TOXECON II™ AND HIGH-TEMPERATURE REAGENTS OR SORBENTS FOR LOW-COST MERCURY REMOVAL

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ABSTRACT

On March 15, 2005, EPA issued the Clean Air Mercury Rule, requiring phased-in reductions of mercury emissions from electric power generators. ADA-ES, Inc., with support from DOE/NETL and industry partners, is conducting evaluations of EPRI's TOXECON II™ process and of high-temperature reagents or sorbents to determine the capabilities of sorbent/reagent injection, including activated carbon, for mercury control on different coals and air emissions control equipment configurations.

The TOXECON II™ technology injects sorbents in the latter fields of an electrostatic precipitator to achieve emissions reduction, allowing recovery and sale of the ash from the first fields since only the last fields are collecting an ash/reagent/sorbent mixture.

Injecting non-carbon-based reagents or sorbents in a high-temperature flue gas zone allows a low-cost approach for moderate levels of mercury removal at plants equipped with hot-side electrostatic precipitators.

This paper presents an outline of the overall testing program, a description of the TOXECON II™ installation and testing at Entergy's Independence Steam Electric Station (ISES) in Newark, Arkansas, and a description of the testing program for testing of high-temperature reagents at MidAmerican Energy Company's Louisa Station in Muscatine, Iowa.

Entergy's Independence Station burns PRB coal and employs high-SCA cold-side electrostatic precipitators for particulate emissions control. This part of the testing program consists of installing injection grids between the latter precipitator fields and injecting powdered activated carbon into the flue gas stream inside of the precipitator and measuring the resulting mercury removal.

MidAmerican's Louisa Station burns PRB coal and employs hot-side electrostatic precipitators with flue gas conditioning for particulate control. This part of the testing program consists of using the existing flue gas conditioning system to inject non-carbon-based reagents upstream of the ESP and measuring the resulting mercury removal.

The field testing efforts at both Independence and Louisa are complete and the data analysis for both sites is in progress at the writing of this paper. This paper contains some preliminary findings, and the conference presentation will include any additional available results.

BACKGROUND

The U.S. Department of Energy's National Energy Technology Lab (DOE/NETL) is conducting a comprehensive research and development program directed at advancing the performance and the resulting economics of mercury control technologies for coal-fired power plants.

This testing program (Program) is a part of the Department of Energy/Office of Fossil Energy's Innovations for Existing Plants (IEP) Program, whose goal is to develop advanced technology and knowledge products that enhance the environmental performance of the existing fleet of coal-fired power plants.

To date, the numerous mercury removal test programs have addressed many combinations of power plant emissions control configurations, including cold-side electrostatic precipitators, FFDCs (baghouses), FFDC/spray dryer absorbers (SDA), and wet scrubbers. In these efforts, these programs have also addressed units burning many different fuels, including Powder River Basin (PRB), subbituminous, bituminous, low and high sulfur, blends, and the like.

An excellent reference that summarizes the past and on-going efforts is the article entitled "*DOE/NETL's Field Test on Mercury Control Technologies for Coal-Fired Power Plants*." by Thomas Feeley, James Murphy, Lynne Brickett, and Andrew O'Palko, published in the August 2005 AWMA EM Journal.

This paper presents an outline of the overall testing program, a description of the TOXECON II™ installation and testing at Entergy's Independence Steam Electric Station (ISES) near Newark, Arkansas, and a description of the testing program for testing of high-temperature reagents at MidAmerican's Louisa Station near Muscatine, Iowa.

OVERALL PROGRAM DESCRIPTION

Process Descriptions

Injecting a sorbent such as powdered activated carbon into the flue gas is one of the simplest and most thoroughly studied approaches to controlling mercury emissions from coal-fired boilers and power plants. The gas-phase mercury in the flue gas contacts the sorbent and attaches to its surface. The sorbent, with the mercury attached, is then collected either by the existing particulate control device, such as an electrostatic precipitator (ESP) or fabric filter, or by a secondary particulate control device. Over the past several years, the results from numerous full-scale evaluations of activated carbon injection (ACI) for mercury removal indicate that activated carbon is a viable technology for mercury control on many coal-fired power plants (Durham, 2005; Sjostrom, 2005).

For plants that sell fly ash for use as a concrete admixture, one of the disadvantages of injecting activated carbon upstream of the main particulate control device is its impact on the salability or reuse of ash. Tests show that the activated carbon interferes with chemicals used in making concrete.

For plants equipped with cold-side ESPs, the TOXECON™ and TOXECON II™ technologies offer an approach for maintaining fly ash sales while using low-cost activated carbon sorbents for mercury removal.

TOXECON™

The TOXECON™ technology injects reagents and/or sorbents, including powdered activated carbon for mercury control, and others for NO_x and SO_x control, into the inlet duct of a secondary particulate control device that is downstream of the existing primary particulate control device. This configuration thus segregates the ash collected in the primary particulate control device from the ash/reagent/sorbent mixture collected in the secondary (downstream) particulate control device, preserving the salability of the of the fly ash from the primary particulate control device. In the TOXECON™ process, the secondary particulate control device is generally a pulse jet fabric filter dust collector.

The advantages of the TOXECON™ configuration are:

- The ash/reagent/sorbent mixture from the secondary particulate control device contains only a small fraction of the ash (typically in the range of 1% of the total ash), which reduces the impact of reagent/sorbent on ash reuse and waste disposal.
- Full-scale field tests confirm that fabric filters require significantly less sorbent than ESPs to achieve similar mercury removal efficiencies.
- Outage time for installing the TOXECON™ technology is significantly less than major ESP rebuilds or upgrades required to handle the increased loading and greater collection difficulty of the injected carbon.

Figure 1 shows the general configuration for the TOXECON™ process.

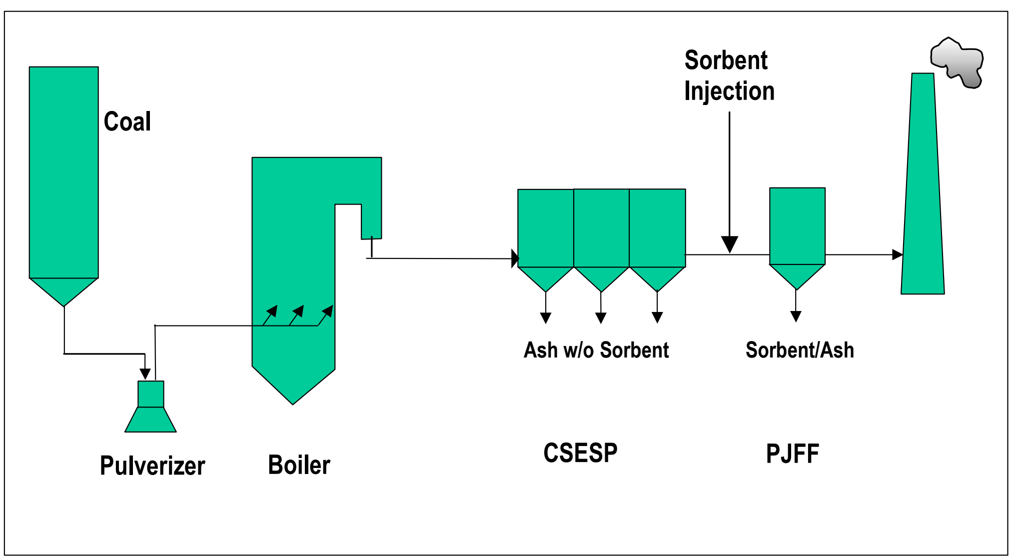

Figure 1. General Configuration for TOXECON™.

TOXECON II™

The TOXECON II™ technology is similar to the TOXECON™ technology described above, except that it injects the reagents and/or sorbents directly into the downstream collecting field(s) of an ESP. Since the ESP collects the majority of the fly ash in the upstream collecting fields, only a small portion of the total collected ash contains reagents/sorbents. The TOXECON II™ technology requires minimal capital investment because it uses only minor retrofits to the ESP for the carbon injection system instead of installing a separate secondary particulate control device.

In this process, the sorbent injection lances are located within the ESP box, injecting sorbent across the front face of a downstream field. A normal sorbent storage silo and feeder system provides the sorbent to the injection grid. The location and design of the injection grid is dependent on the ESP SCA, the number of fields in the ESP, and the physical size of the fields.

Since the sorbent/ash mixture from the latter fields is primarily sorbent, this process also allows for the possibility of recycling of the partially spent sorbent back into the process to achieve greater sorbent utilization.

Figure 2 shows the general configuration and the typical sampling for the TOXECON II™ process.

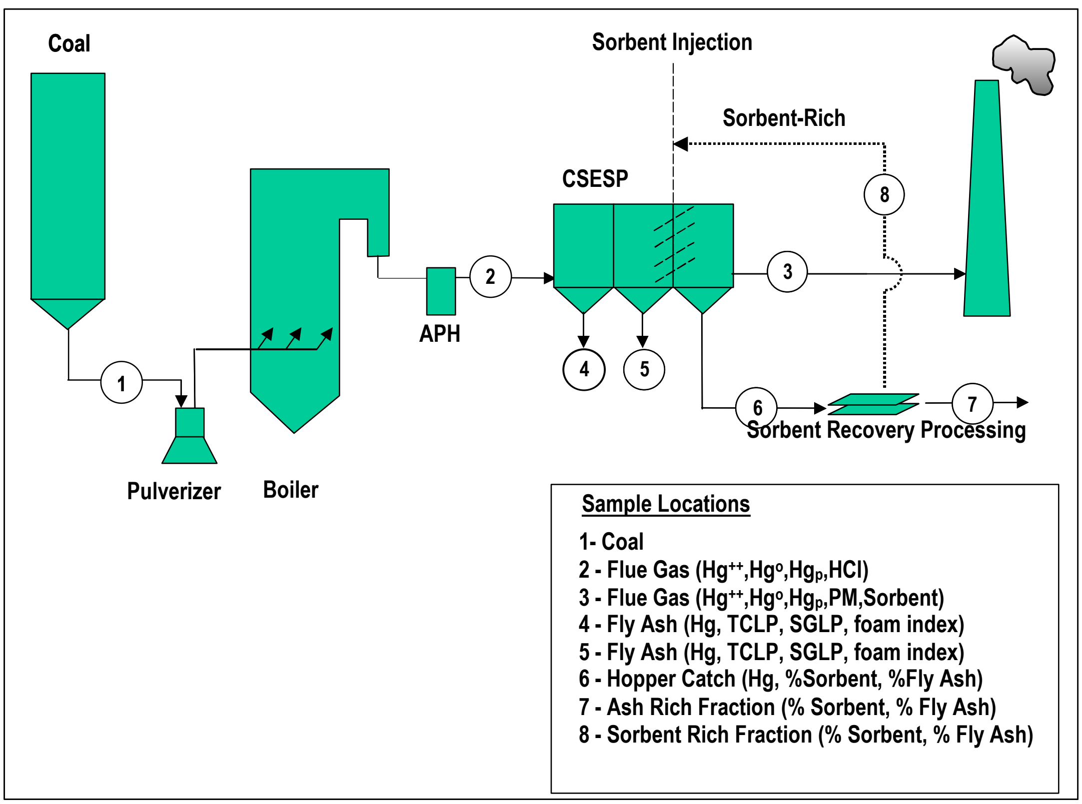

Figure 2. General Configuration and Sampling in TOXECON II™ Tests.

High-Temperature Reagents or Sorbents

For plants equipped with high-temperature electrostatic precipitators, previous testing shows that carbon injection for mercury control is not a viable option due to the poor mercury capture capability of carbon at the elevated temperatures. The various test programs to date have not addressed other options for mercury removal with the high-temperature ESP configuration. The goal of this segment of the Program is to investigate several promising technologies to determine the mercury removal capability and the viability of using high-temperature reagents or sorbents to achieve moderate levels of mercury control.

The majority of the potential reagents or sorbents are the result of either lab-scale or pilot-scale testing efforts. The Program will identify several such reagents or sorbents and test them in a full-scale test approach, similar to the testing efforts using carbon for cold-side ESP and fabric filter dust collector applications. As such, the Program will develop the specific injection details and testing protocol depending on the specific requirements for each potential reagent/sorbent.

The basic process consists of injecting reagents/sorbents upstream of the existing particulate control device and measuring the resulting mercury removal and determining the impacts on the existing plant equipment.

Figure 3 shows the general configuration and the typical sampling for the high-temperature reagent/sorbent process.

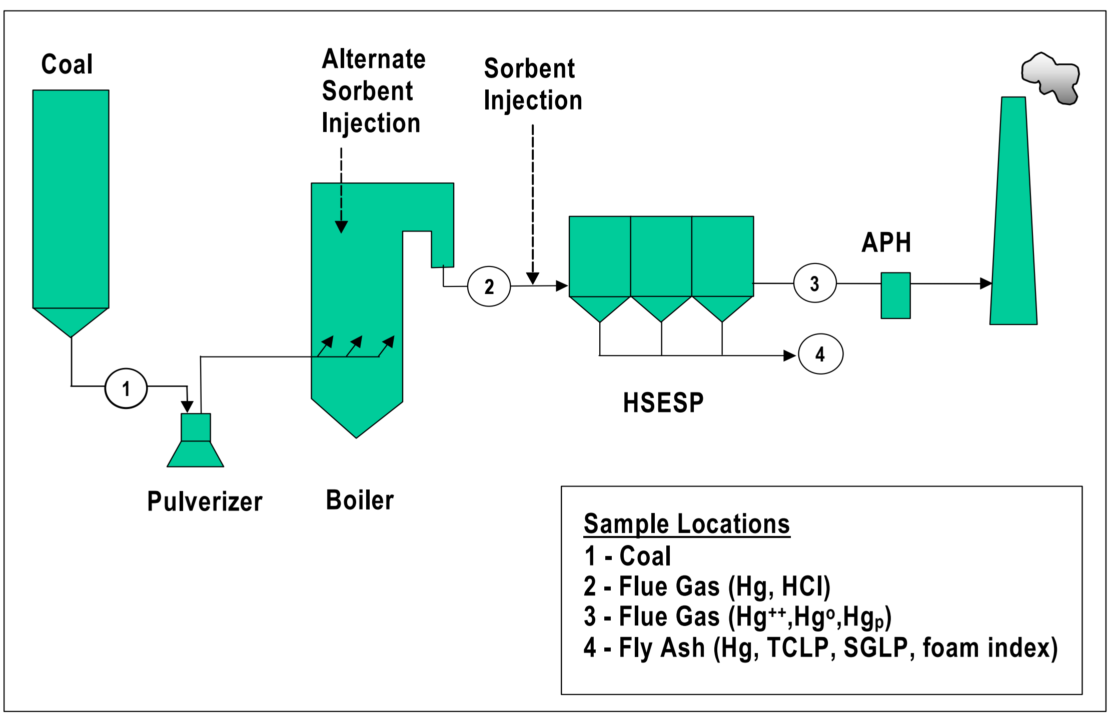

Figure 3. General Configuration and Sampling in High-Temperature Reagents/ Sorbents Tests.

Project Test Program

Objectives

The purpose of this Program is to evaluate two technologies that utilize the injection of sorbent materials to remove mercury from coal-fired power plant flue gas—TOXECON II™ and high-temperature reagents or sorbents.

The primary objectives of the Program are to:

- Test control technologies that can reduce the cost of mercury control
- Test control technologies that are applicable to the largest population of power plant configurations
- Test a control technology that is applicable to hot-side ESPs, a power plant configuration that is currently not adequately addressed
- Continue to expand the available data about mercury removal and control systems

The Program will test TOXECON II™ at Entergy's Independence Station (PRB), and at AEP's Gavin Plant (tentative) (high sulfur bituminous). The Program will test high-temperature reagents at MidAmerican Energy Company's Louisa Station (PRB) and Council Bluffs Station (PRB).

Because these technologies have not had previous widespread testing at plants burning different ranks of coal, testing will include both low-rank sub-bituminous and bituminous coal-burning plants to evaluate whether fuel rank makes a difference in performance of the technologies.

These technologies are directly applicable to coal-fired power plants that employ ESPs as the primary particulate removal system. This configuration represents approximately 797 plants that produce a combined 277,000 MW, or approximately 72% of existing coal-fired generating capacity and potentially a significant portion of new plants.

The test sites for the Program will allow documentation of reagent/sorbent performance on the following configurations:

- PRB coal with cold-side ESP using the TOXECON II™ configuration
- Bituminous coal with cold-side ESP using the TOXECON II™ configuration
- PRB coal with hot-side ESP using high-temperature reagents/sorbents

The secondary objectives of the Program are to:

- Accelerate the scale-up and availability of commercial mercury control systems for subbituminous and bituminous fired plants with conventional particulate control systems
- Evaluate technological advancements likely to improve the performance and reduce the costs of mercury control
- Obtain data on operability, maintainability, and reliability

- Document technology to reduce impacts on the utilization of coal burning byproducts
- Determine maximum mercury removal for various plant configurations
- Determine the total costs associated with mercury control as a function of fuel and plant characteristics, including both capital and operating costs

Test Sites

The Program will test at four host sites. It will test TOXECON II™ at two sites and high-temperature reagents/sorbents at two sites. The characteristics of each site are itemized in Tables 1 and 2.

Table 1 delineates the applicability of the Program's sites to provide test experience and data for configurations with minimal previous testing. Testing at these sites will help round out the base of data for mercury removal with varying site configurations.

Area of Interest	AEP Gavin (tentative)	Entergy Independence	MidAmerican Council Bluffs	MidAmerican Louisa
Technology	TOXECON II™		High-Temperature Reagents/Sorbents	
Approximate no. of units of applicability	715		82	
Low-rank fuels		X	X	X
Bituminous fuels	X			
Blended fuels				
Test size (MW)	200	105	88	700
Longer-term tests (1–2 months)	X	X	*	*

* The Program will test dry sorbents at Council Bluffs and liquid reagents at Louisa. The Program will perform long-term testing at only one site based on the parametric testing results.

Table 2 provides a brief listing of some of the descriptive information for each of the test sites, showing the range of plant characteristics and configurations.

Table 1. Host Site Descriptive Information.

	AEP Gavin (tentative)	Entergy Independence	MidAmerican Council Bluffs	MidAmerican Louisa
Technology	TOXECON II™		High-Temperature Reagents/Sorbents	
Unit No.	1 or 2	2	2	1
Size (MW)	1,200	842	88	700
Test Portion (MW)	200	105	88	700
Coal	Bit	PRB	PRB	PRB
Heating Value (as received)	11,111	8,870	8,425	8,500
Sulfur (% by weight)	3.9	0.32	0.32	0.32
Chlorine (ppm)	1,333	50	50–100	50–100
Mercury (μg/g)	0.17	0.04	0.08	0.08
Particulate Control	CS-ESP	CS-ESP	HS-ESP	HS-ESP
SCA/fields (ft^2/kacfm)	430/6	542/4	224/4	459/5
Sulfur Control	Trona/FGD	Compliance Coal	Compliance Coal	Compliance Coal
Disposition of Ash	Disposed	Sold	Some Sold	Sold
Typical Inlet Mercury (μg/dncm)	13–18	6–7	11.1–13.5	11.1–13.4
Typical Native Mercury Removal	0% ESP 70%+ in FGD	10%–20%	0%–10%	0%–10%

Field Testing Scope of Work

To achieve its overall objectives, the Program will perform extensive field tests at each site. These tests typically include baseline testing, parametric testing, and long-term testing as follows:

<u>Baseline Tests</u>

After equipment installation, the Program conducts a set of baseline tests prior to the parametric testing. These baseline tests characterize the plant operation and the native mercury removal (without sorbent injection). This includes Ontario Hydro mercury measurements concurrent with SCEM measurements. During baseline tests, the unit operates at the conditions expected during the parametric tests, holding boiler load constant at full-load and operating the emissions control equipment under normal full-load conditions (e.g., normal soot blowing and ESP rapping sequences).

<u>Parametric Tests</u>

The parametric tests define the quantity of sorbent required to obtain various levels of mercury removal, such as 30%, 50%, and 70% above the native mercury removal level. The Program conducts parametric tests for up to four weeks depending on the specific host site test plan.

The parametric tests typically evaluate multiple reagents/sorbents varying the injection concentrations and the operating conditions. A parametric test will usually inject sorbent for about 8 hours, and then shut the injection system down to allow the plant equipment to return to baseline conditions prior to the next parametric test.

<u>Long-Term Tests</u>

The long-term tests uses the optimized sorbent and injection rate(s) determined during the parametric tests. Typically, long-term tests cover a period of at least four weeks. The long-term testing goals are to obtain sufficient operational data on mercury removal efficiency over a longer period of time, determine the effects of sorbent injection on the particulate control device, on the sulfur control equipment (if any), on byproducts, and to the balance of plant equipment to prove process viability and economics. This task is the single most important step in gaining acceptance from the utility industry as to the practical implementation of mercury removal technologies on coal-fired power plants.

SPECIFIC SITE TESTING

Entergy Independence Test Site

The Entergy Independence Steam Electric Station consists of two 842-MW PRB coal-fired electric generating units. Testing for this Program is on Unit 2.

These units are balanced draft Combustion Engineering tangentially fired divided furnace boilers, Ljungström regenerative air heaters, and CE Walther rigid frame cold-side electrostatic precipitators. The ESP for each generating unit has four boxes in a two-wide by two-high stacked arrangement, with each box consisting of eight transformer/rectifier (T/R) sets, eight physical fields arranged in a two wide by four deep configuration, and with each T/R set powering one physical fields. The gross SCA at design flow is 542 square feet per 1,000 ACFM.

The inlet and outlet ducts for each box are split into two separate ducts, making it convenient to have a test portion and a control portion in the same ESP box. The Program is testing one-half of one box, or one-eighth of the total flue gas flow.

For this test, the Program installed specially designed injection grids between the second and third fields and between the third and fourth fields. This allows collecting the injected sorbent at either an effective SCA of 270 or of 135.

The carbon injection system for the parametric tests consists of a portable feeder-blower unit that feeds the sorbent from 900 lb capacity bulk storage bags. With the normal parametric testing injection ranges, this configuration allows testing a single sorbent for approximately 8 hours using a single bulk storage bag. The feeder on this unit is a variable speed screw feeder that allows testing at various injection rates.

The carbon injection system for the long-term tests consists of a storage silo with approximately 40-ton storage capacity. Sorbent feeds from the silo into two feeder trains, which mix the sorbent with transport air and convey it to the injection grid connections at the top of the test ESP box. The transport air quantity is constant, but a variable speed screw feeder meters the sorbent into the transport air through an eductor. This allows testing at various sorbent injection rates.

The ash handling system is a dilute phase pressure system with pressure feeders at each ESP hopper outlet and has two storage silos, normally one for each generating unit. With minor modifications to the transport system for this test program, the system segregates the ash/carbon mixture from the four hoppers under the test fields and transports it to a dedicated silo.

For collection of plant operating data, the test site has a work-station connected to the plant control and information system that makes the necessary plant data immediately available to the testing efforts.

Figures 4 and 5 show the carbon injection system and the injection grids for the test installation at Independence:

Figure 4. Long-Term Test Injection Silo.

Figure 5. Injection Grid Between ESP Fields.

The parametric testing at Independence used four powdered activated carbon sorbents during the parametric tests: DARCO® Hg, DARCO® Hg-LH, and two experimental DARCO® sorbents, DARCO® E-10 and DARCO® E-11. The Program selected one sorbent, DARCO® Hg-LH, to use during the long-term tests based on results from the parametric tests.

The data collection at Independence includes mercury measurement using semi-continuous emission monitoring, Ontario Hydro method duct traverses, and sorbent trap method samples. It includes particulate measurement using two BHA CPM 5000 particulate monitors, one across the ESP outlet duct on the test half and the other across the outlet duct on the other half, a TEOM particulate monitor in the ESP outlet duct on the test half, EPA Method 5 or Method 17 duct traverses, and collecting data from the Unit 2 plant opacity monitoring system.

MidAmerican Energy Company's Louisa Test Site

The Louisa Generating Station consists of a single 700-MW PRB coal-fired electric generating unit.

This unit is a balanced draft Babcock & Wilcox front and rear fired boiler with two Ljungström regenerative air heaters, and a Research Cottrell hot-side electrostatic precipitator. The ESP for this unit has 4 boxes in a split wedge arrangement, with each box consisting of 27 transformer/rectifier (T/R) sets, 3 chambers, 51 gas passages, 5 fields, and 8 bus sections. The gross SCA at design flow is 459 square feet per 1,000 ACFM.

The inlet and outlet ducts for each pair of boxes are split into two separate ducts. The Program at Louisa injected the reagent in the entire ESP which is all of the total flue gas flow, but only measured the inlet mercury in the duct for one pair of boxes, This is one-half of the total flue gas flow. Outlet emissions measurements occurred at the 400 ft test elevation in the stack.

The ash handling system at the plant only has one storage silo. It would therefore be impossible under the current configuration to segregate an ash/reagent mixture from non-reagent laden ash. Since Louisa sells its fly ash, it is paramount that the reagents do not impact the marketability of the material.

For collection of plant operating data, the test site has a work-station connected to the plant control and information system that makes the necessary plant data immediately available to the testing efforts.

At Louisa, two liquid reagents were tested. First, a liquid chemical flue gas conditioning reagent was injected into the flue gas stream just upstream of the ESP (pre-ESP) using the existing flue gas conditioning equipment already in service at the site. In the second test, the liquid halogenating reagent was added to the coal in the coal feeders just prior to pulverizing and burning. Mercury measurements occurred upstream of the pre-ESP liquid injection location and downstream of the ESP at the 400 ft level in the stack to measure mercury removal rates.

TEST RESULTS

ENTERGY INDEPENDENCE

The testing at Independence consisted of injecting several carbon-based sorbents into the latter ESP fields to determine the mercury removal. Due to plant operating conditions, testing consisted of two baseline test series, two parametric test series, and one long-term test series. During the first baseline and parametric series, the last field of the test half of the ESP "B" box was not functioning. Because of this, the baseline and parametric test series were repeated approximately one month after the original testing series after making the necessary repairs to achieve normal ESP operating conditions.

Figure 6 shows a general trend of mercury removal efficiency (in percent removal) compared to the sorbent injection concentration (in lb/MMacf) for the two parametric testing series and the long-term tests. Generally, the parametric testing series indicated a slightly higher removal rate than the long-term testing series.

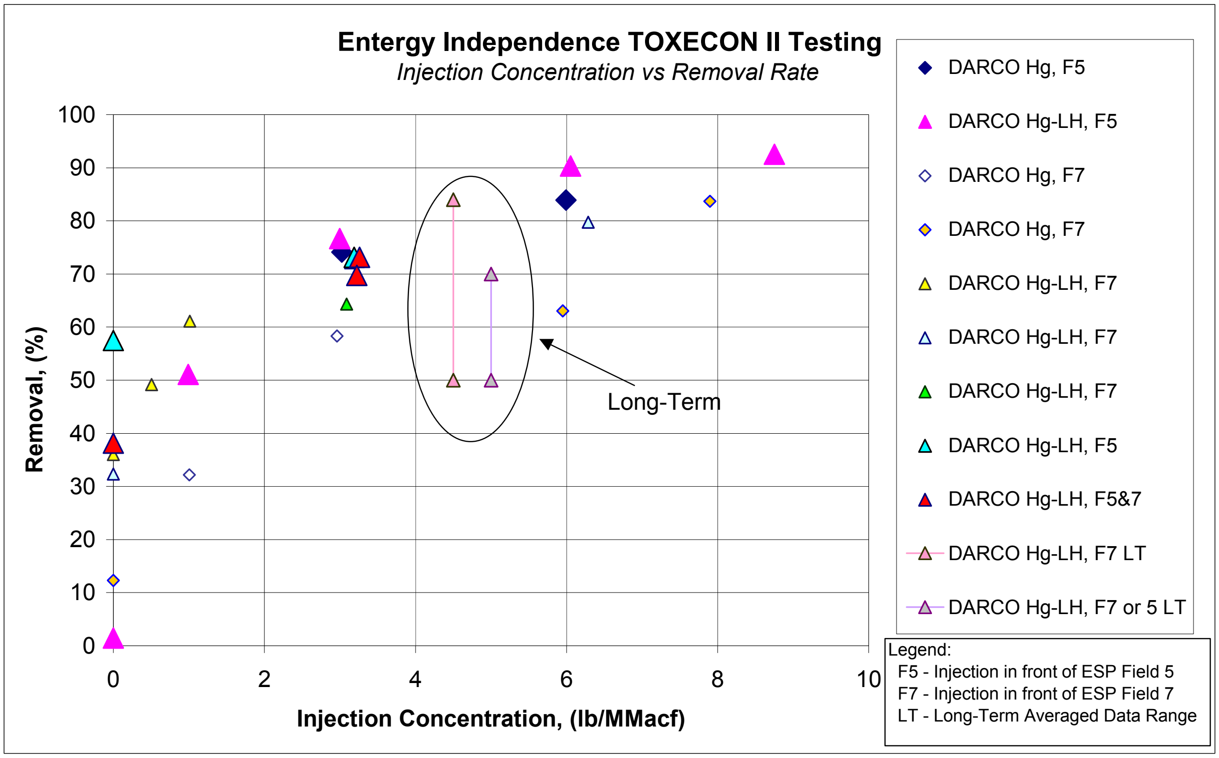

Figure 6 . Independence Injection Concentration vs. Removal Rate

The long-term testing data indicates that the removal rate varies with unit load, increasing as the load decreases and decreasing as the load increases. The data points on the figure for the long-term testing (LT) show a representative range of removal rate averages under a wide variety of plant loads and operating conditions.

The figure also differentiates between injection in front of the third ESP field (ESP Field 5 – F5) and the fourth ESP field (ESP Field 7 – F7), and two sorbents (DARCO Hg and DARCO Hg-LH).

The testing indicates a difference in removal rates between low load and high load, with the high load removal rate being lower than the low load rate and lower than we expected. We have not observed this in previous testing at other sites. Further investigations at Independence during a follow-on program with sorbent injection in front of the ESP indicated more normal (and expected) high load removal rates. This would suggest that the

TOXECON II injection grid is not getting optimum sorbent injection distribution within the ESP possibly due to the very low velocities or non-uniform flow inside of the ESP box, or a less than optimum grid design. To investigate this, the follow-on program is performing flow modeling studies of the flow within the ESP and the injection grid design. The intent is to perform additional injections tests based on the results of the modeling efforts.

MIDAMERICAN LOUISA

The testing at Louisa consisted of evaluating if the ESP flue gas conditioning reagent (ADA-37) affected the mercury removal across the ESP, and evaluating if a halogenating reagent (Alstom KNX) applied to the coal before it enters the pulverizers would affect the mercury speciation in the flue gas and the mercury removal across the ESP.

An earlier (1999) Hg characterization test at Louisa indicated that the post ESP Hg levels were lower than the pre-ESP levels when injecting the flue gas conditioning reagent (ADA-37) upstream of the ESP. This previous observation formed the basis for doing the parametric testing of ADA-37 at Louisa. While the data analysis for the testing continues, the preliminary results indicate that there is no perceptible change in Hg removal with varying ADA-37 injection rates, including periods with no injection.

As a part of this testing effort at Louisa, the Project also tested the injection of the Alstom KNX reagent to observe any changes in Hg speciation with various levels of KNX injection. While the data analysis for this testing continues, the preliminary results indicate that there is increased oxidized mercury at the ESP outlet for varying KNX injection rates.

CONCLUSIONS

Although the parametric test results at Independence show excellent removal rates and indicate promising results, the long-term removal rates were less than expected. We continue to investigate to determine the cause. Because of this and the observations from the subsequent follow-on test program, these data are not fully verified and not ready for publication in this paper.

The preliminary results from the Louisa testing indicate there is no increased Hg removal resulting from the flue gas conditioning reagent, but that the injection of a halogenating reagent on the coal does increase Hg oxidation which may be beneficial for enhancing Hg removal in downstream wet SO2 scrubbers.

REFERENCED PUBLICATIONS

Durham, M.D. (2005). "Mercury Control Fundamentals," presented at the Mercury & Multi-Emissions Compliance: Strategies & Tactics for New & Existing Coal Plants, American Coal Council, St. Louis, MO, March 22–24.

Sjostrom S., (2005). "Evaluation of Sorbent Injection for Mercury Control," presented at the DOE/NETL Mercury Control Technology R&D Program Review Meeting, Pittsburgh, PA, July 12–14.

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DISCLAIMER