FULL-SCALE EVALUATION OF MERCURY CONTROL AT GREAT RIVER ENERGY'S STANTON GENERATING STATION USING INJECTED SORBENTS AND A SPRAY DRYER/BAGHOUSE

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To be presented at the 2002 Air Quality III Conference, Session A3b

Abstract

In December 2000, EPA announced that it would regulate mercury emissions from coal-fired boilers under Title III of the Clean Air Act Amendments of 1990. However, there is limited information available on the capability of existing pollution control technologies for mercury control. Since 1992, EPRI has been assessing the performance of sorbent injection for mercury control in pilot-scale systems installed at full-scale facilities. Much of this data indicates that sorbent injection is one of the most promising technologies to reduce mercury emissions from power generation facilities.

Great River Energy is working with EPRI to evaluate mercury emissions and control options for its plants. This paper represents efforts to characterize emissions at Great River Energy's Stanton Station, Unit 10 and determine the effectiveness of sorbent injection for mercury control for a spray dryer / baghouse configuration. Results from parametric testing using four different sorbents will be presented.

Introduction

On December 14th 2000, the U.S. Environmental Protection Agency (EPA) announced its intent to regulate mercury emissions from coal-fired boilers under Title III of the Clean Air Act Amendments of 1990. EPA plans to issue final regulations by December 15th 2004 and is expected to require compliance by 2008. It is thus very important for utilities to determine the amount of mercury emissions from their power plants, the options for

reducing mercury emissions and their cost effectiveness, and the potential impact on power plant operation and other air pollutant emissions.

The injection of activated carbon or other sorbents upstream of a particulate control device is one of the most promising methods for controlling mercury emissions from utility boilers with electrostatic precipitators (ESPs) and fabric filters. A number of studies carried out at the bench, pilot-, and full-scale have examined the influence of carbon type, carbon structure, carbon surface chemistry, injection method (dry or wet), amount of carbon injected, and flue gas temperature on mercury removal. Results have indicated that a wide variety of factors may influence the mercury removal obtained with sorbent injection upstream of an ESP or fabric filter baghouse. These factors include the mercury species being removed (oxidized vs. elemental), the flue gas composition, process conditions (e.g., temperature), sorbent characteristics (e.g., size), and the presence of other active surfaces (e.g., fly ash). Results have shown that although general trends between different sorbents and test conditions exist, sorbent performance tends to be site specific depending upon the exact nature of the flue gas at a particular site. Notably few of these data sets, which have included various fuel types and particulate control configurations, are on spray dryers or lignite coal. Where spray dryers were tested, testing was done at the inlet and outlet of the whole system, and data were not available to show individual mercury control performance of the spray dryer vs. the baghouse. This site-specific information is key to predicting and planning mercury control options for a given unit.

Great River Energy (GRE) is working with EPRI to evaluate mercury emissions and control options for its plants. Full-scale activated carbon injection tests were conducted at GRE's Stanton Generating Station. Stanton Station, which fires lignite coal, was included in EPA's Information Collection Request (ICR)[1] testing, and little native mercury removal was seen. In the tests reported herein, four activated carbons were evaluated as mercury sorbents. Mercury removal across the spray dryer and across the baghouse of Stanton Unit 10 was measured with and without sorbent injection, and at various injection rates. This paper summarizes the effectiveness of activated carbon injection before a spray dryer-baghouse (SD-BH) for mercury control at Stanton Station, Unit 10. For this effort, EPRI contracted with Apogee Scientific, Inc to design and fabricate the activated carbon injection system and conduct activated carbon injection testing and mercury measurements (using Apogee's semi-continuous mercury emissions monitor).

Mercury Removal across Spray Dryers - Background

Data from 20 units using a fabric filter as either the primary or polishing particulate control device have been reviewed to evaluate the native removal across a fabric filter[2]. This data was available through EPA's ICR database[1] and through other DOE and EPRI programs. This data set of 20 triplicate tests has several variables incorporated within it, including with and without spray dryer, three coal types (subbituminous, bituminous, lignite), a blend of coals, and temperature ranging from 160 to 360 ^{o}F. While this data set does serve to provide trends, those trends may not be comprehensive when applied to an

individual unit because of the limited quantity of data and the large number of influences on mercury removal from a given unit. The trends observed from the 20-unit set, shown on Figure 1, are described here, and provide the background for the results discussion from Stanton Station.

The data collected across SD-BH combinations provide insight into the effect of a spray dryer on the effectiveness of particulates such as fly ash or untreated sorbents on mercury removal. The clearest trend on Figure 1 indicates that for subbituminous coal, the mercury removal on plants with spray dryers (~5-39%) was lower than for the three plants without spray dryers (~55-82%). This occurred in spite of the lower temperature of the fabric filter associated with the spray dryer units, which would usually improve mercury removal. Most of the vapor-phase mercury is expected to be in the elemental form when burning subbituminous coals, and this expectation was confirmed when the inlet mercury speciation measured both with the Ontario Hydro Method and with continuous mercury analyzers indicated that the inlet mercury was elemental for the plants included in this evaluation. Elemental mercury is not readily removed in a spray dryer. Because the overall SD-BH removal was low, it appears that the spray dryer removes components from the flue gas that are critical to mercury removal by subbituminous fly ash collected in a baghouse. Chloride in the coal can result in HCl in the flue gas. It is possible that HCl, or another component removed by a spray dryer, enhances mercury removal by subbituminous fly ash. HCl is also a critical component for untreated activated carbon to be effective in removing elemental mercury. Thus, for plants with low-chloride coals, it is possible that the mercury control effectiveness of baseline fly ash or activated carbon injection into a baghouse with an upstream spray dryer will be suppressed.

Four lignite-firing units are shown on Figure 1, three with spray dryers (one of which is Stanton Station), and one with only a baghouse. The maximum mercury removal seen in these units is about 21%, the lowest of any fuel type. Mercury removal was low for the lignite plants regardless of temperature or the presence of a spray dryer (note that the temperature of the standalone baghouse data point is fairly high at 360^{o}F, which may contribute to the poor performance of the fly ash for mercury control). If HCl is a critical component in the flue gas as discussed above in reference to subbituminous coals, lignite coal may also produce a similar effect (of suppressed mercury removal by the ash) with the presence of a spray dryer.

When a baghouse is present, mercury removal for plants burning bituminous coals is high whether or not a spray dryer is used. Figure 1 shows that bituminous coal mercury removals range from about 85 to close to 100%. Most of the vapor-phase mercury is in the oxidized form at the inlet to the spray dryers, and bituminous coal has higher native chloride concentrations than lignite or subbituminous. For these bituminous-fired plants, it is expected that the spray dryer removed a significant fraction of the oxidized vapor-phase mercury and that a high enough fraction of the other critical flue gas components, such as HCl, are present downstream of the spray dryer so that the fly ash is effective at removing most of the remaining vapor-phase mercury, including any in the elemental form.

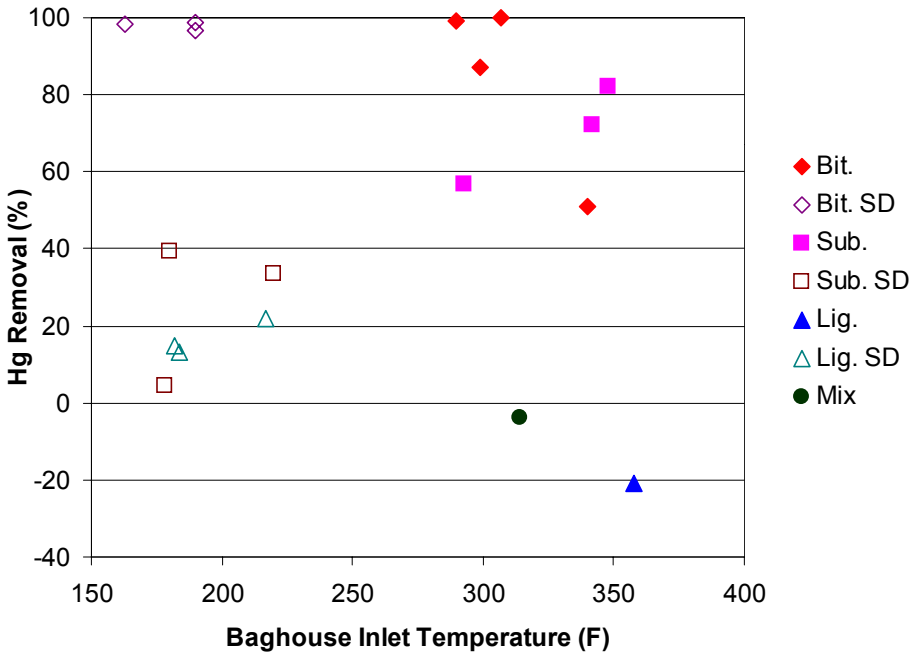

Figure 1. Mercury removal without sorbent injection for several units with baghouses.[2]

Stanton Unit 10 Facility Description

GRE's Stanton Generating Station is located in Stanton, ND. Mercury control testing at Stanton Station was performed on Unit 10. Unit 10 consists of a 60 MW Combustion Engineering PC-tangential-fired boiler retrofitted with low-NOx burners that fire North Dakota lignite coal. Downstream of the air preheater, flue gas passes a triple-wheel pebble lime spray dryer followed by a reverse-gas baghouse with sonic horn cleaning. Research Cottrell designed the SD-BH. Flue gas exits the baghouse at approximately 190°F and flows to the exit stack. Mercury measurements were made: (1) upstream of the spray dryer prior to activated carbon injection; (2) downstream of the spray dryer but upstream of the baghouse; and (3) downstream of the baghouse, by two mercury S-CEM units. There was nominally 1 second of residence time between carbon injection and the entrance of the spray dryer. Figure 2 illustrates the Unit 10 gas path.

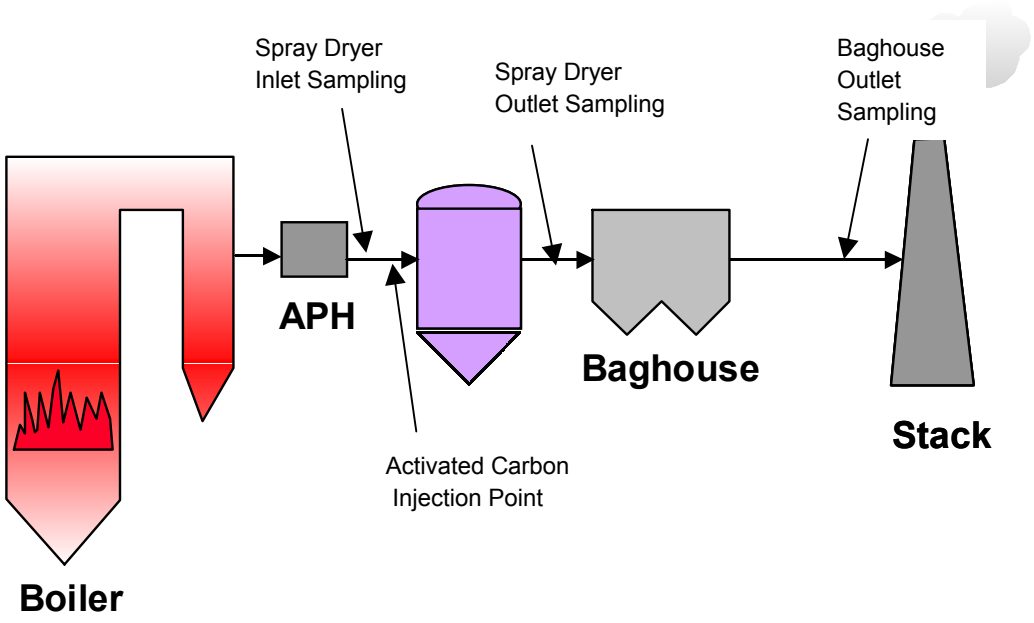

Figure 2. Layout of Unit 10 at Stanton Generating Station.

An analysis of the coal burned during testing at Stanton Station is shown in Table 1.

Table 1. Stanton Unit 10 Coal Properties, 4/24/02

Paramete/r	Description
Mercury and Chlorine	
Mercury (ppm – as received)	0.0489
Chlorine (ppm – as received)	30
Proximate Analysis, % as received	
Moisture	37.81
Volatile Matter	26.12
Fixed Carbon	28.69
Ash	7.38
Heating Value (Btu/lb)	7203
Ultimate Analysis, % as received	
Hydrogen	2.19
Carbon	34.51
Nitrogen	0.52
Sulfur	0.64
Oxygen	16.95

Equipment Description

Sorbent Injection Equipment

The sorbent feeder used at Stanton Station can deliver from 0 to 200 lb/hr Darco FGD activated carbon. Feed rates for other sorbents are similar. The feed assembly is mounted on a load cell to provide continuous feedback of sorbent weight. The revolutions of the helix are also monitored and recorded. In addition, the feed rate was checked manually with a batch collection before and after each test run.

The sorbent was carried from the feeder to a manifold near the injection location through a 1 1/2-inch line. The manifold delivered sorbent to four injection lances installed upstream of the spray dryer. Five pairs of nozzles oriented at 45 degrees were placed at equal spacing along the length of each injection lance. The sorbent was injected co-current to the gas flow.

Mercury Monitor

Two semi-continuous mercury emissions monitors (S-CEM) were used during this program to provide near real-time feedback during baseline, screening, and long-term testing. Continuous measurement of mercury at the inlet and outlet of the particulate collector is considered a critical component of a field mercury control program where mercury levels fluctuate with boiler operation (temperature, load, etc.) and decisions must be made concerning parameters such as sorbent feed rate and cooling. The analyzers used for these tests consisted of a cold vapor atomic absorption spectrometer (CVAAS) coupled with a gold amalgamation system (Au-CVAAS). The system is calibrated using vapor phase elemental mercury. The S-CEMs were configured to automatically switch from measuring total vapor phase mercury to vapor phase elemental mercury during these tests.

Sorbent Descriptions

In order to evaluate the potential of a mercury sorbent and model its performance, the equilibrium adsorption capacity and characteristics of the sorbent must be known. Scientists at URS Corporation conducted fixed-bed adsorption (breakthrough) tests to generate sorbent equilibrium data for the sorbents evaluated during this program.

The capacity of a mercury sorbent is determined by exposing a bed of the sorbent for several hours to gas containing mercury and measuring the effluent from the bed until no mercury is removed by the bed (100% breakthrough). The capacity is typically normalized to 50 $\mu g/Nm^3$ because the capacity of a sorbent is dependent on the concentration of the mercury in the inlet gas stream. For most carbon-based sorbents, the capacity is directly proportional to the inlet mercury. For example, the capacity at 50 $\mu g/Nm^3$ is nominally five times that at 10 $\mu g/Nm^3$.

Four carbon-based sorbents were evaluated for mercury control at Stanton Station during the parametric test period. The sorbents included three commercially available carbons: FGD, HOK300S, and CB.

- Darco FGD is a Texas lignite coal-based commercial carbon from Norit Americas.
- DESOREX HOK300S German is lignite coal-based commercial carbon available in the Unites States through Donau Carbon.
- Type CB (IAC) is a coconut-shell-based carbon that is iodine impregnated and available commercially through Barnebey Sutcliffe.
- LAC0101 is a lower cost experimental carbon made from North Dakota lignite. It is produced by ISGS.

Physical properties and equilibrium adsorption capacities measured in laboratory simulated flue gas representing gas upstream of the spray dryer at Stanton for the four sorbents are included in Table 2. Due to the extra processing steps for the iodine-impregnated type CB, the cost of this sorbent was over $7/lb as compared to nominally $0.5/lb for the FGD.

Table 2. Properties of Sorbents Evaluated at Stanton Station

Activated Carbon Type/Name	**Mean diameter** (μm)	**Laboratory Equilibrium Ads. Cap. (μg/g @ 50 μg/Nm^3)**
Darco FGD	18 μm	450[a]
Type CB (IAC)	25 μm	550[b]
DESOREX HOK300S	19 μm	1449[b]
LAC0101	19μm	670[a]

[a]Test temperature 325°F
[b]Test temperature 275°F

Table 2 provides significant information to project the relative performance of the four carbons. The key information includes:

- The mass mean diameter of the carbons is similar (18 to 25 μm)
- Many carbon-based sorbents have sufficient capacities that the sorbents will be removed from the gas stream long before they approach their equilibrium capacity. This is referred to as being above the "threshold capacity", which means that variations between capacities become irrelevant for dry sorbent injection. Therefore, although the equilibrium adsorption capacities of the sorbents chosen

for testing at Stanton varied, they all are sufficiently high, and when injected into flue gas similar to the laboratory simulated flue gas, the performance was expected to be similar.

- The data shown on Table 2 were obtained in simulated flue gas representative of conditions upstream of the spray dryer. Because the sorbents tested at Stanton were injected into a spray dryer, it was expected that the effectiveness of the untreated sorbents collected on the downstream baghouse would be limited because of the critical flue gas components, such as HCl, that are removed by the spray dryer. The only treated sorbent evaluated during this test program was Type CB. CB is impregnated with iodine and this treatment process allows the activated carbon to effectively remove elemental mercury in the absence of HCl.

Summary and Discussion of Results

The mercury S-CEMs at Stanton Station operated continuously from April 23 through April 30, 2002. From April 23 through April 28, a series of parametric tests were conducted to characterize the performance of each sorbent. The vapor-phase mercury concentration at the inlet to the spray dryer at Stanton ranged from 5.5 to 9.5 $\mu g/Nm^3$ during the test period and was primarily elemental mercury, as would be expected for a low chlorine lignite coal. No measurable mercury removal was noted across the SD-BH in the absence of sorbents. Coal and ash samples collected during baseline (no sorbent injection) confirm that insignificant mercury was removed by the SD-BH.

The mercury removal measured across the spray dryer (SD) alone and across the SD-BH resulting from injecting different concentrations of each of the four sorbents is shown in Figures 3 and 4 respectively. The three untreated sorbents, FGD, LAC, and HOK, all demonstrated similar performance. This reaffirms the projection that the potentially lower cost carbons (such as LAC, HOK) may work as well as other untreated carbons due to mass transfer limitations.

Little data is available to compare the mercury removal measured across the baghouse at Stanton during sorbent injection with mercury removal measured across other baghouses without spray dryers. A pilot-scale (600 acfm) DOE and EPRI-funded demonstration was conducted at Comanche Station in the late 1990's that indicated higher removal could be achieved in this PRB coal flue gas than measured at Stanton for a similar injection temperature. For example, during tests at Comanche Station, the removal across the baghouse (no SD) at an FGD injection concentration of 3 lb/MMacf and a temperature of 330^{o}F (also the inlet temperature of the spray dryer at Stanton) was nominally 70 to 80%[3] as compared to 40 to 45% measured at Stanton across SD-BH (18% across the SD, and 30% across the BH). The mercury removal during Darco FGD carbon injection upstream of the full-scale COHPAC baghouse at Gaston Station (low-sulfur bituminous coal), at 3 lb/MMacf was nominally 85 to 95%[4]. Although COHPAC is a different configuration (e.g. higher air-to-cloth ratio, lower fly ash loading, different bag construction and material, different cleaning frequency and force) the data suggests that higher removal is possible. The Darco FGD results from parametric testing at Stanton are presented with those from Gaston and Comanche for comparison in Figure 5.

Similar lower mercury removal effectiveness was observed in earlier slipstream pilot tests at Stanton when carbon was injected downstream of the SD before a BH.[5] These results indicate that the SD may be removing important flue gas components such as HCl that can improve the adsorption effectiveness of activated carbon, as suggested in the background section of this paper.

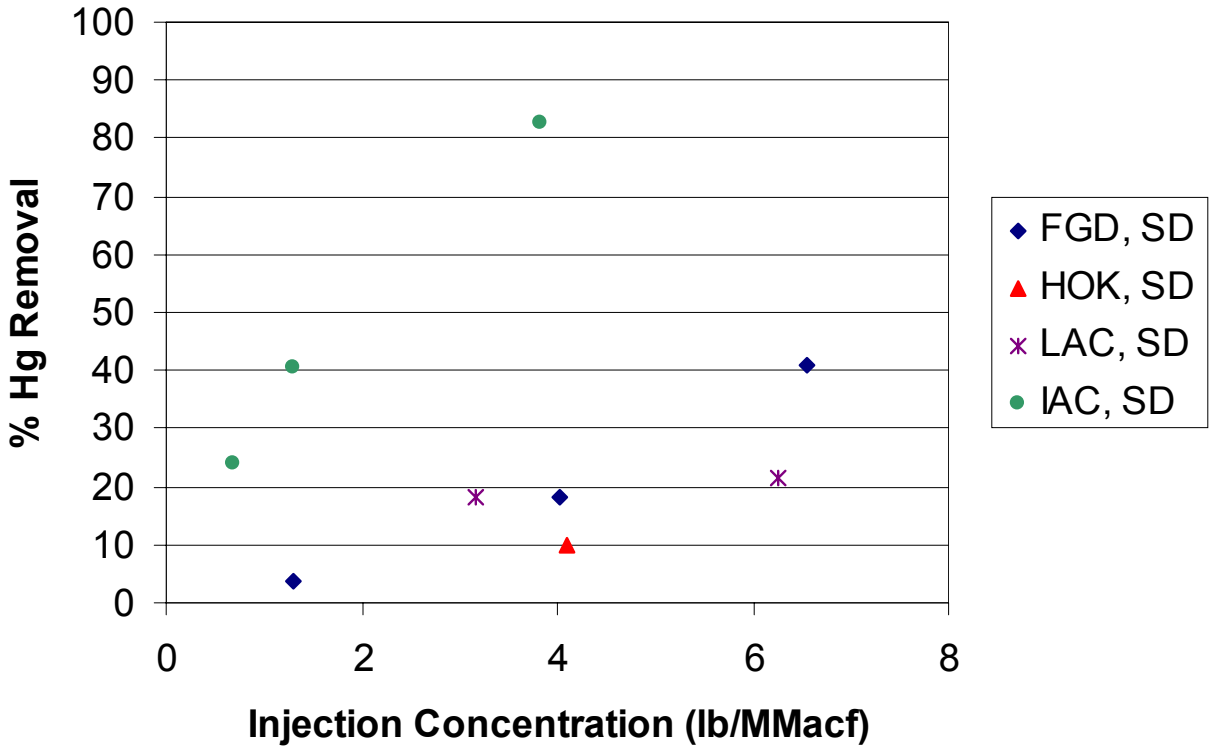

Figure 3. Mercury removal measured across the spray dryer at Stanton Station during parametric testing.

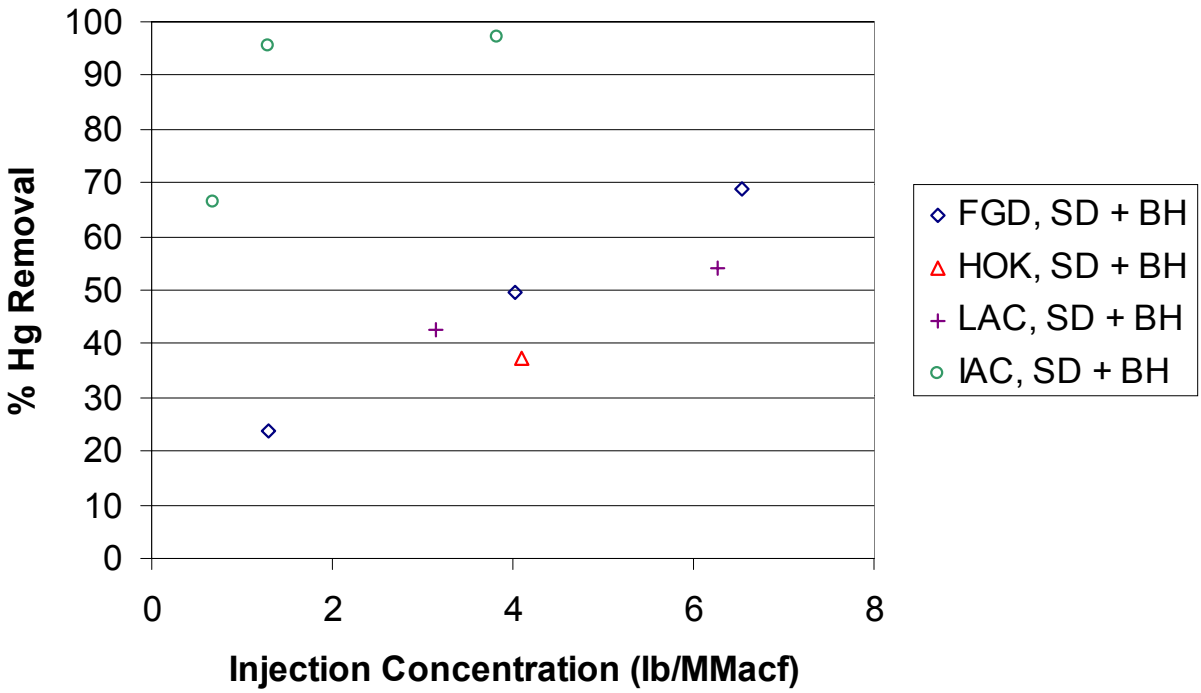

Figure 4. Mercury removal measured across the spray dryer and baghouse at Stanton Station during parametric testing..

The average removal achieved across the SD-BH with untreated activated carbon sorbents was 81% at an injection concentration of 6.1 lb/MMacf during the extended FGD tests. This is somewhat higher than the 70% removal achieved during parametric testing and indicates the effect of prolonged injection on mercury removal.

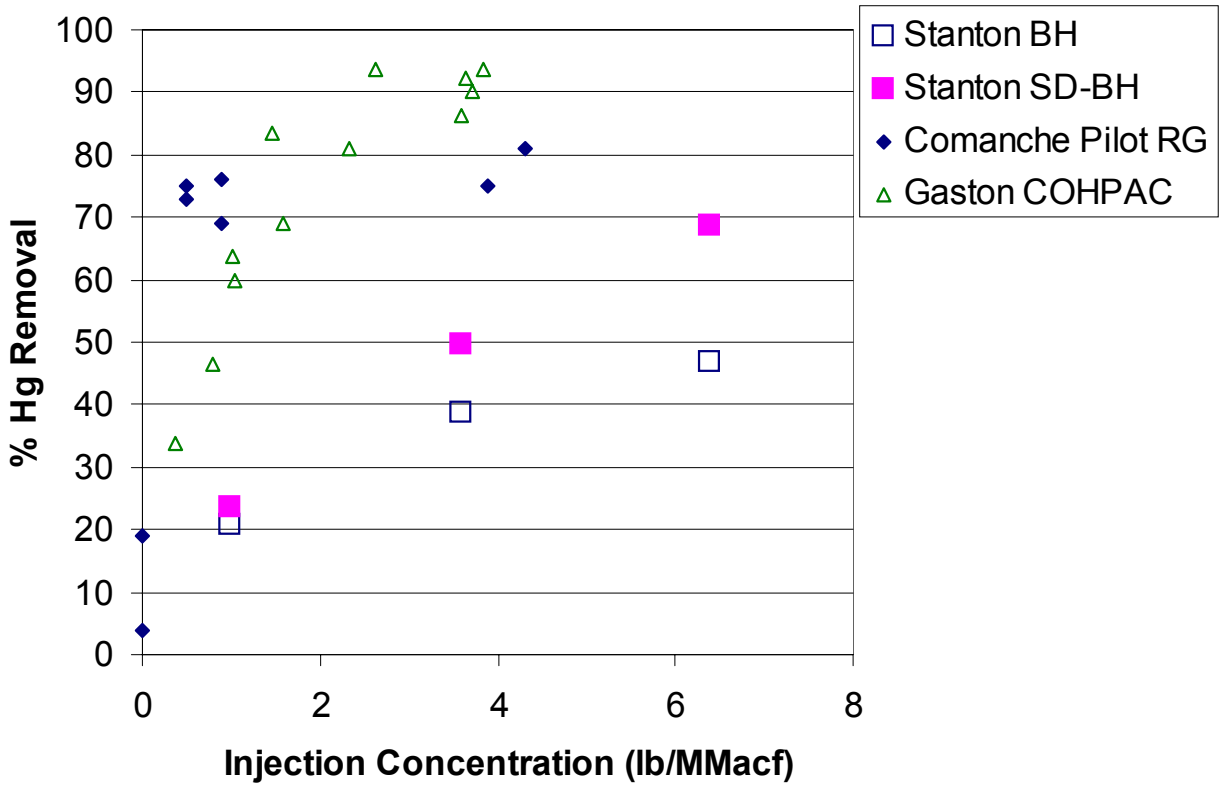

Figure 5. Comparison of results from Darco FGD activated carbon injection evaluations at Comanche Station (slipstream pilot RG baghouse), Gaston (full-scale COHPAC) and Stanton (full-scale SD-BH).

The results from the iodine-impregnated carbon (Type CB IAC) injection at Stanton Station were significantly better than the untreated carbons. At 0.7 lb/MMacf, 41% mercury removal was achieved across the SD and 96% removal was achieved across the SD-BH. At an injection rate of 4.0 lb/MMacf, 83% mercury removal was achieved across the SD and 97% mercury removal was achieved across the SD-BH. This improved performance is a further indication that the spray dryer removes a component critical to the effective performance of untreated activated carbon.

Another trend apparent from testing is the effect on mercury removal of bag cleaning and sorbent accumulation on the bags. The mercury concentration measured at the outlet of the baghouse is compared to the pressure drop across the baghouse in Figure 6. As shown, the saw tooth pattern on the baghouse outlet mercury trend graph clearly defines the baghouse cleaning cycles. As sorbent accumulates with time, the mercury removal increases. Immediately following a clean, the mercury concentration is the highest and the removal is the lowest.

The Darco FGD injected during the extended testing (nominally 6.1 lb/MMacf) represents an increase to the overall particulate loading to the baghouse of nominally 1%.

No effect on the cleaning frequency or rate of pressure drop increase across the baghouse was noted as a result of carbon injection.

The slurry and water feed rate to the spray dryer varied during extended FGD testing. These variations did not appear to affect the mercury concentration measured at the outlet of the spray dryer, however. No correlation between the water or slurry feed and the mercury concentration were noted.

No increase in outlet particulate emissions as measured by the stack opacity monitor due to sorbent injection was noted during the extended FGD testing or parametric testing.

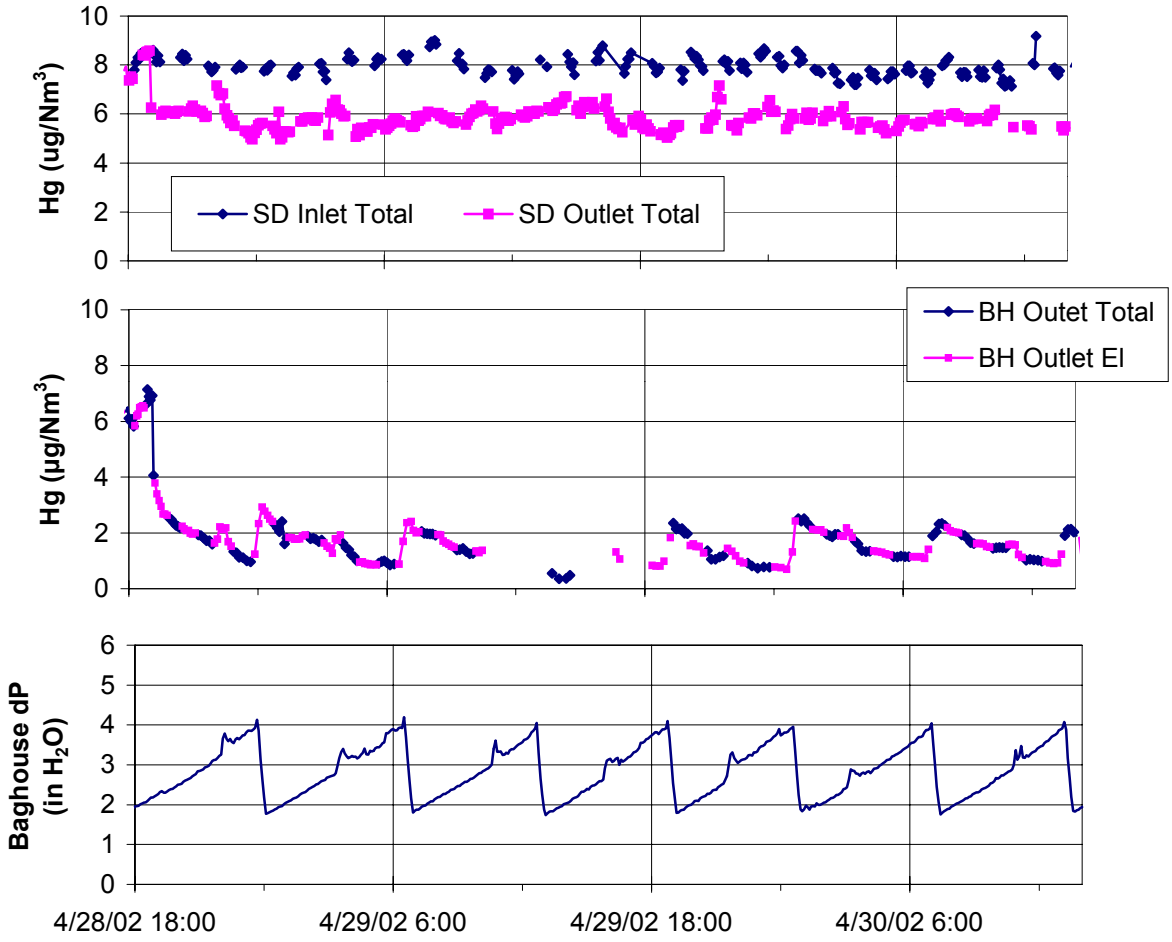

Figure 6. Mercury concentrations and baghouse pressure drop during extended Darco FGD injection tests.

Conclusions

- The mercury removal achieved across the SD-BH with untreated activated carbon injection was 40 to 45% at an injection concentration of 3 lb/MMacf as compared to > 90% removal with treated carbon (iodine impregnated) for the same injection rate. Thus, a SD-BH used for SO_2 control on ND lignite fired units can have a detrimental effect on mercury control when untreated activated carbon is injected before the SD. Iodine impregnated carbon does not appear to be affected by the SD and was significantly more effective at removing mercury at this site.

- With iodine-impregnated carbon, 96% mercury removal was achieved during a short test across the SD-BH at 0.7 lb/MMacf. The average removal achieved across the SD-BH with untreated activated carbon injection was 81% at a Darco FGD injection concentration of 6.1 lb/MMacf. Although, the IAC costs > $7/lb versus nominally $0.5/lb for FGD carbon, it may be possible to use a much lower concentration of IAC than untreated carbon for this application to partially offset the higher per pound sorbent cost.

- The performances of three different untreated activated carbons evaluated during this program (FGD, HOK, LAC0101) were similar.

- The mercury removal across the baghouse is affected by the accumulation of sorbent during the cleaning cycle. At an injection concentration of nominally 6.4 lb/MMacf, the mercury removal immediately before a clean was 90% while the removal immediately following a clean was 70%. The time between cleans during testing was typically between 6 and 7 hours.

References

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