Predicting Mercury Sorbent Performance in a Fabric Filter: Comparison of Slipstream and Full-Scale Results

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ABSTRACT

Dry sorbent injection, as with activated carbon, has shown great potential to control mercury emissions from coal-fired power plants. However, the selection of appropriate candidate sorbents and injection concentrations is complicated by the many interactions between activated carbon, particulate, and the variable constituents in flue gas. These interactions cannot be simulated using traditional laboratory methods to determine the mercury removal capacity of potential sorbents.

To assist in the sorbent selection process, a new sorbent screening device was designed by ADA-ES. This portable device can be taken to any power plant and used to extract and test an actual flue gas sample from anywhere in the process. It is designed to simulate the gas velocity, temperature, sorbent loading, and ash loading of a full-scale fabric filter. It is equipped to test several sorbents simultaneously. Because the device simulates a section of a full-scale fabric filter, results can be directly scaled to full-scale injection applications.

The sorbent screening device (SSD) was recently used to evaluate over 20 sorbents at Sunflower Electric's Holcomb Station (360-MW, PRB coal, dry scrubber, baghouse) as part of the DOE Phase II Mercury Program DE-FC26-03NT41986. The results of the screening tests were used to select several sorbents for the ongoing full-scale demonstration. This paper will describe the design and operation of the SSD and present data showing good agreement between screening tests and full-scale performance.

INTRODUCTION

Due to pending Federal and State mercury regulations, many power companies have begun to explore various methods for achieving compliance. One method, dry sorbent injection, has shown great promise in the last several years (Durham, 2003). However, researchers are finding that the performance of a particular sorbent cannot be accurately predicted for a given site due to the large variations in coal composition and plant equipment layout.

ADA-ES, Inc., has developed a new, slipstream device that can be used to screen several sorbents prior to full-scale implementation. This information can then be used by the plant to predict the performance of existing equipment or to evaluate and develop future options for mercury control. Although the device best simulates a fabric filter, data from screening tests can also provide important information pertaining to ESP applications.

This paper is organized in three sections. The first section provides information on the design and operation of the Sorbent Screening Device (SSD). The next section presents the results of sorbent screening tests recently completed at Sunflower Electric's Holcomb Station. The final section compares the results of screening tests to full-scale results.

Sorbent Screening Tests

Apparatus

Several groups have conducted mercury sorbent screening tests over the past few years and the performance of the sorbents has been reported as the maximum mercury that can be collected by the sorbent, or the capacity of the sorbent (Carey, 1999). Although this data provides valuable information to compare the relative performances of several sorbents, it does not provide a direct indication of the injection concentration required to achieve a given level of mercury removal. The device described in this paper allows simultaneous comparison of several sorbents, provides an indication of the maximum mercury removal achievable with a sorbent, and provides an estimate of the amount of sorbent required to achieve various mercury removal levels in a full-scale application.

The SSD is shown in Figures 1 and 2. It consists of a heated enclosure that houses three sample filters, and is designed to simulate the range of gas velocities, temperature, sorbent loading, and ash loading typical of full-scale fabric filters. Tests can be conducted on site with extracted flue gas or with simulated flue gas in the laboratory. Sorbent loading can be varied to provide data over a range of injection concentrations, nominally 1 to 10 lb/MMacf. A typical test lasts up to 12 hours or can be terminated when the outlet mercury concentration equals the inlet mercury concentration (100% breakthrough).

The important parameters that are measured and controlled consist of the SSD temperature, the inlet and outlet elemental mercury concentration in the flue gas, the gas flow rate through each of the filters, and the weight of the sorbent sample applied to the filter media. The addition rate of any flue gas conditioning agents is also controlled. The mercury semi-continuous emissions monitors (SCEMs) are calibrated at the beginning and end of each run for quality assurance.

At Holcomb, flue gas was extracted from between the dry scrubber and baghouse using an inertial separation probe to remove particulate. The gas was then transported through a heated line to the SSD. Test samples consisted of a mixture of sorbent and Holcomb baghouse ash, and were evenly deposited onto glass filter paper in appropriate concentrations. Treated gas exited the heated box through chemical impingers, to convert all mercury to elemental mercury, and a chiller to remove moisture. The total vapor-phase mercury concentration was measured at the inlet and outlets of the samples using CVAA Hg SCEMs (Sjostrom 2002a). Flue gas conditioning agents could also be added ahead of the sample filters to evaluate the effect of conditioning agents on sorbent performance.

Figure 1. Sorbent Screening Device—Sample Filters.

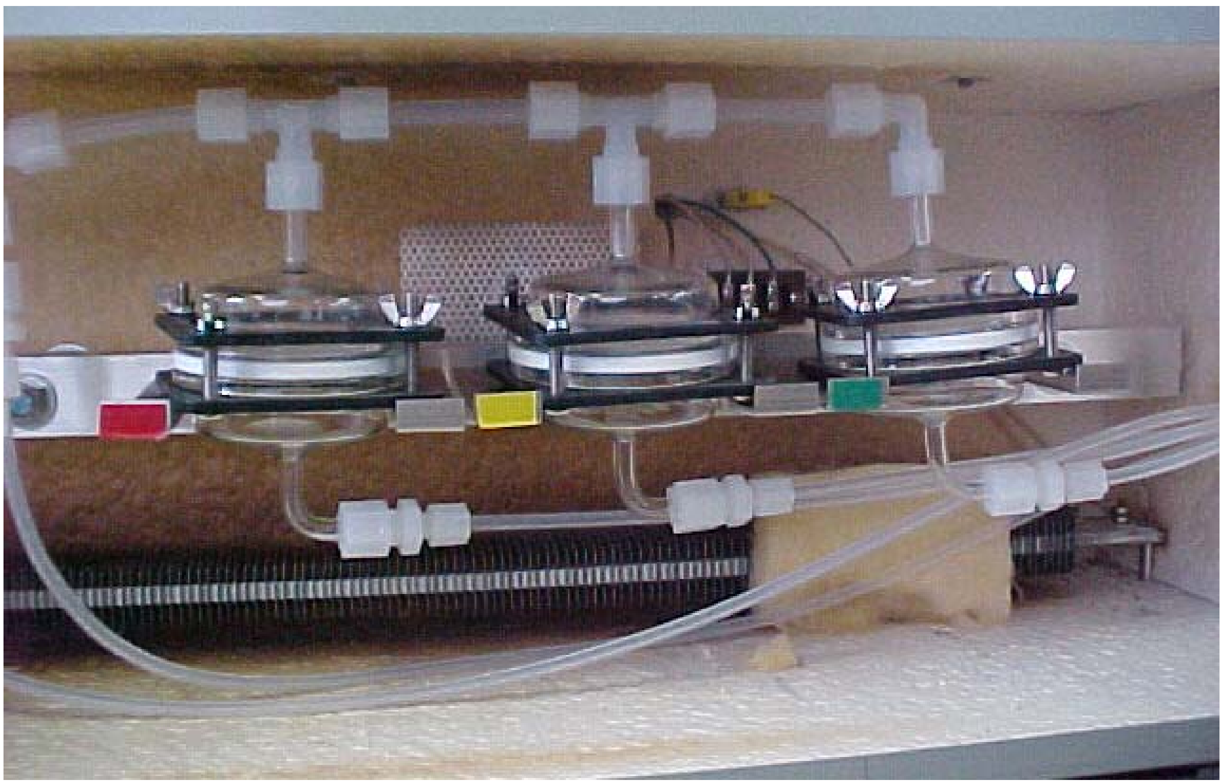


Figure 2. Sorbent Screening Device—Heated Box and Impingers.

Holcomb Sorbent Screening Tests

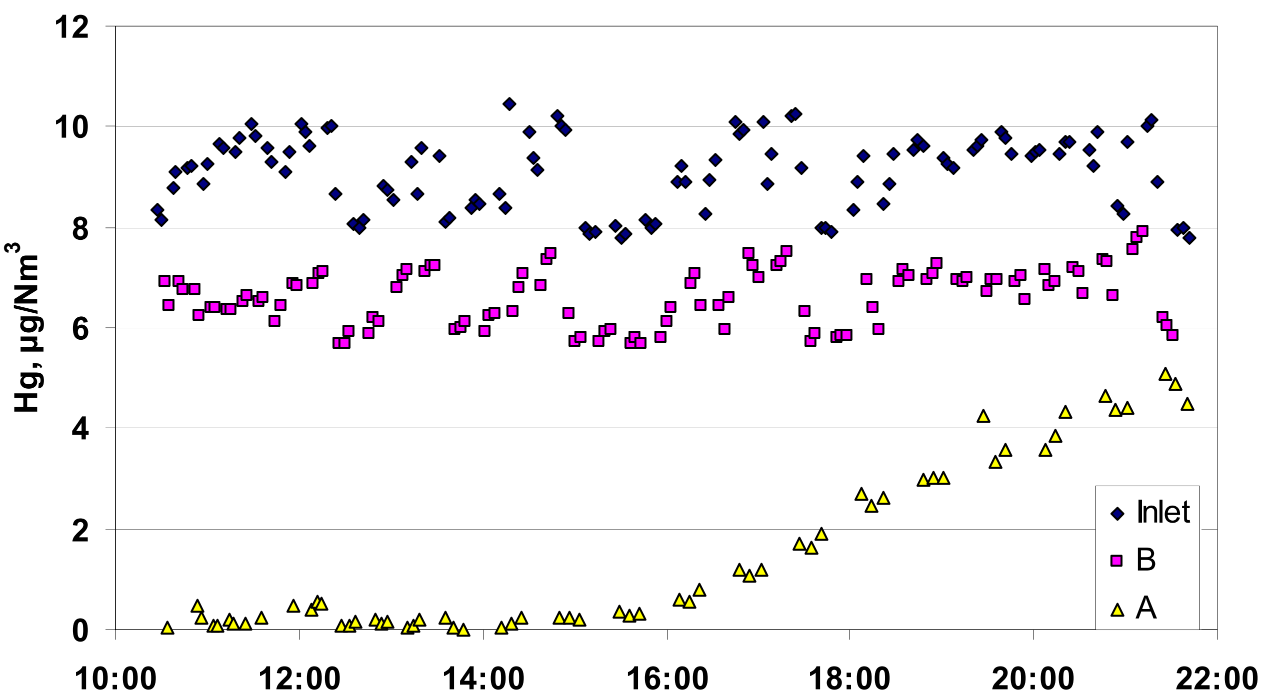
The Holcomb Power Station is a 360-MW, PRB-fired unit utilizing a spray dryer and baghouse for pollution control. Sorbent screening tests were completed between February 23 and March 2, 2004. Overall, 23 tests were conducted with 20 different sorbents from 10 different suppliers. The sorbents ranged from commercially available activated carbon to straight baghouse ash to experimental sorbents treated with a variety of conditioning agents such as sulfur, iodine, or other halogens.

CB200xF, an iodine-treated sorbent available from Calgon, was designated the high-benchmark sorbent based upon results from tests sponsored by EPRI and GRE at Stanton Station Unit 10 (Sjostrom, 2002b). Stanton Unit 10 fires a North Dakota lignite coal and has a spray dryer absorber and fabric filter for SO_2 and particulate control. Based upon the chlorine concentrations in the coal from Stanton and the coal from Holcomb, sorbents should demonstrate similar performance at these two sites. Sorbent B, DARCO FGD available from NORIT Americas, was identified as the low-benchmark sorbent, also based upon results from Stanton testing. Prior to testing at Stanton, URS Group conducted screening tests in their laboratory with each of these sorbents at conditions simulating the flue gas at the inlet to the SDA. The resulting equilibrium adsorption capacity for each of these sorbents was 450 µg/g normalized to 50 µg/Nm^3 for

DARCO FGD, and 550 µg/g normalized to 50 µg/Nm^3 for CB200xF. It is expected that the capacity of the DARCO FGD would be lower at the outlet of the SDA because of the enhancing effect of halogens present in the flue gas upstream of the SDA. The CB200xF should remain unchanged in the presence of the SDA.

Figure 3 shows raw data from a typical screening test. The y-axis represents the total elemental mercury concentration at the inlet and outlets of the three sample filters as measured by the CVAA SCEMs. For all runs in this test, the sorbent loading was chosen to represent equivalent injection concentrations tested during previous full-scale test programs. All sorbents were evaluated at the same filter loading for comparison. For the run shown in Figure 3, the performance of the two benchmark sorbents are compared—DARCO FGD (Sorbent B), and CB200xF (Sorbent A). The figure demonstrates the large variation in mercury removal performance for the two sorbents. Sorbent A achieved nearly 100% removal for about 5 hours and was still getting about 40% removal after 11 hours, while Sorbent B removed approximately 30% of the incoming mercury throughout the test.

Figure 3. Raw Data from a Typical Sorbent Screening Test.



The data in Figure 3 can be used to predict the performance of a full-scale application **AND** to estimate the sorbent loading needed to achieve the desired level of mercury removal. This type of information cannot be calculated directly from the usual information provided by vendors or from laboratory tests using a bed of sorbent. Fixed-bed testing can provide both capacity and reactivity (slope of the breakthrough curve) data and this can be incorporated into a model for predictions. However, the applicability of the data is limited because sorbents are typically removed from the gas stream before the equilibrium capacity has been reached.

The equivalent sorbent injection concentration, in lb/MMacf, is calculated by the following equation:

Equivalent Concentration=(Sorbent Loading)/(Cumulative Gas Volume)/2

Therefore, if 0.01 g sorbent is preloaded onto a filter and the average flow for the first hour is 1 actual liter per minute, the equivalent loading is 5.2 lb/MMacf.

EC=0.01 g*(1 lb/454 g)/[1 lpm*(1 cf/28.32 l)*(60 min/hr)*1hr]/2*1E6 cf/MMacf
EC=5.2 lb/MMacf

The sorbent loading represents the amount of sorbent that would have collected on a section of a full-scale bag over the entire filtering cycle. To calculate the equivalent concentration, the loading is divided by two because the ***average*** amount of sorbent present on a full-scale bag between cleaning cycles is half the amount present on the bag at the end of the filtering cycle. For the sorbent screening tests, since the test sorbent is pre-loaded onto the filter before being introduced to flue gas, the *equivalent sorbent injection concentration* is much higher at the beginning of the test and decreases as the test progresses. In this example, if 90% mercury removal is achieved over the first hour, this indicates that 90% removal would be achieved in a full-scale application at an injection rate of 5.2 lb/MMacf. If the cumulative average mercury removal of this sorbent was 40% after 4 hours, this suggests that 40% removal would be achieved by this sorbent at an injection rate of 1.3 lb/MMacf (5.2/4).

For Sorbent A in Figure 3, the data indicates that over 95% mercury removal could be achieved with this sorbent in a full-scale application at an equivalent concentration of:

EC_A=0.01/454/(0.934/28.32*60*6)/2*1000000=0.93 lb/MMacf

For comparison purposes, the equilibrium adsorption capacity for Sorbent A can be extrapolated from the data collected at Holcomb by assuming the slope shown in Figure 3 continues until the mercury concentration at the outlet of Sorbent A equals the concentration at the inlet. For this test, the equilibrium adsorption capacity normalized to 50 $\mu g/Nm^3$ is 962 μg/g compared to 550 μg/g from the fixed-bed screening tests in laboratory.

The technique described above to calculate equivalent injection concentration was used to estimate the full-scale performance of all the sorbents tested at Holcomb. The mercury removal performance results of sorbents tested at Holcomb for three ranges of equivalent injection concentrations are shown in Table 1. This information was used as one of the criteria to select sorbents for full-scale testing.

Three sorbents are highlighted in the table: the two benchmark sorbents (Sorbent A and Sorbent B) and one of the sorbents chosen for additional full-scale testing at Holcomb (Sorbent F). Sorbent F, FGD-E3, is available from NORIT Americas. It was chosen for further full-scale testing at Holcomb because of its promising performance in the screening tests, relatively low cost ($0.65/lb compared to $0.42 for DARCO FGD and >$7.00/lb for CB200xF), and availability in the quantities required for the full-scale test for the program. The sorbents identified with "Mod" were studied with the addition of enhancing agents. Sorbents B and T showed significant improvement with the addition of enhancing agents, while Sorbent S did not.

Reviewing Table 1, it is apparent that some sorbents (such as Sorbent D) show little improvement at increased injection concentrations. This sorbent achieved fairly high removal early in the screening test and continued to remove mercury at the same level throughout the test. In Table 1, this translates to little improvement in performance at increasing injection concentrations. In comparison, Sorbent F also showed high removal early in the screening test but the performance degraded over time. This translates to high removal at high injection concentrations (96% at 3–4 lb/MMacf), but unlike Sorbent D, the resulting performance at lower injection concentrations was measurably lower (63% at 1–2 lb/MMacf). It is possible that the capacity of the sorbents in the previous two examples is similar, but it is obvious that their full-scale performance will be very different and either may be chosen for full-scale mercury control depending upon the level of removal required. For example, if the costs of the two sorbents are similar and only 70% mercury removal is required, Sorbent D would be the recommended sorbent because it can achieve >70% removal at low injection concentrations. However, if >90% mercury removal is required, Sorbent F would be recommended because it can achieve very high removal efficiencies at higher injection concentrations.

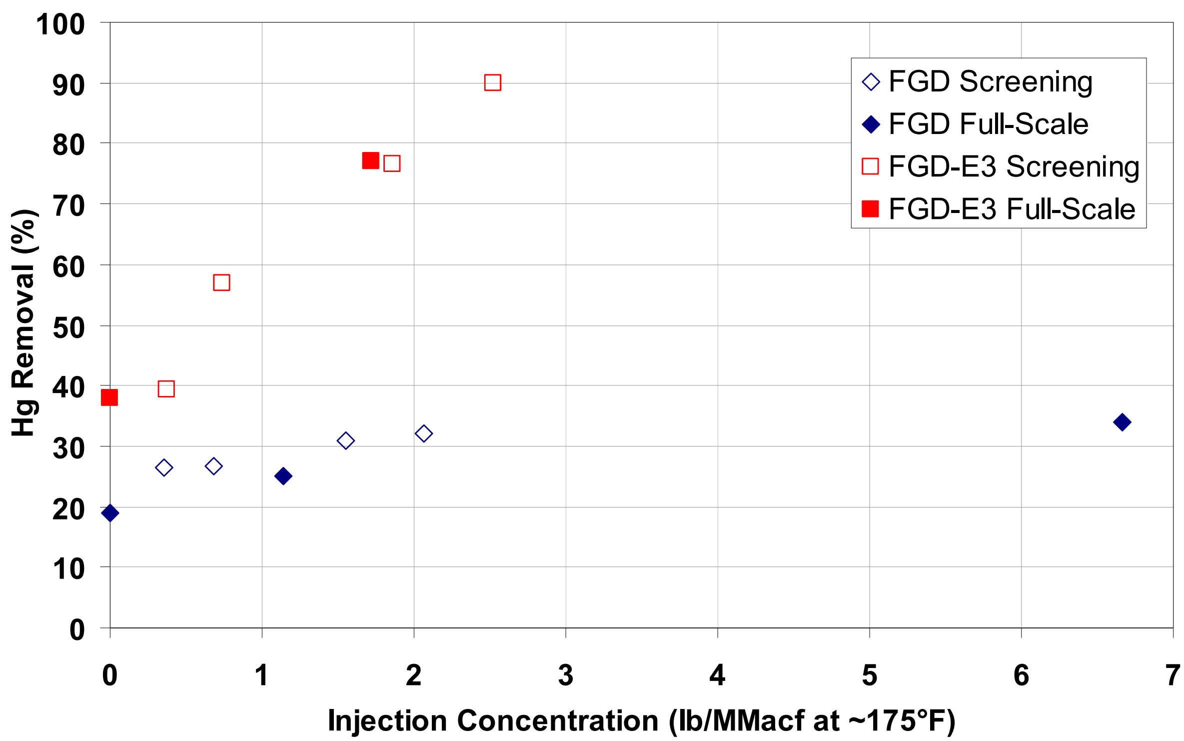
Table 1. Results of the Sorbent Screening Tests at Holcomb.

	Cumulative Average Mercury Removal, %		
Sorbent	**1–2 lb/MMacf**	**2–3 lb/MMacf**	**3–4 lb/MMacf**
A		94	99
D	85	85	89
C	79	88	91
F	63	82	96
G		78	93
Mod B	71	79	80
H	70	65	55
E	60	77	87
I	52	65	63
J	60	58	51
L	55	53	54
N	58	48	35
K	45	55	69
M		45	52
O	34	40	39
B	28	30	29
Mod T	22	28	36
Q	21	23	21
R	21	20	16
Mod S	17	15	12
S	14	13	10
P		16	23
T		4	0

Slipstream vs. Full-Scale Results

Sorbents B and F were chosen for further testing at full-scale at Holcomb as explained above. Figure 4 is a comparison of the results from the sorbent screening tests and full-scale parametric testing at Holcomb. The figure shows that the data from the SSD agrees very well with full-scale results. FGD-E3 clearly outperforms FGD as predicted by the SSD tests. It also confirms the prediction that FGD would not perform significantly better even at high injection rates. ADA-ES now feels confident that the SSD and corresponding method of data analysis can be used at any plant and with any sorbent to collect the data necessary to estimate the full-scale mercury removal performance of a fabric filter. Additional information on the full-scale results from testing at Holcomb Station are available elsewhere (Sjostrom, 2004).

Figure 4. Comparison of Sorbent Screening and Full-Scale Test Results.



CONCLUSIONS

- The newly developed ADA-ES sorbent screening device is capable of acquiring the data necessary to estimate the full-scale, fabric filter, mercury removal performance of a variety of sorbents and sorbent enhancement methods.

- Data from the SSD can be used by utilities to evaluate the performance and cost of implementing dry sorbent injection with existing equipment, or for the proposed installation of future fabric filters.

- The SSD accurately simulated the full-scale performance of DARCO FGD and FGD-E3 activated carbon at Sunflower Electric's Holcomb Station.

- Although the SSD best simulates a fabric filter, data from screening tests can also provide important information pertaining to ESP applications. The SSD will be modified and used at an "ESP-Only" site in September of 2004. Results from this study will be used to refine the data analysis procedure to better predict the performance of sorbent injection for mercury control in ESP applications.

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- Nebraska Public Power District
- Sunflower Electric Power Corporation
- Tri-State/Missouri Basin Power Project
- Westar Energy
- Western Fuels Association
- Wisconsin Public Service

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