Journal of the Air & Waste Management Association
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uawm20

Full-Scale Evaluation of Mercury Control with Sorbent Injection and COHPAC at Alabama Power E.C. Gaston

C. Jean Bustard [a], Michael Durham [a], Charles Lindsey [a], Travis Starns [a], Ken Baldrey [a], Cameron Martin [a], Richard Schlager [a], Sharon Sjostrom [b], Rick Slye [b], Scott Renninger [c], Larry Monroe [d], Richard Miller [e] & Ramsay Chang [f]

[a] ADA-ES, LLC , Littleton , Colorado , USA

[b] Apogee Scientific , Englewood , Colorado , USA

[c] U.S. Department of Energy , National Energy Technology Laboratory , Morgantown , West Virginia , USA

[d] Southern Company , Birmingham , Alabama , USA

[e] Hamon Research Cottrell, Inc. , Walnutport , Pennsylvania , USA

[f] EPRI , Palo Alto , California , USA

Published online: 27 Dec 2011.

TECHNICAL PAPER

ISSN 1047-3289 *J. Air & Waste Manage. Assoc.* **52**:918-926

Full-Scale Evaluation of Mercury Control with Sorbent Injection and COHPAC at Alabama Power E.C. Gaston

C. Jean Bustard, Michael Durham, Charles Lindsey, Travis Starns, Ken Baldrey, Cameron Martin, and Richard Schlager
ADA-ES, LLC, Littleton, Colorado

Sharon Sjostrom and Rick Slye
Apogee Scientific, Englewood, Colorado

Scott Renninger
National Energy Technology Laboratory, U.S. Department of Energy, Morgantown, West Virginia

Larry Monroe
Southern Company, Birmingham, Alabama

Richard Miller
Hamon Research Cottrell, Inc., Walnutport, Pennsylvania

Ramsay Chang
EPRI, Palo Alto, California

ABSTRACT

The overall objective of this project was to determine the cost and impacts of Hg control using sorbent injection into a Compact Hybrid Particulate Collector (COHPAC) at Alabama Power's Gaston Unit 3. This test is part of a program funded by the U.S. Department of Energy's National Energy Technology Laboratory (NETL) to obtain the necessary information to assess the costs of controlling Hg from coal-fired utility plants that do not have scrubbers for SO_2 control. The economics will be developed based on various levels of Hg control.

IMPLICATIONS

Sorbent injection technology represents one of the simplest and most mature approaches to control Hg emissions from coal-fired boilers. However, no application experience was available from actual full-scale installations in the U.S. power industry. A field test program representing the initial step toward defining technology to be used by power-generating companies in meeting new Hg regulations is being conducted for the NETL. The first full-scale test was completed in the spring of 2002 on a unit that burns a low-sulfur bituminous coal and uses a COHPAC baghouse to collect the carbon and fly ash.

Gaston Unit 3 was chosen for testing because COHPAC represents a cost-effective retrofit option for utilities with existing electrostatic precipitators (ESPs). COHPAC is an EPRI-patented concept that places a high air-to-cloth ratio baghouse downstream of an existing ESP to improve overall particulate collection efficiency. Activated carbons were injected upstream of COHPAC and downstream of the ESP to obtain performance and operational data.

Results were very encouraging, with up to 90% removal of Hg for short operating periods using powdered activated carbon (PAC). During the long-term tests, an average Hg removal efficiency of 78% was measured. The PAC injection rate for the long-term tests was chosen to maintain COHPAC cleaning frequency at less than 1.5 pulses/bag/hr.

INTRODUCTION

In December 2000, the U.S. Environmental Protection Agency (EPA) announced their intent to regulate Hg emissions from the nation's coal-fired power plants. Draft legislation indicates that new regulations may require removal efficiencies as high as 90% from existing sources. In anticipation of these regulations, a great deal of research has been conducted during the past decade to characterize the emission and control of Hg compounds from the combustion of coal. The U.S. Department of Energy,

EPA, and EPRI funded much of this research. The results are summarized in the comprehensive 1999 Air & Waste Management Association Critical Review article.[1] As a result of these efforts, the following was determined: (1) trace concentrations of Hg in flue gas can be measured relatively accurately, (2) Hg is emitted in a variety of forms, (3) Hg species vary with fuel source and combustion conditions, and (4) control of Hg from utility boilers will be both difficult and expensive.

This latter point is one of the most important and dramatic findings from the research conducted to date. Because of the large volumes of gas to be treated, the low concentrations of Hg, and the presence of difficult-to-capture species such as elemental Hg, some estimates show that 90% Hg reduction for utilities could cost the industry as much as $5 billion per year.[1] Most of these costs will be borne by power plants that burn low-sulfur coal and do not have wet scrubbers as part of their air pollution equipment.

With regulations rapidly approaching, it is important to concentrate efforts on the most mature retrofit control technologies. Injection of dry sorbents such as powdered activated carbon (PAC) into the flue gas and further collection of the sorbent by electrostatic precipitators (ESPs) and fabric filters commonly is used in municipal waste incinerators for Hg control and represents the most mature and potentially most cost-effective control technology for power plants.

Under a U.S. Department of Energy National Energy Technology Laboratory (NETL) cooperative agreement, ADA-ES is working in partnership with PG&E National Energy Group (NEG); Wisconsin Electric, a subsidiary of Wisconsin Energy Corp.; Alabama Power Co., a subsidiary of Southern Company; and EPRI on a field evaluation program of sorbent injection upstream of existing particulate control devices for Hg control.[2] The test program, which will take place at four different sites during 2001 and 2002, is described in detail in the July 2001 *EM*.[3] Other organizations participating in this program as industry cost-share participants include Ontario Power Generation, First Energy, TVA, Kennecott Energy, Hamon Research-Cottrell, EnviroCare, and Norit Americas.

Gaston Unit 3 was chosen as the first test site, because Compact Hybrid Particulate Collector (COHPAC) represents a cost-effective retrofit option for utilities with ESPs. The COHPAC is an EPRI-patented concept that places a high air-to-cloth ratio baghouse downstream of an existing ESP to improve overall particulate collection efficiency. The advantages of this configuration are

(1) sorbents are mixed with a small fraction of the ash (nominally 1%), which reduces the impact on ash reuse and waste disposal;
(2) pilot plant studies and theory[4] indicate that compared with ESPs, baghouses require one-tenth the sorbent to achieve similar removal efficiencies;
(3) capital costs for COHPAC are less than other options, such as replacing the ESP with a full-sized baghouse or larger ESP;
(4) COHPAC requires much less physical space than either a larger ESP or full-size baghouse system; and
(5) outage time can be reduced significantly with COHPAC systems in comparison with major ESP rebuilds/upgrades.

E.C. GASTON SITE DESCRIPTION

The E.C. Gaston Electric Generating Plant, located in Wilsonville, AL, has four 270-MW balanced-draft and one 880-MW forced-draft coal-fired boilers. All units fire a variety of low-sulfur, washed, eastern bituminous coals. The primary particulate control equipment on all units is a hot-side ESP. Units 1 and 2 and Units 3 and 4 share common stacks. In 1996, Alabama Power contracted with Hamon Research-Cottrell to install COHPAC downstream of the hot-side ESP on Unit 3. This COHPAC system was designed to maintain the stack opacity levels of Units 3 and 4 at less than 5% on a 6-min average.[5]

The COHPAC system is a hybrid pulse-jet type baghouse, designed to treat flue gas volumes of 1,070,000 acfm at 290 °F (gross air-to-cloth ratio of 8.5 ft/min with on-line cleaning). The COHPAC baghouse consists of four isolatable compartments—two compartments per air-preheater identified as either A- or B-side. Each compartment consists of two bag bundles, each having a total of 544 23-ft-long polyphenylene sulfide (PPS) felt filter bags, 18-oz/yd^2 nominal weight. This results in a total of 1088 bags per compartment, or 2176 bags per casing.[5] The evaluation was conducted on half of the gas stream, nominally 135 MW. The side chosen for testing was B-side. A-side was monitored as the control unit.

The hot-side ESP is a Research-Cottrell weighted wire design. The specific collection area (SCA) is 274 ft^2/1000 acfm. Depending on the operating condition of the hot-side ESP, nominally 97–99+% of the fly ash is collected in the ESP. The remaining fly ash is collected in the COHPAC system. The average inlet particulate mass concentration into COHPAC between January 1997 and April 1999 was 0.0413 gr/acf.[5] Hopper ash from both the ESP and the baghouse are sent to a wet ash pond for disposal. A hydrovactor system delivers the fly ash to the pond.

Figure 1 shows a diagram of the location of the various components of the air pollution control train. Design parameters obtained from Alabama Power for Gaston Unit 3 are presented in Table 1. For the Hg control program, carbon-based dry sorbents were injected upstream of COHPAC and downstream of the ESP over an 8-week period.

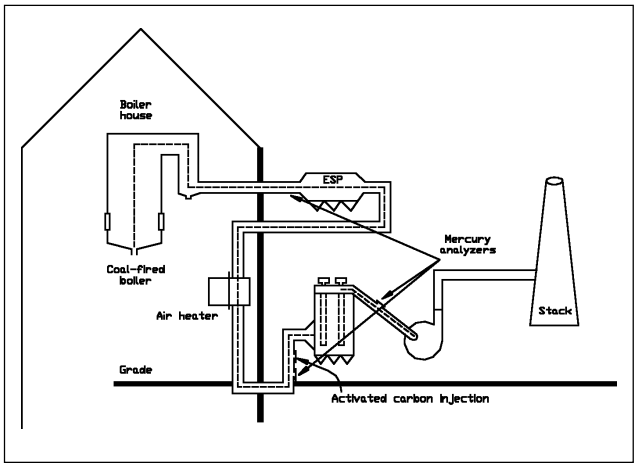

Figure 1. Flow schematic of Gaston Unit 3, showing injection and measurement locations.

TEST EQUIPMENT

The critical elements of the program were the actual field tests and measurements, which relied on accurate, rapid measurements of Hg concentration and an injection system that realistically represented commercially available technology. Near-real-time vapor-phase Hg measurements were made using a semi-continuous emissions monitor (S-CEM) designed and operated by Apogee Scientific. This instrument was developed with EPRI funding to facilitate EPRI research and development efforts.[6] The locations of the analyzers are shown in Figure 1. The S-CEMs operated continuously for more than 7 weeks providing speciated, vapor-phase Hg concentrations at the inlet and outlet of COHPAC. Norit Americas supplied a portable dilute-phase pneumatic injection system that is typical of those used at municipal solid waste facilities for Hg control with activated carbon. ADA-ES designed the distribution and injection components of the system.

Sorbent requirements for various levels of Hg control were predicted based on empirical models developed through EPRI funding.[4] The values used were based on a uniform sorbent size of 15 μm (size of commercially available PAC) and a bag cleaning frequency of 2 pulses/bag/hr (it was also assumed all bags were cleaned at the same time when, in practice, the bags are cleaned in sections or rows). Rates used to design equipment for the Gaston test are presented in Table 2. The system was sized for a maximum injection rate of 100 lb/hr.

Figure 2 shows the portable injection skid supplied by Norit Americas and installed for use at Plant Gaston Unit 3B. Activated carbon delivered to the plant in 900-lb supersacks was loaded onto the skid by a hoist. The sorbent was metered by a variable speed screw feeder into the conveying line. A blower/eductor provided the motive air to carry the sorbent ~100 ft to the injection point.

Sorbent was pneumatically transported via flexible hose from the feeder to a distribution manifold at the injection level and injected into the flue gas through six injection probes (three/duct). Figure 3 shows the distribution manifold. The injection system operated without plugging while injecting carbon-based products with D50 particle size of 18 μm. The distribution system plugged once while feeding a finer material with a D50 of 6–7 μm.

Table 1. Site description summary, Gaston Unit 3.

Parameter Identification	Description
Boiler manufacturer	B&W wall-fired
Burner-type	B&W XCL
Low NO_x burners	Yes
NO_x control (post-combustion)	None
Temperature (APH outlet)	290 °F
Coal (Typical—This Unit Fires a Variety of Coals)	
Type	Eastern bituminous
Heating value (Btu/lb)	13,744
Moisture (%)	6.9
Sulfur (%)	0.9
Ash (%)	13.1
Hg (μg/g)	0.06
Cl (%)	0.03
Control Device	
Type	Hot-side ESP with COHPAC
ESP manufacturer	Hamon Research-Cottrell
Design	Weighted wire
Specific collection area (ft^2/1000 afcm)	274
Flue gas conditioning	None
Baghouse manufacturer	Hamon Research-Cottrell
Design	Pulse-jet, low-pressure–high-volume
Air-to-cloth ratio (acfm/ft^2)	8.5:1 (gross), on-line cleaning

TEST RESULTS

Pre-Baseline Tests

The first field measurements were made prior to installing the injection equipment. The objectives for the pre-baseline

Table 2. Predicted injection rates for FGD carbon on B-side of COHPAC.[3]

Target Hg Removal Efficiency (%)	Predicted Injection Concentration (lb/Mmacf)	Predicted Injection Rate[a] (lb/hr)
50	0.5	<30
75	1.5	45
90	3.0	90

[a]Injection rate based on nominal flow at full load of 500,000 acfm.

Figure 2. Carbon injection skid installed at Plant Gaston.

tests were to (1) document Hg emissions across COHPAC, and (2) perform screening tests for Hg adsorption characteristics of several activated carbons that were candidate sorbents for the full-scale tests. Table 3 presents vapor-phase

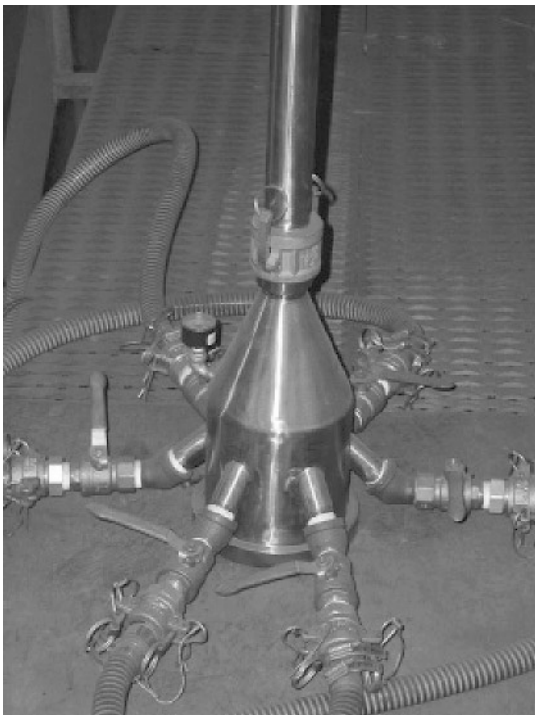

Figure 3. Distribution manifold for injection lances at Plant Gaston.

Table 3. Pre-baseline Hg measurement results (S-CEM).

Location	Total Hg μg/dncm @ 3% O_2 [a]	Oxidized Hg %
ESP inlet	7–10	5–33
ESP outlet/COHPAC inlet	7–10	29–51
COHPAC outlet	7–10	52–76
Mercury removal across ESP	0%	
Mercury removal across COHPAC	0%	

[a]Normal: T = 32 °F

Hg measurements during the pre-baseline tests in January on Unit 3. Two analyzers were used for these tests. The analyzers were set up to measure simultaneously across either the hot-side ESP or COHPAC. Because the hot-side ESP outlet and the COHPAC inlet are the same sampling ports, this analyzer was not moved. Flue gas temperatures were nominally 650 °F at the inlet to the hot-side ESP and between 240 and 270 °F at the COHPAC inlet and outlet.

The results show that vapor-phase Hg varied between 7 and 10 μg/dncm at all three locations. These variations appeared to be caused by changes in coal, because there was no measurable removal of vapor-phase Hg across either the hot-side ESP or COHPAC. These results are comparable to those made during the EPA information collection request (ICR) measurements in 1999 on Unit 1 for total Hg concentrations and removal efficiencies. The ICR measurements showed total Hg concentrations between 6.0 and 7.5 μg/dncm and no Hg removal across the hot-side ESP.[7]

No Hg removal was measured across COHPAC without the addition of sorbents. A review of data collected through the ICR at other plants shows that there was significant natural Hg capture on units with conventional-type baghouses when firing bituminous coals.[7] This natural collection is assumed to occur because of exposure of the flue gas to ash on the bag dustcake. Ash samples from both the hot-side ESP and COHPAC were tested for loss-on-ignition carbon and Hg adsorption capacity by URS Corp. Analysis of the ash showed high carbon content throughout the total size distribution and an adsorption capacity that indicates the ash should be capable of collecting Hg. However, because COHPAC is downstream of the hot-side ESP and the ESP was in excellent condition at the time of the tests, the inlet loading to COHPAC was very low (0.04 g/acf on average and less than 0.01 g/acf during the tests), so there was a relatively small amount of ash present on the bags to react with the Hg.

The portion of vapor-phase Hg in the oxidized state increased in the direction of flow. There was a greater percentage of elemental Hg at the hot-side inlet (economizer outlet) than there was at either the COHPAC inlet

or outlet. The most significant oxidation occurred across the COHPAC baghouse. Similar phenomena have been documented across baghouses with fiberglass and PPS fabric bags.[8]

Baseline Tests

After equipment installation and checkout, a set of baseline tests was conducted immediately prior to the first parametric test series to document current operating conditions. During this test, boiler load was held steady at "full-load" conditions during testing hours, nominally 7:00 a.m.–7:00 p.m. The Hg across the B-side of the COHPAC was measured using two separate methods: S-CEMs and modified Ontario Hydro method.

In addition to monitoring Hg removal, it was also important to document the performance of COHPAC during sorbent injection. The primary COHPAC performance indicator at this site was cleaning frequency. Pressure drop/drag is controlled by the cleaning frequency. It was expected that cleaning frequency would increase with the increased particulate loading from sorbent injection. Cleaning frequency was monitored before, during, and after sorbent injection.

Results from the Ontario Hydro tests conducted by Southern Research Institute are presented in Table 4. Similar to pre-baseline measurements, there was no measurable Hg removal across COHPAC. The average of the inlet and outlet total Hg measurements was ~15 μg/dncm. Coal analyses showed Hg levels in the three coal samples varied between 0.06 and 0.17 μg/g. Because Gaston burns coals from several different coal sources each day, it is difficult to correlate Hg level in the coal to a specific flue gas measurement; however, the higher coal Hg values correlate well with Hg measured in the flue gas. For example, a coal Hg level of 0.17 μg/g is equivalent to an Hg concentration of 15.0 μg/dncm in the flue gas.

The Ontario Hydro measurements also showed oxidation across COHPAC. At the inlet, the average fraction of oxidized Hg was 61%, and it increased to 77% at the outlet. Flue gas temperatures during these tests were nominally 255 °F.

Table 4. Baseline Ontario Hydro measurements at COHPAC inlet and outlet.

Date/Location	Particulate (μg/dncm[a])	Oxidized (μg/dncm[a])	Elemental (μg/dncm[a])	Total (μg/dncm[a])	Percent Oxidized
3/6/2001 inlet	0.0	11.6	6.6	18.2	63
3/6/2001 inlet	0.0	8.0	7.0	15.0	53
3/7/2001 inlet	0.2	9.0	4.3	13.5	67
Average inlet	0.1	9.5	5.9	15.6	61
3/6/2001 outlet	0.0	10.2	4.6	14.8	69
3/6/2001 outlet	0.0	12.5	3.0	15.5	81
3/7/2001 outlet	0.0	10.9	2.4	13.3	82
Average outlet	0.0	11.2	3.3	14.5	77

[a]Normal: T = 32 °F

Parametric Tests

A series of parametric tests was conducted to determine the optimum operating conditions for several levels of Hg control up to 90% Hg removal, for several activated carbon products. The NETL scope of work required that only commercially available sorbents should be considered in these technology demonstration tests. Norit Americas lignite-based PAC, Darco FGD, was chosen as the benchmark sorbent. Sorbent type and injection concentration for the long-term tests were chosen based on results from these tests.

In all, 15 different parametric conditions were tested. The primary variables were carbon type and target Hg removal level. Other variables included COHPAC cleaning settings and flow through the baghouse. Although lower flue gas temperatures have been correlated with increased Hg removal, temperature was not a key variable during these tests, because normal operating temperatures at this plant were between 250 and 270 °F, which is cool enough for acceptable removal. Results from laboratory and pilot plant tests suggest Hg capture is more difficult at temperatures greater than 300 °F. A summary of the parametric tests is presented in Table 5. Unless noted, all tests were conducted with the boiler at full load conditions and COHPAC cleaning at a drag initiate set point of 0.6 in. w.c./ft/min. A description of the different carbons used in these tests is presented in Table 6.

Parametric tests measured Hg removal as a function of injection concentration and sorbent type and the impact of sorbent injection on COHPAC performance. Feedback from the S-CEMs was invaluable in making timely, real-time decisions on test conditions. Examples of the data provided from the S-CEMs are presented in Figure 4. These data are from the first week of parametric tests 1–4, with Darco FGD. Reduction and recovery of outlet Hg concentration can be seen to correlate with relative injection rates.

Figure 5 presents Hg removal efficiencies as activated carbon injection concentrations were varied during the parametric tests for several activated carbons (see Tables 5 and 6 for description of test conditions). This figure shows that Hg removal increased nearly linearly with injection rate up to 2 lb/Mmacf, and then leveled off at ~90% removal with higher injection providing no additional benefit. This figure also shows that there was no measurable performance difference between the different PACs.

Table 5. Summary of parametric test conditions.

Test Series	Carbon Name Efficiency (%)	Target Hg Removal	Non-Standard Conditions
1–5	Darco FGD	50, 75, and 90	Standard
6–9	Norit PAC2B	50, 75, and 90	Standard
10	None	Baseline	Standard
11	Darco Insul	90	Standard
12	HydroDarco-C	90	Standard
13 a–c	Darco FGD	75	Change to pressure drop initiate clean
14	Darco FGD	50	Lower A/C to 4 ft/min
15	Darco FGD	50	Compare to test 14 with A/C = 7 ft/min

Carbon injection significantly increased the cleaning frequency of the COHPAC baghouse. Figure 6 presents actual cleaning frequencies at different carbon injection concentrations. At an injection concentration of 2.0 lb/Mmacf, the cleaning frequency increased from 0.5 to 2 pulses/bag/hr, or a factor of 4. Acceptable cleaning frequencies at this site to maintain long-term bag life are considered to be less than 1.5 pulses/bag/hr.

Long-Term Tests

Long-term testing at "optimum" plant-operating conditions as determined from the parametric tests was planned to gather data on Hg removal efficiency over time, the effects on COHPAC and balance of plant equipment of sorbent injection, and operation of the injection equipment to determine the viability and economics of the process. During these tests, carbon was injected continuously 24 hr/day, for 9 days. Based on results from the parametric tests, Darco FGD activated carbon was chosen as the sorbent for these tests. Injection rate was determined taking into consideration both Hg removal and the projected increase in COHPAC cleaning frequency. An injection concentration of 1.5 lb/Mmacf was chosen to maintain COHPAC cleaning frequency at less than 1.5 pulses/bag/hr.

Table 6. Description of Norit carbons used in parametric tests.

Name	Description	Particle Size Distribution[a]		
		D95	D50	D5
Darco FGD	Lignite AC	52	15–20	<3
Norit PAC2B	Subbit/Bit blend AC	52	15–20	<3
Darco Insul	Fine chemically washed specialty product	25	6–7	<2
HydroDarco-C	Coarser FGD	100	30	3

[a]Percent of particles less than size in μm.

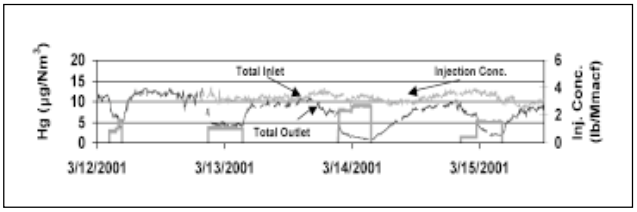

Figure 4. S-CEM Hg measurements during the first week of parametric tests with Norit Darco FGD PAC.

Similar to the baseline test series, Hg was measured by both the S-CEMs and manual methods (Ontario Hydro). The COHPAC performance, coal and ash samples, and plant CEM data were collected. During these tests, an EPA audit of the manual measurements was performed.

The long-term tests started on April 18, and carbon was injected continuously until April 26. Full-load boiler conditions were held between the times of 7:00 a.m. and 8:00 p.m., with load under dispatch control at other times for the first 5 days. During the three days when the Ontario Hydro tests were conducted, full load was maintained 24 hr/day. At the beginning of this test series, time was needed to work out a COHPAC cleaning logic issue, and there was a short period when load was lowered to fix a mill problem. The final 7 days of the test were conducted at the optimized PAC feed rate and COHPAC cleaning logic.

Three sets of Ontario Hydro measurements were made at three locations: (1) inlet of the hot-side ESP, (2) COHPAC inlet, and (3) COHPAC outlet. Arcadis G&M Inc. conducted the hot-side measurements using an experimental in-duct, quartz thimble to minimize sampling artifacts often seen with this method. Artifacts have been known to occur when the particulate collected on the filter captures vapor-phase Hg, resulting in higher particulate-phase Hg than is actually present. Sampling artifacts from particulate on the filter were not as much of a concern at the other two locations, because either the hot-side ESP or COHPAC already had removed most of the particulate.

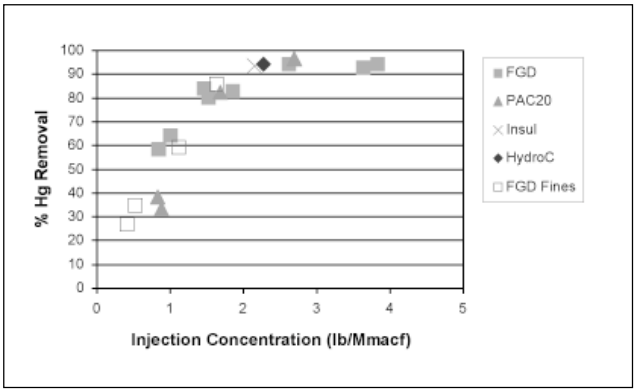

Figure 5. The Hg removal trends across COHPAC as a function of PAC injection concentrations. Measurements made during parametric tests, March 2001.

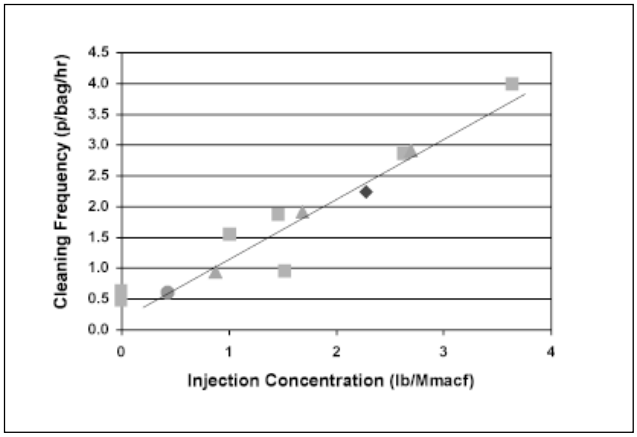

Figure 6. COHPAC cleaning frequency in pulses/bag/hr as a function of PAC injection concentration. Measurements made during parametric tests, March 2001.

Table 7 presents the results from each of the Ontario Hydro measurements. These data show that the inlet to the hot-side ESP and the inlet to COHPAC have similar average Hg concentrations and speciation. The outlet Hg concentrations show the effect of carbon injection with overall low Hg emissions for all species. Table 8 presents average speciated Hg removal across COHPAC. The overall average reduction in total Hg is 90%. At the outlet, the predominant species of Hg is the oxidized form; however, it is still 85% less than what was present upstream of PAC injection.

Figure 7 presents inlet and outlet Hg concentrations as measured by the S-CEMs, boiler load, and PAC injection concentration during the last 5 days of the long-term test. Periods when Ontario Hydro measurements were made are also identified. The S-CEMs indicate that Hg removal was nominally 87, 90, and 88% during the Ontario Hydro tests. This correlates well with the manual measurements. However, it is important to note that the S-CEMs showed that the average Hg removal efficiency over the multi-day time period was 78%, with variations from 36 to more than 90%. This difference is probably caused by varying coal and operating conditions over time. Figure 7 also shows that, during this 5-day period, inlet Hg concentration varied by nearly a factor of 5. Outlet concentrations can be seen to follow the inlet, and there are times during these transitional periods when removal efficiencies are fairly low. During the period when the Ontario Hydro tests were run, inlet Hg levels were low and fairly steady. These tests were conducted under ideal conditions and may show the best-case condition for Hg control at this injection rate.

During the test program, sorbent was injected at a constant rate, with no attempt to increase sorbent when the inlet Hg concentration increased. However, the data in Figure 7 highlight the importance of having CEMs to use as process control for a permanent Hg control system. The most challenging time for COHPAC performance was during the period with continuous full-load operation and PAC injection. The cumulative cleaning frequency increased to a high of 1.3 pulses/bag/hr, but was mostly maintained at levels less than 1.0 pulse/bag/hr.

Table 7. Long-term Ontario Hydro measurements at hot-side ESP inlet, COHPAC inlet, and COHPAC outlet.

Date/Location	Particulate (μg/dncm[a])	Oxidized (μg/dncm[a])	Elemental (μg/dncm[a])	Total (μg/dncm[a])	Percent Oxidized
4/24/2001 ESP inlet[b]	0.5	2.9	5.6	9.0	32
4/25/2001 ESP inlet[b]	0.0	7.3	3.7	11.0	66
4/26/2001 ESP inlet[b]	0.1	6.2	3.0	9.3	66
Average ESP Inlet	**0.2**	**5.5**	**4.1**	**9.8**	**55**
4/24/2001 COHPAC inlet	0.1	4.9	5.2	10.3	48
4/25/2001 COHPAC inlet	0.4	5.6	3.4	9.4	60
4/26/2001 COHPAC inlet	0.2	8.5	5.2	13.9	62
Average COHPAC Inlet	**0.2**	**6.3**	**4.6**	**11.2**	**56**
4/24/2001 COHPAC outlet	0.1	0.9	0.1	1.0	91
4/25/2001 COHPAC outlet	0.2	0.9	0.1	1.1	78
4/26/2001 COHPAC outlet	0.1	0.9	–0.0	1.0	93
Average COHPAC Outlet	**0.1**	**0.9**	**0.1**	**1.0**	**87**

[a]Normal: T = 32 °F; [b]Tests conducted by Arcadis using an in-stack (heated) quartz thimble.

Coal and Ash Characterization

Coal and ash samples were collected daily during the baseline, parametric, and long-term tests. Gaston fires a variety of washed, low-sulfur eastern bituminous coals. Because several different coals can be fired in a day, the daily coal samples provide relative Hg concentrations but may not be representative of specific test periods. Standard ultimate and proximate analyses were conducted, as were measurements for Hg, Cl, and S.

Ash samples were collected from the hot-side ESP, control-side (A-side) COHPAC, and test-side (B-side) COHPAC hoppers. Ash generated from the E.C. Gaston Plant is impounded using a wet ash handling system. The ash is not currently beneficially reused; therefore, ash characterization testing concentrated on measuring Hg and carbon content. Archived ash samples will be submitted for leaching tests at a later date.

The Hg content of coal samples taken during the long-term tests varied between 0.09 and 0.21 mg/g. This is consistent with flue gas Hg measurements that showed considerable variability in Hg concentration. This variability has implications on how Hg

Table 8. Average Hg removal efficiencies across COHPAC as measured with Ontario Hydro method.

Sampling Location	Particulate (μg/dncm[a])	Oxidized (μg/dncm[a])	Elemental (μg/dncm[a])	Total (μg/dncm[a])
COHPAC inlet	0.2	6.4	4.6	11.2
COHPAC outlet	0.1	0.9	0.0	1.1
Removal efficiency (%)	50	86	99	90

[a]Normal: T = 32 °F

control technologies will be implemented. The B-side ash, mixed with sorbent, showed ~30% carbon content as compared with 12% in the A-side ash. The sorbent-ash mixtures from the B-side had ~30 times the Hg of the A-side hopper ash, indicating removal of Hg by the sorbent across COHPAC.

PAC ANNUAL COSTS

The requirements and costs for full-scale, permanent, commercial implementation of the necessary equipment for Hg control using PAC injection technology are being finalized for Gaston Unit 3. Preliminary capital and sorbent costs for 80% Hg removal have been developed. The estimated uninstalled cost for a sorbent injection system and storage silo for the 270-MW Unit 3 is $575,000 ± 30%. Sorbent costs were estimated for nominally 80% Hg control based on the long-term PAC injection concentration of 1.5 lb/Mmacf. For Gaston Unit 3, this would require an injection rate of nominally 80 lb/hr. Assuming a unit capacity factor of 80% and a delivered cost of $0.50/lb for PAC, the annual sorbent cost for injecting PAC into the existing COHPAC baghouse would be about $300,000. Additional cost information is being developed for balance of plant impacts.

CONCLUSIONS

A full-scale evaluation of Hg control using activated carbon injection upstream of a COHPAC baghouse was conducted at Alabama Power Co.'s Plant Gaston Unit 3. Results and trends from these relatively short-term tests were encouraging.

- Effective Hg removal, up to 90% efficiency, was obtained for short operating periods (8 hr) by injecting PAC upstream of COHPAC.
- A significant increase in the cleaning frequency of the COHPAC baghouse occurred with the injection of activated carbons. At this site, the maximum acceptable cleaning frequency and pressure drop limited the amount of sorbent that could be injected and, therefore, the maximum Hg removal actually achievable. Based on these results, it will be necessary to take into consideration the sorbent injection rate in the design of future COHPAC baghouses and perhaps design the baghouses more conservatively.
- On average, ~78% Hg removal was obtained when PAC was injected into COHPAC 24 hr/day during long-term tests. The Hg removal varied throughout the period and ranged from 36 to 90%.
- To verify S-CEM measurements during the long-term tests, Hg removal across COHPAC was measured following the draft Ontario Hydro method. Results show an average 90% removal for the three test periods. These results confirm the high Hg removal measured with the S-CEMs.
- Actual Hg removals were in reasonably close agreement with theoretical model predictions for

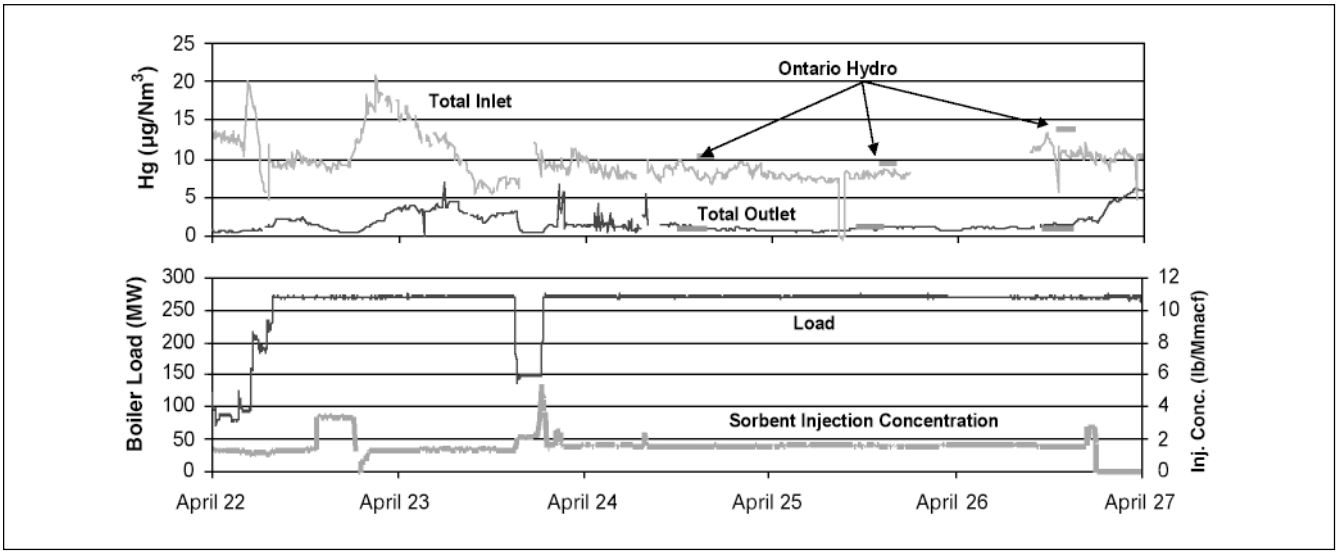

Figure 7. Inlet and outlet COHPAC Hg concentrations, boiler load, and PAC injection concentration during long-term tests, April 2001.

80–90% removal (1.5–2 vs. 3 lb/MMacf), considering that the model is based on a uniform PAC particle size of 15 μm when, in fact, the actual FGD carbon used has a wide size distribution with significant numbers of particles less than 15 μm.[4] The model also assumed a cleaning frequency of 2 pulses/bag/hr (all bags cleaned at the same time), whereas the bags were actually cleaned at ~1–2 pulses/bag/hr [bags cleaned 15 (one row) at a time] during the tests.

- Additional testing over longer periods (up to a year) must occur to determine the impact of carbon injection on bag life (pressure drop and bag strength) and outlet particulate emissions.

REFERENCES

1. Brown, T.D.; Smith, D.N.; Hargis, R.A.; O'Dowd, W.J. Mercury Measurement and Its Control: What We Know, Have Learned, and Need to Further Investigate; *J. Air & Waste Manage. Assoc.* **1999**, *49*, 1-97.
2. Durham, M.D.; Bustard, C.J.; Schlager, R.; Martin, C.; Johnson, S.; Renninger, S. Field Test Program to Develop Comprehensive Design, Operating, and Cost Data for Hg Control Systems on Non-Scrubbed Coal-Fired Boilers. Presented at the Annual Conference and Exhibition of A&WMA, Orlando, FL, June 24–28, 2001.
3. Durham, M.D.; Bustard, C.J.; Schlager, R.; Martin, C.; Johnson, S.; Renninger, S. Controlling Hg Emissions from Coal-Fired Utility Boilers: A Field Test; *EM* **2001**, *July*, 27-33.
4. Meserole, F.B.; Chang, R.; Carey, T.R.; Machac, J.; Richardson, C.F. Modeling Hg Removal by Sorbent Injection; *J. Air & Waste Manage. Assoc.* **1999**, *49*, 694-704.
5. Miller, R.; Harrison, W.; Corina, B.; Cushing, K.; Chang, R. COHPAC: The Next Generation in Particulate Control Technology at Alabama Power Co.'s E.C. Gaston Units 2 and 3, A Success Story. Presented at the EPRI-DOE-EPA Combined Utility Air Pollution Control Symposium: The MEGA Symposium, Atlanta, GA, August 16–20, 1999.
6. Sjostrom, S.; Ebner, T.; Ley, T.; Slye, R.; Richardson, C.; Machalek, T.; Richardson, R.; Chang, R.; Meserole, F. Assessing Sorbents for Hg Control in Coal-Combustion Flue Gas. Presented at A&WMA's Specialty Conference on Hg Emissions: Fate, Effects, and Control, Chicago, IL, August 21–23, 2001.
7. The U.S. Environmental Protection Agency Web site: http://www.epa.gov/ttn/atw/combust/utiltox/utoxpg.html; accessed 2001.
8. Sjostrom, S.M.; Bustard, J.; Durham, M.; Chang, R. Hg Removal Trends in Full-Scale ESPs and Fabric Filters. Presented at A&WMA's Specialty Conference on Hg Emissions: Fate, Effects, and Control, Chicago, IL, August 21–23, 2001.
9. Hassett, D.J.; Pflughoeft-Hassett, D.F.; Laudal, D.L.; Pavlish, J.H. Hg Release from Coal-Combustion Byproducts to the Environment. Presented at the Mercury in the Environment Specialty Conference, Minneapolis, MN, September 15–17, 1999.

About the Authors

C. Jean Bustard (corresponding author) is executive vice president, Michael Durham, Ph.D., is president, Charles Lindsey is specialist, Travis Starns is project engineer, Ken Baldrey is director of product development, Cameron Martin is director of engineering, and Richard Schlager is vice president of contract research and development at ADA-ES, LLC, 8100 South Park Way, B-2, Littleton, CO 80120. Sharon Sjostrom is director of pollution control technology development and Rick Slye is an engineering specialist at Apogee Scientific, 2875 W. Oxford Avenue, Suite 1, Englewood, CO 80110. Scott Renninger is program manager at the National Energy Technology Laboratory, U.S. Department of Energy, Collins Ferry Road, P.O. Box 880, Morgantown, WV 26507-0880. Larry Monroe, Ph.D., is principal research engineer at Southern Co., 600 North 18th St., Birmingham, AL 35203. Richard Miller is sales manager at Hamon Research Cottrell, Inc., 4589 Lehigh Drive, Walnutport, PA 18088. Ramsay Chang, Ph.D., is a manager at EPRI, P.O. Box 10412, Palo Alto, CA 94393-0813.