

Full-Scale Activated Carbon Injection for Mercury Control in Flue Gas Derived from North Dakota Lignite

Paper 83

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ABSTRACT

URS Group, in conjunction with DOE-NETL, EPRI, Great River Energy, North Dakota Industrial Commission, Apogee Scientific, and ADA-ES, is evaluating the effectiveness of sorbent injection for reducing mercury emissions from flue gas derived from North Dakota lignite. This paper reports full-scale tests performed at Great River Energy's Stanton Station Unit 10 to evaluate sorbent injection performance across a spray dryer-baghouse combination. Six mercury sorbents were chosen based upon pre-determined selection criteria and were evaluated during short-term parametric tests on each unit. Parametric tests determined optimal process conditions for each sorbent and were used to select a sorbent for longer-term testing. Results provide insight to the long-term performance and variability of this process as well as any effects on plant operations. Data from this program will also be used to perform an economic analysis of the costs associated with full-scale implementation of a sorbent-based injection system.

INTRODUCTION

Carbon injection technology is one of the most studied mercury control technologies available for coal-fired power plants. The technology has shown the capability to achieve fairly high mercury removals in plants burning specific coals and employing specific pollution control devices. For plants firing lignite fuels, injection of untreated activated carbons has shown lower mercury removal performance than for other coals, such as bituminous coals. The low chlorine and high calcium content of lignite fuel results in low reactivity between the mercury and sorbent, thereby resulting in poorer performance. The reactivity between mercury and sorbent can be improved by using chemically-treated carbons or by using furnace additives to increase

the chloride content of the flue gas. Both of these technologies have been successfully demonstrated in short-term, full-scale tests.

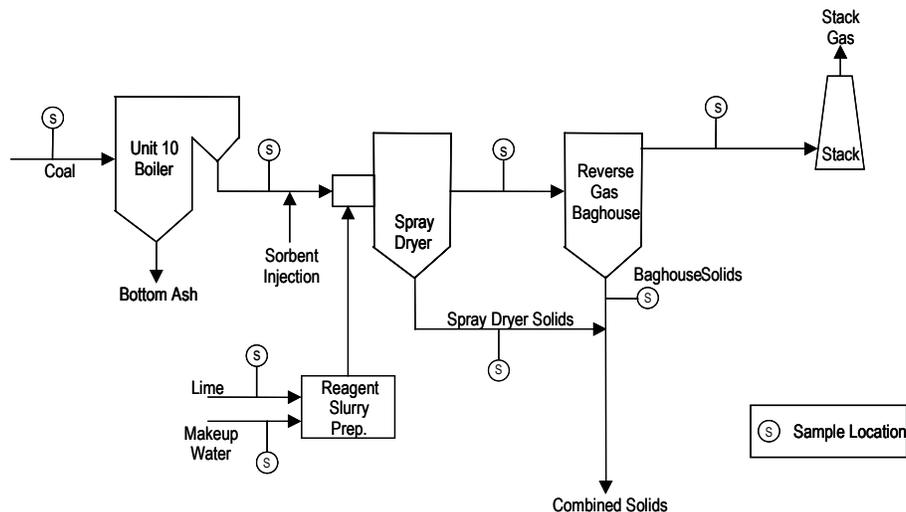
Full-scale testing of chemically treated carbons was undertaken at Stanton Station as part of a larger DOE-NETL program investigating methods to enhance the capability of carbon sorbents to remove mercury from lignite combustion gases. In this program sorbent injection will be tested at plants equipped with electrostatic precipitators (ESPs) only and at plants equipped with spray dryer/baghouse (SD/BH) combination. Stanton Station consists of two units. Unit 1 is equipped with an ESP, while Unit 10 is equipped with a spray dryer/baghouse. For each unit parametric testing of various carbons will be performed in order to evaluate the effect of chemical treatment on flue gas mercury adsorption. Based on the results from the parametric tests, a single sorbent will be selected for long-term testing. The long-term testing provides an opportunity to evaluate balance-of-plant effects of sorbent injection.

The parametric and long term testing on Stanton Unit 10 has been completed and the results are presented in this paper. Testing on Unit 1 has yet to commence.

DESCRIPTION OF STANTON UNIT 10

Various sorbent materials were injected upstream of spray dryer/baghouse (SD/BH) combination at Great River Energy's Stanton Station Unit 10. Unit 10 fires North Dakota lignite and is rated for a load of 60 MW. Figure 1 shows the basic plant configuration, sorbent injection points, and flue gas sample locations for Units 10. Characteristics of the Unit 10 (and Unit 1) are summarized in Table 1.

Figure 1. Stanton Unit 10 Configuration With Flue Gas and Solid Sample Locations



TEST METHODS

For the short-term parametric tests, an EPRI sorbent injection system was installed to service the Unit 10 spray dryer inlet. 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. 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 mercury measurements for baseline and injection testing were performed with mercury semi-continuous analyzers, which are described below in more detail. Flue gas extraction probes and mercury analyzers were situated at the spray dryer inlet, baghouse inlet, and baghouse outlet. The analyzers continuously monitored the flue gas mercury concentration throughout the test program.

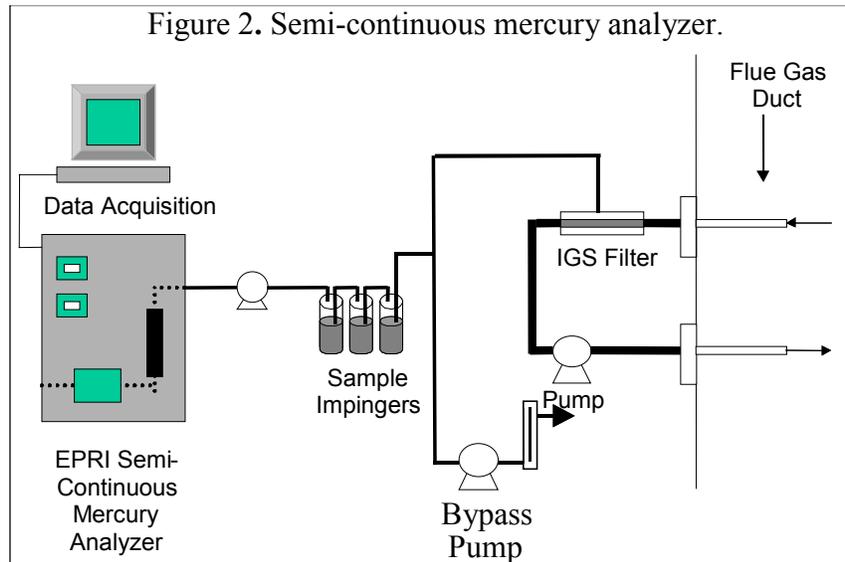
Solid and liquid samples, such as makeup water, fly ash, and coal, were collected and analyzed for mercury content. Fly ash and coal mercury were digested with ASTM 3684 and analyzed for mercury by CVAA.

Table 1. Stanton Unit 10 Configuration

	Stanton Unit 1	Stanton Unit 10
Boiler		
Type	Foster Wheeler, PC Wall-Fired	Combustion Engineering, PC Tangential
Nameplate (MW)	150 Gross	60 Gross
Fuel		
Type	ND Lignite	
Source	Coteau Freedom Mine	
Moisture	37.8	
Sulfur (wt %, as received)	0.64	
Heating Value (Btu/lb, as received)	6,635	
Mercury (mg/kg, dry)	0.055	
Chloride (mg/kg, dry)	<30	
Particulate Control		
Type	Cold-Side ESP	Reverse Gas Baghouse
Manufacturer	Research-Cottrell	Research-Cottrell
ESP Specific Collection Area (ft ² /1000acfm)	470	NA
ESP Plate Spacing (in.)	9	NA
Baghouse Air/Cloth Ratio (acf/ft ²)	NA	1.6 to 1
Baghouse Cleaning Cycle	NA	12-hr
Device Inlet/Outlet Temp. (°F)	325	190
NO_x Controls	LoNO _x Burners	LoNO _x Burners
SO₂ Controls		
Type	None	Lime Spray Dryer
Manufacturer	NA	Research-Cottrell
Design SO ₂ Removal (%)	NA	>80%
Recycle Rate (lb lime/lb recycle)	NA	0 (no recycle)
Inlet / Outlet Temp (°F)	NA	350 / 190
Flue Gas Flow Rate (scfm)	360,000	160,000

EPRI SCEM Mercury Analyzer

Flue gas vapor-phase mercury analyses were made using EPRI semi-continuous analyzers depicted in Figure 2. At each sample location, a sample of the flue gas is extracted from the duct and then passes 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 that has been treated with a Restek Silcosteel coating. 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.

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

Six sorbents were tested at Unit 10 as shown in Table 2. FGD™ carbon has been tested at Stanton and a number of other coal-fired plants and serves as a benchmark sorbent. Selection of the remaining five sorbents was based on the following criteria: 1) delivered cost; 2) mercury removal performance as verified in previous lab and/or field sorbent injection testing programs; and 3) vendor ability to supply the quantity of sorbent needed to conduct long-term testing.

Barnebey Sutcliffe’s iodated carbon (CB 200xF™ and referred to in this paper as BS IAC) has been tested previously at Stanton Station and has shown up to 90% removal of mercury. It was tested again to verify performance and serve as a benchmark for the other treated carbons. While this sorbent has demonstrated higher mercury removal performance, its price is \$7.71/lb, which is an order of magnitude higher than Norit FGD™.

As a lower price alternative product, an untreated, super-activated version of the Barnebey Sutcliffe carbon (208CP™ and referred to in this paper as BS SAC) was tested. The untreated carbon BS SAC has a price of \$0.85/lb.

Two chemically-treated carbons from Norit Americas were tested on Unit 10, FGD-E1 and FGD-E3. The sorbent FGD-E3 was expected to be a higher performing carbon than the FGD-E1; however, it was more slightly more costly than FGD-E1 (\$0.65/lb vs \$0.60/lb). A brominated lignite-derived activated carbon from Sorbent Technologies (ST BAC) was also tested. This carbon has been demonstrated in full-scale tests at other sites to have high mercury removal efficiency at low injection rates. The projected price of ST BAC ranges from \$0.50 to \$1.00/lb.

Table 2. Sorbents Selected for Test Program

Sorbent Name	Unit to be Tested	Manufacturer	Average Particle Size (µm)	Description	F.O.B. Price (\$/lb)
FGD™	Unit 10	Norit Americas	19	Lignite-derived activated carbon; baseline carbon	\$0.50
CB 200xF™ BS IAC	Unit 10	Barnebey Sutcliffe	88	CB 200xF iodated coconut shell activated carbon; “by fines” particle size; received 2004	\$7.71
FGD-E1	Unit 10	Norit Americas	17	Chemically-treated, lignite-derived activated carbon	\$0.60
FGD-E3	Unit 10	Norit Americas	19	Halogenated, lignite-derived activated carbon	\$0.65
208CP™ BS SAC	Unit 10	Barnebey Sutcliffe	46	Super activated coconut shell carbon	\$0.85
ST BAC	Unit 10	Sorbent Technologies	20	Brominated lignite-derived activated carbon	\$0.50-1.00

All testing occurred with the unit at full load or very near to full load. Prior to commencement of injection tests, a week of baseline (no sorbent injection) testing was conducted on the 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.

RESULTS

Parametric Test Results

Flue gas temperatures at the air heater outlet (spray dryer inlet), as measured by the plant, ranged from 312°F to 338°F. Flue gas temperatures at the baghouse outlet ranged from 175°F to 184°F. During the baseline and parametric evaluations, the targeted bag cleaning differential pressure for cleaning was 3.0-inches H₂O with a time period between cleanings of about 3-4 hours. During parametric evaluations, the targeted bag cleaning differential pressure for cleaning was 4.5-inches H₂O with a time period between cleanings of about 7-8 hours. Neither the sorbent injection rate nor the sorbent type seemed to affect the baghouse cleaning frequency.

No noticeable differences were observed in the operation of the spray dryer system during the baseline and the sorbent injection test periods. Slurry feed rates and water flows were run as under normal plant operations. Other plant parameters, including opacity, did not vary much during the evaluation period and no correlation with the amount of sorbent injected or sorbent type was observed.

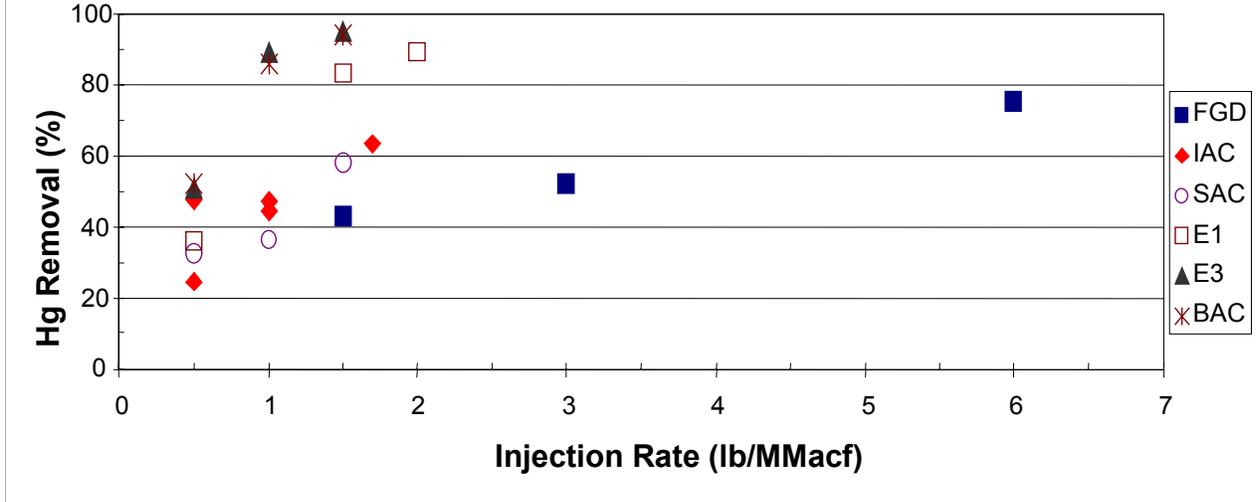
Baseline measurements were taken at the spray dryer inlet and baghouse outlet prior to each set of sorbent parametric evaluations. During baseline evaluations, the total vapor-phase mercury concentration ranged from 7.5 to 13 µg/Nm³ for all sampled locations. The baseline flue gas contained little (< 10%) oxidized mercury. Native removal across the SD/BH configuration was less than 10% during baseline periods.

Six sorbents were evaluated at various injection rates ranging from 0.5 to 6.0 lb/MMacf to achieve target removals ranging from 40% to greater than 90%. Mercury removals across the SD/BH for the six sorbents are presented in Figure 3. Removals were calculated by comparing the baghouse outlet mercury concentration to the spray dryer inlet concentration.

The benchmark sorbent, Norit Darco FGDTM, achieved 75% mercury removal at an injection rate of 6.0 lb/MMacf. The super activated (but untreated) SAC carbon achieved higher removals than the Darco FGDTM, over the injection range of 0.5 to 1.5 lb/MMacf. At the maximum tested injection rate of 1.5 MMacf, the SAC carbon achieved almost 60% removal.

The chemically treated carbons (BS IAC, Norit E-1, Norit E-3, and ST BAC) provided improved mercury removal performance over the untreated carbons. At an injection rate of 1.0 lb/MMacf, both the FGD E-3 and the ST BAC produced mercury removals greater than 85%. Mercury removals greater than 90% were achieved at an injection rate of 1.5 lb/MMacf with both sorbents. The Norit E-1 performed better than the untreated Darco FGDTM, but not as well as the Norit E-3.

Figure 3. Results from Full-Scale Parametric Testing of Sorbents at Stanton Unit 10.



In this round of parametric testing the BS IAC carbon did not produce the 90+% mercury removals that it had achieved in previous test programs at Stanton Station. The BS IAC tested for this round of parametric tests was from a different manufacturer’s lot than the previous tests. BS IAC carbon sample from the previous (year 2000) lot were available on-site and was briefly tested. The older BS IAC carbon produced 90+% removals, indicating that there were significant differences between the two batches of carbon. Post test analysis showed that the average particle size of the 2004 lot was 87 μm , while the 2000 lot had an average particle size of 47 μm .

Long-term Test Results

After review of the parametric test results, Norit’s E-3 was selected for extended evaluations on Stanton Unit 10. This decision was based on the sorbent’s mercury removal performance, cost, and ability to be delivered in the quantity needed for the test program. A target removal of 60% to 75% mercury removal across the SD/BH was set for the long-term testing, which occurred over a period of 24 days.

The spray dryer inlet mercury vapor-phase concentrations ranged from 7.5 to 12 $\mu\text{g}/\text{Nm}^3$ during the evaluation. For the long-term test period, an injection rate of 1.0 lb/MMacf was needed to achieve 65% to 75% mercury removal across the SD/BH. The outlet concentration from the SD/BH was typically in the range of 2.5-3.5 over the course of the long-term tests. An additional mercury-sampling probe was located after the sorbent injection point, but upstream of the SD, in order to observe any in-flight removal. No mercury removal was observed in-flight nor across the SD.

The cleaning frequency of the baghouse increased to every three to four hours, as compared to six to eight hours during baseline operation (i.e. no sorbent injection). However, the slurry feed to the SD was not held constant during long-term testing because of coal sulfur variations. These coal sulfur variations did not occur during the baseline testing. The slurry feed rate can affect the frequency of cleaning; therefore, it is not possible to quantify the contribution of the sorbent injection to the compressed cleaning cycle. It is estimated that the added particulate loading due to sorbent injection was nominally 0.2% at 1 lb/MMacf. It is unlikely that this small increase in

loading could influence the cleaning frequency of the baghouse. In addition to a change in cleaning frequency, a 4 - 6% increase in opacity was observed for a very short time period (< 5 minutes) immediately after each baghouse clean.

CONCLUSION

Six sorbents were tested on Stanton Station Unit 10 for their ability to remove flue gas mercury. Two of the chemically treated sorbents (ST BAC and Norit E-3) were able to achieve mercury removals greater than 90% across the spray dryer/baghouse combination at sorbent injection rates as low as 1.5 lb/MMacf. In contrast, the non-treated sorbents were limited to 75% mercury removal, even at injection rates as high as 6 lb/MMacf. The Norit E-3 sorbent was selected for 24 days of continuous sorbent injection testing. During the long-term tests, an injection rate of 1 lb/MMacf was maintained in order to achieve 65-75% mercury removal across the spray dryer/baghouse combination. The resulting outlet mercury concentration was in the general range of 2.5-3.5 $\mu\text{g}/\text{Nm}^3$. The most notable change in plant operation during sorbent injection was a doubling of the baghouse cleaning frequency. The increased particulate load to the baghouse was estimated to be less than 0.2%. Therefore, it is unlikely the increase in cleaning frequency is attributable to sorbent injection.