EVALUATION OF LOW-ASH IMPACT SORBENT INJECTION TECHNOLOGIES AT A TEXAS LIGNITE/PRB FIRED POWER PLANT

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ABSTRACT

A sorbent injection test program was carried out at NRG Texas Power LLC's (NRG) Limestone Electric Generating Station. Limestone Station fires a 30/70 blend of Powder River Basin (PRB) and Texas Lignite, and is equipped with a cold-side ESP and a wet scrubber. The plant markets its fly ash for beneficial use, so development of a low ash impact mercury control technology is important to the economics of implementing a mercury control system at this site. Two different low-ash impact mercury control technologies were evaluated in parametric tests: a low-ash impact sorbent and Toxecon II™. The mercury removal effectiveness of these technologies was compared to activated carbon injection upstream of the ESP. Results from the parametric tests were used to select one sorbent and sorbent injection configuration for a subsequent two-month injection test. During the long-term test, mercury removal across the ESP was evaluated, and the effect of the injection system on the fly ash was monitored. This paper presents the results from the parametric tests only.

INTRODUCTION

Activated carbon injection (ACI) is a relatively low capital cost mercury control option for power plants; however, power plants that fire Texas Lignite can generate a grade of fly ash that is suitable for sale to the concrete industry. The carbon sorbent in the fly ash competitively adsorbs the air-entraining admixtures (AEAs) that are added to concrete for air entrainment and stabilization. This competition results in a larger volume of AEA being needed, and more significantly to ready-mix concrete manufacturers, it results in variability in the amount of AEA needed. It is generally assumed that if ACI is employed, the resulting fly ash will not be saleable for cement/concrete applications. This poses an economic liability to the plant due to both the loss in ash sales and extra disposal cost. Therefore, it is desired to design a sorbent injection process that preserves fly ash marketability.

Full-scale sorbent injection tests were performed at a power plant that fires a blend of Texas Lignite and PRB to evaluate potential low ash impact designs of sorbent injection. Three approaches were tested: (1) injection of a "low ash impact" sorbent, (2) injection of an activated carbon sorbent into the process after a majority of the ash has been collected using EPRI's Toxecon™II process, and (3) injection of a small amount of carbon upstream of the ESP such that the ash can still be acceptable for concrete use. All three approaches were evaluated in this program.

Low Ash Impact Sorbents

There are several approaches to developing a "low ash impact" sorbent; two of these approaches are the most advanced and so are discussed here. The first approach is to passivate the carbon content of the activated carbon so that it still adsorbs mercury but does not adsorb the AEA. This approach is being pursued by Sorbent Technologies, with their C-PAC™ sorbent. The second approach is to use non-carbon based sorbents, as are being developed by Amended Silicates, LLC and BASF Catalysts, LLC.

C-PAC™

Full-scale tests with C-PAC™ were conducted in 2006 at Midwest Generation's Crawford Power Plant.[1] The unit fires PRB coal and is equipped with a cold-side ESP (SCA = 118 ft^2/kacfm). A thirty-day continuous injection test with C-PAC™ yielded an average 81% removal at 4.5 lb/Macf. Concrete prepared with the C-PAC™ containing ash retained a high compressive strength; however there was an increase in the amount of air entraining agent needed to stabilize the concrete. The baseline ash on average required 14±5 drops of 1% AEA Vinsol, while the C-PAC™ containing ash required 45±4 drops. While the C-PAC™ containing ash required more AEA, it was very consistent in its AEA requirement, which is critical to concrete producers.

Amended Silicates, LLC

Amended Silicates, LLC is a joint venture between ADA Technologies and CH2M Hill. The Amended Silicate™ sorbents uses a silicate mineral as a substrate upon which chemical reagents are impregnated. These reagents reportedly have a high affinity for heavy metals. The Amended Silicate™ sorbent is injected as a powder, serving as a direct replacement for activated carbon. Tests have been completed by Boral Material Technologies to demonstrate that the sorbent is suitable for use in making concrete.

Full-scale demonstrations of the sorbent have been conducted at Xcel Energy's Arapahoe Station (2004) and Cinergy's Miami Fort Unit 6 (2005). The Miami Fort Unit 6 has a 10% baseline mercury removal. For the long-term test, injecting the Amended Silicates sorbent at a rate of 5-6 lb/Macf resulted in an average 40% mercury removal.[2]

BASF Catalysts, LLC Hg Sorbents

BASF Catalysts, LLC (previously Engelhard) is developing mineral-based sorbents from either fly ash and/or molecular sieve materials. The sorbents have been tested at pilot-scale and in limited full-scale tests with actual flue gas at PRB sites.

Toxecon II™

Another method for preserving fly ash sales while employing activated carbon injection for mercury control is to alter the carbon injection location. Toxecon II™ is an EPRI patented concept that involves injecting activated carbon midway through an existing ESP. The majority of the fly ash is collected in the first two or three fields upstream of the carbon injection point, thus allowing fly ash sales to continue for concrete or other applications. The remaining ash and the injected carbon are collected in the fields downstream of the injection point.

The first full-scale test was conducted at a plant that fires North Dakota lignite and that had a relatively large ESP (>400 ft^2/kacfm SCA). EPRI reported evidence of carbon carryover when conducting a short-term test in a Toxecon II™ configuration; however, it was believed that this problem could have been overcome with a better-timed rapping sequence.

A full-scale installation of Toxecon II™ started operation at Entergy's Independence Station in Summer 2006. Independence Station fires PRB coal and is equipped with a cold-side ESP with an SCA of 540 ft^2/kacfm. One-eighth of the 780 MW unit was treated by the Toxecon II™ injection grid, which was installed mid-stream in the

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[1] Zhou, Q. et al. "Concretes and Fly Ashes from a Full-Scale Concrete-Friendly™ C-PAC™ Mercury Control Trial." World of Coal Ash, 2007.Covington, KY. May 7-10, 2007.

[2] Butz, J. et al. "Amended Silicates™ for Mercury Control - Final Report." December 31, 2006. Available at http://www.netl.doe.gov/technologies/coalpower/ewr/mercury/control-tech/pubs/41988/

41988%20Final%20Report.pdf.

ESP. Initial results indicated that mercury removal was low, perhaps due to poor sorbent distribution.[3] After the Summer 2006 testing, ADA-ES re-designed the sorbent injection skid to achieve better sorbent distribution in the ESP. Tests with the new design started in mid-January 2007. Preliminary results indicated much improved performance: 60% removal with 1 lb/Macf, 85% removal with 3 lb/Macf, and 95% removal with 6 lb/Macf.[4] This performance is comparable with injecting sorbent upstream of the ESP. However, the injection grid was prone to plugging with carbon and activated carbon penetrated through the ESP. Operating the ESP at a higher power level has reduced the magnitude of the carbon breakthrough.

Minimize the Impact of Activated Carbon

Maintain Low or Consistent Levels of Activated Carbon

The amounts of activated carbon used can be minimized to maintain the amount of air entrainment agent (AEA) used in concrete formation within acceptable levels. The mercury removal achievable with the low carbon injection rate needs to be determined to assess if adequate mercury removals can be attained.

Alternatively, if the amount of AEA needed can be held relatively constant over long periods of plant operation, it may also be acceptable to the ash user. However, our short-term parametric tests will not be able to demonstrate this.

Ash Surfactant for Carbon Passivation

Several of the fly ash marketers have developed surfactants that are applied to passivate carbon (typically unburned carbon) in the fly ash. These surfactants are intended to be applied to the fly ash at the power plant site, so that the fly ash arrives ready-to-use at the concrete manufacturing site. It has not yet been demonstrated with full-scale ACI tests whether these surfactants will be effective in passivating activated carbon.

EXPERIMENTAL

Description of Limestone Electric Generating Station Unit 1

NRG's Limestone Electric Generating Station (LMS) Unit 1 served as the host site for this test program. Unit 1 typically fires a blend of 70% Texas lignite and 30% PRB and is rated at 890 MW. Unit 1 is equipped with two air heaters, four ESP modules, and five scrubber modules. Table 1 summarizes the basic design parameters of the unit. Figure 1 shows the Unit 1 ESP ductwork along with the injection and sampling locations. Testing was conducted across the Unit 1A ESP.

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[3] Muggli, D. "Toxecon II™: DOE Innovations for Existing Plants Program, Demonstration for Low-Cost Alternatives for Moderate Levels of Mercury Control – Entergy Independence Station." Power Plant Air Pollutant Control MEGA Symposium. Baltimore, MD. August 28-31, 2006.

[4] Bustard, J. "High Temperature Sorbents and Toxecon II Demonstrations: A Testing Update." Electric Utilities Environmental Conference, Tucson, AZ. January 22-24, 2007.

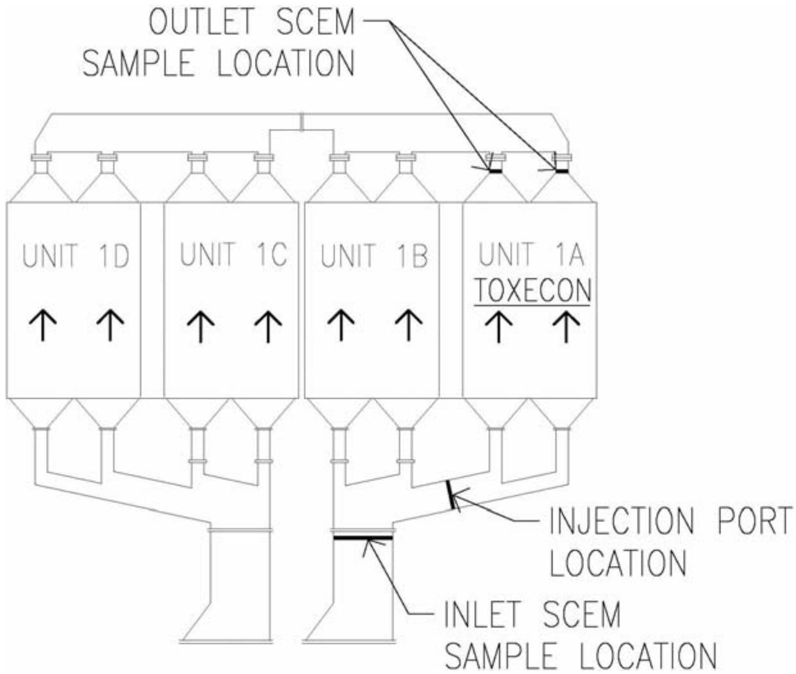

Figure 1. ESP duct configuration and sampling locations.

Test Methods

The mercury measurements for baseline and injection testing were performed with mercury semi-continuous analyzers. For the test program, flue gas extraction probes and mercury analyzers were situated at the ESP inlet, treated ESP outlet (Unit 1A), and untreated ESP outlet (Unit 1B).

All parametric testing occurred with the unit at or near full load. For parametric 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 to achieve steady outlet mercury concentrations. Once steady concentrations were achieved, the carbon injection rate was changed to a new value.

The results from the parametric tests were used to select a sorbent type, injection rate, and injection location for a subsequent 60-day test in which carbon was injected continuously.

Sorbent Injection System Design

The upstream sorbent injection lances were inserted vertically into eight of the ten existing four-inch sample ports on the ESP 1A inlet duct. The two centermost ports were not used because of an internal obstruction to flue gas flow. The duct is 20-feet wide by 11.75-feet deep at the injection location. A flexible pneumatic conveying hose carried the sorbent from the injection system on the ground level, which was approximately 80-feet below the ducting. A steel pipe manifold divided the flow via smaller diameter flex lines to each of the eight lances. The lances were fabricated from steel pipe and consisted of paired holes or nozzle openings at 1-foot intervals along the length to provide for uniform distribution of the sorbent across the duct.

The design of the TOXECON II™ injection grid was based on a revision of the TOXECON II™ testing at Entergy's Independence Station near Newark, Arkansas. The results of extended testing at Independence Station were promising, but less than optimum sorbent distribution limited the mercury removal rates. Based on results from physical and CFD modeling of the injection grid at Independence, ADA-ES modified the original Independence grid design to give better distribution and also address a difference in removal between low load and high load. ADA-ES installed this revised grid design at Independence and tested this grid in January 2007. Results indicated improved sorbent distribution, such that the mercury removal performance curves for injection upstream of the ESP and injection mid-stream of the ESP were comparable. However, this grid was prone to plugging with sorbent. A further revision of this grid was used as the basis for the installation at Limestone.

Table 1. LMS Unit 1 Design Parameters.

Boiler		
Type	Tangentially-fired, pulverized coal furnace	
Nameplate (MW)	890	
Coal		
Type	**Texas Lignite**	**PRB**
Weight Fraction in Coal Feed	0.7	0.3
Sulfur (wt%, dry)	0.9-1.0%	0.3-0.5%
Mercury (mg/kg, dry)	0.15-0.22 ppm	0.06-0.10 ppm
Chloride (mg/kg, dry)	50-100 ppm	25-60 ppm
ESP		
Type	Cold-side	
ESP Manufacturer	Lodge-Cottrell	
ESP Conditioning	None	
Specific Collection Area (ft^2/1000 acfm)	452	
Plate Spacing (in)	11	
Plate Height (ft)	44'-6	
Electrical Fields	7	
ESP Inlet Temperature (°F)	290	
NO_x Controls	Low-NOx Combustion System	
SO_2 Controls	Wet FGD; limestone inhibited oxidation	

The TOXECON II™ injection system at Limestone included the following design features:

- The TOXECON II™ lances were installed to treat 1/3 of the ESP 1A box, which is 1/12 of the flue gas flow. Eight lance bundles were installed.
- The injection grid was installed at the downstream end of the fourth field, injecting in front of the fifth field.
- The grid design included the capability to insert and retract the injection lances with the unit on line. For safety reasons, the fields immediately upstream and downstream of the grid will be out of service during retraction.
- The guide system for the grid lances attached to the walkway at the bottom end of the plates, at a mid-support bar, and at the top of the box. The ports penetrated the ESP roof between the two trailing edge plate rapper hammer supports.
- The distribution manifold was in the penthouse, thus distributing the sorbent and transport air outside of the ESP box.
- The lances were installed in between every fourth plate
- The fourth field was de-energized during operation of the injection system.
- The design assumed that the flue gas distribution through the ESP was essentially uniform across the plane of the plate trailing edges.

The TOXECON II™ system was initially tested at LMS in April 2007. The performance of the TOXECON II™ system did not meet the project goals of 50-70% mercury removal at the ESP outlet. It was determined that the designed TOXECON II™ injection grid only provided about 20% coverage of carbon across the cross-sectional area of the ESP. ADA-ES revised the Limestone injection grid design in an attempt to improve duct carbon coverage. Modeling results indicated that the duct coverage of injected carbon was less than 40%. The revised grid was evaluated during tests conducted in May 2007. Some improvement in sorbent distribution was achieved; however, no appreciable improvement in performance was observed.

Sorbent Selection

Several types of sorbents were tested on Unit 1: a standard activated carbon, a brominated carbon, and a low ash-impact sorbent. The sorbents selected for screening with the injection lances configured upstream of the ESP are listed in Table 2. This list included Norit America's DARCO-Hg as the standard activated carbon and four brominated activated carbons: Norit America's DARCO Hg-LH, Sorbent Technology's B-PAC and C-PAC, and Calgon Carbon's Flue PAC MC Plus.

Norit Americas was chosen as a vendor because of its proximity (158 miles) to the plant. The large mass of carbon that will be needed for this plant will likely make transportation costs the determining factor when selecting a sorbent vendor, should LMS decide to employ sorbent injection as its mercury control technology.

Several vendors were approached for a low ash impact sorbent. The MS200 from BASF and C-PAC from Sorbent Technologies were evaluated as low ash impact sorbents.

Table 2. Sorbents Selected for Evaluation at LMS Unit 1.

Sorbent Name	Manufacturer	Manufacturing Location	Price ($/lb, FOB)	Sorbent Description	d_{50} (µm)
Darco Hg	Norit Americas	Marshall, TX	$0.50	Texas lignite derived activated carbon	19
Darco Hg-LH	Norit Americas	Marshall, TX	$0.85	Texas lignite derived activated carbon, treated with bromine	19
B-PAC™	Sorbent Technologies	Twinsburg, OH	$0.85	Activated carbon, treated with bromine	20
C-PAC™	Sorbent Technologies	Twinsburg, OH	$1.20	Activated carbon treated with bromine and passivated to be low-ash impact	20
Flue PAC MC Plus	Calgon Carbon	Pittsburgh, PA	$0.90-$0.95	Activated carbon, treated with bromine	unknown
MS200	BASF	Gordon, GA and Attapulgus, GA	$0.90	Enhanced molecular sieve material	15-20

RESULTS

Mercury Removal When Injecting Upstream of ESP

The first step in the test program was to evaluate the mercury removal performance of different sorbents when they were injected upstream of the ESP. Each sorbent was tested at several injection rates to develop a mercury removal performance curve. Parametric testing of sorbent injection upstream of the ESP occurred at three different times over a six-month period.

Figure 2 shows the results for all sorbents injection upstream of the ESP. The data points in the plot represent from a two- to four- hour average of collected data. The plot shows the removal of vapor-phase mercury across the ESP versus the injection rate. The removal of vapor-phase mercury across the ESP was calculated by comparing the treated ESP outlet mercury concentration to the ESP inlet mercury concentration. In Figure 2, the baseline removal is represented by the points that fall along the y-axis (i.e. an injection rate of 0 lb/Macf). Baseline mercury removal across the ESP varied from 5% to 50% over the parametric test program.

Because the baseline mercury removal varied so greatly over the program, the data are also presented in terms of the percent reduction of mercury at the ESP outlet (Figure 4). The percent reduction was calculated by comparing the treated ESP outlet mercury concentration to the untreated ESP outlet mercury concentration. The calculation of percent reduction indicates the amount of mercury removal the sorbent achieves beyond the baseline removal.

From Figure 3, it is readily noted that there are several data Darco Hg and Darco Hg-LH points that do not fall on the generally established curve. One cluster of these points occurred on a single day when the unit was undergoing a transition from PRB to PRB/TxL blend. The other cluster of points occurred randomly throughout the six months of parametric testing. It is currently unclear why the sorbents had these isolated periods of poorer performance.

Excluding these isolated periods of poorer performance, three of the brominated sorbents (Darco Hg-LH, B-PAC, and C-PAC) performed very similarly. The mercury removal performance curve of the fourth tested brominated sorbent (Flue PAC MC Plus) fell significantly below the other brominated sorbents. The Flue PAC MC Plus was tested at two different times during the six-month program, and on days when the other brominated sorbents were performing better. The non-carbon sorbent from BASF was limited to 50% mercury reduction in Hg at ESP outlet.

It is interesting to note that the non-halogenated activated carbon (Darco Hg) performed as well as its brominated counterpart, Darco Hg-LH, on a percent removal basis (Figure 3). Previous comparisons of these two sorbents in low-chloride flue gas have occurred on units firing 100% PRB. For these 100% PRB fired plants, the Darco Hg had significant limitations in the amount of mercury removal as compared to the Darco Hg-LH. For example, at Great River Energy's Stanton Station, the Darco Hg was limited to approximately 50% removal, even at the highest injection rates, while the Darco Hg-LH could achieve greater than 90% removal. [5] While Texas lignite is considered a low chloride coal (50-100 ppm), it does have a higher chloride content than PRB coal (20-60 ppm). This small increase in chloride may be sufficient to enable the Darco Hg to achieve high (> 90%) levels of mercury removal in a 70/30 TxL/PRB blended gas.

[5]Holmes, M. et al. "Enhancing Carbon Reactivity for Mercury Control in Coal-Fired Power Plants: Results from Leland Olds, Stanton, and Antelope Valley Stations". Presentation at 2006 DOE-NETL Mercury Control Technology Conference. Presentation can be found at http://www.netl.doe.gov/publications/proceedings/06/mercury/presentations/Holmes_presentation_121106.pdf

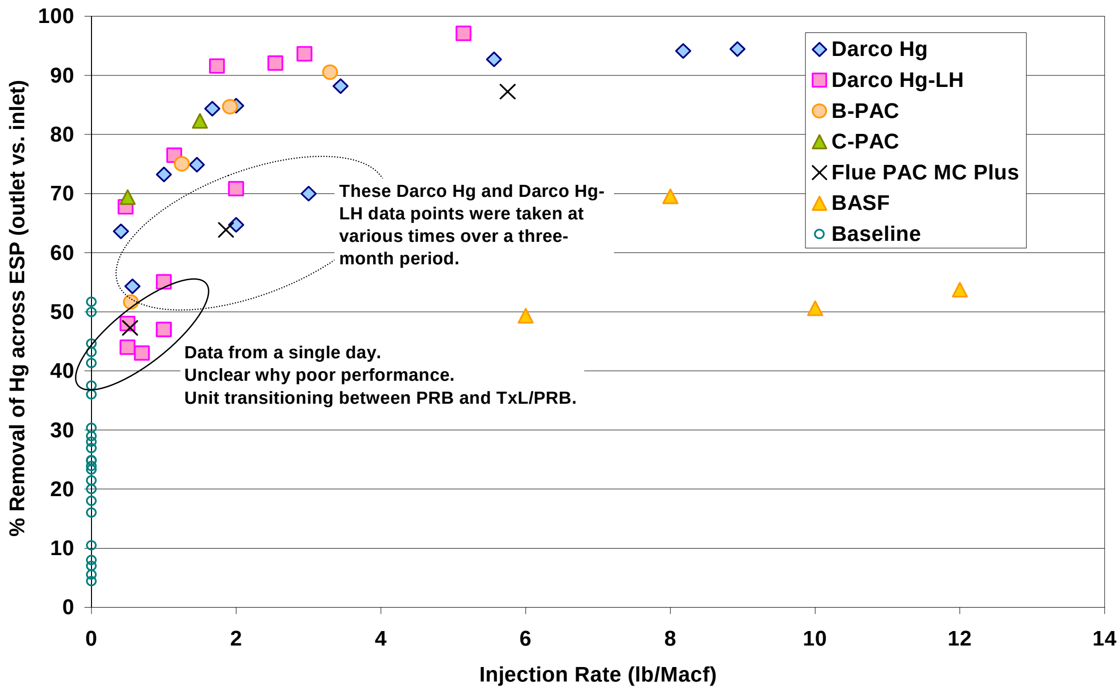

Figure 2. Mercury removal across ESP (injection upstream of ESP).

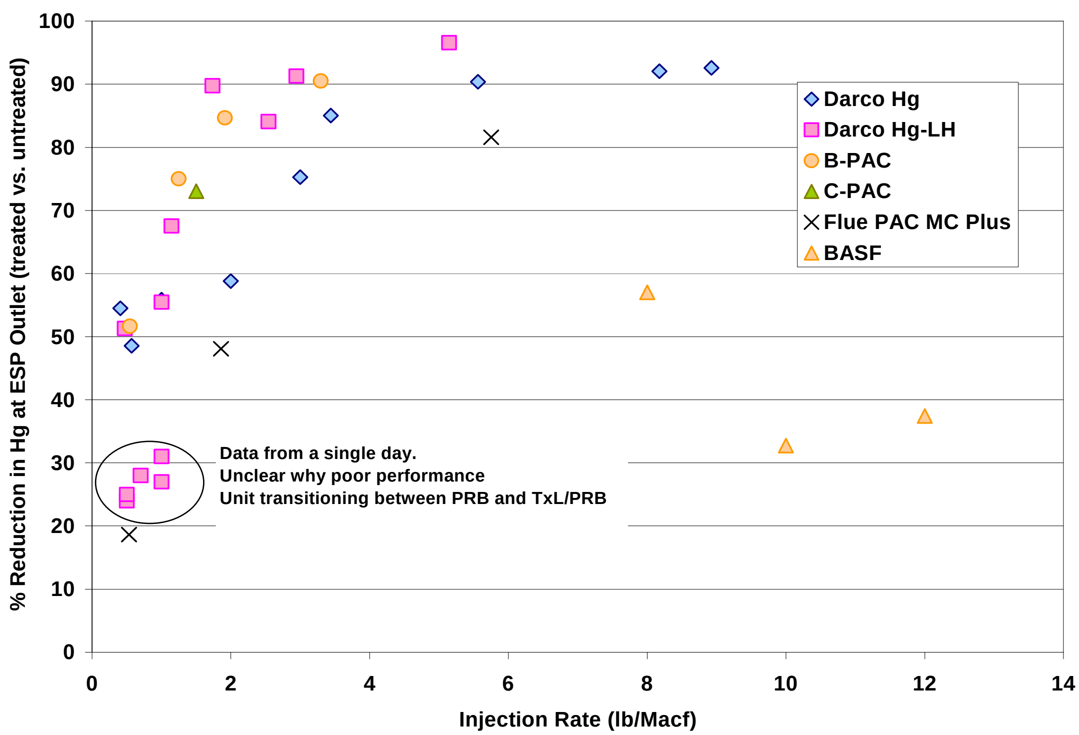

Figure 3. Reduction in mercury concentration at ESP outlet (injection upstream of ESP).

Mercury Removal with TOXECON II™ and Staged Injection

Based on the results from the parametric tests conducted upstream of the ESP, Norit Americas' Darco Hg and Darco Hg-LH sorbents were selected for testing in the TOXECON II™ and staged injection configurations. These sorbents were selected because they were among the highest performing sorbents and because of the proximity of the Norit Americas' manufacturing center to the power plant.

Figure 4 shows the percent mercury reduction for these two sorbents, using various sorbent injection configurations.

TOXECON II™ (injection mid-stream of the ESP) was tested at two different weeks in this program. The original tests were performed in April 2007. Despite the lances providing poor carbon coverage across the ESP cross-sectional area (~20% area coverage), mercury reductions up to 60% were measured at the ESP outlet. A TOXECON II™ lance re-design was implemented and tested in May 2007. Results from May 2007 overlapped with the April 2007 results, indicating no improvement in mercury removal performance. The volume and pressure of the air delivered to the TOXECON II™ lances were varied, but no improvements in mercury removal performance were observed.

A series of tests were conducted with staged injection, in which a small amount of carbon was injected upstream of the ESP, with the bulk of the carbon injected in the TOXECON II™ lances. This arrangement did not offer any improvements in Hg removal over the TOXECON II™-only arrangement. It may be that the injection upstream of the ESP was not performing as well as in previous tests (see circled points in lower left corner of Figure 5, indicating data collected during same test week with injection upstream of ESP *only*).

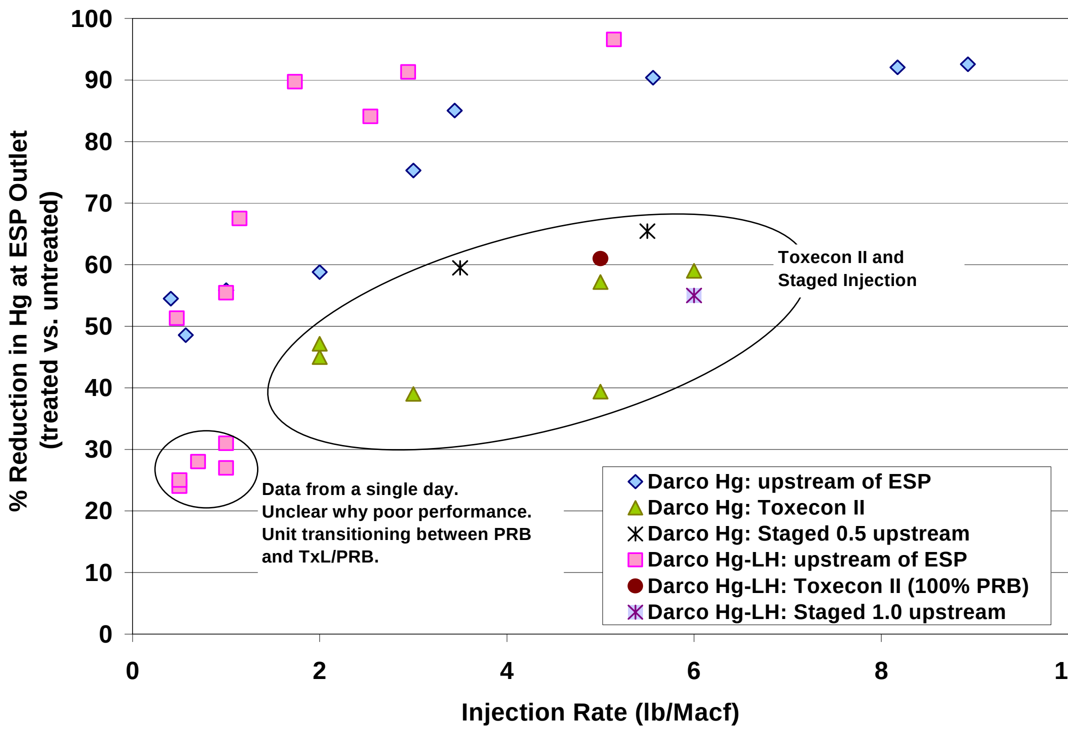

Figure 4. Reduction of mercury concentration at ESP outlet (effect of injection location).

Oxidation of Mercury across ESP

Figure 5 shows the percent of vapor-phase mercury present as oxidized mercury under three conditions: at the inlet, at the outlet when there is no sorbent, and at the outlet when there is sorbent. This plot shows that the mercury at the ESP outlet is still highly oxidized when carbon sorbent is being injected. In summary, this plot indicates the following

- Inlet Hg oxidation ranged from 15-40%.
- Outlet oxidation (no sorbent) ranged from 35% (single point) to 65-85%.
- Outlet oxidation (with sorbent) ranged from 45% (two points) to 60-80% (a dozen points).

Oxidized mercury is readily soluble in the wet scrubber at LMS; therefore, to achieve a specified overall target mercury removal across ESP/FGD system, a lower mercury removal can be targeted for the ESP alone. In this test program, the resulting mercury removal across the FGD system was not measured. Only one-fourth of the unit's flue gas was treated with ACI. This treated flue gas mixed with untreated flue gas prior to the wet FGD, making it impossible to accurately determine the FGD mercury removal attributable to ACI.

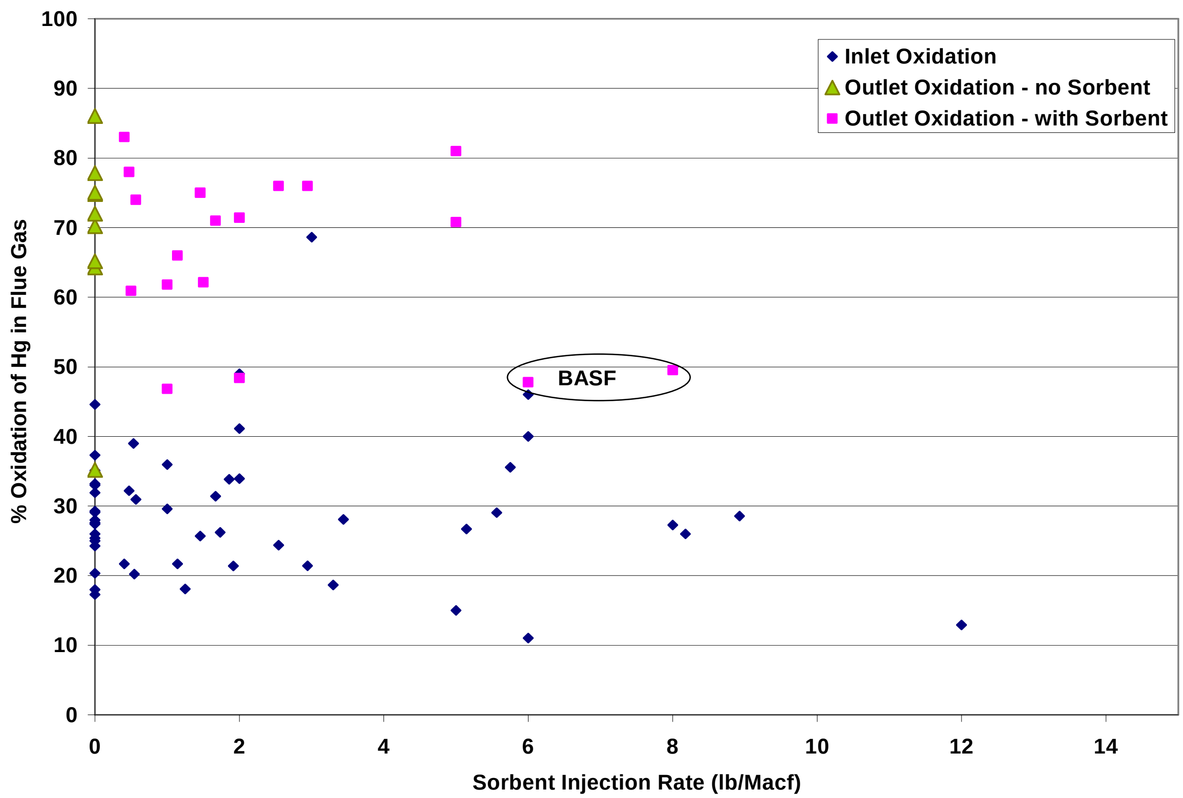

Figure 5. Oxidation of vapor-phase mercury at ESP inlet and ESP outlet.

Particulate Breakthrough from ESP

The injection of a sorbent into the ESP may result in increased particulate emissions at the ESP outlet. For units equipped with a downstream scrubber (such as LMS), the particulate could be scrubbed so that stack particulate emissions do not increase. However, in such a case the scrubber slurry may darken and render the gypsum unsuitable for sale.

For each sorbent and injection rate, the particulate emissions were quantified with single port EPA Method 17 isokinetic traverses. Carbon breakthrough from the ESP was qualitatively observed on the filter, which darkened when sorbent broke through the ESP.

Figure 6 shows results from all Method 17 samples collected during the parametric test period. In the plot, unless noted, sorbent injection was conducted upstream of the ESP. Baseline PM emissions ranged from 2 to 7 milligrain/dscf. When injecting activated carbon upstream of the ESP, much of the data fell within this range; however, almost half of the data points were higher (8-10 milligrain/dscf) than the range of baseline concentrations. It should be noted that PM measurements were conducted via a duct traverse through one vertical sampling port and thus, do not account for possible concentration gradients that may occur across the duct. The results thus provide a relative comparison between baseline and ACI conditions but do not reflect an accurate measure of PM concentrations.

All of the particulate emissions data for TOXECON II™ were gathered in a different ESP outlet port than was used for the Method 17 measurements for the injection upstream of the ESP. This was because the TOXECON II lances treated only 1/3 of the ESP, so the test ports had to be moved to ensure measurement of only treated flue gas. The flow was lower and the flue gas oxygen concentration was higher at the traverse points tested from these ports. As a result, the baseline emissions measured in the TOXECON II™ ports were significantly lower (1-2 milligrain/dscf) than the baseline emissions measured in the outlet port used during injection upstream of the ESP. Likewise, the particulate emissions measured during sorbent injection with TOXECON II™ were significantly lower (< 2 milligrain/dscf) than the emissions when injecting upstream of the ESP. Because of the emissions bias in the TOXECON II™ measurement port, these results do not indicate that TOXECON II™ results in lower particulate emissions.

All of the filters collected during TOXECON II™ testing were grey, indicating a visual observation of carbon breakthrough from the ESP. For filters collected with injection upstream of the ESP, approximately half of the filters were grey.

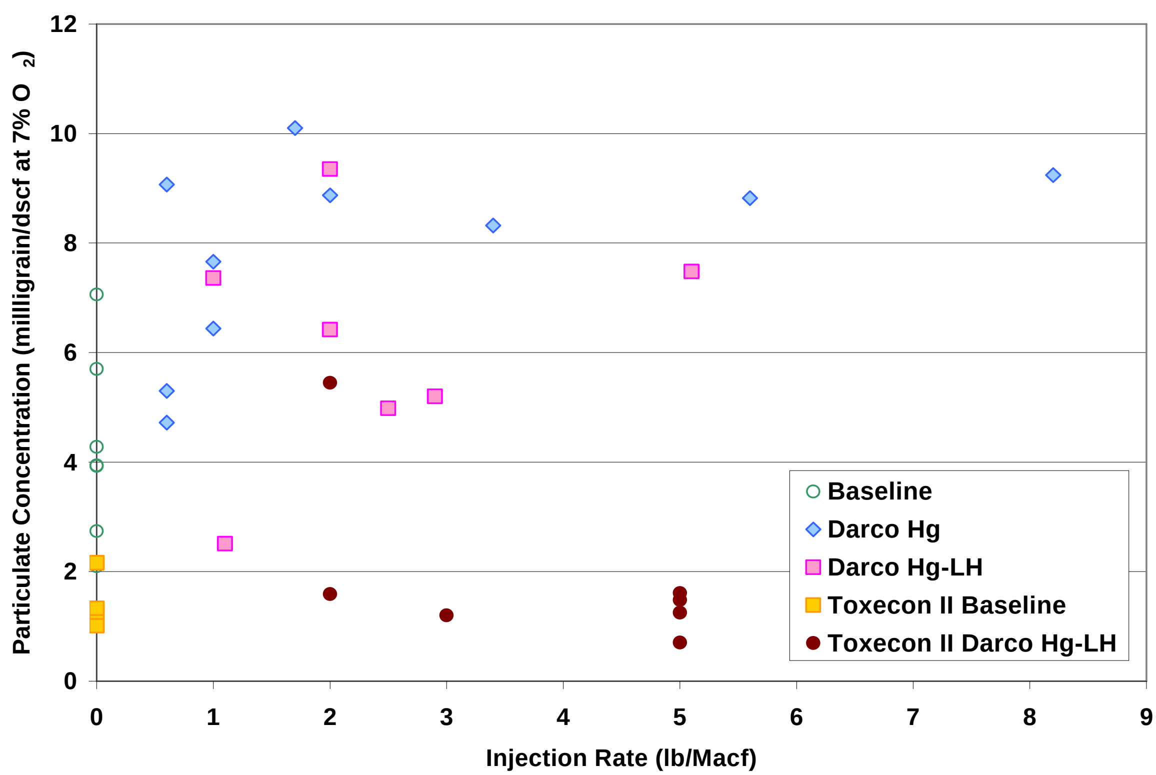

Figure 6. Method 17 results from parametric testing.

Concrete Testing Results

Because of the short-term nature of the parametric tests, representative ash samples could not be obtained for concrete testing. Instead, simulated ash/carbon mixtures were made and subjected to foam index testing. The ash/carbon mixtures were made with baseline LMS ash and Darco Hg carbon for injection rates ranging from 0.5 to 2.0 lb/Macf. One parametric test was run for 24 hours at 0.6 lb/Macf. An ash sample from the end of this test period was tested. The foam index tests produced the following results:

- Baseline ash - 3 to 4 drops
- 0.6 lb/Macf injection (24-hour period of injection) - 3 to 4 drops
- Simulated ash/carbon mixtures of

    0.5 lb/Macf - 3 to 4 drops

    1.0 lb/Macf - 5 drops

    1.5 lb/Macf - 5 to 6 drops

    2.0 lb/Macf - 6 to 8 drops

For a given set of foam index tests performed by the same operator with the same AEA, the large the number of drops, the lower quality the concrete. These results indicate that small amounts of carbon (<0.6 lb/Macf) might be injected and result in ash that is not significantly different in air entraining qualities from a baseline ash. For the LMS ash, higher injection rates result in modest increases in the foam index test result. The results from these simulated ash/carbon mixtures show promise for the injection of small amounts of carbon with an ACI system while still preserving fly ash sales. However, full-scale testing would be required to demonstrate the quality and consistency of the formed concrete.

CONCLUSIONS

The parametric ACI test program conducted at Limestone Electric Generating Station demonstrated that high (>90%) levels of mercury removal could be achieved with carbon sorbents. The TOXECON II™ design used at LMS did not provide for as high a mercury removal as injection upstream of the ESP. The limitations in removal were likely related to poor coverage of the cross-sectional area of the ESP. It is unknown if further lance design enhancements could increase coverage and thereby mercury removal. Staged injection was not determined to have any additional benefit in reducing sorbent usage. Of the low ash impact sorbents that were tested, C-PAC was demonstrated to achieve mercury removals similar to the standard brominated carbons. The non-carbon BASF sorbent only produced 50% reduction in mercury concentration at the ESP outlet.

Limited concrete testing was performed with simulated ash/carbon mixtures. As expected, the amount of AEA required increased with increasing carbon content in the ash. However, it appeared that the small amounts of non-passivated carbon (such as Darco Hg-LH or B-PAC) might be acceptable in fly ash for concrete use. Further testing at full-scale is required to investigate this possibility. The effect of the carbon may be further mitigated by use of a surfactant, which will be tested in the long-term portion of this test program.

Carbon injection, whether conducted upstream of the ESP or mid-stream in the ESP, consistently resulted in carbon breakthrough at the ESP outlet. LMS has relatively large ESPs (SCA of 452 ft^2/kacfm) as compared to many power plants. While LMS has a downstream FGD scrubber to remove any particulate breakthrough, the resulting gypsum may be compromised for re-sale. For plants that do not have downstream FGD scrubbers or that have similar or smaller sized ESPs, the potential for ACI to cause carbon breakthrough (and therefore an increase in particulate emissions) must be carefully assessed.

Long-term tests will help determine the mercury removal capability and cost of ACI control systems, as well as associated particulate emission and ash marketability impacts.