Sorbent Injection for Mercury Control Upstream of Small-SCA ESPs

Paper #65

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ABSTRACT

URS Group, in conjunction with EPRI, Southern Company, Georgia Power, and ADA-ES is evaluating sorbent injection for mercury control upstream of small-SCA ESPs in flue gas derived from low-sulfur Eastern bituminous fuel. The project is funded by DOE-NETL and is divided into two phases, parametric testing and long-term testing. This paper reports the results from the full-scale parametric testing conducted at Georgia Power's Plant Yates Units 1 and 2. Both units are equipped with cold-side ESPs and fire the same fuel. In addition, Unit 1 also has a wet scrubber, and Unit 2 typically runs with SO_3 and NH_3 flue gas conditioning. Parametric tests were performed with three sorbent materials to determine the effect of addition rate upstream of the ESP on mercury removal and supplemental removal across the wet scrubber. Parametric tests also evaluated the effect of sorbent addition rate and flue gas conditioning on sorbent performance.

INTRODUCTION

Sorbent injection is currently the most studied mercury control technology for coal-fired utilities. The technology has been tested in numerous pilot and full-scale demonstrations sponsored by DOE-NETL, EPRI, and others. Most previous activated carbon injection testing has been performed on units with relatively large ESPs (electrostatic precipitators). In these tests, high levels of mercury removal were possible, and little to no detrimental effects were observed on the ESP. However, in the current fleet of U.S. coal-fired utility ESPs, over 70% have specific collection areas (SCAs) less than 300 ft^2/1000 acfm. The mercury removal capabilities and balance of plant effects for sorbent injection have not been tested on plants with small ESPs.

The purpose of this project is to evaluate full-scale sorbent injection on two small size ESPs for a plant that fires eastern bituminous coal. One of the ESPs is equipped with a dual flue-gas conditioning system, allowing for the effects of NH_3 and SO_3 injection on mercury removal to be explored.

Short-term parametric tests were conducted on Georgia Power's Plant Yates Units 1 and 2 to evaluate the performance of activated carbon sorbents. In addition, the effects of the dual flue gas conditioning system on mercury removal performance were evaluated as part of the short-term parametric test on Unit 2. Based on the results of the parametric tests, a single sorbent will be selected for longer term full-scale tests on Unit 1 to observe long term performance of the sorbent, and its effects on ESP and JBR FGD (jet bubbling reactor flue gas desulphurization) system operations and combustion byproduct properties. The results of this study will provide data required for assessing the performance, long-term operational impacts, and estimating the costs of full-scale sorbent injection processes for flue gas mercury removal.

DESCRIPTION OF PLANT YATES UNITS 1 AND 2

Various sorbent materials were injected upstream of small SCA ESP systems at Georgia Power's Plant Yates Unit 1 and Unit 2. Both Unit 1 and Unit 2 fire a low sulfur bituminous coal. Unit 1 is equipped with a JBR wet FGD system downstream of the ESP for SO_2 control. Unit 2 is not equipped with downstream SO_2 controls; however, a dual flue gas conditioning system is used to enhance ESP performance. The dual flue gas conditioning system consists of SO_3 and NH_3 injection.

Figures 1 and 2 show the basic plant configuration, sorbent injection points, and flue gas sample locations for Units 1 and 2, respectively. Characteristics of each unit are summarized in Table 1.

TEST METHODS

For the short-term parametric tests, a sorbent injection system was installed to service both the Unit 1 and Unit 2 ESP inlet injection points. This portable dry injection system pneumatically conveys a predetermined and adjustable amount of powdered activated carbon (PAC) from bulk bags into the flue gas stream via six sorbent injection lances. The PAC is metered using a volumetric feeder into a pneumatic eductor, where the air supplied from the regenerative blower provides the motive force needed to transport the carbon to the final injection locations. The Porta-PAC (portable powdered activated carbon) system can deliver from 20 – 400 lb/hr of activated carbon.

The mercury measurements for baseline and injection testing were performed with mercury semi-continuous analyzers, which are described below in more detail. For each unit, flue gas extraction probes and mercury analyzers were situated at the ESP inlet and outlet locations. For Unit 1, a mercury analyzer was also placed at the JBR scrubber outlet. The analyzers continuously monitored the flue gas mercury concentration throughout the test program.

For each sorbent injection test, particulate loading was measured via single-point Method 17. Solid and liquid samples, such as makeup water, fly ash, and coal, were collected and analyzed for mercury content. Fly ash and coal mercury were digested with ASTM 3684 and analyzed for mercury by CVAA.

Figure 1. Unit 1 Configuration and Flue Gas Sample Locations

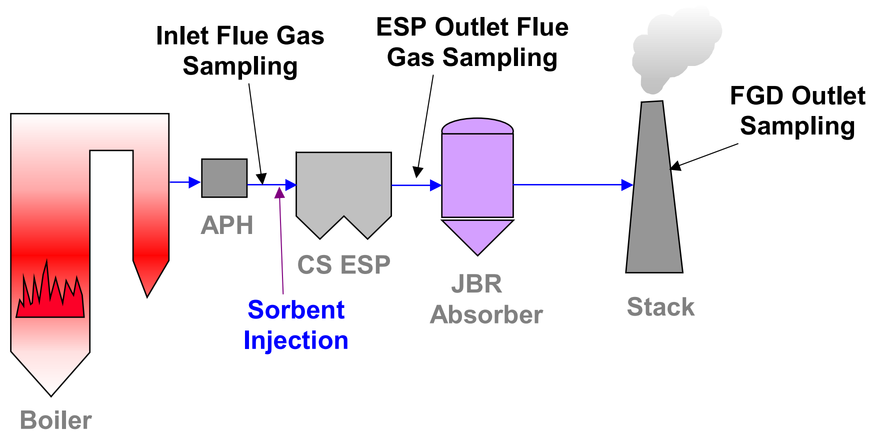


Figure 2. Unit 2 Configuration and Flue Gas Sample Locations

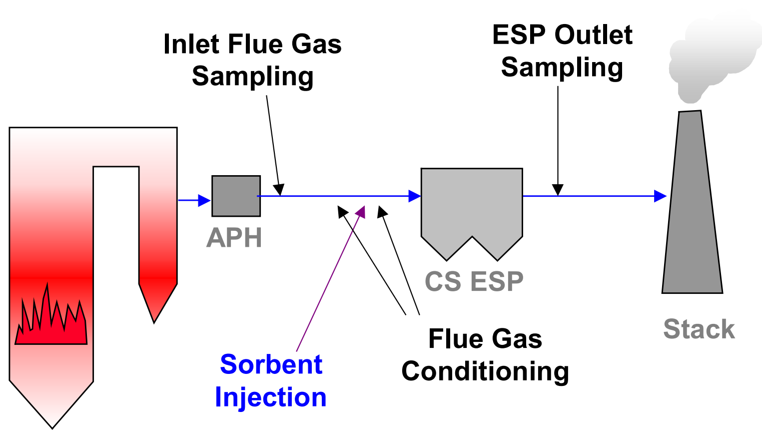


Table 1. Plant Yates Unit 1 and 2 configurations.

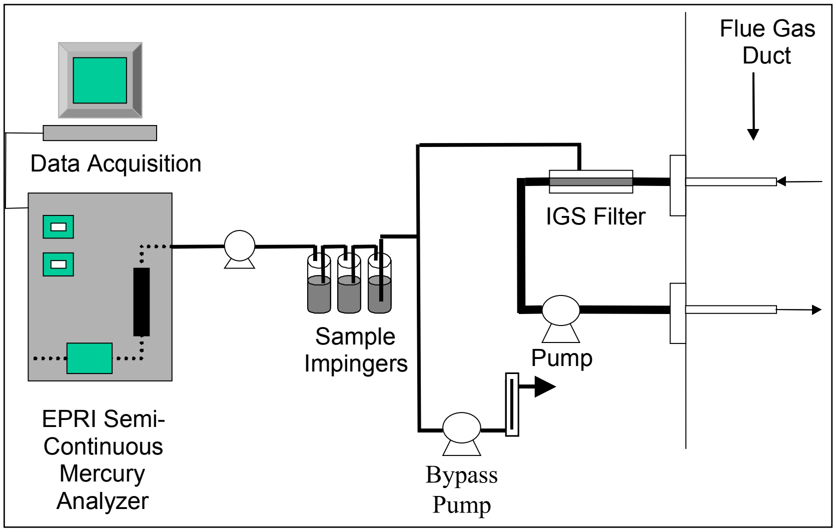
	Yates Unit 1	Yates Unit 2
Boiler		
Type	CE Tangential Fired	
Nameplate (MW)	100	
Coal		
Type	Eastern Bituminous	
Sulfur (wt %, dry)	1.0	
Mercury (mg/kg, dry)	0.06-0.14	
Chloride (mg/kg, dry)	150-450	
ESP		
Type	Cold-Side	
ESP Manufacturer	Buell (1968 and 1971 vintage, refurbished in 1997)	
Specific Collection Area (ft^2/1000afcm)	173	144
Plate Spacing (in.)	11	
Plate Height (ft)	30	
Electrical Fields	3	2
Mechanical Fields	4	3
ESP Inlet Temp. (°F)	310	300
ESP Design Flow Rate (ACFM)	490,000	420,000
NO_x Controls	Low NOx Burners	None
SO_2 Controls	Chiyoda CT-121 wet scrubber (JBR)	None
Flue Gas Conditioning	None	Dual NH_3/SO_3

EPRI SCEM Mercury Analyzer

Flue gas vapor-phase mercury analyses were made using EPRI semi-continuous analyzers depicted in Figure 3. At each sample location, a sample of the flue gas is extracted from the duct and then drawn through an inertial gas separation (IGS) filter to remove particulate matter. This IGS filter consists of a heated stainless steel tube lined with sintered material. A secondary sample stream is pulled across the sintered metal filter and then is directed through the mercury analyzer at a rate of approximately 1-2 L/min thus providing near real-time feedback during the various test conditions. The analyzer consists of a cold vapor atomic absorption spectrometer (CVAAS) coupled with a gold amalgamation system (Au-CVAAS). Since the Au-CVAAS measures mercury by using the distinct lines of the UV absorption characteristics of elemental mercury, the non-elemental fraction is converted to elemental mercury prior to analysis using a chilled reduction solution of acidified stannous chloride. Several impingers containing alkaline solutions are placed downstream of the reducing impingers to remove acidic components from the flue gas; elemental mercury is quantitatively transferred through these impingers.

To measure elemental mercury only, an impinger containing either 1M potassium chloride (KCl) or 1M Tris Hydroxymethyl (aminomethane) and EDTA is placed upstream of the alkaline solution impingers to capture oxidized mercury. Oxidized forms of mercury are captured and maintained in the KCl or Tris impingers while elemental mercury passes through to the gold system. Comparison of “total” and “elemental” mercury measurements yields the extent of mercury oxidation in the flue gas. All mercury concentrations reported in this paper are normalized to 3% O_2.

Figure 3. Semi-continuous Mercury Analyzer



Gas exiting the impingers flows through a gold amalgamation column where the mercury in the gas is adsorbed (<60° C). After adsorbing mercury onto the gold for a fixed period of time (typically 1-3 minutes), the mercury concentrated on the gold is thermally desorbed (>400° C) in nitrogen or air, and sent as a concentrated mercury stream to a CVAAS for analysis. Therefore, the total flue gas mercury concentration is measured semi-continuously with a 1 to 3-minute sample time followed by a 2-minute analytical period.

TEST MATRIX

Three different sorbents were selected for testing on Plant Yates Unit 1. A description of the each sorbent is provided in the table below. The Darco FGD™ carbon will serve as the benchmark sorbent since it has been used in numerous other sorbent injection test programs and its performance characteristics are well defined. The Super HOK sorbent is a German lignite-derived activated carbon selected for its cost, performance in previous tests and availability in quantities necessary for this test program. The third sorbent (NH carbon) is an iodated activated carbon which was not originally included in the test plan, but it was made available at no cost to the project. The project team made the decision to test this chemically treated activated carbon because it offered the potential for higher removals, although the cost is about 75% higher than that of the benchmark Darco FGD™ carbon.

Table 2. Sorbents selected for test program.

Carbon Name	Manufacturer	Description	Cost ($/lb)
Darco FGD™	Norit Americas	Lignite-derived activated carbon; baseline carbon (19 µm mean particle size)	0.50
Super HOK	RWE Rhinebraun	German lignite-derived activated carbon (23 µm mean particle size)	0.35
NH Carbon	Ningxia Huahui Activated Carbon Co. LTD	Chinese iodated bituminous-derived activated carbon (24 µm mean particle size)	0.88

The test conditions for Units 1 and 2 are summarized in Tables 3 and 4. All testing occurred with the units at full load. Prior to commencement of injection tests, a week of baseline (no sorbent injection) testing was conducted on each unit. For injection testing, baseline mercury concentrations were measured at the beginning and end of each test day. On each injection test day, one to four injection rates were tested. At least two hours were needed at each test condition in order to achieve steady outlet mercury concentrations. Once steady concentrations were achieved, the carbon injection rate was changed to a new value.

Table 3. Unit 1 test conditions.

Sorbent	Test Week	Range of Carbon Injection Rates Tested (lb/MMacf)
Baseline (no sorbent)	2/24/04 - 2/27/04	0
Darco FGD™	3/1/04 - 3/5/04	2.1 - 12.7
Super HOK	4/6/04 - 4/7/04	3.3 - 17.0
NH Carbon	3/29/04 - 3/30/04	4.2 - 12.5

Table 4. Unit 2 test conditions.

Sorbent	Test Week	Range of Carbon Injection Rates Tested (lb/MMacf)
Baseline (no sorbent)	3/15/04 - 3/19/04	0
Darco FGD™	3/22/04 - 3/26/04	2.1 - 12.7

RESULTS

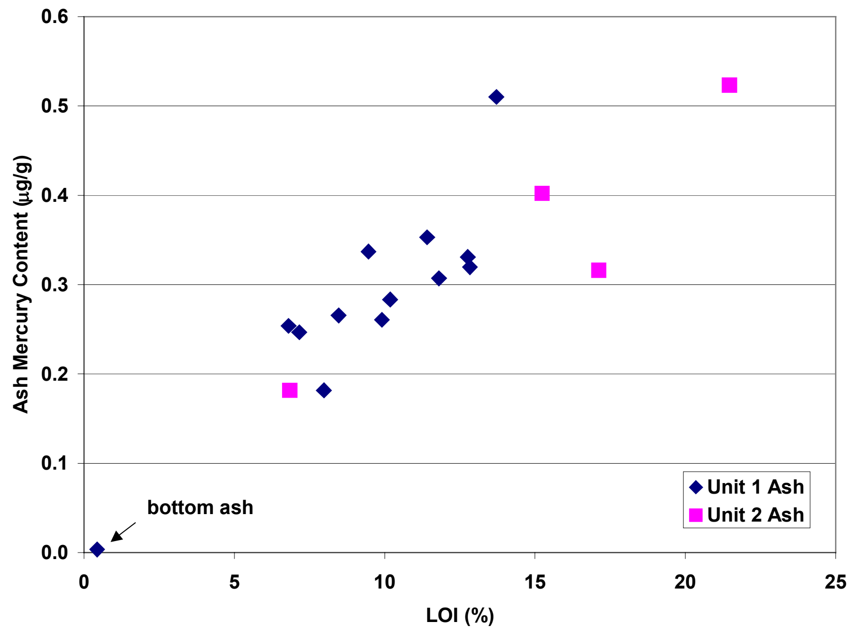
Baseline Results

During baseline testing on Unit 1 (SCA = 173 ft^2/1000 acfm), the average vapor-phase ESP inlet mercury concentration was 4.02 $\mu g/Nm^3$ and the average ESP outlet concentration was 2.64 $\mu g/Nm^3$ (at 3% O_2). On average, a 34% native removal across the ESP was measured during the baseline period. For Unit 2 (SCA = 144 ft^2/1000 acfm) during the baseline week of testing, the average ESP inlet mercury concentration was 6.04 $\mu g/Nm^3$and the outlet was 3.89 $\mu g/Nm^3$, indicating 36% native removal across the ESP.

Inlet and outlet mercury concentrations at full load varied during the course of the day, depending upon the coal mercury content and the temperature of the flue gas. Baseline mercury measurements were also made before and after each injection test day. ESP inlet mercury was typically between 4.0 and 7.0 $\mu g/Nm^3$,while ESP outlet concentrations were between 2.5 and 5.0 $\mu g/Nm^3$.

Coal and ash samples were collected during the baseline testing week and measured for mercury content. The fly ash had a high LOI content, typically in the 9-13% range. As seen in Figure 4, the mercury content of the ash increased proportionately to the LOI content, indicating that the LOI of the ash may play a role in the high native removals observed across the ESP.

Figure 4. Ash mercury content as a function of the LOI content



Injection Results

Three carbon-based sorbents were tested at Plant Yates Unit 1 for their ability to remove mercury from the flue gas. These sorbents were injected at various rates and the resulting mercury concentrations at the ESP outlet and JBR outlet were monitored. In order to assess the performance of the sorbents, two different mathematical metrics were used. The first metric was the percent removal of mercury across the ESP, which was calculated as

$$\% \text{ Removal Across ESP} = 1 - (\text{HgVapor}^{\text{ESP,out}})_t / (\text{HgVapor}^{\text{ESP,in}})_t$$

where $(\text{HgVapor}^{\text{ESP,out}})_t$ is the vapor phase mercury concentration at the ESP outlet measured at time *t,* and $(\text{HgVapor}^{\text{ESP,in}})_t$ is the vapor phase mercury concentration at the ESP inlet measured at time *t.* The percent removal metric incorporates native mercury removal across the ESP. Because at times native removals were as high as 50%, a second metric was designed in order to attribute the percent mercury reduction at the ESP outlet due to sorbent injection. The mercury reduction was calculated as

$$\% \text{ Reduction at ESP Outlet} = 1 - (\text{HgVapor}^{\text{ESP,out}})_t / (\text{HgVapor}^{\text{ESP,out}})_0$$

where $(\text{HgVapor}^{\text{ESP,out}})_t$ is the vapor phase mercury concentration at the ESP outlet measured at time *t,* and $(\text{HgVapor}^{\text{ESP,out}})_0$ is the vapor phase mercury concentration at the ESP outlet measured just prior to the start of injection (i.e. the baseline ESP outlet mercury concentration).

Similar metrics were devised in order to evaluate the percent removal across the combined ESP/JBR system and the percent mercury reduction at the JBR outlet.

Figures 5 through 8 summarize the results from the three sorbents tested on the Unit 1 ESP. Figures 5 and 6 show the percent removal across the ESP and the percent mercury reduction at the ESP outlet, respectively, as a function of sorbent injection rate. All three carbons exhibited similar performance in the Unit 1 ESP. Overall mercury removal (due to both native removal and removal by PAC) across the ESP plateaued between 50 and 70% for injection rates greater than 6 lb/MMacf. For the three carbons, the maximum achieved percent reduction of mercury at the ESP outlet was about 40%. The curves for the Darco FGD™ and the NH carbon are nearly identical, and the Super HOK curve is just slightly lower.

Figures 7 and 8 show the percent removal across the combined ESP/JBR and the percent mercury reduction at the JBR outlet, respectively, as a function of sorbent injection rate. The NH carbon resulted in the highest combined removal across the ESP/JBR. However, the native removal across the combined system was higher during the NH carbon injection testing week than during the other injection test weeks. The reduction of mercury at the stack was higher for the NH carbon. The Darco FGD™ and the Super HOK curves were nearly identical.

Sorbent injection tests were conducted with Darco FGD™ upstream of the Plant Yates Unit 2 ESP, which employs dual flue gas conditioning. Results from the tests are shown in Figure 9. These short-term test data indicate an additional 30 to 40 percent reduction in total vapor-phase mercury was achieved at an injection rate of 2 lb/MMacf. No additional reduction was observed at higher injection rates up to 13 lb/MMacf. It should be noted that the higher injection rates were tested on a day when the baseline ESP outlet mercury concentration was lower than normal (2.6 rather than 5.0 $\mu g/Nm^3$), which could bias low the mercury reduction measured. Figure 9 also indicates the set points for the dual flue gas conditioning system during each test period. The dual flue gas conditioning system appeared to have no effect on the reduction in total vapor-phase mercury at the ESP outlet.

Native removals across the Unit 2 ESP ranged from 20-60% during the testing weeks, which is similar to the Unit 1 ESP. For the Unit 2 ESP system, the removal curve (Figure 10) flattens out near 70 percent for sorbent injection rates of 6 lb/MMacf and above.

Figure 5. Comparison of Mercury Removal Efficiency Across the ESP of the Three Sorbents Tested on Unit 1

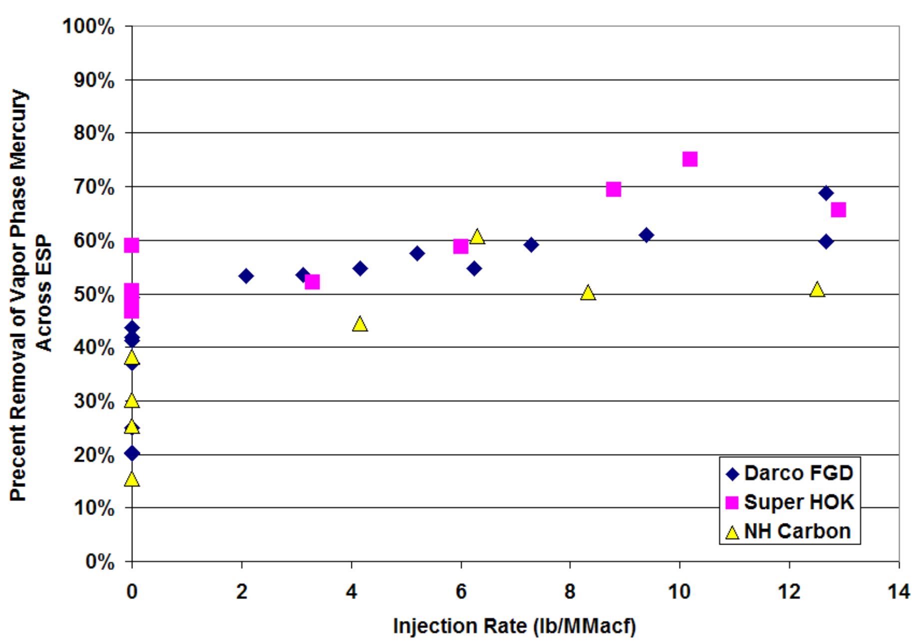


Figure 6. Comparison of Mercury Reduction at the ESP Outlet for the Three Sorbents Tested on Unit 1

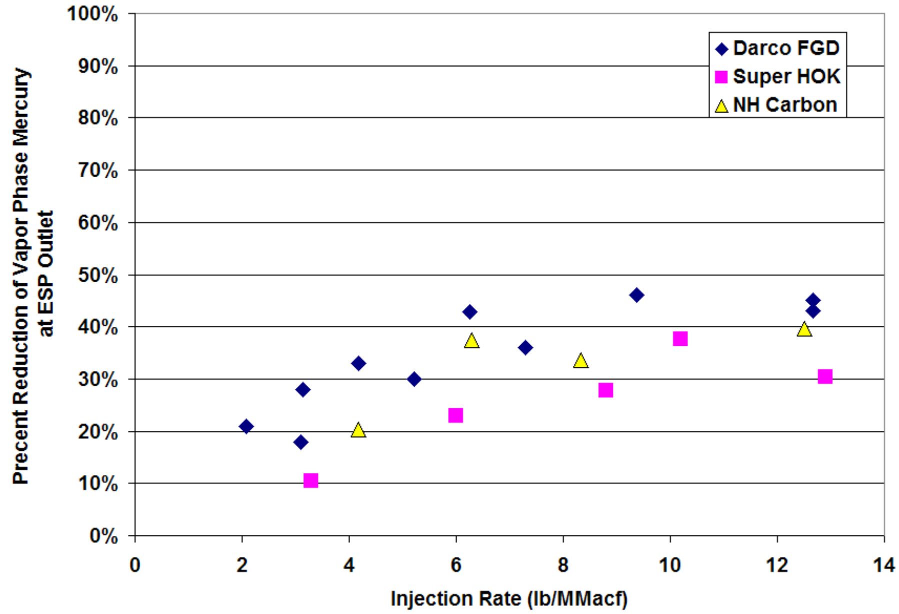


Figure 7. Comparison of Mercury Removal Efficiency Across the Combined ESP/JBR of the Three Sorbents Tested on Unit 1

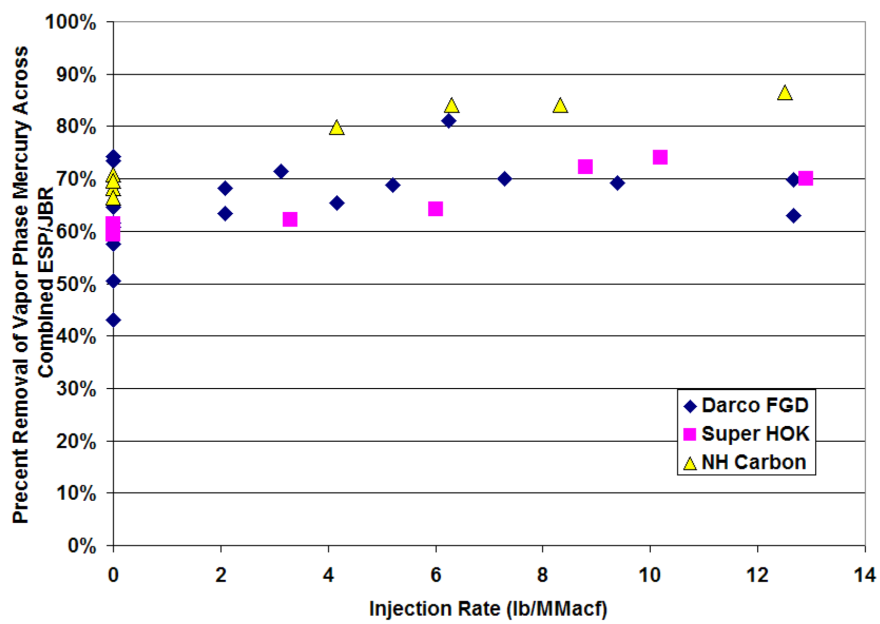


Figure 8. Comparison of Mercury Reduction at the JBR Outlet for the Three Sorbents Tested on Unit 1

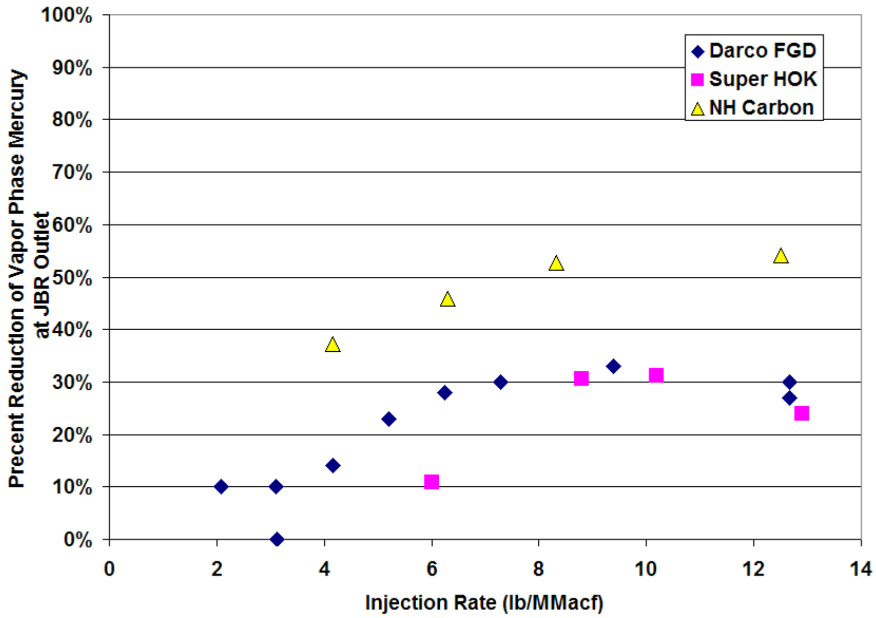


Figure 9. Percent Reduction in Vapor Phase Mercury at Unit 2 ESP Outlet

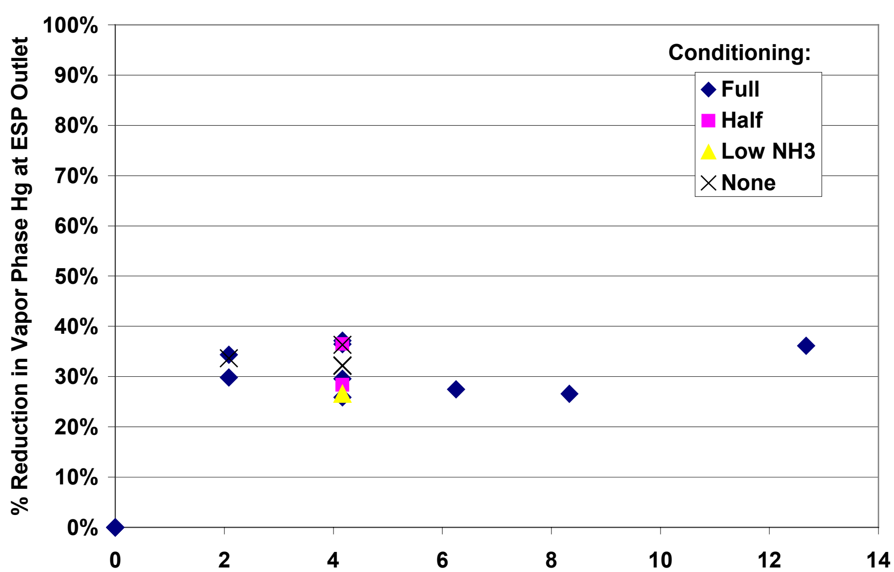
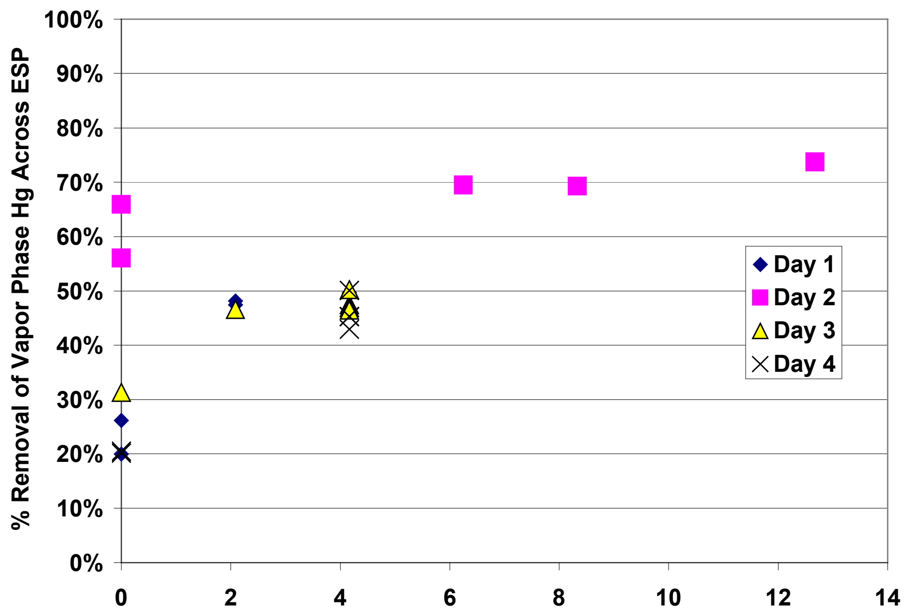


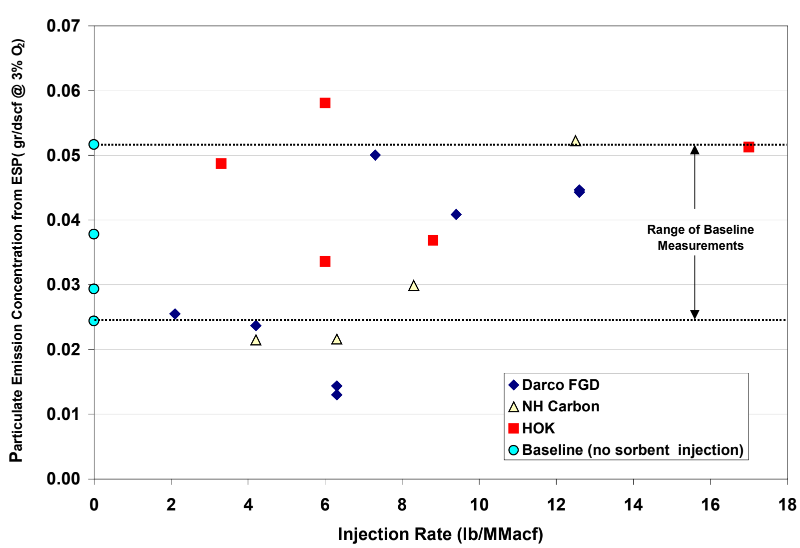
Figure 10. Removal of Vapor Phase Mercury Across Unit 2 ESP



ESP Performance

The impact of sorbent injection on the ESP performance was quantified by taking single point Method 17 particulate samples during each injection rate and by monitoring the arc rate in each field. Figure 11 shows the Unit 1 ESP outlet particulate concentrations measured during baseline and injection testing. During baseline conditions (sorbent injection rate = 0 lb/MMacf), the ESP outlet particulate concentration ranged from 0.024 to 0.052 grains/dscf at 3% O_2, with an average of 0.036 gr/dscf. For the tested carbon injection rates of 2 to 17 lb/MMacf, the measured outlet particulate concentrations were mostly within or below the range of concentrations measured during baseline testing. These results indicate that carbon injection caused no significant increase in ESP outlet particulate concentration. Similar results were seen for Unit 2.

Figure 11. Particulate Emissions as Measured by Single Point Method 17 at Unit 1 ESP Outlet



CONCLUSIONS

Three sorbents were tested during short-term parametric tests on Plant Yates Units 1 and 2 for their ability to remove flue gas mercury. The results from baseline (no sorbent injection) and parametric testing indicated:

- During baseline testing, the mercury content of the ash increased proportionately to the LOI content, likely contributing to the native mercury removal observed during this period (Unit 1 = 34% average Hg removal, Unit 2 = 36% average Hg removal).
- All three tested sorbents (Darco FGD^{TM}, Super HOK, and NH Carbon) had approximately the same dose-response curve for mercury removal from the flue gas, reaching 30-40% additional reduction in ESP outlet mercury at a sorbent injection concentration of approximately 6 lb/MMacf.
- Mercury removal reached a plateau at 6 lb/MMacf and injecting additional sorbent did not result in additional mercury removal.
- Carbon injection caused no significant increase in ESP outlet particulate concentration on Unit 1 or Unit 2 as measured by single-point EPA Method 17.
- The dual flue gas conditioning system appeared to have no effect on the reduction in total vapor-phase mercury at the ESP outlet.

Longer term tests, to be conducted in Fall 2004, will enable better assessment of sorbent injection performance and balance-of-plant impacts.