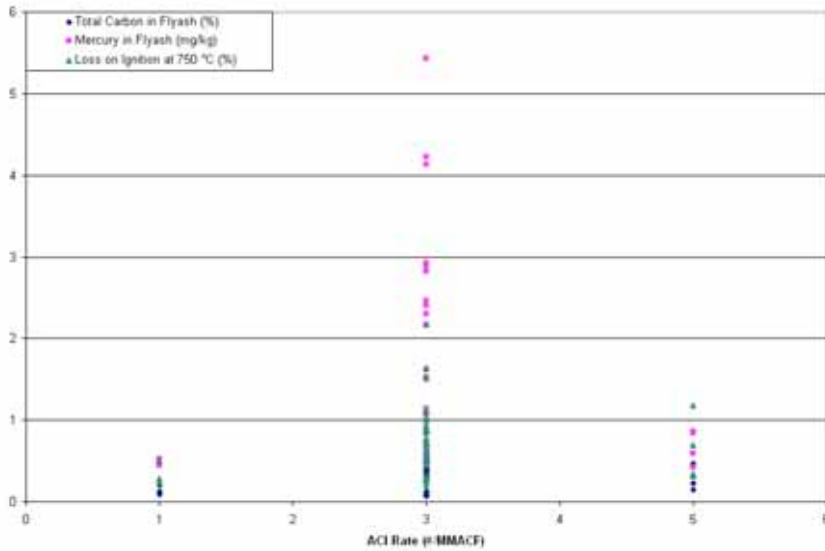


Figure 11: LOI, Carbon and Mercury Data for All Analyzed Flyash at Site 2

Readability must be improved

Figure 11 shows the great amount of variability that arises when all of the precipitator hoppers are taken into account. Although it appears that carbon, LOI, and mercury increase with increasing ACI rate, trying to develop a correlation becomes much more difficult when all data is considered.

When attempting to determine the amount of carbon in ash on average it is better to calculate that value instead of using data that can be highly variable. If flyash samples from every hopper are included it becomes apparent that carbon does not collect uniformly throughout the ESP. It then becomes very difficult to draw a clear conclusion due to the non-uniform addition of carbon to each hopper, although the addition of carbon to the bulk of the flyash should be consistent with a steady ACI rate and a reasonable amount of variability in the ash content of the fuel.

((Did you look into the capture of mercury e.g. by analyzing size fractions with respect to noncarbonaceous and carbon material at their Hg contents? Doing that, you might see that all mercury is on the carbon Further you might see that most of the mercury is at the carbon particle surface, as I have shown in 2002 ...))

Ability of ACI to Capture Metals Other than Mercury

EPA Method 29 Testing was employed during baseline measurement and during carbon injection to measure the amount of metals that are removed in the ESP. Figure 12 shows the removal of particulate and gaseous metals measured during baseline testing with no ACI.

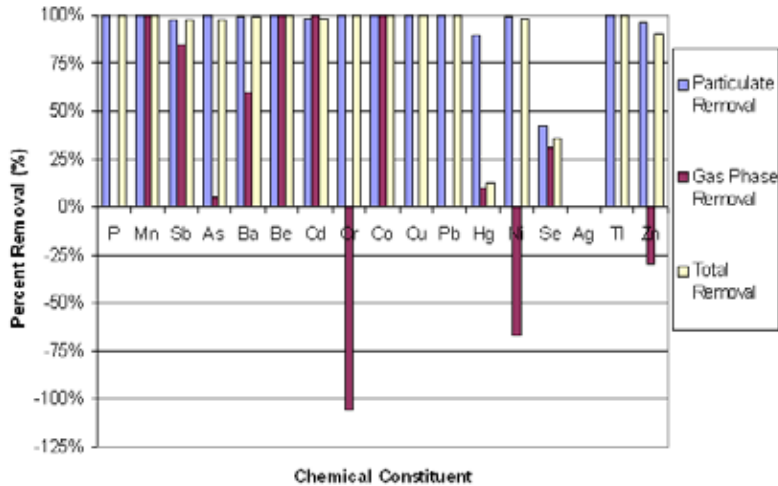


Figure 12: Baseline Removal of Metals Across the ESP at Site 2

From Fig. 12 it can be seen that overall the removal of metals across the ESP was high. In the instances where an increase (shown as a negative removal) in a metal was measured across the ESP, the increase across the ESP is negligible due to very small concentrations of that species. For instance chromium (Cr), nickel (Ni), and zinc (Zn) showed increases across the ESP in the gas phase of 106%, 67%, and 30%, respectively. However, the total removal of those same metals was 99.7%, 98.7%, and 90.4%, respectively. This is due to very low gas phase concentrations, which do not greatly affect the overall removal calculation. And, as gas concentrations become so low, a very small variation from inlet to outlet can seem to produce a negative removal, however, these negative removals shown are expected to be due only to variability in the test method.

((Mention: Heavy metal capture is identical with particle capture, except Hg and partially Se and Tl. Nothing else to be expected))

Figure 13 shows the removal of metals across the ESP measured while injecting 3 #/MMACF BAC into the flue gas.

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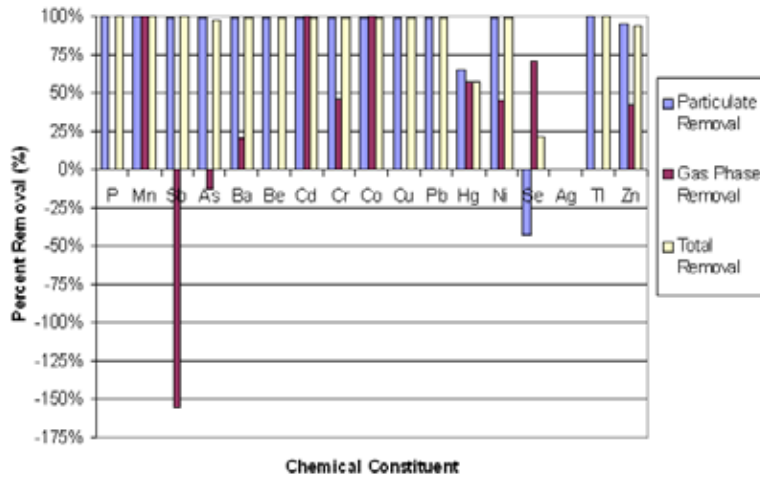


Figure 13: Removal of Metals Across the ESP with an ACI Rate of 3 #/MMACF at Site 2

From Figure 13 it can be seen that, as in Figure 12, some metals showed negative removals across the ESP in the gas phase. As was the case with Figure 12, these apparent increases of gas phase metals across the ESP were very small and had a negligible affect on the overall removal.

Similar to the previous testing performed at Site 1 the majority of metals were removed at very high percentages across the ESP. It is important to note though, that some degradation of the EPA Method 29 samples taken at Site 2 occurred during shipping. The degradation during shipping would affect the mercury results much more than the results of the other metals, since mercury is more volatile than any of the other metals that were measured.

Figure 14 shows the relative deviation of the capture of metals between the baseline and ACI tests.

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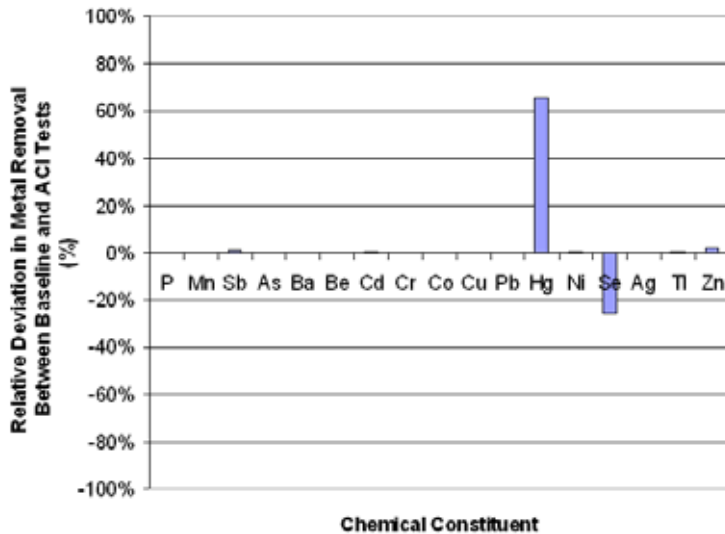


Figure 14: Relative Deviation in Metals Capture Between the Baseline and ACI Tests at Site 2

Please do control the definition of RD in Metal Removal (see my comments to your equations))

Figure 14 shows the relative deviation in the removal of metals in the ESP from the baseline condition to the ACI test. Figure 14 shows that there was only a noticeable difference in the capture of mercury and selenium. ((Must be a problem of "very small values", near or even below detection limit??)). The cause for the decrease in the capture of selenium is not known, and was not seen in the testing at either Site 1 or Site 3.

Impact of ACI on Duct Opacity

As activated carbon is injected upstream of the ESP, the bulk particulate properties change and the loading to the ESP is increased. Due to this fact it is necessary to closely monitor opacity at the ESP outlet to ensure that there is no sign of an increase in opacity due to ACI. Each ESP box at Site 2 is equipped with separate downstream opacity monitors, so it was possible to monitor the opacity directly downstream of the ESP box subjected to ACI.

Figure 15 shows opacity data with no ACI (corresponding to 0 #/MMACF), as well as at various ACI rates during the testing at Site 2.

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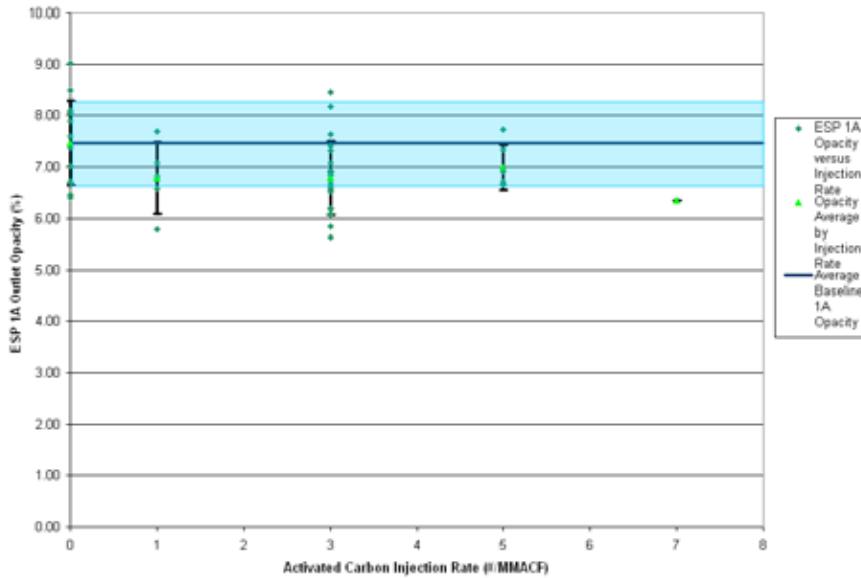


Figure 15: Opacity at the ESP 1-A Outlet as a Function of ACI Rate at Site 2

((Again: Explain what means Opacity %??))

The shaded region of the graph shows the average baseline opacity plus and minus one standard deviation. From Figure 15 it can be seen that the greatest average opacity occurred at an ACI rate of 0 #/MMACF. At ACI rates of 1, 3, 5, and 7 #/MMACF the average opacity was lower than the baseline, indicating that the ACI did not have any adverse impact on plant opacity during the testing at Site 2.

ESP performance data was also monitored by specialists within AEP. The data from the ESP showed that there was no deterioration in performance during the test, indicating that the ACI did not cause any operational issues with the ESP at Site 2.

Effect of SO₃ Injection for Flue Gas Conditioning (FGC) on Mercury Capture

Previous testing both internal and external to AEP has demonstrated that sulfur, and more specifically SO₃, may inhibit activated carbon's ability to adsorb mercury, and thus hinder the capture of mercury across the ESP. It is generally believed that SO₃ competes for pores on the carbon particle's surface, making it less likely that mercury will be captured. Although SO₃ is a byproduct of combustion and is present in flue gas, Site 2 also uses an SO₃ injection system to enhance ESP performance. While this system only injects a few parts per million (ppm) of SO₃ into the flue gas, an attempt was made to quantify the effects of the SO₃ on the ability of ACI to capture mercury within the normal injection range of the FGC system.

On August 24th, 2006 the SO₃ injection rate was reduced from the typical operating value of 4 ppm to 2 ppm, and eventually to 1 ppm to determine the effect on the mercury removal across the ESP. The results of this change in SO₃ injection rate are shown in Fig. 16.

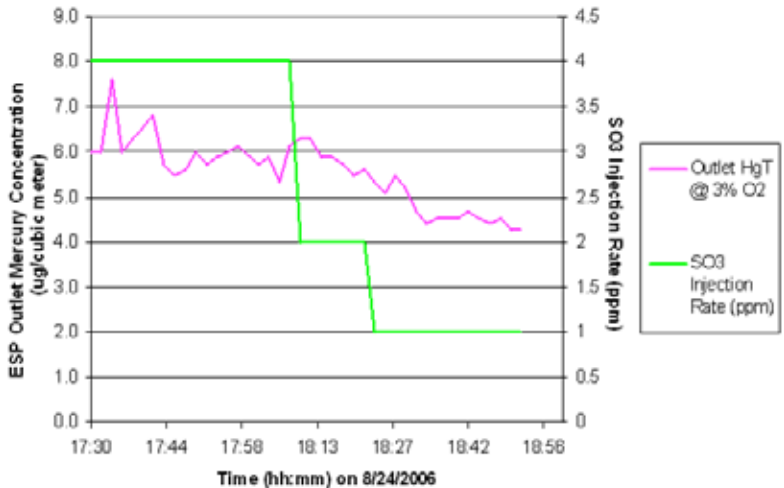


Figure 16: ESP Outlet Mercury Concentration with a Change to SO₃ Injection Rate at Site 2 and an ACI Rate of 3 #/MMACF

Please say what was applied during ACI: SAC or BAC? ((It is important that SO₃ interacts too with the bromine compound on the BAC.))

Figure 16 shows that when the SO₃ injection rate was decreased the ESP outlet mercury concentration appears to decrease as a result. This suggests, as does other research, the SO₃ is negatively affecting the carbon's ability to capture mercury. Because this data implied that the ESP outlet mercury concentration was dependent on SO₃ injection rate, a longer-term test to measure mercury removal at different SO₃ injection rates was performed.

During the baseline and parametric testing at Site 2, SO₃ was being injected at the typical rate of 4 ppm. On September 27th, 28th, and 29th activated carbon was injected at 1, 3, and 5 #/MMACF at each of three different SO₃ injection rates (0, 2, and 6 ppm).

For each day's test the SO₃ injection rate was changed the night before so that the ESP would operate for approximately 12 hours at that rate, which was believed to be enough time to come to steady state with respect to SO₃ injection. Then the following day three ACI rates would be tested, and the SO₃ injection rate then changed for the following day.

Figure 17 shows the results of varying the SO₃ and ACI rates on the removal of mercury across the ESP, as measured by the CMMs.

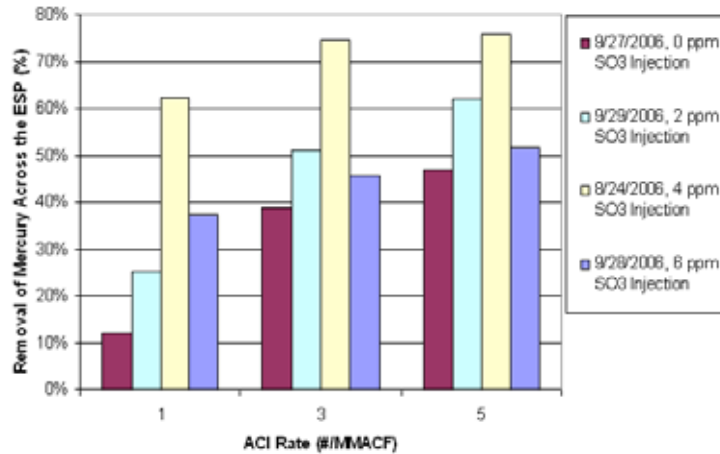


Figure 17: Mercury Removal Across the ESP as a Function of ACI and SO₃ Injection Rate at Site 2

((Once asgasin: What is the definition of the Removal rate here in this diagram??))

It can be seen in Fig. 17 that the highest removals of mercury, based on percentage of mercury removed, were achieved at an SO₃ injection rate of 4 ppm, which also coincided with earlier test dates. This indicates that ESP operation and internal condition are the dominant factors when evaluating mercury removal across the ESP at Site 2. Although the SO₃ concentration may play some role in the removal of mercury by ACI across the ESP, the SO₃ concentration effect seems to be a smaller factor than whether or not the ESP plates are clean, and the degree to which carbon is present in the flue gas within the ESP.

One other factor that should be considered is that due to the large mercury variability in the TxL that Site 2 burns the mercury concentrations were not the same from test to test. For those tests where the SO₃ injection rate was varied the mercury concentration at the ESP inlet varied from 17.7 to 46.3 µg/Nm³. Figure 18 shows the mercury removal across the ESP, as well as the inlet mercury concentration, as a function of SO₃ injection rate and ACI rate.

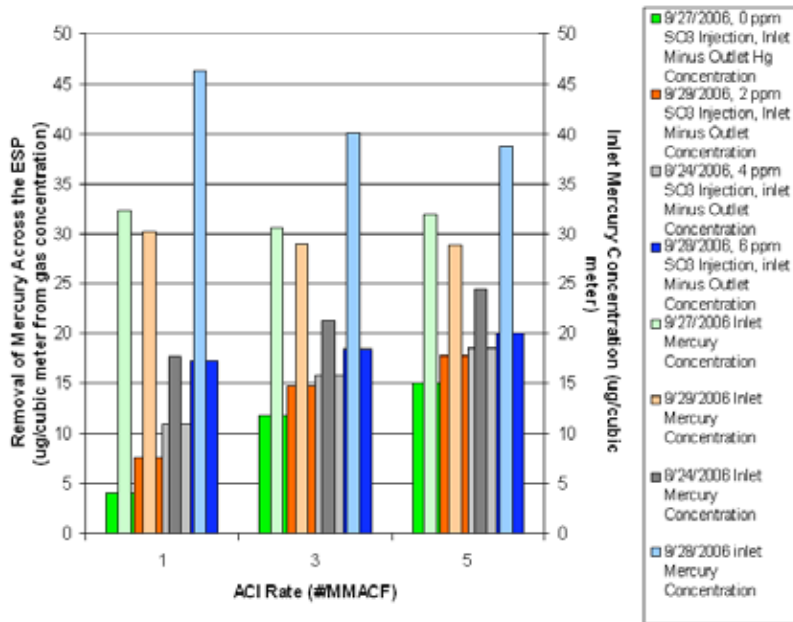


Figure 18: Mercury Removal Across the ESP as a Function of SO₃ Injection Rate and Inlet Mercury Concentration at Site 2

(once again should be μg . Further: Is it cubic meter or is it dscm?)

The readability of the legend and even more its different meanings is hard to understand ??? Must be improved.

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Figure 18 shows the mercury removal in terms of concentration removed (or the inlet concentration minus the outlet concentration), as well as the mercury inlet reading from the CMM for the same test. For each ACI rate it appears that as the SO₃ injection rate is increased, more mercury is removed. This is important to note because Fig. 17 shows that the percentage removal of mercury dropped from the case of 4 ppm injection to 6 ppm injection. Figure 18 shows that, although the percentage removal decreased, the mass of mercury captured increased. This is important to note because it shows that the drop in percentage removal was only due to an increased inlet mercury concentration, and not due a decline in the actual capture of mercury across the ESP by activated carbon. ((Slightly confusing))

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This result does not agree with prior experience with EB coal in that the SO₃ at Site 2 did not appear to have a negative effect on mercury capture using ACI. However, injection rates of equal to or less than 6 ppm are much smaller concentrations of SO₃ than can be seen with EB fuels. It is possible, as the data from Site 2 suggests, that the small amount of SO₃ injected does not negatively affect the ability to capture mercury in the ESP using ACI on a 100% TxL fuel.

Mercury Capture in WFGD System

Previous testing at Site 2 showed that Hg⁺² was captured in the WFGD with an average efficiency of 83%. However, the capture of elemental mercury across WFGDs was very small by comparison, at 9.8%. ((definition here??)). Therefore, the oxidation of the mercury at the ESP outlet becomes very important when considering total capture in the plant as a whole. As the oxidized fraction of mercury increases, so does the overall capture by the plant.

CMM data from baseline testing showed that the mercury at the ESP outlet was between 47 and 73% oxidized. CMM data during the long-term ACI test showed that the mercury at the ESP outlet was between 32 and 61% oxidized. Table 2 shows the ESP outlet oxidation of mercury for the baseline and long-term testing.

	Date	% Hg as Hg+2	Average
BASELINE DATA	8/9/2006	73%	58%
	8/16/2006	56%	
	8/17/2006	55%	
	8/18/2006	60%	
	8/21/2006	47%	
LONG-TERM DATA	9/12/2006	61%	50%
	9/13/2006	53%	
	9/14/2006	55%	
	9/15/2006	53%	
	9/18/2006	56%	
	9/19/2006	41%	
	9/20/2006	59%	
	9/21/2006	48%	
	9/22/2006	57%	
	10/3/2006	33%	
10/4/2006	32%		

Table 2: ESP Outlet Oxidation of Mercury for the Baseline and Long-term Testing at Site 2

QSEMS were used to measure mercury at the FGD outlet. Downstream of the WFGD the flue gas contains a high percentage of moisture, which makes measurement of mercury very difficult with QSEMS. Although multiple QSEMS were attempted downstream of the WFGD, only two carbon traps were not contaminated by moisture from the system.

The two traps that were not contaminated with moisture averaged a removal of total mercury across the WFGD system of 46%. For these two tests, the flue gas exhibited mercury that was 46% oxidized on average, resulting in a calculated average removal across the WFGD system of 100% of the oxidized mercury in the flue gas. ((Why not omit these unqualified statements??))

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Site 3

Site Description

Site 3 is a 450 MWn super-critical boiler. The boiler is fired with 100% PRB fuel. The unit is equipped with one Ljungström-type regenerative air heater. Gas from the air heater is split into four ducts, which feed the inlets of two cold-side ESP boxes with a total specific collecting area (SCA) of 661 ft²/1000 acfm.

After exiting the ESP, the flue gas travels through two parallel, induced draft (ID) fans prior to entering the stack. The stack is common between units 3 and 4, which are mirror images of one another. Figure 19 shows the equipment layout of Site 3.

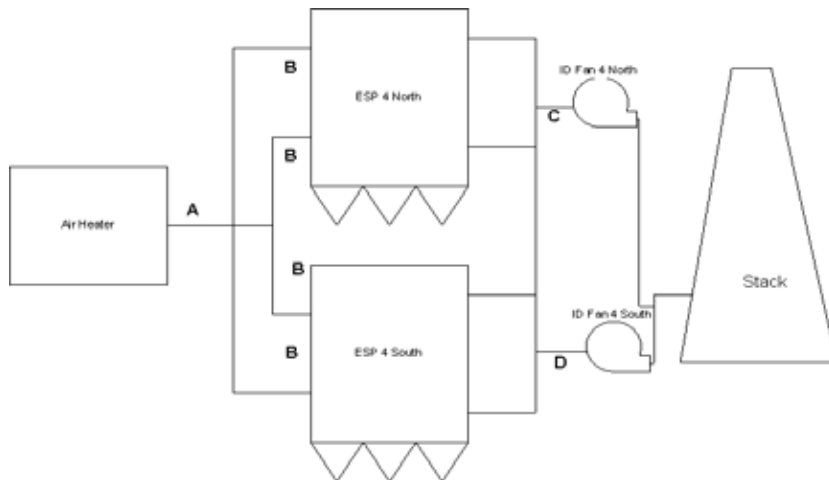


Figure 19: Site 3 Test Layout

Where the locations in Figure 19 are defined as: Location A is the inlet test location, B denotes the ACI locations, C is the hot-side outlet test location, and D is the cold-side outlet test location.

The tests in this report were carried out on the unit 4 ESP inlet and outlet ducts, with 100% of the unit's flue gas being treated with activated carbon. The CMM, Ontario Hydro, EPA Method 29, and hot side QSEMS (HS QSEMS) were all performed on the North ESP outlet duct. The cold side QSEMS (CS QSEMS) were performed on the South ESP outlet duct, which averaged 57°F (31°C) cooler than the North duct over the course of the test. The difference in temperature in the two ESP outlet ducts is due to the rotation of the single air heater that feeds the ESPs.

Baseline Test Results

During normal operation, baseline removal of mercury across the ESP ranged from 0.8% to 16.5% with an average native capture of 7.6%. Over the course of testing at Site 3 the sulfur content of the PRB fuel varied from 0.95 to 1.26 #SO₂/MMBTU ([\(\(translate into mg SO2/dscm, as well\)\)](#) in the fuel, based on fuel analysis data ([continuous emissions monitor, or CEM, data was not available for Site 3 during the time of the test, so fuel analysis data is the most accurate available](#)). Changes in constituents such as sulfur can lead to slight differences in the flue gas chemistry that can affect the native capture in the ESP, however the relatively consistent native capture of Hg in the ESP at Site 3 shows that there was little variation in the PRB fuel that was burned there during the test. Some small amount of the variation may also be due to imperfections in the test methods.

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During the baseline testing, the CMMs were used to measure the speciation of the Hg at the inlet and outlet of the ESP. The Hg at the ESP inlet was 4.0% oxidized on average, and the Hg at the ESP outlet was 13.5% oxidized. Only CMM data for oxidation is available as no OH method testing was performed during baseline.

Results show that in all tests performed, Hg^P constituted less than 2.9% of the mercury found downstream of the ESP, with the average value being 1.7%. Therefore, it is assumed that the Hg^P downstream of the ESP is negligible. Because the Hg^P is negligible, it is of little importance that the CMM does not measure Hg^P.

Parametric Test Results

During the parametric testing at Site 3 BAC1 was injected at rates of 1, 3, and 5 #/MMACF into the flue gas downstream of the air heater, and both a CMM and QSEMS were used to measure the total removal of mercury across the ESP. The results of the parametric testing are shown in Fig. 20.

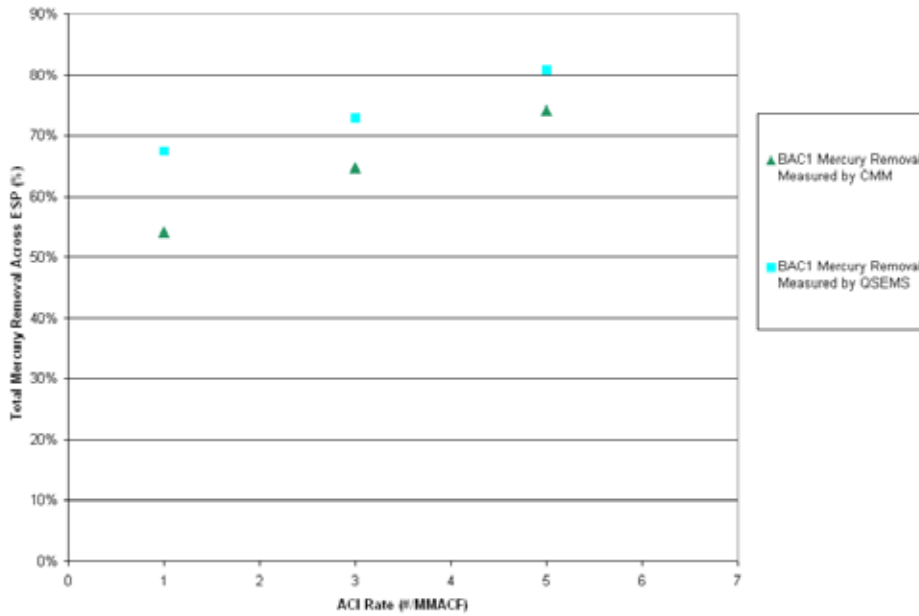


Figure 20: Results from Parametric Testing at Site 3

Long-Term Test Results

Figure 21 shows the removal of mercury by all test methods over the long-term test. It can be seen that there was some variation for each test method employed at Site 3. This is believed to be due to the use of various ports at the ESP outlet, and some gas stratification at the sampling points.

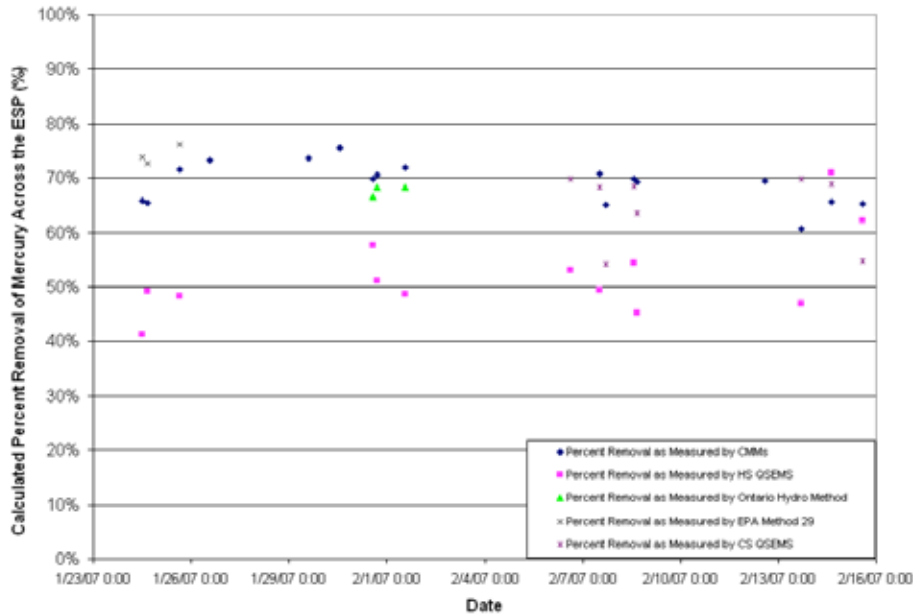


Figure 21: Percent Removal of Mercury as a Function of Time for the Long-Term Test at Site 3

It can be seen in Fig. 21 that the CMMs, OH Method, Method 29, and CS QSEMS all showed excellent agreement in the removal of mercury across the ESP. The HS QSEMS showed lower removal, which was due to a higher Hg concentration at the ESP outlet measured by the HS QSEMS. This is believed to be due to gas concentration stratification in the ESP outlet duct. To ensure that this problem was not due to a problem with the Ohio Lumex analyzer multiple carbon traps were sent to Dolan labs to be analyzed by acid digestion, which is a chemical method to determine the amount of Hg captured in the trap. The chemical digestion results agreed with the Ohio Lumex results in that the Hg measured by the HS QSEMS was greater than the Hg that was measured by the CMMs (although the HS QSEMS and the CMMs were in the same location).

It was also found during the testing at Site 3 that ACI affected the speciation of the Hg at the ESP outlet. Because there is halogen present on the surface of the activated carbon, Hg is able to undergo an oxidation reaction with the halogen. Table 3 shows the speciation of mercury at the inlet and outlet of the ESP during baseline testing and during the long-term test.

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Test	ESP Inlet Average Mercury Speciation (% Oxidized)	ESP Outlet Average Mercury Speciation (% Oxidized)
Baseline Data	4.0%	13.5%
Long-Term Test Data	4.4%	39.6%

Table 3: Mercury Speciation Data During the Baseline and Long-Term Testing at Site 3

Mention in table 3 how much BPAC was used, please.

While the speciation of Hg at the ESP was very consistent throughout the entire testing period, a pronounced change can be seen in the Hg speciation at the ESP outlet from the baseline testing to the long-term testing. This is evidence that the addition of bromine and activated carbon into the flue gas stream is increasing the amount of Hg⁺² measured in the flue gas.

Effect of ACI on Ash Collected in the ESP

Effects of ACI on flyash at Site 3 are extremely important because Site 3 sells the majority of the flyash produced there for use as a concrete substitute.

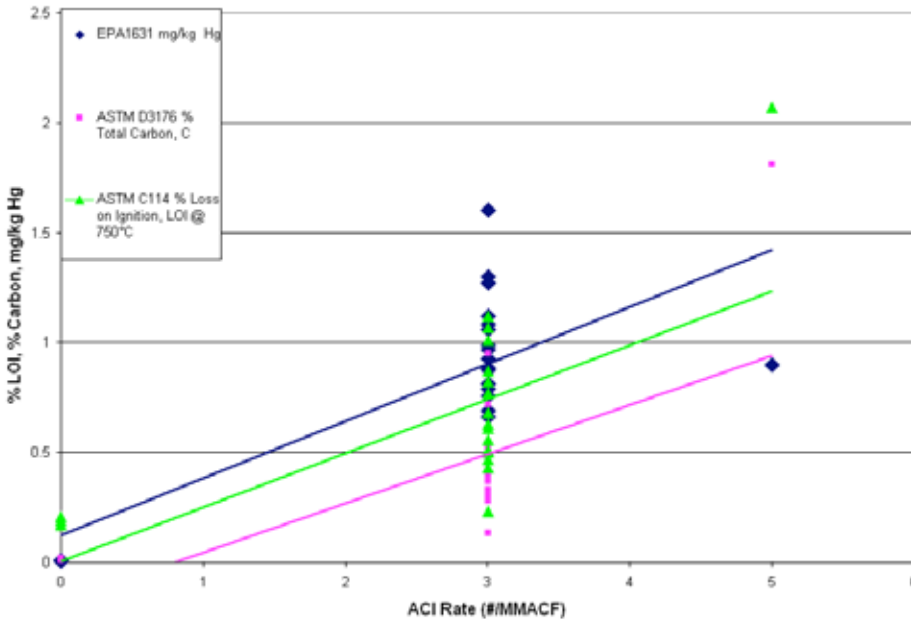


Figure 22: Carbon and Mercury Concentration in Flyash From the 4N1S Hopper as a Function of BAC1 Injection Rate at Site 3

((Nobody can read the diagram with these overlapping compilation of points of completely different quality?? Any other form of data evaluation might be better.))

Figure 22 shows the carbon in ash (%), the loss on ignition (LOI, %), and the mercury concentration (mg/kg) for all of the ash samples pulled from the 4N1S (north Box, first row, south hopper) location on the ESP on Site 3. From Fig. 22 it can be clearly seen that as the ACI rate is increased the amount of carbon, LOI, and mercury in the fly ash increase for a constant sampling point (a specific hopper). However, over the precipitator as a whole, it is much more difficult to determine such a relationship. Figure 23 shows the LOI, carbon and mercury concentrations for all of the ash samples taken from the Site 3 ESP.

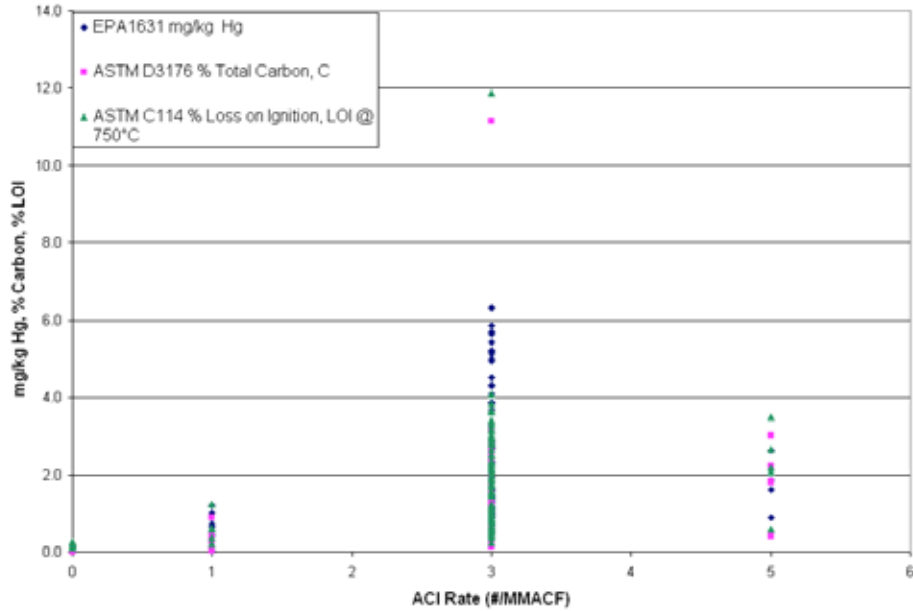


Figure 23: LOI, Carbon and Mercury Data for All Analyzed Flyash at Site 3

((The deadability of this figure is even worse))

Figure 23 shows the great amount of variability that arises when all of the precipitator hoppers are taken into account. Although it appears that carbon, LOI, and mercury increase with increasing ACI rate, developing a correlation becomes much more difficult when all the ESP hopper samples are considered.

When attempting to determine the amount of carbon in ash on average it is better to calculate that value instead of using data that can be highly variable. As the data points in Fig. 23 show, when including samples from every hopper, carbon does not collect uniformly throughout the ESP. Therefore, it then becomes very difficult to draw a clear conclusion due to the non-uniform addition of carbon to each hopper, although the addition of carbon to the bulk of the flyash should

be consistent with a steady ACI rate and a reasonable amount of variability in the ash content of the fuel.

As part of the Site 3 testing, ash samples were taken from all of the hoppers in the first three rows of the 4N ESP. Taking ash samples from farther back in the ESP, where less ash collects, takes a much longer amount of time, and could not be performed reliably during the testing period. Figure 24 shows the distribution of the percent LOI by hopper location, based on the average measurement from the hopper over the long-term test.

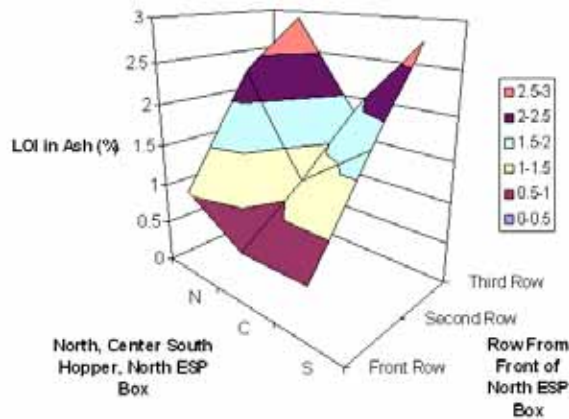


Figure 24: LOI in Ash as a Function of Hopper Location at Site 3

Figure 24 shows that more carbon was collected on the north and south sides of the north ESP box than in the center (there are 3 hoppers across the width of each ESP box), but that the distribution at each location was relatively even. It is expected that as the LOI due to ACI increases, the Hg in the same hoppers should increase. Figure 25 shows the distribution of Hg, based on the average measurement from the hopper over the long-term test.

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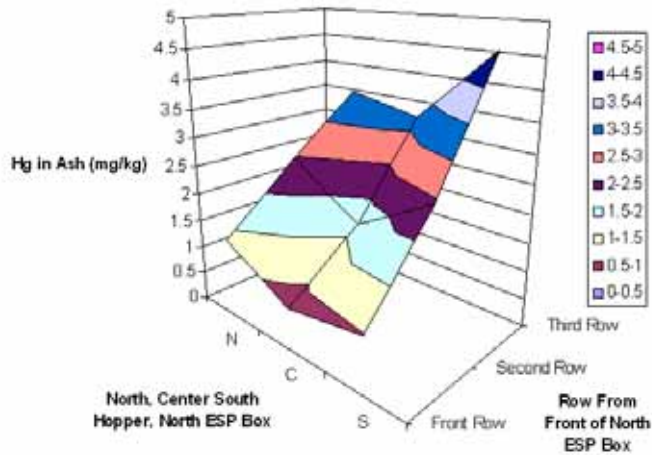


Figure 25: Hg in Ash as a Function of Hopper Location at Site 3

Figure 25 shows that the Hg distribution very closely matches the LOI distribution in Figure 24. This plot confirms that as the LOI from ACI increases, the amount of Hg captured increases.

((Good))

As part of the testing at Site 3 TCLP tests were performed to determine what the effects of AC addition were to the flyash in the ESP in terms of disposal. The average results of the TCLP tests, maximum results of the TCLP tests, and 40 CFR 261.24 limits are shown in Table 4.

Constituent	Average Test Result mg/L	Maximum Test Result mg/L	40 CFR 261.24 Limits mg/L	Maximum as Percent of Limit %
Arsenic, As	0.1	0.2	5.0	4.0%
Barium, Ba	0.28	0.31	100.0	0.3%
Cadmium, Cd	0.005	0.005	1.0	0.5%
Chromium, Cr	0.130	0.237	5.0	4.7%
Lead, Pb	0.05	0.05	5.0	1.0%
Mercury, Hg	0.0002	0.0003	0.2	0.2%
Selenium, Se	0.6	0.9	1.0	90.0%
Silver, Ag	0.014	0.019	5.0	0.4%

Table 4: Results from TCLP Testing at Site 3 and 40 CFR 261.24 Limits

Table 4 shows that the only constituent that is more than 5.0% of the TCLP limit is Se, which was found at a maximum of 90% of the TCLP limit. However, based on the very high removal of Se from the gas stream in the ESP as measured by EPA Method 29, it does not appear that ACI had a noticeable effect on the capture of Se in the ESP at Site 3. Therefore, this constituent would be expected to be found in the ash in the same concentrations, regardless of whether or not ACI was occurring. It should be noted that high levels of Se, within 40 CFR 261.24 Limits, are common for many PRB fuels.

Over the course of the testing, mercury never was found at more than 0.2% of the TCLP limit. Such negligible quantities of Hg in the leachate indicate that increasing mercury capture in the ESP with ACI will not create ash disposal problems at this site.

Ability of ACI to Capture Metals Other than Mercury

EPA Method 29 Testing was employed during baseline measurement and during long-term carbon injection to measure the amount of metals that are removed in the ESP. Figure 26 shows the removal of particulate and gaseous metals measured during baseline testing with no ACI.

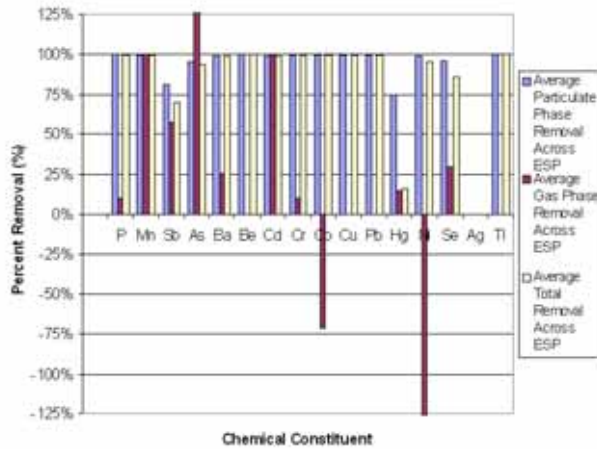


Figure 26: Baseline Removal of Metals Across the ESP at Site 3

From Fig. 26 it can be seen that overall the removal of metals across the ESP was high. Similar to testing at Site 1 and Site 2, the gas phase removal of some metals across the ESP was negative. However, the gas phase concentrations of these metals were very small and did not greatly affect the overall capture of the metals in question.

Figure 27 shows the removal of metals across the ESP measured while injecting 3 #/MMACF Hg-LH into the flue gas.

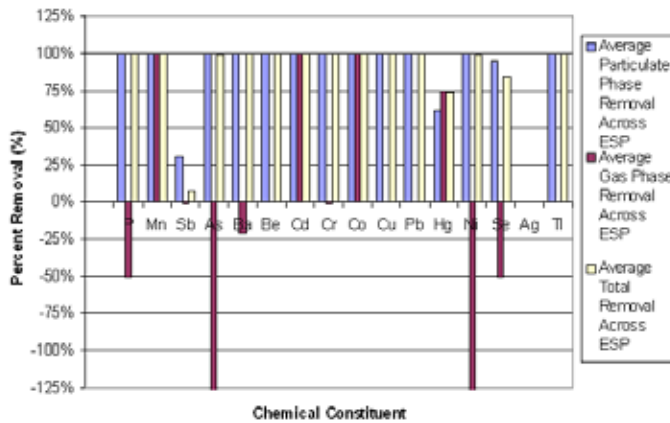


Figure 27: Removal of Metals Across the ESP with an ACI Rate of 3 #/MMACF at Site 3

From Fig. 27 it can be seen that, as in Fig. 26, some metals showed negative removals across the ESP in the gas phase. As was the case with Figure 26, these apparent increases of gas phase metals across the ESP were very small and had a negligible effect on the overall removal. However, a decrease in the capture of antimony (Sb) was measured. The baseline total capture of Sb was 70.4%, while a removal of 7.0% was measured with ACI.

Figure 28 shows the relative deviation in the total removal of metals during baseline and a BAC1 injection rate of 3#/MMACF.

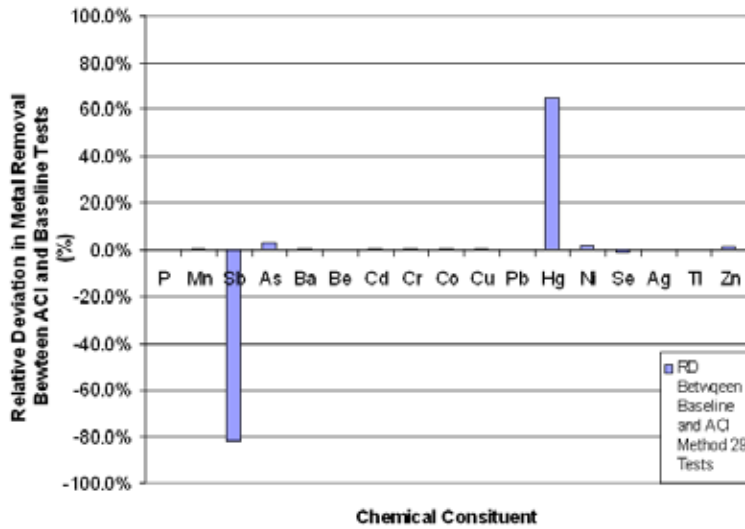


Figure 28: Relative Deviation of the Removal of Metals Across the ESP Comparing Baseline to ACI at Site 3

[\(\(Once again: RD definition\)\)](#)

From Fig. 28 it can be noted that the two largest changes in removal of metals across the ESP due to ACI were a decrease in capture of Sb, and an increase in the capture of Hg. While the increase in capture of Hg was certainly due to ACI, it is not clear what caused the decrease in the capture of Sb. This decrease in the capture of Sb was not witnessed during the previous ACI testing at Site 1 or Site 2. However, each Method 29 value is an average of 3 runs and all 3 of the runs showed a lower capture of Sb than the baseline testing, so it is not likely that the decrease in the capture of Sb was an artifact of the testing method.

Impact of ACI on Stack Opacity

As activated carbon is injected upstream of the ESP, the bulk particulate properties change and the loading to the ESP is increased. Due to this fact it is necessary to closely monitor opacity at the ESP outlet to ensure that there is no sign of an opacity increase due to ACI.

Figure 29 shows stack opacity data with no ACI (Corresponding to 0 #/MMACF), as well as various ACI rates during the testing at Site 3.

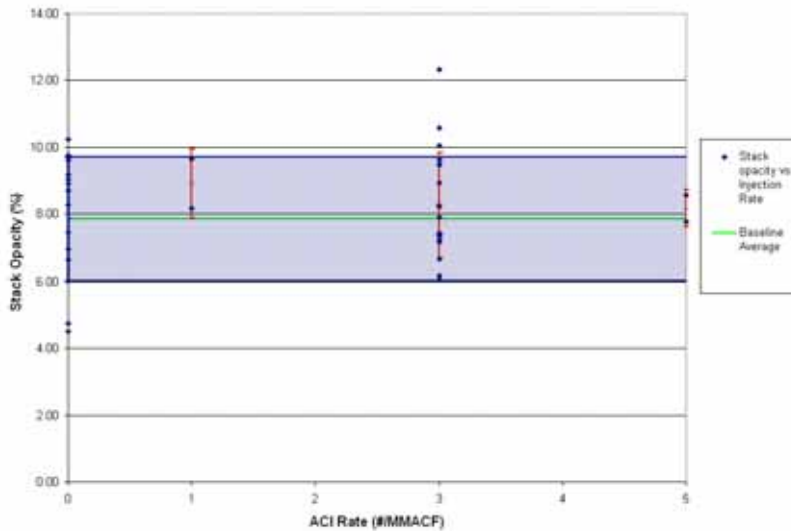


Figure 29: Stack Opacity Versus ACI Rate at Site 3

In Fig. 29 the blue bands represent the baseline opacity plus and minus one standard deviation. The red error bars indicate the average opacity at each injection rate plus and minus one standard deviation.

When considering only the stack opacity data, the baseline opacity (shown as the green line) gave the lowest average value when compared to the three injection rates that were tested. However, there is no clear upward trend that can be tied to injection rate, since the average opacity at ACI rates of 3 and 5 #/MMACF is lower than the average stack opacity at an injection rate of 1 #/MMACF. This lack of a clear upward trend in opacity indicates that ACI did not have a direct effect on ESP outlet opacity.

CONCLUSIONS

Testing performed by AEP on three coal-fired power plants showed that ACI is a viable option for mercury removal on a variety of fuels. Through the correct choice of activated carbon, as well as injection rate and range, it is possible to design a system capable of consistent removal of mercury.

Injecting untreated activated carbon upstream of a cold-side ESP into the flue gas of a PRB/EB blend proved beneficial. Although this fuel blend exhibits a high native capture of mercury in the ESP, consistent removal of mercury is possible with a less-expensive untreated activated carbon.

Mercury removal was possible with both untreated and brominated activated carbon when injected upstream of a cold-side ESP into the flue gas from 100% Texas lignite fuel, although the brominated carbon was able to remove a higher percentage of mercury at lower injection rates than the untreated carbon.

Injection of a brominated carbon upstream of a cold-side ESP on flue gas from 100% PRB fuel produces very consistently high removal of mercury.

Testing of activated carbons from two major suppliers showed that there was not a significant difference in performance between the products.

Ash marketing considerations are also very important, as the amount of AC injected will most likely affect ash marketing activities. This is an extremely important consideration for any plant that markets its ash or has limited space for disposal of coal combustion byproducts. Close attention should also be paid to developments in more advanced types of activated carbon and non-carbon sorbents that may have less of an impact on the use of flyash as a concrete additive. It may also be possible to use the ash for products other than concrete.

Because each plant that was included in the test program must operate under a given opacity limit, it is extremely important to choose sites appropriately. Opacity was not adversely affected at any of the sites that AEP tested.

There are many considerations to be made with regard to utilizing ACI for mercury mitigation, but if these decisions are made while contemplating the operation of the power plant as a whole it is possible to design, install, and operate an effective ACI system for the purpose of controlling mercury emissions from a coal-fired power plant.

REFERENCES

1. Sjostrom et al., 2006, "Full Scale Evaluation of Carbon Injection for Mercury Control at a Unit Firing High Sulfur Coal", Paper #14, 2006 MEGA Symposium.