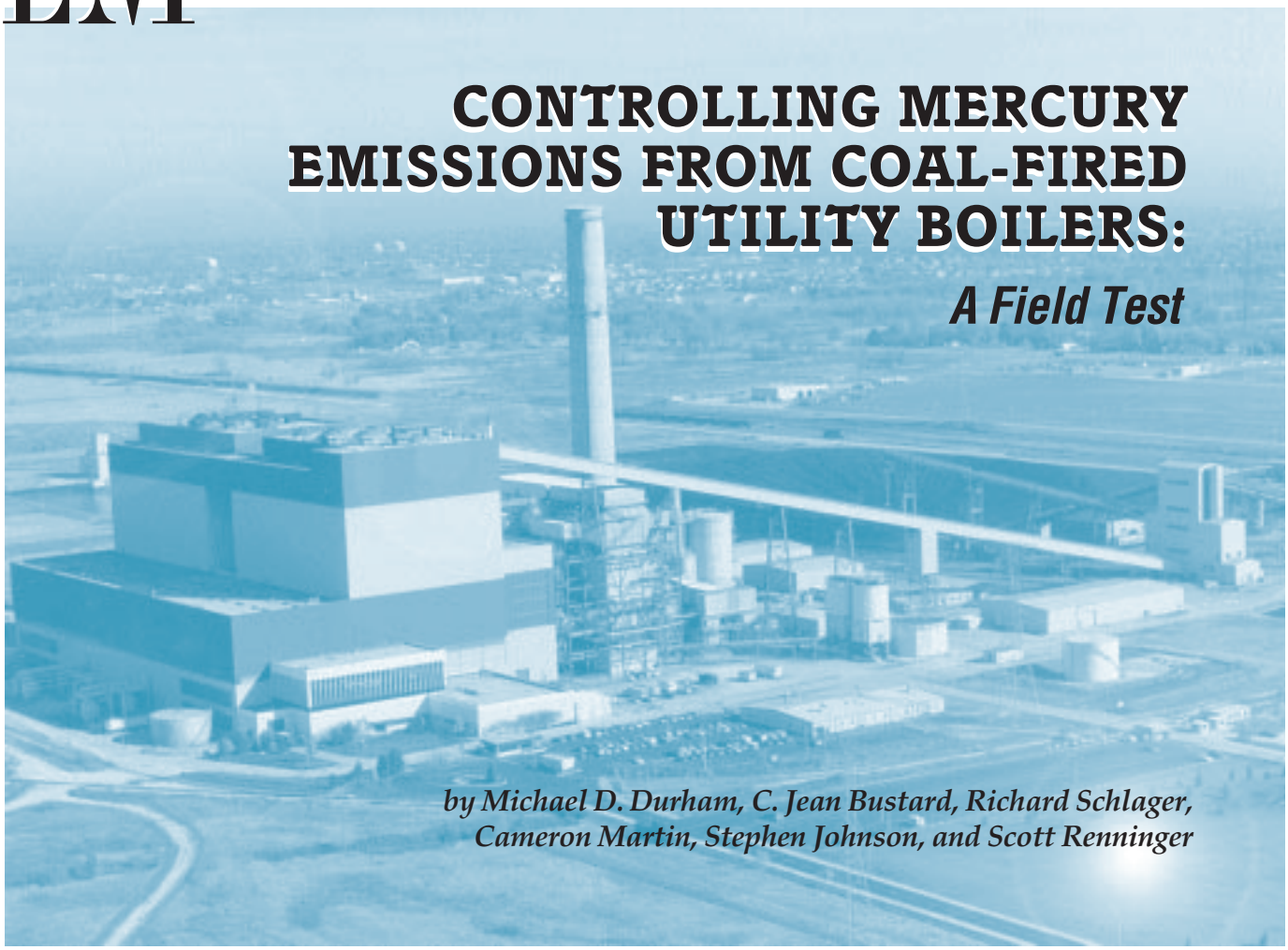
CONTROLLING MERCURY EMISSIONS FROM COAL-FIRED UTILITY BOILERS:

A Field Test



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This article is based on a presentation given at A&WMA's 94th Annual Conference & Exhibition in June in Orlando, FL. It describes a comprehensive multisite test program to demonstrate mercury control at four full-scale power plants. Tests results from three of these sites will be presented for the first time at A&WMA's Specialty Conference on Mercury, "Mercury Emissions: Fate, Effects, and Control," which will be held at the Arlington Heights Sheraton in Chicago, IL, August 21–23, 2001. For more details on the conference, see p 33.

The following article describes a field test program being conducted by ADA-ES that represents EPA's first step toward defining technology to be used by power-generating companies in meeting new mercury regulations. The company is working in partnership with several organizations to design and engineer systems to maximize effectiveness and minimize costs in order to reduce mercury emissions from coal-fired utility boilers.

INTRODUCTION

On December 14, 2000, the U.S. Environmental Protection Agency (EPA) announced that it plans to develop regulations to reduce mercury emissions from coal-fired utility boilers (see "EPA Studies on the Control of Toxic Air Pollution Emissions from Electric Utility Boilers," *EM*, January 2001, pp 30-36). This decision is based on growing concerns of adverse health effects due to current levels and potential buildups of methylmercury in lakes and rivers. Methylmercury is capable of bioaccumulation, resulting in higher levels being found in game fish. Mercury is a neurotoxin that impacts rapidly developing cells; people at greatest risk of exposure are pregnant women who consume fish with elevated levels of mercury.

The levels currently being found in lakes in several areas of the country are sufficiently high that state health agencies are issuing advisories to restrict fish consumption. Over the past 10 years, much effort has been directed toward reducing the use of mercury in consumer products. In addition, new emission control technologies have been implemented on medical waste and municipal waste incinerators. As a result, coal-fired electric generators now represent the largest single source of anthropogenic mercury emissions in the United States.

In anticipation of potential regulations, considerable research has been conducted during the past decade to characterize the emissions and control of mercury compounds from coal combustion. The U.S. Department of Energy (DOE), EPA, and the Electric Power Research Institute (EPRI) funded much of this research. These research efforts are summarized in A&WMA's 1999 Critical Review, entitled "Mercury Measurement and Its Control: What We Know, Have Learned, and Need to Further Investigate."[1]

PROGRAM OBJECTIVES

With stricter regulations imminent, it is important to concentrate the development effort on the most mature control technologies. Injection of dry sorbents (e.g., such as activated carbon) into the flue gas and further collection of the sorbent by conventional particulate control devices, such as electrostatic precipitators (ESPs) and fabric filters, represents the most mature and potentially most cost-effective control technology for power companies. However, work has been limited to bench-scale and pilot experiments.[2,3] Although these reduced-scale programs provide valuable insight into many important issues, they cannot fully account for impacts of additional control technology on plantwide equipment. For example, it has been possible to measure high mercury capture at relatively low temperatures in small pilot systems for relatively short periods. However, these lower temperatures may not be practical in a full-scale system continuously without deposition and corrosion in cold spots of ducting and particulate control equipment. Therefore, it is necessary to perform full-scale field tests to document actual performance levels and determine accurate cost information. The objectives of this field test program are to

- accelerate the availability of commercial mercury control systems for coal-fired plants;
- obtain data on the control systems'operability, maintainability, and reliability;
- determine maximum mercury removal for various plant configurations; and
- determine the total costs associated with mercury control as a function of fuel and plant characteristics.

The program is intended to provide critical data that will be used by many different groups: It will provide EPA with accurate information on the levels of control that can be reasonably attained for different plants; it will complement the emission inventory data obtained during the 1999 EPA Information Collection Request (ICR) data collection effort; and it will provide power-generating companies with the means to estimate costs to perform strategic planning on a systemwide basis. The economic analysis will include capital costs; sorbent usage costs; impact on operation of particulate control equipment; balance of plant; waste disposal and byproduct utilization issues; enhancements, such as cooling; and operation and maintenance (O&M) requirements.

ADA Environmental Solutions (ADA-ES) has assembled a program team consisting of technical leaders in the areas of mercury measurement, transformation during coal combustion, capture by existing emission control equipment, and design of integrated emission control systems. The qualifications of individual team members were determined by their contribution to pioneering mercury control work in the United States over the past decade. Organizations represented on the team include URS Radian, Inc.; Physical Sciences, Inc.; Apogee Scientific; EPRI; Energy & Environmental Strategies; EnviroCare; Microbeam Technologies; Energy and Environmental Research Center (EERC); Environmental Elements Corp.; Consol Energy, Inc.; Hamon Research Cottrell; and NORIT Americas.

TEST SITES

The program is directed at providing sufficient data to determine costs and capabilities for plants that do not have flue gas desulfurization (FGD) systems. This group represents not only the largest proportion of coal-fired power generators (83% by number or 75% by generation capacity), but it also represents the most difficult application for mercury control. To gather data on the application of sorbent injection for removal of mercury from coal combustion flue gas that can be used for as many plants as possible, sites were selected to take into account factors related to the fuel characteristics, the operating conditions of the unit, and interactions with other air pollution control devices. Sites that burn both eastern bituminous and western subbituminous coals were included because of differences in speciation of mercury in the flue gas, which greatly affects the efficiency of mercury removal in air pollution control devices. Measurements of the concentration of mercury species taken in the stacks of pilot and full-scale coal combustion systems reported anywhere from 10% to 95% Hg^0 upstream of the air pollution control device.[1] Oxidized mercury, particularly when present as $HgCl_2$, is far easier to capture than is mercury in elemental (Hg^0) form.

In addition to differences in the forms of mercury produced by different coals, the fly ash produced by bituminous and subbituminous coals result in different mercury capture characteristics.

Table 1. Mercury emissions data from three of the host sites.

Plant and Unit Sampling Location	Particle Bound	Oxidized Hg^{2+}	Elemental Hg^{0}	Total Hg
Brayton Point U3				
Inlet (µg/dscm)	1.58	2.53	<1.18	5.3
Outlet (µg/dscm)	0.39	2.09	<1.19	3.67
Removal efficiency (%)	76.46	16.93	-3.25	31.92
Salem Harbor U3				
Inlet (µg/dscm)	2.83	0.10	0.29	3.22
Outlet (µg/dscm)	0.0554	0.0925	0.2501	0.3980
Removal efficiency (%)	97.96	-23.07	8.62	87.28
Gaston U1[a]				
Inlet (µg/dscm)	2.26	1.72	2.81	6.80
Outlet (µg/dscm)	0.60	3.99	2.06	6.65
Removal efficiency (%)	73.45	-131.98	26.69	2.21

[a]Measurements made across hot-side ESP not COHPAC baghouse.

For example, subbituminous ashes produce higher absorption rates of mercury at higher temperatures and lower levels of carbon than do ashes from bituminous coals. There are other important differences between the flue gas produced by eastern and western coals. For eastern bituminous coals, a small proportion (2% to 3%) of the sulfur dioxide (SO_2) is converted to sulfur trioxide (SO_3). SO_3 is important because it reacts with the water vapor to form sulfuric acid. The gas stream for a low-sulfur eastern coal will have sufficient SO_3 that sulfuric acid will begin to condense at 270 ºF. This means that the gas stream cannot be cooled for enhancement of mercury capture without first eliminating the SO_3, or else severe corrosion of ducting and ESP components would be expected. On the other hand, the higher alkali content of a western subbituminous coal neutralizes all of the SO_3, resulting in a dew point of 120 ºF. This means that a flue gas cooling system could be operated without sulfuric acid corrosion. If an SO_3 injection system is used to control particle resistivity in the ESP, its operation must be integrated with the gas cooling system to provide both resistivity and control without causing corrosion problems.

Although fabric filters represent only 10% of the current power plant applications, they are an important part of the program because the number of fabric filters could increase significantly as a result of stricter mercury control regulations. If a high level of mercury removal is mandated, a baghouse may be the most economical choice. Meserole[4] predicts that achieving 80% mercury removal at a plant with an ESP would require 10 times the amount of sorbent as would be required if a fabric filter were installed. The difference in the cost of the additional sorbent would be greater than the annualized cost of a new fabric filter. In addition, a number of power plants use ESPs with small specific collection areas (SCAs) that would have difficulty dealing with the additional loading of the difficult-to-collect carbon sorbent.

As a result, we decided to include a COHPAC baghouse in the test program, a cost-effective retrofit option for power plants with ESPs. COHPAC, EPRI's patented Compact Hybrid Particulate Collector concept, places a high air-to-cloth ratio baghouse downstream of an existing ESP to improve overall particulate collection efficiency. Dry sorbents can be injected upstream of the COHPAC and downstream of the ESP. There are three main advantages to this configuration:

1. sorbents are mixed with a small fraction of the ash (nominally 1%), which reduces the impact on ash reuse and waste disposal;
2. sorbent requirements are reduced by a factor of 10 relative to the existing ESP; and
3. capital costs for COHPAC are less than other options, such as replacing the ESP with a baghouse or installing a larger ESP.

Four power plants are participating in the field test program: Alabama Power Co.'s Gaston facility; Wisconsin Electric Power Co.'s Pleasant Prairie facility; and PG&E National Energy Group's Salem Harbor and Brayton Point facilities. These four plants provide a means to document the performance of mercury control technology

for both subbituminous Powder River Basin (PRB) coals and low-sulfur bituminous coals. Three of the plants have ESPs, while the fourth plant has both a hot-side ESP and a COHPAC baghouse. Table 1 presents data on mercury emissions from three of the four plants as determined during the ICR testing. Additional details on the four plants are provided below.

Alabama Power's Gaston Unit 3 is a 270 MW B&W wall-fired boiler that burns a washed Alabama bituminous coal. The coal has a heating value of 13,700 BTU/lb, with a mercury content of 0.06 µg/g and 0.03% chlorine. Particulate is captured by a Hamon Research Cottrell hot-side weighted-wire ESP with an SCA of 274 ft²/kacfm. A Hamon Research Cottrell COHPAC baghouse is used with an air-to-cloth ratio of 8.5:1 gross; the temperature of the baghouse ranges from 240 to 300 ºF. During the test program, the sorbent will be injected downstream of the ESP and air preheater and upstream of the baghouse. This test program was conducted during spring 2001.

Wisconsin Electric's Pleasant Prairie Unit 2 is a 600 MW Riley Stoker balanced-draft, turbo-fired boiler that burns PRB coal. The coal has a heating value of 11,897 BTU/lb, with 0.1 µg/g mercury and 0.0015% chlorine. Particulate is captured by a Hamon Research Cottrell cold-side weighted-wire ESP with an SCA of 468 ft²/kacfm. A Wahlco SO_3 system is used to condition the fly ash. The unit operates in a temperature range of 280 to 310 ºF. Mercury control testing will be conducted during September and October 2001.

PG&E's Salem Harbor Unit 1 is an 85 MW B&W radiant boiler that fires a South American bituminous coal. The coal has a heating value of 11,300 BTU/lb, with 0.03µg/g mercury and 0.03% chlorine. Particulate is captured by an Environmental Elements cold-side rigid-electrode ESP with an SCA of 474 ft²/kacfm. A FuelTech urea-based selective noncatalytic reduction system is used to control levels of nitrogen oxides (NO_x). The ESP operates at temperatures as low as 250 ºF. Tests were scheduled to be completed in spring 2001.

PG&E's Brayton Point is a 122 MW CE tangential, twin-furnace boiler burning a low-sulfur eastern bituminous coal. The coal has a heating value of 12,319 BTU/lb, with 0.05 µg/g mercury and 0.08% chlorine. A pair of ESPs is used in series to capture particulate: a Koppers weighted-wire cold-side ESP with an SCA of 156 ft²/kacfm and a Hamon Research Cottrell rigid-electrode ESP with an SCA of 403 ft²/kacfm. An EPRICON SO_3 system is used to condition the fly ash. The plant uses Separations Technology equipment to process the collected fly ash by electrostatically separating carbon from the fly ash.[5] These tests are scheduled for fall 2002.

SORBENT SELECTION AND SCREENING

The test program at each site allows for the evaluation of two sorbents: a lignite-derived activated carbon supplied by NORIT (referred to as Darco FGD carbon) and one alternative sorbent. FGD is considered the benchmark for these tests because of its wide use in DOE/EPRI/EPA-sponsored testing. Because of the economic impact of sorbent costs on the overall cost of mercury control, it is desirable to find either less expensive sorbents, such as fly ash-derived products, or a less expensive form of activated carbon. Sorbent selection criteria have been developed so that sorbent vendors/developers can clearly understand the needs and requirements of this program. In summary, an alternative sorbent must be

- at least 25% less expensive than FGD carbon;
- available in quantities of at least 15,000 lbs (and potentially as high as 250,000 lbs) for site tests;
- available in sufficient quantities to supply at least 100,000 tons per year by 2007; and
- demonstrate a capacity for mercury capture of at least 100 µg/g as measured by URS.

Sorbents will be tested on a slipstream of flue gas for site-specific mercury capacity using URS' fixed-bed mercury absorption device. This device was developed with funding from EPRI and has been used to screen dozens of sorbents. Adsorption tests are conducted by saturating sorbents with either elemental mercury or mercuric chloride in the presence of simulated flue gas. The test apparatus is illustrated in Figure 1. In the laboratory, simulated flue gas is prepared by mixing heated nitrogen gas streams containing SO_2, hydrochloric acid (HCl), NO_x, carbon dioxide, water, and ozone. Mercury is injected into the gas by contacting nitrogen carrier gas with either recrystallized mercuric chloride solids or an elemental mercury permeation tube housed in a mercury diffusion vessel; mercury concentration is controlled by the temperature of the diffusion vessel and the nitrogen carrier gas flow rate. During field tests, actual flue gas is drawn into the apparatus.

The amount of mercury exiting the sorbent column is measured on a semi-continuous basis. Gas is passed through the column until 100% of the inlet mercury is detected at the outlet (100% breakthrough). The 100% breakthrough (equilibrium) capacity of the sorbent (µg Hg/g sorbent) is determined by summing the total mercury adsorbed until the outlet mercury concentration is first equal to the inlet concentration.

SEMI-CONTINUOUS EMISSIONS MONITOR

Semi-continuous gaseous mercury analyzers built by Apogee Scientific will be used during this program to provide near real-time feedback during baseline, parametric, and long-term testing. Continuous measurement of mercury at the inlet and outlet of the particulate collector, where mercury levels fluctuate with boiler operation (temperature, load) and decisions must be made concerning parameters such as sorbent feedrate and cooling, is considered a critical component of a field mercury control program. The analyzers that will be used for this program consist of a commercially available cold vapor atomic absorption spectrometer (CVAAS) coupled with a

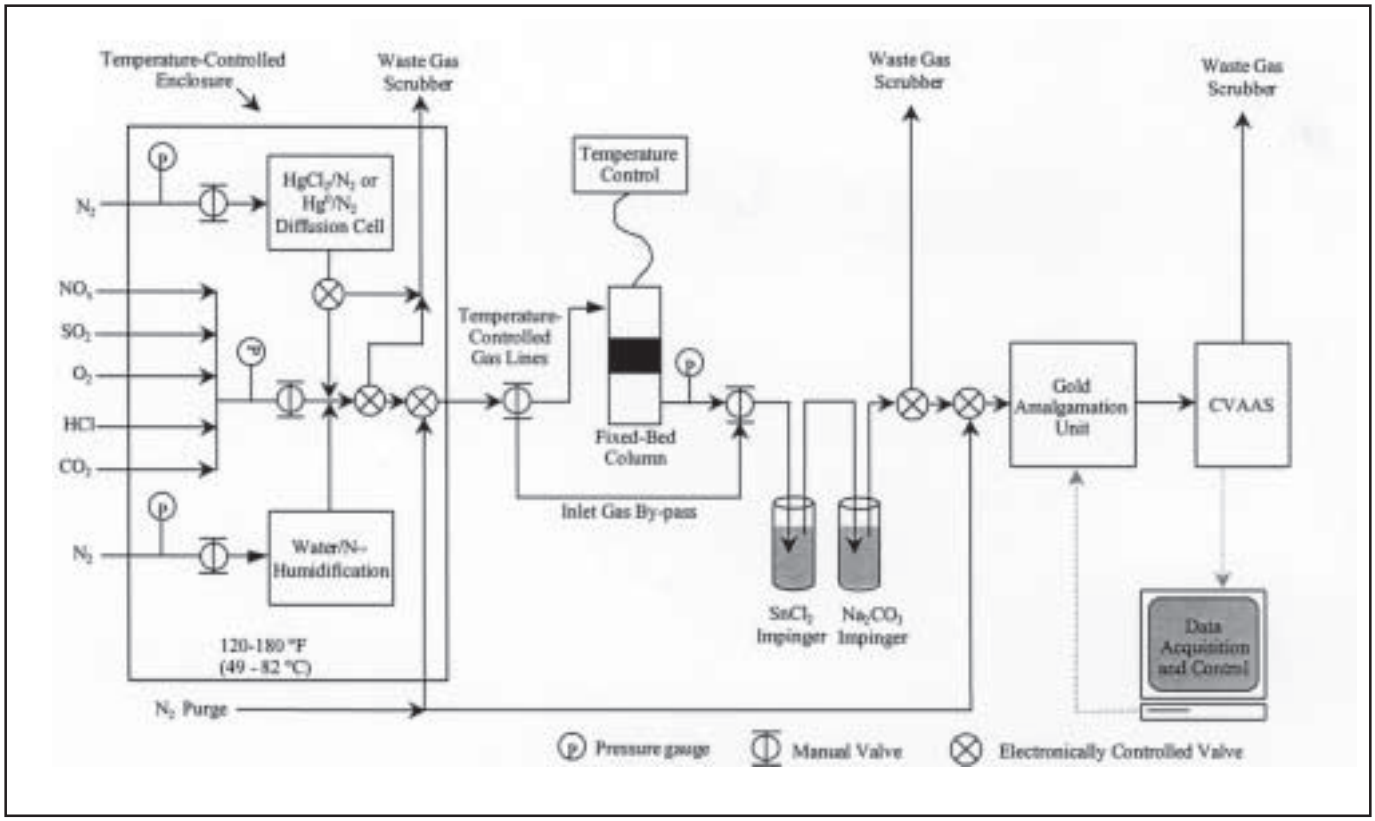

Figure 1. Bench-scale, fixed-bed mercury adsorption system.

gold amalgamation system (Au-CVAAS). One analyzer will be placed at the inlet and one at the outlet of the particulate collector during this test program.

Although it is very difficult to transport nonelemental mercury in sampling lines, elemental mercury can be transported without significant problems. Since the Au-CVAAS measures mercury by using the distinct lines of ultraviolet absorption characteristic of elemental Hg^0, the nonelemental fraction is either converted to elemental mercury (for total mercury measurement) or removed (for measurement of the elemental fraction) near the sample extraction point. This minimizes any losses due to the sampling system. For total vapor-phase mercury measurements, all nonelemental vapor-phase mercury in the flue gas must be converted to elemental mercury. A reduction solution of stannous chloride in HCl is used to convert Hg^{2+} to Hg^0. The solution is mixed as prescribed in the draft Ontario Hydro Method for manual mercury measurements.[6]

To measure speciated mercury, an impinger of potassium chloride solution mixed as prescribed by the draft Ontario Hydro Method is placed upstream of the stannous chloride solution to capture oxidized mercury. Unique to this instrument is the ability to continuously refresh the impinger solutions to assure continuous exposure of the gas to active chemicals. The Au-CVAAS system is calibrated using elemental mercury vapor, by injecting a metered volume of mercury-laden air from the air space of a vial containing liquid mercury at a precisely measured temperature into the analyzer.

The Au-CVAAS can measure mercury over a wide range of concentrations. Since the detection limit of the analyzer is a function of only the quantity of mercury on the gold wire and not the concentration in the gas, the sampling time can be adjusted for different situations. Laboratory tests with stable permeation tube mercury sources and standard mercury solutions indicate that the noise level for this analyzer is 0.2 ng mercury. To sample at 50 to 100 times the noise level during field testing, the sampling time is set so at least 10 ng mercury is collected before desorption. For example, if the mercury concentration is 5 $\mu g/m^3$, a one-minute sample time would be required, where as for a concentration of 0.5 $\mu g/m^3$, 10 minutes of sample time would be required.

Particulate is separated from the gas sample using a self-cleaning inertial gas separation arrangement modified for use with this mercury analyzer under an EPRI mercury control program. This arrangement uses a system where excess sample flow continuously scours particulate from a secondary filter so as to minimize any mercury removal or conversion due to the presence of particulate.

SORBENT INJECTION EQUIPMENT

The sorbent injection equipment is a skid-mounted, portable, dilute-phase pneumatic system. The activated carbon will be delivered to the plant in 900-lb supersacks, which will be stored on pallets adjacent to the injection skid. The reagent is metered by a variable-speed, screw feeder into an eductor that provides the motive force to carry the reagent to the

injection point. A positive displacement blower provides the conveying air. A programmable logic controller is used to control system operation and adjust injection rates. Flexible hoses will carry the reagent from the feeder to a distribution manifold located upstream of the particulate collector feeding multiple injection probes inserted into the duct to distribute the sorbent evenly across the flue gas.

FIELD TESTING

Prior to installing injection equipment, preliminary system operation, performance, and mercury-level measurements will be made. Mercury will be measured using a semi-continuous emissions monitor (S-CEM) across the particulate control device, which will be run continuously for a minimum of 24 hours at each site. These measurements will be used to expedite the parametric evaluation and provide insight as to current mercury removal efficiencies during "normal" operation with varying boiler load. These data will be used to design the parametric tests with the minimum number of uncontrolled variables.

After installation of the sorbent injection equipment, a second set of baseline tests will be conducted to fully document baseline conditions. During this test, boiler load will be held steady at "full-load" conditions during testing hours (7:00 a.m. to 7:00 p.m.). Mercury levels across the particulate control device will be measured using two separate methods: the S-CEM and standard Ontario Hydro Testing. This baseline test is expected to run for one week.

Following the baseline test, a parametric series of tests will be conducted to document mercury removal levels as a function of injection rate and gas temperature. The flue gas temperature will be lowered at each condition to document the effect of a 10 to 20 °F decrease in temperature on mercury removal efficiencies. The maximum sorbent injection rate will be established using either a 90% mercury removal level or a sorbent feed proportional to 30 lb/Macf, which is considered an economic maximum.

The next series of parametric tests will be conducted using an alternative sorbent. Mercury removal as a function of injection rate will be measured at the optimum temperature measured during the previous test series. After this test the field crew will analyze the data and work with team members on establishing conditions for the long-term test. The final test will be a mercury removal validation program conducted for a maximum of 14 days at the "optimum" plant operating conditions (lowest cost/highest mercury removal) as determined from the parametric tests. The S-CEM will be used for continuous monitoring of mercury removal. Ontario Hydro measurements will be conducted at the inlet and outlet.

During each field test program, samples of the ash/sorbent mixture from the hoppers will be collected and analyzed. The standard testing technique used for assessing hazardous waste characteristics is the Toxicity Characteristic Leaching Procedure (TCLP). A 100-g sample of ash is exposed to 1 liter of acidic solution (acetic acid- or acetate-based) for 24 hours. The solution is then analyzed for several metals (including mercury) to determine how much of each target metal was leached from the solid sample. Results are compared against limits established by regulation. In the case of mercury, a maximum leachable level of 0.2 µg/liter has been established.

A second series of tests will be performed by EERC to answer the question of the stability of the mercury. The potential long-term environmental impact of the mercury-laden ash will be determined using two techniques: leaching and thermal desorption. Leaching tests are done using a method known as the synthetic groundwater leaching procedure (SGLP).[7] This test is modeled after the TCLP, but modified to allow for disposal scenarios. A shake-extraction technique is used to mix the solid sample with an aqueous solution; aliquots of the liquid are analyzed after 18 hours, two weeks, and four weeks. Thermal desorption tests will be performed using a special test fixture that is heated using a programmable temperature controller. The temperature of the ash sample is ramped to 500 °C at a rate of 20 °C per minute. Mercury that is released by the sample is swept into a spectrophotometer for mercury measurement as a function of time and temperature.

After completion of testing and analysis of the field data, the requirements and costs for full-scale, permanent commercial implementation of the necessary equipment for mercury control using sorbent injection technology will be determined. The following need to be considered: the size and design of process equipment, based on test results and plant-specific requirements (reagent storage capacity, plant arrangement, retrofit issues, winterization, controls interface); modifications to existing plant equipment, including the particulate collector, ash handling system, compressed air supply, electric power capacity, other plant auxiliary equipment, utilities, and other balance of plant engineering requirements; and type and source of reagent to determine the most cost-effective reagent(s) for the site.

TECHNOLOGY TRANSFER

Transferring the information generated during this field test program to the coal-fired power-generation industry will be an important part of the program. This will be accomplished through technical papers presented at various forums, including A&WMA's Annual Conference and Specialty Conference on mercury, Institute for Clean Air Companies (ICAC) meetings, and the EPRI/DOE/EPA Mega Symposium (see opposite). In addition, results from the test programs will be made available to the public via the ADA-ES Web site, *www.adaes.com* as soon as DOE approves them.

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