Field Testing of Mercury Control Technologies for Coal-Fired Power Plants

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The U.S. Department of Energy/National Energy Technology Laboratory (DOE/NETL) is conducting a comprehensive research, development, and demonstration (RD&D) program directed at advancing the performance and economics of mercury control technologies for coal-fired power plants. The program also includes evaluating the fate of mercury in coal by-products and studying the transport and transformation of mercury in power plant plumes. This paper presents results from ongoing full-scale and slip-stream field testing of several mercury control technologies and approaches and plans for future testing.

INTRODUCTION

On March 15, 2005, the U.S. Environmental Protection Agency (EPA) issued a final regulation for the control of mercury emissions from coal-fired power plants.[1] The Clean Air Mercury Rule (CAMR) establishes a nationwide cap-and-trade program that will be implemented in two phases and applies to both existing and new plants. The first phase of control begins in 2010 with a 38 ton mercury emissions cap based on "co-benefit" reductions achieved through further sulfur dioxide (SO_2) and nitrogen oxides (NOx) emission controls required under EPA's recently issued Clean Air Interstate Rule (CAIR). The second phase of control requires a 15 ton mercury emissions cap beginning in 2018. It has been estimated that U.S. coal-fired power plants currently emit approximately 48 tons of mercury per year.[2] As a result, the CAMR requires an overall average reduction in mercury emissions of approximately 69% to meet the Phase II emissions cap.

Previous testing has demonstrated that some degree of mercury co-benefit control is achieved by existing conventional air pollution control devices (APCD) installed for removing NOx, SO_2, and particulate matter (PM) from coal-fired power plant combustion flue gas. However, the capture of mercury across existing APCDs can vary significantly based on coal properties, fly ash properties (including unburned carbon), specific APCD configurations, and other factors, with the level of control ranging from 0% to more than 90%. Mercury is present in the flue gas in varying percentages of three basic chemical forms: particulate-bound mercury, oxidized mercury (primarily mercuric chloride – $HgCl_2$), and elemental mercury. The term *speciation* is used to describe the relative proportion of the three forms of mercury in the flue gas. Mercury speciation has a large affect on co-benefit mercury control of existing APCDs. For example, elemental mercury is not readily captured by existing APCD, while particulate-bound mercury is captured by electrostatic precipitators (ESP) and fabric filters (FF). Oxidized mercury is water-soluble and therefore readily captured in flue gas desulfurization (FGD) systems. The use of selective catalytic reduction (SCR) for NOx control has shown to be effective in converting elemental mercury to oxidized mercury that can be subsequently captured in a downstream FGD absorber.[3] In general, plants burning subbituminous and lignite coals demonstrate significantly lower mercury capture than similarly equipped bituminous-fired plants. The lower performance observed for these low-rank coals has been linked to higher levels of elemental mercury, associated with the coal's low chlorine content. Table 1 presents a summary of average co-benefit mercury capture for various APCD configurations and coal rank based on testing conducted by the EPA in 1999.

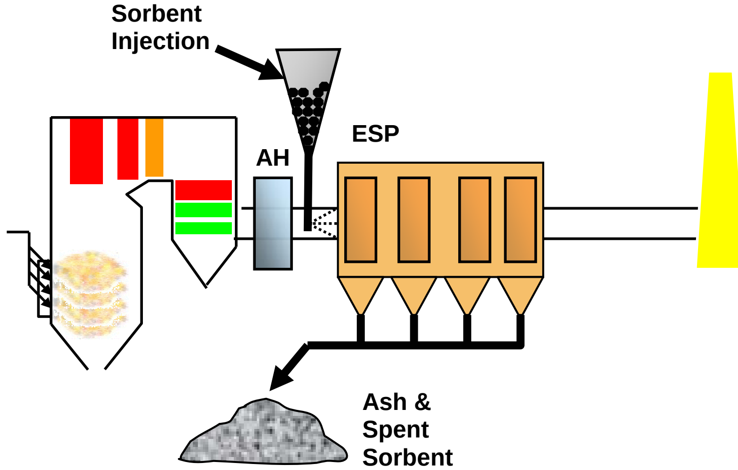
Table 1 – Average Mercury Capture by Coal Rank and APCD Configuration

APCD Configuration	**Average Percentage Mercury Capture**		
	Bituminous	**Subbituminous**	**Lignite**
CS-ESP	36	3	- 4
HS-ESP	9	6	NA
FF	90	72	NA
PS	NA	9	NA
SDA + ESP	NA	35	NA
SDA + FF	98	24	0
SDA + FF + SCR	98	NA	NA
PS + Wet FGD	12	- 8	33
CS-ESP + Wet FGD	74	29	44
HS-ESP + Wet FGD	50	29	NA
FF + Wet FGD	98	NA	NA

CS-ESP = cold-side ESP
HS-ESP = hot-side ESP
PS = particulate scrubber
SDA = spray dryer adsorber

Although conventional APCD technology can capture some mercury, new mercury control technologies will be needed to help achieve the level of control necessary to meet the CAMR Phase II mercury emission cap. To date, use of activated carbon injection (ACI) has shown the most promise as a near-term mercury control technology. In a typical configuration, powdered activated carbon (PAC) is injected downstream of the plants' air heater and upstream of the particulate control device – either an ESP or FF (Figure 1). The PAC adsorbs the mercury from the combustion flue gas and is subsequently captured along with the fly ash in the ESP or FF. Although initial field testing of ACI has been relatively successful, additional RD&D is required before it is considered a commercial technology for coal-fired power plants. For example, the effect of long-term use of PAC (or any other injected sorbent or additive) on plant operations has yet to be determined. In addition, for plants that sell their fly ash, an increase in carbon content (or the addition of other chemical compounds) may adversely affect its sale and lead to increased cost for disposal.

Figure 1 – Activated Carbon Injection Technology Schematic



More recently, field testing has begun on a number of alternative approaches to enhance ACI mercury capture performance for low rank coal applications, including: 1) the use of chemically-treated PACs that compensate for low chlorine concentrations in the combustion flue gas; and 2) coal and flue gas chemical additives that promote mercury oxidation. In addition to ACI, other mercury control technologies are being tested to enhance mercury capture for plants equipped with wet FGD systems. These FGD-related technologies include: 1) coal and flue gas chemical additives and fixed-bed catalysts to increase levels of oxidized mercury in the combustion flue gas; and 2) wet FGD chemical additives to promote mercury capture and prevent re-emission of previously captured mercury from the FGD absorber vessel. These approaches are discussed in more detail in later sections. Additional research is needed on all of these mercury control technologies so that coal-fired power plant operators eventually have a suite of control options available in order to cost-effectively comply with the CAMR.

DOE/NETL's MERCURY RD&D PROGRAM

Recognizing the potential for mercury regulation, DOE/NETL has been carrying out comprehensive mercury research under the DOE Office of Fossil Energy's Innovations for Existing Plants (IEP) program.[4] Working collaboratively with power plant operators, the Electric Power Research Institute (EPRI), academia, state and local agencies, and EPA, the program has greatly advanced our understanding of the formation and capture of mercury from coal-fired power plants. Continued RD&D is necessary in order to bring advanced mercury control technology to the point that it is ready for commercial demonstration. Initial efforts in the early 1990s were directed at characterizing power plant mercury emissions and focused on laboratory- and bench-scale control technology development. The current program is directed at slip-stream and full-scale field testing of mercury control technologies, as well as continued bench- and pilot-scale development of novel control concepts. The near-term goal is to develop mercury control technologies that can achieve 50-70% mercury capture at costs 25-50% less than baseline estimates of $50,000-$70,000/lb of mercury removed. These technologies would be available for commercial demonstration by 2007 for all coal ranks. The longer-term goal is to develop advanced mercury control technologies to achieve 90% or greater capture that would be available for commercial demonstration by 2010.

MERCURY CONTROL TECHNOLOGY FIELD TESTING

DOE/NETL initiated pilot-scale slip-stream and full-scale field testing of mercury control technologies in 2001. While the scale of testing is large, this is still viewed as an R&D activity, rather than a commercial demonstration. Phase I field testing included an evaluation of ACI at four power plants during 2001-04. These tests included use of conventional commercially-available activated carbon sorbents. In addition, a proprietary chemical additive to improve mercury capture in wet FGD systems was evaluated at two other power plants. In further support of the near-term program goal, DOE/NETL selected eight new projects in September 2003 to test and evaluate mercury control technologies under a first round Phase II (Phase II-1) solicitation. Building on promising advances that resulted from Phase I activities, these projects focus on longer-term, large-scale field testing on a broad range of coal-rank and APCD configurations. These tests are providing important information on mercury removal effectiveness, cost, and the potential impacts on plant operations including by-product characteristics. Phase II-1 testing was initiated in 2004 and should be completed in 2006. In October 2004, DOE/NETL awarded a second round of six additional Phase II projects (Phase II-2). These projects will begin in 2005 and are scheduled for completion in 2007. Previous pilot- and full-scale testing has demonstrated that the low chlorine concentrations of most low-rank coals is a major limiting factor in the mercury control performance of conventional activated carbons. As a result, several of the Phase II projects include testing of chemically-treated activated carbons or oxidation additives that compensate for the lack of naturally-occurring chlorine (or other halogens) levels in the combustion flue gas. The Phase II testing also includes evaluation of non-carbon sorbents and oxidation catalysts. In addition, Phase II includes testing sorbents at several power plants with either low specific collection area (SCA) cold-side ESPs or hot-side ESPs – both of which can be difficult ACI applications. Table 2 presents a matrix of the Phase II projects by coal rank and APCD configuration. DOE/NETL is also planning to issue a Phase III solicitation in June 2005 to conduct additional long-term field testing of mercury control technologies capable of 90% or greater mercury capture. Project awards should be announced by February 2006. The following sections present a brief description of the Phase I and II projects and a summary of test results where available.

Table 2 - Phase II Mercury Control Field Testing Technology Matrix

Coal Rank	Cold-side ESP (low SCA)	Cold-side ESP (medium or high SCA)	Hot-side ESP	TOXECON	ESP/FGD	SDA/FF or SDA/ESP
Bituminous	Miami Fort 6	Lee 1	Cliffside	Independence	Yates 1	
		Lee 3	Buck	Gavin	Yates 1	
	Yates 1&2	Portland			Conesville	
		Monroe			Conesville	
Subbituminous	Crawford	Meramec	Council Bluffs			Holcomb
		Dave Johnston	Louisa			Laramie River
		Stanton 1	Will County			
Lignite (North Dakota)		Leland Olds 1			Milton Young	Antelope Valley 1
		Leland Olds 1				Stanton 10
						Stanton 10
Lignite (Texas)					Monticello	
					Monticello	
					Monticello	
Blends		St. Clair		Big Brown		

- Sorbent Injection
- Sorbent Injection & Oxidation Additive
- Oxidation Additive
- Oxidation Catalyst
- Chemically-treated sorbent
- Other – MERCAP, FGD Additive, Combustion

PHASE I FIELD TESTING (2001-04)

Full-Scale Testing of Mercury Control via Sorbent Injection

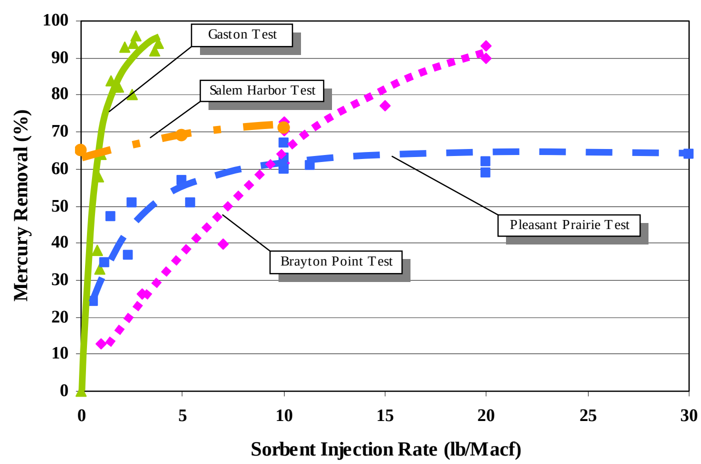
ADA Environmental Solutions (ADA-ES) conducted large-scale field tests at the four coal-fired plants described in Table 3. Results from this testing have been published previously.[5,6,7,8,9] The following is a brief summary of these results. Testing included parametric tests using several commercially available powdered activated carbon (PAC) products at various feed rates and operating conditions, followed by a one- to two-week long-term test with a PAC selected from the parametric testing. Figure 2 presents an overall comparison of the mercury removal versus PAC injection rate at the four plants. As Figure 2 suggests, the level of mercury reduction and PAC injection rate can vary significantly based on APCD configuration, coal rank, as well as baseline level of mercury reduction co-benefits. The following is a brief summary of the test results for each plant.

Table 3 –Phase I Field Test Sites for Activated Carbon Injection

Company	Plant	Coal Rank	APCD Configuration	Test Completed
Alabama Power	E.C. Gaston	Low sulfur bituminous	Hot-side ESP and COHPAC	April 2001
We Energies	Pleasant Prairie	Subbituminous	Cold-side ESP	November 2001
PG&E	Brayton Point	Low sulfur bituminous	Cold-side ESP	August 2002
PG&E	Salem Harbor	Low sulfur bituminous	Cold-side ESP and SNCR	November 2002

E.C.Gaston- The Gaston Plant is equipped with a hot-side ESP and a downstream pulse-jet fabric filter (PJFF) baghouse. The retrofit of a high air-to-cloth ratio PJFF downstream of an ESP to improve particulate collection performance was developed by EPRI and is known as a compact hybrid particulate collector (COHPAC™) system. Baseline measurements indicated less than 10% mercury capture across the PJFF. Average PJFF inlet mercury concentration was approximately 11 microgram per dry normal cubic meter (µg/dncm), and 40% was elemental mercury. PAC was injected upstream of the PJFF during ACI testing. While there was no measurable performance difference between the PACs used during the parametric testing, Norit's DARCO Hg (formerly known as DARCO FGD) activated carbon was selected for the nine-day, long-term test. Mercury capture averaged 87–90% with a PAC injection rate of 1.5 pounds per million actual cubic feet (lb/MMacf) of flue gas based on three Ontario Hydro test results. However, mercury continuous emissions monitor (CEM) data indicated an average capture of 78% that varied from 36-90%. The use of a fabric filter enhanced ACI performance compared to the other test sites that used an ESP for particulate collection. However, as a result of the increased particulate loading during ACI, the required cleaning

Figure 2 – Phase I ACI Test Results



frequency of the PJFF significantly increased. This led to a concern of possible premature failure of the filter bags that could pose a reliability problem under long-term ACI operation. There was no improvement in mercury capture using a water spray cooling system to lower flue gas temperature.

E.C. Gaston – Extended Long-Term Testing. A one-year long-term performance evaluation of the impact of ACI on the PJFF was conducted at E.C. Gaston Unit 3 beginning in April 2003. The long-term testing included six-month ACI operation with the existing filter bags and six-month ACI operation with new high-permeation filter bags. The high-permeation filter bags were tested in order to reduce pressure drop across the bags and therefore reduce bag cleaning frequency during ACI, which was a concern during the earlier Phase I testing conducted in 2001. Baseline test conditions in April 2003 were significantly different than in April 2001: 1) higher PJFF cleaning frequency; 2) large variation (0-90%) in baseline mercury removal (compared to less than 10% in 2001); and 3) higher carbon content in the PJFF hopper ash. Average mercury removal was 86% at 0.55 lbs/MMacf PAC injection rate during the July-November 2003 long-term testing using the original filter bags. The new high-permeation bags were installed in December 2003 and initial baseline testing indicated a significant reduction in cleaning frequency from 4.4 pulses per bag per hour (p/b/h) to less than 1 p/b/h. Baseline mercury removal varied from 0-95%. The long-term testing of the high-permeation bags was started in January 2004 with a target PAC injection rate of 1.3 lb/MMacf and a bag cleaning frequency of 1.0 p/b/h. Results from the first two weeks indicated an average mercury removal greater than 90%. Unfortunately, the long-term testing was interrupted by a two-month outage on Unit 3. A second round of baseline testing was conducted after unit start-up in April 2004 during which mercury removal varied from 0-83%. The high-permeation bag long-term testing was then resumed for one month in May 2004. Average mercury removal was greater than 90% with a PAC injection feed rate of 1.3-1.6 lb/MMacf. The loss-on-ignition (LOI) levels of the fly ash, which serves as a measure of unburned carbon, was relatively high in 2003-04. This resulted in higher baseline co-benefit mercury removal and more frequent filter bag cleaning. The year-to-year change in operating conditions and resultant change in ACI performance at Gaston serve as a good example for why the results of short-term testing may not be reflective of long-term performance at either the test site or other similarly designed plants.

Pleasant Prairie. ACI mercury capture performance was limited on this subbituminous coal-fired plant compared to the other test sites that burned bituminous coal. Baseline measurements indicated less than 10% mercury capture across the ESP. Average ESP inlet mercury concentration was approximately 17 μg/dncm and 70-85% of it was elemental mercury. Norit's DARCO Hg activated carbon was used during the three five-day, long-term tests at PAC feed rates of 1.6-11.3 lb/MMacf, with mercury capture ranging from 46-66% based on CEM test results. Although ACI did not deteriorate ESP performance, the ESP was relatively large (468 ft^2/1000 acfm specific collection area, SCA) and additional testing needs to be conducted on units with smaller ESPs. However, the PAC in the fly ash rendered the ash unsuitable for sale as a supplement for Portland cement in concrete. As in the Gaston testing, there was no improvement in mercury capture using a spray cooling system.

Brayton Point. The Brayton Point Plant is equipped with two cold-side ESPs in series. During baseline testing the average mercury removal ranged from 30-90% across both ESPs and 0-10% across the second ESP. Average mercury concentration at the inlet to the first ESP was approximately 6 μg/dncm, of which 85% was particulate-bound and 5% elemental mercury.

Norit's DARCO Hg was injected between two cold-side ESPs at feed rates of 3-20 lb/MMacf, with mercury capture ranging from 25-90%, respectively, across the second ESP. The carbon injection did not deteriorate ESP performance. However, the second ESP was relatively large (403 SCA) and additional testing needs to be conducted on units with smaller ESPs.

Salem Harbor. This plant burns a South American bituminous coal that is not typical for U.S. power plants. During baseline testing average mercury capture across the ESP was approximately 90%. Average mercury concentration at the inlet to the ESP was approximately 10 µg/dncm of which 95% was particulate-bound mercury. The high baseline mercury removal was attributed to high levels of unburned carbon (25-30% LOI) and low flue gas temperature (~270 ºF). During parametric testing, baseline mercury removal decreased from approximately 90% to 20% while flue gas temperature was increased from 270°F to 350°F. A maximum mercury capture of only 45% was achieved at 350 °F during ACI with DARCO Hg at 20 lb/MMacf. While increasing temperature clearly caused a decrease in baseline mercury capture, the effect that increased temperature has on ACI performance is uncertain.

Enhanced Mercury Control in Wet FGD

There is evidence that a portion of the oxidized mercury captured in a wet FGD absorber can be reduced to elemental mercury and emitted out the stack. A method to prevent the reduction of oxidized mercury would enhance the overall mercury capture across the wet FGD system. Babcock & Wilcox and McDermott Technology Inc. carried out full-scale field tests of a proprietary liquid reagent to enhance mercury capture in coal-fired plants equipped with wet FGD systems.[10] The project was initiated in 2000 and completed in 2002. Testing was conducted at two power plants: Michigan South Central Power Agency's 60-MW Endicott Station and Cinergy's 1300-MW Zimmer Station. Both plants burn high-sulfur bituminous coal and use cold-side ESPs for particulate control. The Endicott Station uses a limestone wet FGD system with in situ forced oxidation and the Zimmer Station uses a magnesium-enhanced lime wet FGD system with ex situ forced oxidation.

Test results were mixed, with a favorable outcome at Endicott in that the reagent was able to suppress mercury reduction across the wet FGD system. Testing at Zimmer did not achieve the desired effect and reduction of oxidized mercury to elemental mercury continued across the wet FGD system during reagent usage. Possible explanations for the poor results at Zimmer include the higher sulfite concentration and lower liquid-to-gas ratio in the magnesium-enhanced lime wet FGD system, which may have impeded the reagent performance.

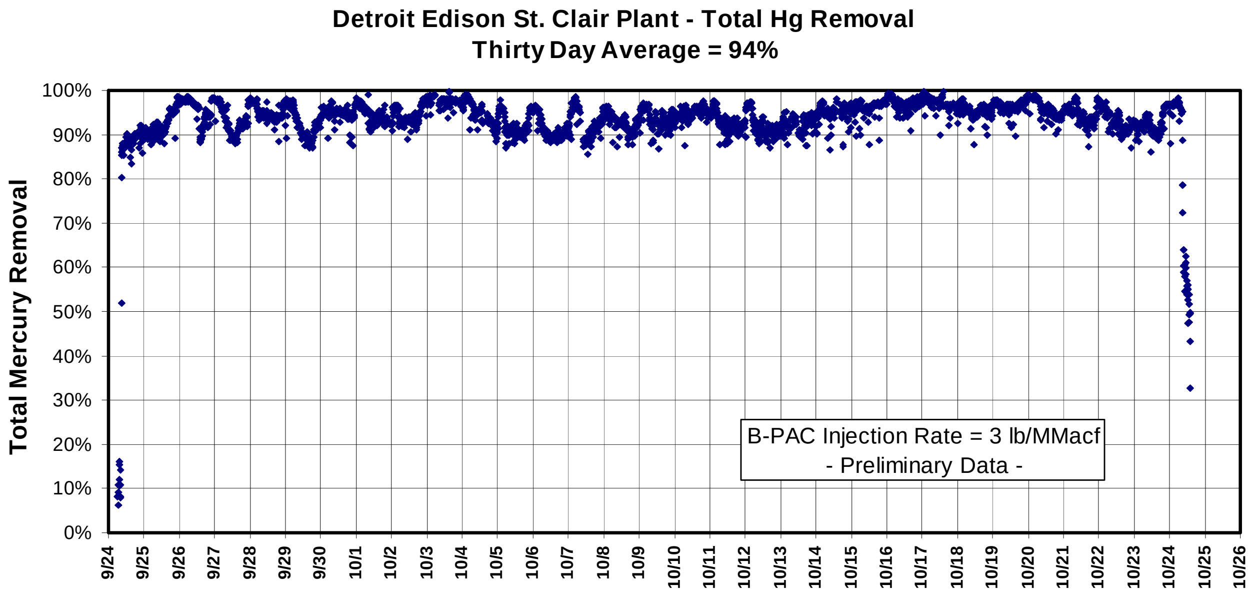
PHASE II, ROUND 1 FIELD TESTING (2004-06)

Chemically-Treated PAC

Sorbent Technologies Corporation is testing brominated-PACs that can be used as a cost effective alternative to conventional PACs for mercury capture in both cold-side and hot-side ESP applications.[11,12] A short-term trial was conducted at Duke Energy's Cliffside Plant that is equipped with a hot-side ESP. Long-term testing is being conducted at two plants.

St. Clair. Detroit Edison's 80 MW St. Clair Station burns a blend of 85% PRB and 15% bituminous coal and is equipped with an ESP (700 SCA). Testing was completed fourth quarter 2004. Baseline mercury removal across the ESP varied from 0-40%. Mercury concentration at the ESP inlet varied from 4-10 µg/dncm of which 80-90% was elemental mercury. Average mercury removal during the one-month long-term test was 94% using a brominated PAC (B-PAC™) at 3 lb/MMacf (Figure 3).

Figure 3 - St. Clair ACI Long-Term Test Results



Buck. Duke Energy's 140 MW Buck Plant burns low-sulfur bituminous coal and is equipped with a hot-side ESP (240 SCA). Testing is scheduled to begin second quarter 2005.

Chemically-Treated PAC and Additives

ADA Environmental Solutions (ADA-ES) is evaluating the use of chemically treated PACs and chemical additives to capture mercury for a variety of coal and APCD configurations at five power plants.[13,14]

Holcomb. Sunflower Electric's 360 MW Holcomb Station burns PRB subbituminous coal and is equipped with a spray dryer absorber and fabric filter baghouse (SDA/FF). Testing was completed third quarter 2004. Baseline mercury capture was only 13% across the SDA/FF while burning 100% PRB coal. SDA inlet mercury concentration was 11.7 µg/dncm and was almost 100% elemental mercury. Three methods for mercury control were evaluated during parametric testing - coal blending, ACI, and ACI combined with a coal additive to promote mercury oxidation. Blending 15% western bituminous coal with the PRB increased mercury capture to almost 80% (Figure 4). The mercury concentration of the western bituminous coal was similar to the PRB, but the chlorine concentration was higher (106 µg/g vs. 8 µg/g). Three sorbents were evaluated during the ACI parametric testing: 1) Norit DARCO Hg – a conventional PAC; 2) Calgon 208CP - a highly activated, but untreated PAC; and 3) Norit DARCO Hg-LH – formerly known as DARCO FGD E-3 – a brominated PAC. Mercury removal was approximately 50% with both the DARCO Hg and 208CPA untreated PACs at a feed rate of 1.0 lb/MMacf. However, the DARCO Hg-LH brominated PAC achieved 77% mercury capture at only 0.7 lb/MMacf and greater than 90% at 4.3 lb/MMacf. A proprietary chemical coal additive, ALSTOM Power's KNX, increased mercury removal from 50% to 86% when used with DARCO Hg at 1.0 lb/MMacf. The KNX additive decreased the percentage of elemental mercury at the SDA inlet to 20-30%. However, there was no improvement in mercury capture using the KNX without ACI. The DARCO Hg-LH was selected for further evaluation during a 30-day long-term test and was injected at 1.2 lb/MMacf with average mercury removal of 93% (Figure 5). No adverse balance-of-plant impacts were observed during the long-term testing. In particular, no excess levels of bromine were measured in the flue gas.

Figure 4 Holcomb Station Parametric Test Results with Coal Blending

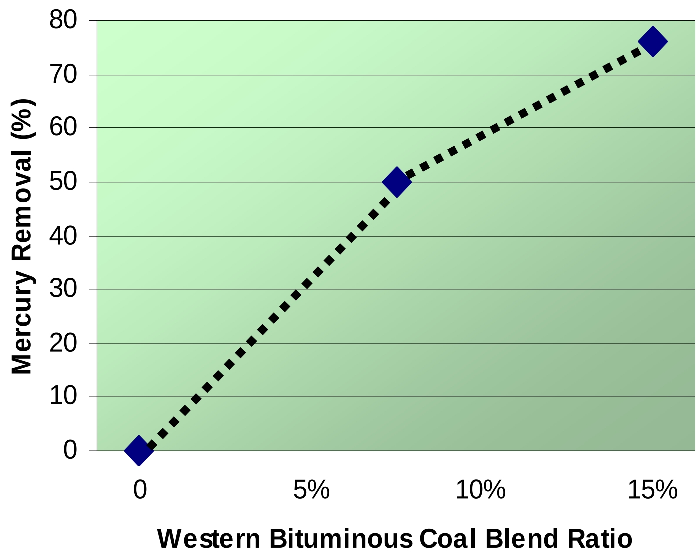
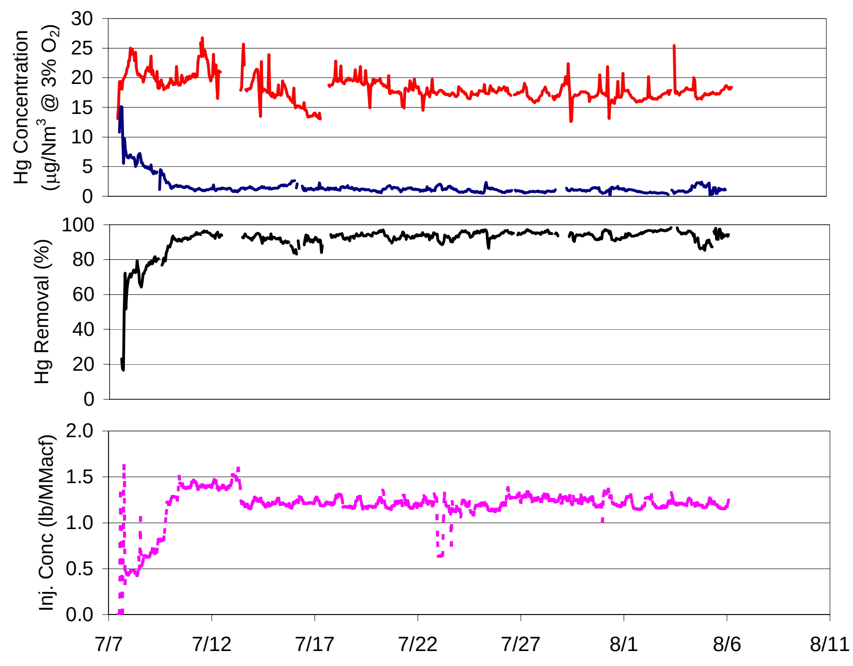
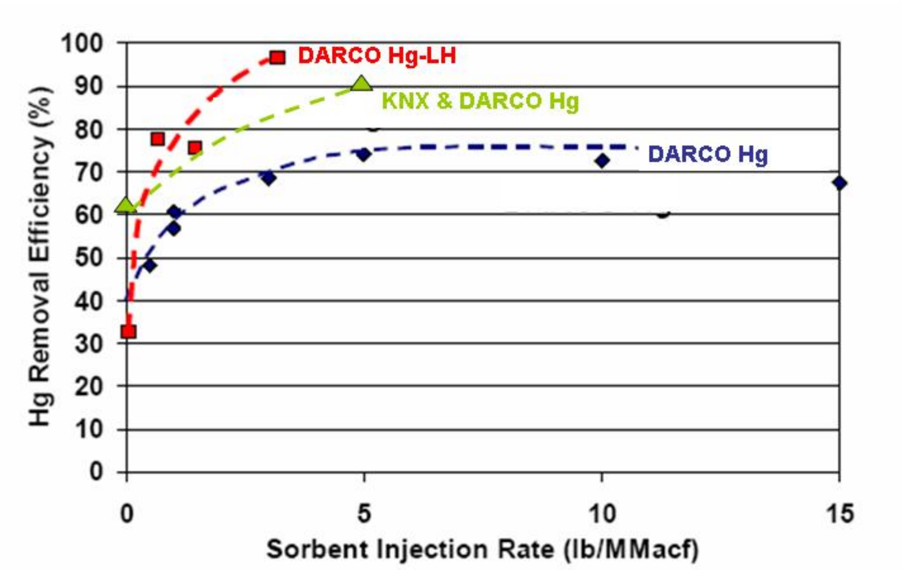


Figure 5 – Holcomb Station ACI Long-Term Test Results



Meramec. AmerenUE's 140 MW Meramec Station Unit 2 burns PRB coal and is equipped with an ESP (320 SCA). Testing was completed fourth quarter 2004. Baseline mercury capture across the ESP ranged from 15-18% with an inlet mercury concentration of approximately 8.5 µg/dncm while burning 100% PRB coal. During the parametric and long-term testing Unit 2 experienced a mill outage that resulted in variations of LOI that may have contributed to higher levels of particulate-bound mercury and consequently higher than normal baseline mercury removal. For example, during long-term testing the percentage of particulate-bound mercury was approximately 30%. Two methods for mercury control were evaluated during parametric testing - ACI and KNX with and without ACI. Norit DARCO Hg and Hg-LH sorbents were evaluated during the ACI parametric testing. Mercury removal peaked at 74% using DARCO Hg at a feed rate of 5 lb/MMacf compared to 97% at 3.2 lb/MMacf with DARCO Hg-LH (Figure 6). Mercury removal was 87% using a combination of the KNX and DARCO Hg at a feed rate of 5 lb/MMacf. With the KNX coal additive alone, mercury removal ranged from 57-64% compared to 34% without the additive.

Figure 6 - Meramec ACI Parametric Test Results



Norit DARCO Hg-LH was selected for further evaluation during the 30-day long-term test and was injected at 3.3 lb/MMacf with average mercury removal of 93%. As at Holcomb, no adverse balance-of-plant impacts were observed during the long-term testing and no excess levels of bromine were measured in the flue gas.

Laramie River. Basin Electric's 550 MW Laramie River Plant Unit 3 burns PRB coal and is equipped with a SDA/ESP. Testing was completed first quarter 2005, but results are not yet available.

Monroe. Detroit Edison's 800 MW Monroe Plant Unit 4 burns a blend of PRB and bituminous coal and is equipped with an ESP (258 SCA). Testing began first quarter 2005.

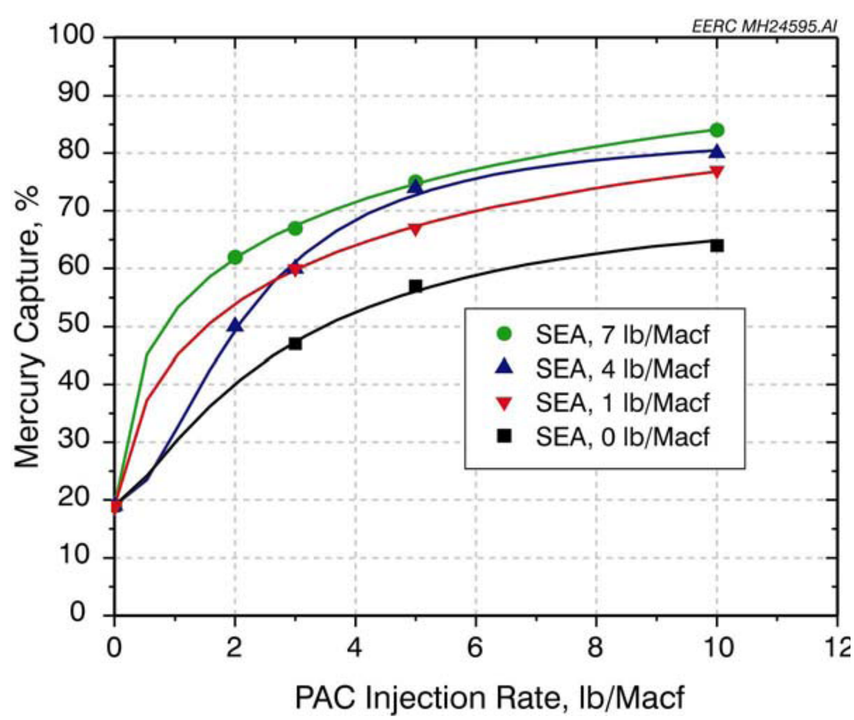
Conesville. American Electric Power's (AEP's) 400 MW Conesville Station Unit 6 burns bituminous coal and is equipped with an ESP (301 SCA) and wet FGD. Testing is scheduled to begin first quarter 2006.

Chemically-Treated PAC and Additives for North Dakota Lignite-Fired Plants

The University of North Dakota Energy & Environmental Research Center (UNDEERC) is testing enhancements to ACI to increase mercury capture for plants burning low-rank North Dakota lignite coals.[15,16,17] Two different technology approaches are being evaluated: (1) injection of chemical additives (generically known as sorbent enhancement additives or SEA) in conjunction with conventional PACs, and (2) injection of chemically-treated PACs. Two SEAs are being evaluated – SEA-1 (calcium chloride) and SEA-2 (a proprietary halogen-based chemical). The two technology approaches will be tested at two plants each, one with an ESP and one with a SDA/FF.

Leland Olds. The first approach was tested at Basin Electric's 220 MW Leland Olds Station Unit 1 that is equipped with an ESP (320 SCA). Testing was completed second quarter 2004. Baseline mercury removal was 15% across the ESP. Average ESP inlet mercury concentration was 7.3 µg/dncm of which 56% was elemental mercury. Figure 7 presents a summary of the parametric test results. At a PAC injection rate of 3 lb/MMacf, mercury removal was ~45% without the SEA-1 and ~65% with an SEA-1 feed rate of 7 lb/MMacf (calcium chloride equivalent to ~500 ppm chlorine in the coal). Average mercury removal was 63% during the one-month long-term testing with a PAC injection rate of 3 lb/MMacf and an SEA-1 feed rate of 7 lb/MMacf.

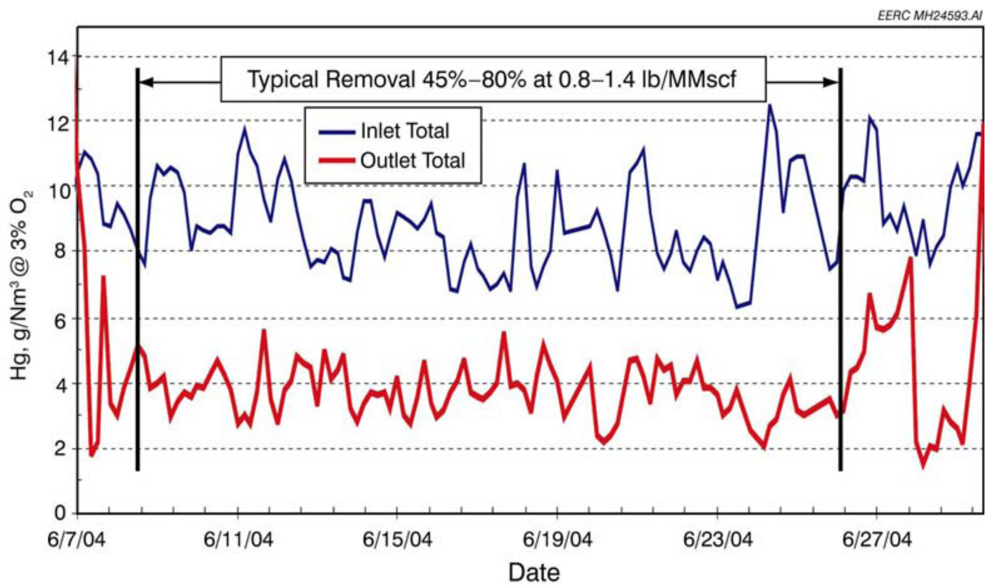
Figure 7 - Leland Olds Unit 1 ACI/SEA Parametric Test Results



Antelope Valley. The first approach is also being tested at Basin Electric's 440 MW Antelope Valley Station Unit 1 that is equipped with a SDA/FF. Testing began second quarter 2005 and includes evaluation of the SEA-2 additive. Test results are not yet available.

Stanton 10. The second approach was tested at Great River Energy's 60 MW Stanton Station Unit 10 that is equipped with a SDA/FF. Testing was completed third quarter 2004. Baseline mercury removal across the SDA/FF was less than 10%. Total vapor-phase mercury concentrations ranged from 7.5-13 µg/dncm at both the SDA inlet and FF outlet with less than 10% oxidized mercury. Five enhanced PACs (iodine, a proprietary chemical, a super activated carbon, and two with bromine) were evaluated during short-term parametric testing and Norit's DARCO Hg was also tested as a benchmark. The DARCO Hg achieved 75% mercury removal at a feed rate of 6 lb/MMacf. However, the two brominated PACs achieved greater than 90% mercury removal at feed rates of only 1.5 lb/MMacf. One of the brominated PACs, DARCO Hg-LH, was selected for use during the one-month long-term testing with mercury removal ranging from 45-80% (60% average) at a PAC injection rate of 0.7 lb/MMacf (Figure 8).

Figure 8 – Stanton Unit 10 ACI Long-Term Test Results

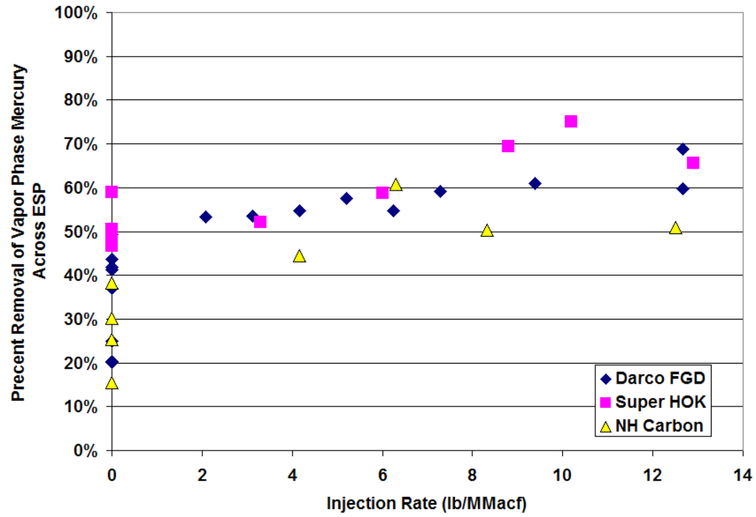


Stanton 1. The second approach is also being tested at Great River Energy's 140 MW Stanton Station Unit 1 that is equipped with an ESP (470 SCA). The Stanton Station has recently switched from North Dakota lignite to PRB coal. Testing is scheduled to begin second quarter 2005 and will be conducted with the unit burning PRB coal.

Sorbent Injection for Low SCA ESP Applications

URS Group, Inc. (URS) conducted an evaluation of ACI upstream of low SCA ESPs.[18,19] Testing was conducted at Southern Company's 100 MW Plant Yates Unit 1 and 2 that burn bituminous coal. Yates Unit 1 is equipped with an ESP (173 SCA) and wet FGD while Yates Unit 2 is equipped with an ESP (144 SCA) that utilizes ammonia and sulfur trioxide flue gas conditioning to improve performance. Testing was completed fourth quarter 2004. Average baseline mercury removal was approximately 35% for both Units 1 and 2. Parametric tests lasting approximately two hours each were conducted on Unit 1 at various feed rates using three PACs (DARCO Hg, RWE Rhinebraun's Super HOK, and Ningxia Huahui's NH Carbon). Performance was similar for the three PACs with maximum mercury removal of approximately 60% across the ESP with PAC injection at 6 lb/MMacf (Figure 9). Similar results were achieved during parametric testing on Unit 2 using only DARCO Hg. There was no significant increase in ESP outlet particulate concentrations during the parametric testing. However, there was an apparent increase in ESP sparking at higher sorbent injection feed rates.

Figure 9 - Yates Unit 1 ACI Parametric Test Results



The Super HOK PAC was selected for use during the one-month long-term testing on Unit 1. Mercury concentrations ranged from 5-13 µg/dncm at the ESP inlet of which 60-75% was oxidized mercury. Baseline mercury removals were 50% across the ESP and a total of 80% across the ESP and wet FGD. PAC injection rates ranged from 4-10 lb/MMacf with mercury removal ranging from 60-85% across the ESP and a total of 70-94% across the ESP and wet FGD. However, it appeared that PAC injection rates above 4.5 lb/MMacf did not significantly improve mercury capture. Approximately 30% of the particulate measurements taken at the ESP outlet exceeded baseline concentrations. However, there was no correlation between the PAC injection rate and the level of ESP outlet particulate concentration. In addition, the wet FGD slurry samples were an unusually dark color (suggesting PAC carryover from the ESP) during a two-week period of the long-term test. Results of the wet FGD slurry analysis are not yet available.

Non-Carbon Based Sorbent

Amended Silicates, LLC (a joint venture of ADA Technologies, Inc. and CH2M Hill) is testing a new non-carbon sorbent, Amended Silicates™, which could provide cost effective mercury capture while avoiding adverse impacts on fly ash sales.[20] Testing will be conducted at Cinergy's 175 MW Miami Fort Station Unit 6 that burns bituminous coal and is equipped with three ESPs in series (190, 163, and 179 SCA). The sorbent will be injected upstream of the first ESP and controlled mercury emissions will be measured downstream of the second ESP. Testing is scheduled to begin first quarter 2006.

Catalysts to Promote Mercury Oxidation Upstream of Wet FGD Systems

URS is conducting pilot-scale testing of fixed-bed honeycomb catalysts at four plants to promote the oxidation of elemental mercury in order to increase overall mercury capture in downstream wet FGD systems.[21,22,23,24] Unlike a NOx SCR catalyst that is located in a high temperature flue gas zone upstream of the air heater, these catalysts would be located in a low temperature zone downstream of the air heater and upstream of the wet FGD system. Four catalyst materials are being tested over a 14-month period at each plant: palladium (Pd #1), titanium/vanadium (SCR), gold, and carbon (Carbon #6). (The four catalysts tested at Coal Creek included a subbituminous ash-based catalyst (SBA #5), which did not perform well and was subsequently replaced with a gold catalyst at the other three plants.)

Coal Creek. Great River Energy's 605 MW Coal Creek Station Unit 1 burns North Dakota lignite coal and is equipped with an ESP and wet FGD. Mercury concentration after the ESP varies from 13-18 µg/dncm, of which approximately 15% is oxidized. Catalyst testing was initiated in October 2002. However, due to fabrication delays, not all of the catalysts were immediately available. Pilot testing for the Pd #1 and SCR catalysts began in October 2002. Testing of the SBA #5 catalyst began in December 2002 and the Carbon #6 catalyst testing began in June 2003. The initial percentage of elemental mercury oxidized by the catalysts ranged from 65-95%, but gradually decreased thereafter. The final catalyst activity measurements were conducted in June 2004. Oxidation of elemental mercury across Pd #1 decreased from 90% to 65% after 20 months in-service and oxidation across Carbon #6 decreased from 95% to 80% after 13 months. However, oxidation activity decreased more rapidly for the SCR and SBA #5 catalysts. After 21 months, oxidation across SCR decreased from 65% to less than 30% and oxidation across SBA #5 decreased from 75% to less than 20% after 18 months. There was some concern that the catalysts might also lead to oxidation of SO_2 and NO that could produce undesirable balance-of-plant effects. However, there was no apparent oxidation of SO_2 to SO_3 and approximately 10 ppmv (7%) oxidation of NO to NO_2.

J. K. Spruce. City Public Service (CPS) of San Antonio's 546 MW J.K. Spruce Plant burns a PRB coal and is equipped with a FF and wet FGD. Testing began in September 2003 and should be completed second quarter 2005. Mercury concentration after the FF varies from 10-13 µg/dncm of which 65-90% is oxidized. This is a relatively high level of oxidized mercury compared to oxidation levels of less than 25% for most plants burning PRB coal. As a result, there has been some difficulty in accurately measuring the elemental mercury concentration due to low values of 1-3 µg/dncm. After approximately one-year in-service, oxidation of elemental mercury across the Pd #1 catalyst was 76%, Carbon #6 was 80%, SCR was 41% and the gold catalyst was 92%.

Monticello. TXU's 750 MW Monticello Station Unit 3 burns Texas lignite and is equipped with an ESP (452 SCA) and wet FGD. Testing began first quarter 2005 and is scheduled to be completed first quarter 2006. Test results are not yet available.

Yates. Southern Company's 100 MW Plant Yates Unit 1 burns low-sulfur bituminous coal and is equipped with an ESP (173 SCA) and wet FGD. Testing scheduled to begin second quarter 2005 and to be completed third quarter 2006.

Chemical Additives to Promote Mercury Oxidation Upstream of Wet FGD Systems

UNDEERC is testing the effectiveness of using chemical additives to increase mercury oxidation and therefore enhance mercury capture at lignite-fired plants equipped with an ESP and wet FGD.[25] Testing is being conducted at two plants:

Milton R. Young. Minnkota Power Cooperative's 450 MW Milton R. Young Unit 2 burns North Dakota lignite and is equipped with an ESP (375 SCA) and wet FGD. Testing began first quarter 2005 and is scheduled to be completed second quarter 2005.

Monticello. TXU's 750 MW Monticello Unit 3 burns Texas lignite and is equipped with an ESP (452 SCA) and wet FGD. Testing is scheduled to begin third quarter 2005.

MerCAP - A Different Approach

URS is testing EPRI's Mercury Control via Adsorption Process (MerCAP™) technology.[26,27] The process involves placing a regenerable, fixed-structure gold sorbent into the flue gas stream to capture mercury. Testing is being conducted at two plants:

Stanton. Great River Energy's 60 MW Stanton Station Unit 10 previously burned North Dakota lignite, but switched to PRB after the testing had begun. The unit is equipped with a SDA/FF. The MerCAP sorbent structures are retrofitted into a single compartment of the fabric filter baghouse equivalent to a 6 MW demonstration. Testing began third quarter 2004 and is scheduled to be completed second quarter 2005. Baseline mercury capture was less than 10% across the SDA/FF with mercury concentration at the FF outlet ranging from 6-12 µg/dncm and was typically greater than 95% elemental mercury. Three configurations of MerCAP plates are being evaluated: 1) acid-treated gold plates with 1" spacing; 2) untreated gold plates with 1" spacing; and 3) untreated gold plates with ½" spacing. Table 4 presents a summary of results available to date. The acid-treated plates have shown the best performance with an average mercury removal of 30-35%. Regeneration of the MerCAP plates was attempted, but showed only a modest improvement (5-15%) in performance.

Table 4 – Stanton Unit 10 MerCAP Preliminary Test Results

Substrate	Plate Spacing	Installation Date	Hours in Service	Average Mercury Removal
Acid-treated	1"	8/22/04	3,123	30-35%
Untreated	1"	11/18/04	1,035	15-18%
Untreated	½"	11/18/04	1,035	25-30%
Baseline	N/A	N/A	N/A	0%

Yates. Southern Company's 100 MW Plant Yates Unit 1 burns low-sulfur bituminous coal and is equipped with an ESP (173 SCA) and wet FGD. The MerCAP sorbent structures are configured as a mist eliminator located downstream of a 1 MW pilot-scale wet FGD absorber. Testing is scheduled to begin second quarter 2005 and is scheduled to be completed fourth quarter 2005.

PHASE II, ROUND 2 FIELD TESTING (2005-07)

Brominated Sorbents for Low SCA Cold-Side and Hot-Side ESPs

Sorbent Technologies will conduct additional testing of brominated-PACs at three plants: (1) Midwest Generation's 216 MW Crawford Station Unit 7 that burns subbituminous coal and is equipped with an ESP (112 SCA); (2) Progress Energy's 75 MW Lee Station Unit 1 that burns bituminous coal and is equipped with an ESP (300 SCA); and (3) Midwest Generation's 262

MW Will County Station Unit 3 that burns subbituminous coal and is equipped with a hot-side ESP (173 SCA). In addition to their standard brominated-PAC, B-PAC™, Sorbent Technologies will also evaluate a modified formulation for hot-side ESP applications, H-PAC™, and a formulation that enables continued fly ash use in concrete, C-PAC™. Initial testing is scheduled to begin third quarter 2005 at the Lee Station.

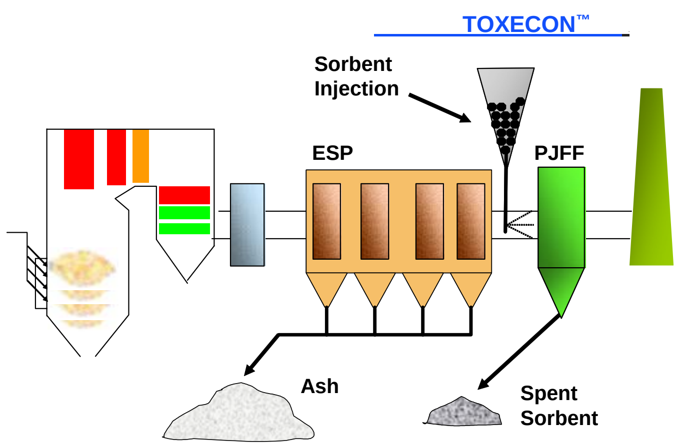
Mer-Cure – A New Proprietary PAC

ALSTOM Power will evaluate a proprietary chemically-treated activated carbon sorbent injection process – Mer-Cure™ - that promotes oxidation and capture of mercury across an ESP. Testing will be conducted at three plants burning different coals: (1) PacificCorp's Dave Johnston Plant Unit 3 that burn PRB coal and is equipped with an ESP (~600 SCA); (2) Basin Electric's 220 MW Leland Olds Station Unit 1 that burns North Dakota lignite and is equipped with an ESP (320 SCA); and (3) Reliant Energy's Portland Station Unit 1 that burns bituminous coal and is equipped with an ESP (284 SCA). Initial testing is scheduled to begin third quarter 2005 at the Dave Johnston Plant.

TOXECON for Texas Lignite-Fired Plants

UNDEERC will evaluate the long-term feasibility of using ACI to reduce mercury emissions at TXU Energy's Big Brown Steam Electric Station that typically burns a 70% Texas lignite with 30% subbituminous coal blend and occasionally 100% Texas lignite. The two 600 MW units at Big Brown are equipped with an ESP (162 SCA) and a downstream PJFF in a COHPAC configuration. The project will test several PACs and SEAs to cost-effectively remove mercury from lignite combustion gases using EPRI's toxic emission control (TOXECON™) process (Figure 10). TOXECON is a process in which PAC is injected downstream of the primary particulate control device and upstream of a pulse-jet baghouse. The TOXECON configuration allows for separate treatment or disposal of the ash collected in the primary particulate control device. Initial testing is scheduled to begin first quarter 2006.

Figure 10 - EPRI's TOXECON Process Configuration

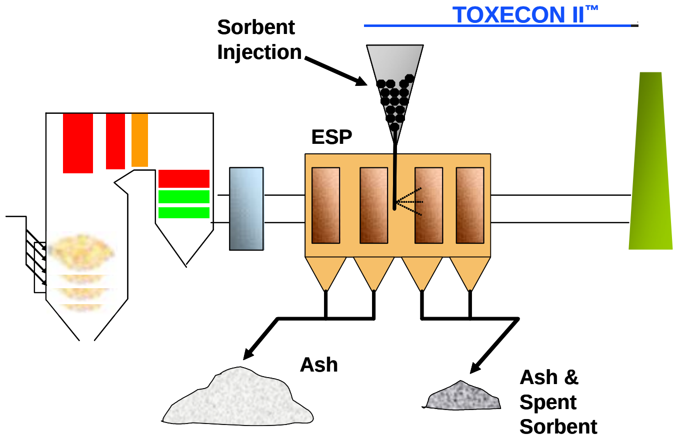


Low-Cost Options for Moderate Levels of Mercury Control

ADA-ES will test two new mercury control technologies for plants equipped with ESPs: TOXECON II™ for cold-side ESPs and proprietary sorbents for hot-side ESPs. The TOXECON II technology injects a sorbent directly into the downstream collecting fields of a cold-side ESP

(Figure 11). The majority of the fly ash is collected in the upstream collecting fields, resulting in only a small portion of carbon-contaminated ash.

Figure 11 - EPRI's TOXECON II Process Configuration



The TOXECON II technology will be tested at AEP's 1300 MW Gavin Station Unit 1 or 2 (430 SCA) that burn bituminous coal and Entergy's 835 MW Independence Station Unit 1 (542 SCA) that burns PRB coal. The proprietary sorbents for hot-side ESPs will be tested at MidAmerican's 80 MW Council Bluffs Energy Center Unit 2 (224 SCA) and MidAmerican's 740 MW Louisa Station Unit 1 (459 SCA), both of which burn PRB coal. Initial testing is scheduled to begin third quarter 2005 at the Independence Station.

Chemical Additive for Prevention of Mercury Re-Emission from Wet FGD

URS will demonstrate the use of an additive in wet lime or limestone FGD systems. The additive is designed to prevent oxidized mercury from being reduced and subsequently re-emitted from the FGD absorber as elemental mercury. Testing will be conducted at three plants: (1) TXU's 750 MW Monticello Station Unit 3 that burns Texas lignite coal and is equipped with an ESP (452 SCA); (2) Southern Company's 100 MW Plant Yates Unit 1 that burns low-sulfur bituminous coal and is equipped with an ESP (173 SCA) and wet FGD; and (3) AEP's 400 MW Conesville Station Unit 5 or 6 that burn high-sulfur bituminous coal and are equipped with an ESP (301 SCA) and wet FGD. Testing is scheduled to begin second quarter 2005 at the Monticello Station.

Combustion Modifications for Mercury Control

GE Energy's Energy & Environmental Research Corporation (GE EERC) has developed a new, cost-effective technology that combines mercury removal with NOx emission control. GE EERC will conduct a field demonstration of its technology at Progress Energy's 250 MW Lee Unit 3 that burns a bituminous coal and is equipped with an ESP (~300 SCA). The objective of the demonstration is to demonstrate at least 90 percent mercury removal. Initial testing is scheduled to begin third quarter 2005.

COMMERCIAL DEMONSTRATION

In addition to field testing mercury control technologies, DOE/NETL is also funding a $53 million commercial demonstration of EPRI's TOXECON process through the Clean Coal Power Initiative (CCPI). This first-of-a-kind commercial demonstration of TOXECON will be implemented at We Energies' Presque Isle Power Plant located in Marquette, Michigan. Presque Isle burns PRB subbituminous coal, and the TOXECON process will be installed to treat the combined flue gas stream of Units 7, 8, and 9, which total 270 MW. The project was initiated in 2003 and construction is scheduled for completion in December 2005. Extended long-term testing of the process will begin in January 2006 and be completed in December 2008.

SUMMARY

The DOE/NETL mercury control technology research program has helped to advance the understanding of the formation, distribution, and capture of mercury from coal-fired power plants. Some general observations can be drawn from the results of mercury control technology field testing that has been carried out to date:

1. Coal properties, such as chlorine content, can impact the potential mercury capture performance of mercury control technologies.
2. Significant variability in baseline mercury capture of existing APCDs has been observed at similar units as well as at individual units tested at different times.
3. Mercury capture with ACI has been demonstrated in short-term and long-term full-scale field testing. However, the range of effectiveness depends on coal type and plant APCD configuration. More long-term evaluation is necessary to determine realistic cost and performance estimates for various plant arrangements.
4. For all of the mercury control technologies, uncertainties remain regarding the capture effectiveness with various coal-rank and existing APCD configurations, balance-of-plant impacts, and by-product use and disposal. For example, there is the potential for activated carbon carryover for low SCA ESPs.
5. Baseline mercury capture performance for lignite and PRB coal-fired plants with an ESP or SDA/FF is relatively low and untreated activated carbon injection performance is limited. This testing demonstrated that mercury capture may be enhanced through addition of halogens via coal blending, coal additives, or use of chemically-treated activated carbon.

While our knowledge of the formation, distribution, and capture of mercury from coal-fired power plants has greatly advanced over the past decade, many uncertainties and challenges remain. Moreover, the technology to effectively remove mercury from the diverse population of coal-fired plants currently in operation is not yet commercially available. Therefore, as U.S. coal-fired power plant operators begin to formulate plans for compliance with Phase II of EPA's CAMR, it is critical that RD&D continues to address these challenges.

In response, DOE/NETL is continuing to partner with industry and other key stakeholders in carrying out a comprehensive mercury control technology RD&D program. This effort is being carried out through both extramural and in-house research focused on (1) enhancing the capture of mercury across existing APCDs, and (2) developing novel stand-alone control concepts to achieve high levels of mercury removal at costs considerably lower than current technology. For more information, visit the Web site: *http://www.netl.doe.gov/coal/E&WR/index.htm*.

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