

# **DEMONSTRATION OF ADDITIVE USE FOR ENHANCED MERCURY EMISSIONS CONTROL IN WET FGD SYSTEMS**

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## **ABSTRACT**

The Babcock & Wilcox Company (B&W) and McDermott Technology, Inc. (MTI, currently the B&W Research and Development group) have had a continuing program over the past decade for characterizing and optimizing mercury control in flue gas desulfurization (FGD) systems. These efforts have led to the characterization of mercury emissions control at two utility installations and full-scale demonstration (55 MW and 1300 MW) of the effect of a mercury control performance enhancement additive for wet FGD systems. This paper presents the results of the mercury emissions control testing conducted at these two sites. The performance is related to EPA Information Collection Request (ICR) data from an FGD system supplier's perspective, highlighting the need to consider the effects of system design and operation when evaluating mercury emissions control performance.

## **INTRODUCTION**

The directives provided in the Clean Air Act Amendments of 1990 (CAAA) have resulted in the intensive study of hazardous air pollutants (HAPs, also known as air toxics) by numerous federal and state agencies, academic and independent research organizations, and private

industry.<sup>1,2</sup> One outcome of this work was the December 2000 decision by the United States Environmental Protection Agency (U.S. EPA) to regulate HAPs from coal- and oil-fired electrical generating stations. Among the various HAPs generated, the U.S. EPA concluded that mercury and its compounds presented the greatest concern. This arises from the fact that their volatility allows them to pass through many conventional control devices. Subsequent widespread dispersion and deposition on land and in surface waters then provides a relatively direct pathway for eventual bioaccumulation in the food chain, ingestion, and potentially adverse neurological and developmental health effects.

With the impetus provided by the CAAA, development of mercury emission control technologies has progressed hand in hand with a growing understanding of its concentration in the fuels, and its chemical transformations in the flue gas as it is exposed to the conditions of the various gaseous and particulate control technologies (selective catalytic reduction (SCR), wet and dry flue gas desulfurization (FGD), electrostatic precipitation (ESP), and fabric filtration (FF)). Prior to 1990, there was little reliable data available on mercury concentrations anywhere within the combustion train. The U.S. EPA, the U.S. Department of Energy (U.S. DOE), and the Electric Power Research Institute (EPRI) collaborated among themselves and with various other interested organizations to support the increasingly detailed studies that eventually led to the decision to regulate mercury emissions. Prominent among these and performed with the cooperation of numerous utilities throughout the country, the U.S. EPA's 1999 Information Collection Request<sup>3</sup> generated the single largest database that contains:

- basic information on all U.S. coal-fired utility boilers
- coal analyses for mercury, chlorine, sulfur, moisture, ash, and calorific value for 1,143 U.S. power generating units, and
- inlet/outlet flue gas analyses for total and speciated (elemental and oxidized) mercury, together with additional corresponding coal analyses, for 81 units representing a cross-section of the various types of boilers and fuels used in the U.S.

Numerous other studies have been and continue to be conducted to shed further light upon the various aspects associated with mercury emissions control. Many of the studies have focused on the injection of some form of powdered activated carbon (PAC) as adsorption is a technique that has often been successfully applied for the separation and removal of trace quantities of undesirable components. Although this "brute force" approach may have appeared attractive in some early work, the economics of high injection rates can be prohibitive. More refined studies are now in progress to define more precisely what can and cannot be achieved with PAC.<sup>4</sup> Still other studies seek to enhance PAC technology by impregnation with additives such as halides and sulfur to yield improved chemisorption of the mercury species that may be present in a flue gas.<sup>5</sup>

The significance of mercury speciation lies at the heart of virtually every other technological approach beyond basic PAC injection which appears to adsorb a good portion of whatever mercury species may come in contact with it. Chemical thermodynamics favors transformation from a predominantly elemental mercury species ( $\text{Hg}^0$ ) at the high temperatures leaving the combustion zone to an oxidized species ( $\text{Hg}^{+2}$ ) as the flue gas cools.<sup>6</sup>

Kinetic effects, influenced by the surrounding species including chlorine and the nitrogen and sulfur oxides, and catalysis either intentional (SCR) or unintentional (ash chemistry and/or heat transfer surface metallurgy), are responsible for the relative concentrations of the two species that may be present at any particular location at any point in time. Generally speaking, the  $\text{Hg}^0/\text{Hg}^{+2}$  ratio should remain relatively constant for a given fuel and set of “normal” boiler operating conditions, though some variation might be expected to occur.

The extent to which such changes could be responsible for some of the unexpected variations in the ICR data is a matter of conjecture. The sampling and analytical techniques available then and now have yet to reach the level of development and sophistication that would be needed to make such fine distinctions. While mercury analyzers themselves have generally been capable of detecting mercury at the low parts per million and parts per billion concentrations involved, the challenge has been and continues to be the development of compatible, commercial flue gas sampling systems that can provide sufficient representative samples on a continuous or near-continuous basis, reliably and around the clock. While suppliers and their customers continue to work together to overcome hardware and sampling process difficulties, the manual “Ontario Hydro” (OH) sampling and analytical procedure developed in the mid-1990s continues to be the one method generally recognized as providing the most reliable data on the mercury species present in flue gas from coal- and oil-fired units.

In spite of the difficulties described, efforts to develop mercury emission control technology have progressed to the point of full-scale demonstration. During 2001, ADA Environmental Solutions ran full-scale (150 MW equivalent) PAC injection tests at Alabama Power’s Plant Gaston and at Wisconsin Electric’s (now We Energies’) Pleasant Prairie Power Plant. At about the same time, Babcock & Wilcox (B&W) and McDermott Technology, Inc. (MTI, formerly the B&W Research and Development Division) conducted full-scale tests at both Michigan South Central Power Agency’s (MSCPA) 55 MW Endicott Station and at Cinergy’s 1300 MW Zimmer Station. The balance of this paper discusses the results of the latter test program and their relationship to work done by others, especially the ICR data.

Wet FGD systems are currently installed on about 25 percent of the coal-fired utility generating capacity in the U.S., representing about 15 percent of the total number of coal-fired units. Depending on the effects of the operating parameters mentioned above, FGD systems can provide a cost-effective, near-term mercury emissions control option with a proven history of commercial operation. For boilers already equipped with FGD systems, the incremental cost of any vapor-phase mercury removal achieved is minimal. To be widely accepted and implemented, technical approaches that improve mercury removal performance for wet FGD systems should also have low incremental costs and have little or no impact on operation and  $\text{SO}_2$  removal performance.

The ultimate goal of the project was to demonstrate a commercial method for the enhanced control of mercury emissions in coal-fired boilers equipped with wet FGD systems at full scale over an extended period of time. Pilot tests had shown that the additive technology would permit consistently high levels of oxidized mercury capture and retention in the scrubber loop at a cost far less than would be associated with use of PAC injection. Although overall

control of 90 percent of the mercury entering with the coal was considered a reasonable target, the cost of conducting a full material balance from coal pile to the stack was far beyond the scope of the project. The tests therefore focused on the mercury removal achieved across the FGD systems.

## EXPERIMENTAL

B&W/MTI's enhanced mercury removal process adds very small amounts of a proprietary reagent to an existing wet FGD system to increase mercury removal efficiency. The Endicott and Zimmer sites chosen for the demonstrations represented significant differences in both size and scrubber chemistry. The technologies employed at these plants represent the two commercial FGD methods most commonly employed throughout the world. Both burn Ohio high-sulfur, bituminous coal. Table 1 presents notable characteristics for the two locations.

**Table 1. Characteristics of the Demonstration Test Locations**

	<b>MSCPA Endicott Station</b>	<b>Cinergy Zimmer Station</b>
<b>Gross generation capacity, MW<sub>e</sub></b>	60	1300
<b>Particulate collection</b>	4 field cold-side ESP	4 field cold-side ESP
<b>Number of FGD modules</b>	1	6 (5 operating + 1 spare)
<b>FGD inlet SO<sub>2</sub> concentration, ppmv</b>	3600 ppm	3300 ppm
<b>FGD reagent</b>	Limestone	Magnesium-enhanced lime
<b>Recycle slurry pH</b>	5.4 – 5.6	5.8 – 6.0
<b>FGD liquid-to-gas ratio, gal/1000 ft<sup>3</sup></b>	78	21
<b>FGD forced oxidation method</b>	<i>In situ</i>	<i>Ex situ</i>
<b>Slurry dewatering</b>		At the time of the tests:
<b>Primary</b>	Thickener	Hydroclone
<b>Secondary</b>	Rotary drum vacuum filter	Horizontal belt vacuum filter
<b>Gypsum use</b>	Cement	Wallboard

The additive was expected to be about equally effective at both plants, despite their differences. For this reason, the initial tests at the Endicott Station consisted of two phases of Parametric Testing with the additive to ascertain optimal dosage conditions. A planned break in the schedule permitted time for mercury analyses and an assessment of dosage effectiveness. Testing resumed and additive use continued virtually uninterrupted for the next four months. Two weeks of intensive Verification Testing were directed at characterization of the performance of the process at the selected operating conditions. Additive use then continued through the Long-term Testing phase that sought to demonstrate commercial viability and to assure that there were no deleterious effects on SO<sub>2</sub> removal, materials of construction, or by-product utilization. At Zimmer the test plan called only for the two-week Verification Testing at a dosage level close to that used at Endicott as the effectiveness was

expected to be similar. Simultaneous FGD system inlet/ (stack) outlet OH mercury measurements were generally made in triplicate for each condition within the Parametric and Long-term Testing periods, with single sets of simultaneous individual inlet/outlet measurements each day during the Verification Testing periods. The demonstration was intended to operate 24 hr/day with continuous additive feed through the normal load variations. Each plant cooperated by maintaining a constant load condition during the “test periods” when OH mercury sampling was performed. Of the 44 “test periods,” 6 of 30 at Endicott were at approximately 48 MW, and 2 of 14 at Zimmer were at about 820 MW. All the other tests periods occurred at full-load conditions, 60 and 1300 MW, respectively. Because the small amount of additive used represented such a small operating expense, feed rate was kept constant. The data obtained during the reduced load conditions are virtually indistinguishable from those at full load.

With tank trucks serving as the additive storage vessel, equipment transfer permitted quick disassembly at Endicott and reconnection at Zimmer. Here the test plan called only for the two-week intensive verification tests that corresponded closely to those conditions for which the Endicott preliminary analyses offered promising results. The reagent was delivered to all operating wet scrubber modules simultaneously.

### **Additive Feed Equipment**

The skid-mounted feed system included two metering pumps with variable frequency controllers that permitted a combined 200:1 turndown ratio and approximately the same dosage rate capabilities at both plants. A dilution water connection/control system added flexibility in varying additive feed concentration. A calibration tube upstream of the pumps provided delivery rates. Materials of construction were commonly 316 stainless steel, with elastomers where required for the process conditions. Plant modification essentially consisted of providing a connection to each plant’s piping system.

### **Sampling and Analysis**

The flue gas sampling port locations and planned traverse points were consistent with EPA Method 1 - Sample and Velocity Traverses for Stationary Sources. The details for each location at each of the demonstration sites are summarized in Table 2. Sampling performed at both inlet locations was conducted through multiple ports in the same plane. Sample train and equipment preparation and recovery took place in a fully equipped, mobile laboratory trailer at each site.

The OH method was used to measure total and speciated mercury emissions during all testing phases of this program. A variation of EPA Method 29, this method applies to the determination of particulate and gaseous metals emissions from industrial, utility, and municipal sources. Particulate and gaseous emissions are withdrawn isokinetically from a

**Table 2. Flue Gas Sampling Details**

	MSCPA - Endicott		Cinergy - Zimmer	
	Wet FGD Inlet	Wet FGD Outlet (Stack)	Wet FGD Inlet	Wet FGD Outlet (Stack)
Flue dimensions (W x H), ft	8 x 10.75	--	37.5 x 37.5	--
Stack diameter, ft	--	10	--	42.7
Flue orientation	Vertical	--	Horizontal	--
Port diameter, in	4	4	4	4
Number of ports	5	4	3	4 (2 used)
No. of traverse points	25 (5 x 5)	12 (4 x 3)	12 (3 x 4)	12 (2 x 6)
No. of sampling planes	1	1	1	1
Gas temperature, F	350 - 370	120 - 130	330 - 350	120 - 130
Nominal pressure, in w.c.	-7	+0.4	-19	-0.9
Filter temperature, F	340	275	340	275

source and pass through a quartz fiber filter and solutions of potassium chloride (KCl), acidic peroxide and acidic potassium permanganate (KMnO<sub>4</sub>). The oxidized forms of mercury collect in the KCl impingers and elemental mercury collects in the peroxide and KMnO<sub>4</sub> impingers. The impinger solutions from the OH method sample trains are analyzed for mercury using cold vapor atomic absorption spectroscopy (CVAAS). The analysis follows EPA reference method SW7470 (CVAAS).<sup>3</sup>

On-line mercury analysis was attempted with a sampling/analyzer system manufactured by PS Analytical (PSA) in the hope of obtaining real-time mercury trending. The basic principle of operation is that gas samples are drawn across a gold trap (Amasil tube) to capture mercury over a known period of time for the selected flow rate. The trap is then periodically heated every few minutes to release mercury that is delivered to an atomic fluorescence detector. The PSA system did not perform as expected throughout this program. The analyzer itself performed well for short periods of time, showing the expected response when additive feed was initiated or changed. However, the difficulties associated with the sample preconditioning system which led to adsorption of mercury in the sampling system precluded acquisition of sufficient data to provide the level of confidence needed to make definitive statements about the variations in the mercury concentrations and the removal efficiency for extended periods of time on a continuous basis. These difficulties were observed at both the FGD inlet and outlet sampling locations. For this reason, its use was limited to providing guidance during the initial Parametric Testing phase at Endicott. The system continues to be improved upon and evaluated by various interested organizations, including the Energy and Environmental Research Center (EERC) at the University of North Dakota, B&W/MTI, and the U.S. DOE.

## RESULTS AND DISCUSSION

The pilot tests that preceded the full-scale demonstration project had identified dosage rate as the primary and most practical means of enhancing mercury capture with the wet FGD system additive and provided an order of magnitude feed rate for the feed system design. The Parametric Testing phase of the demonstration project followed this approach to identify what were thought to be the optimal conditions commensurate with the mercury concentrations anticipated at the full-scale demonstrations and the feed equipment design. The almost twofold range of total gas-phase mercury concentration found in the flue gas (Figure 1) during the Baseline and Parametric Testing phases, coupled with the enhancement effects found (Figure 2), led to the decision to set the dosage at 1.0 gal/hr as a reasonable level that would accommodate some substantial variation of the inlet mercury concentration at Endicott. Furthermore, it was seen as being compatible with the concept of using the same equipment at Zimmer for which scale-up to the larger size unit had been taken into account.

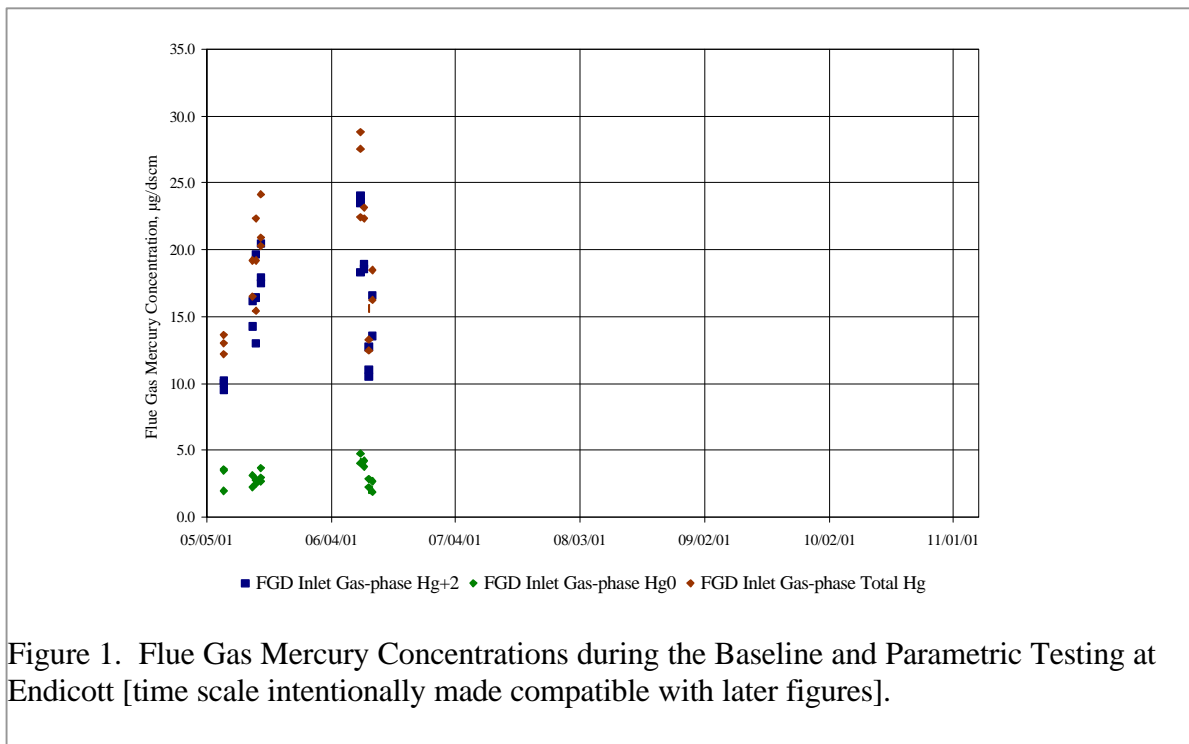


Figure 1. Flue Gas Mercury Concentrations during the Baseline and Parametric Testing at Endicott [time scale intentionally made compatible with later figures].

The purpose of the Verification Testing at both Endicott and Zimmer was to demonstrate and characterize the mercury emission control achievable across the wet FGD systems with continuous additive feed at the selected dosage. Each plant was to operate over its normal range of operating conditions, although unit loads were generally held constant at or near full load for most of the actual “test periods” when OH sampling took place. At Endicott, the Verification Testing phase was followed by a three month Long-term Testing phase. This extension of the verification period continued demonstration of the removal efficiency, but also served as evidence that there were no long-term deleterious effects on SO<sub>2</sub> removal performance, materials of construction, or by-product utilization and acceptability.

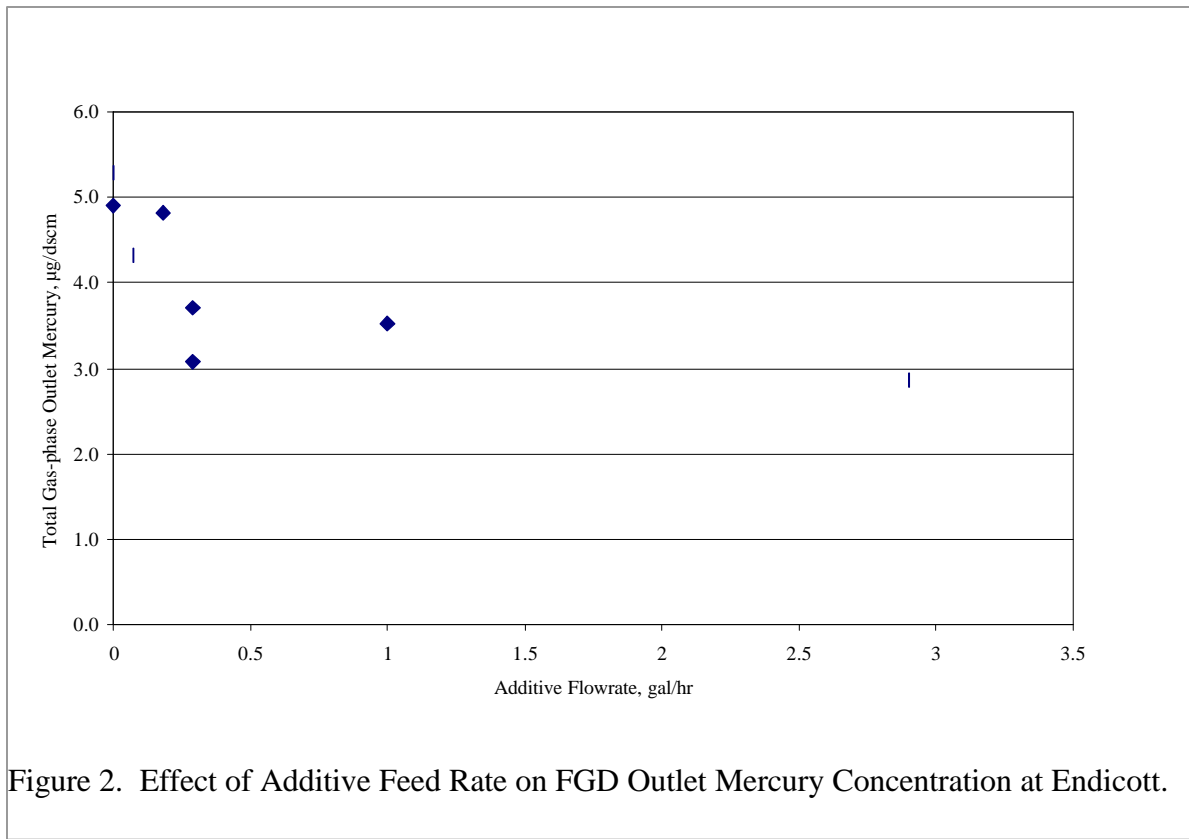
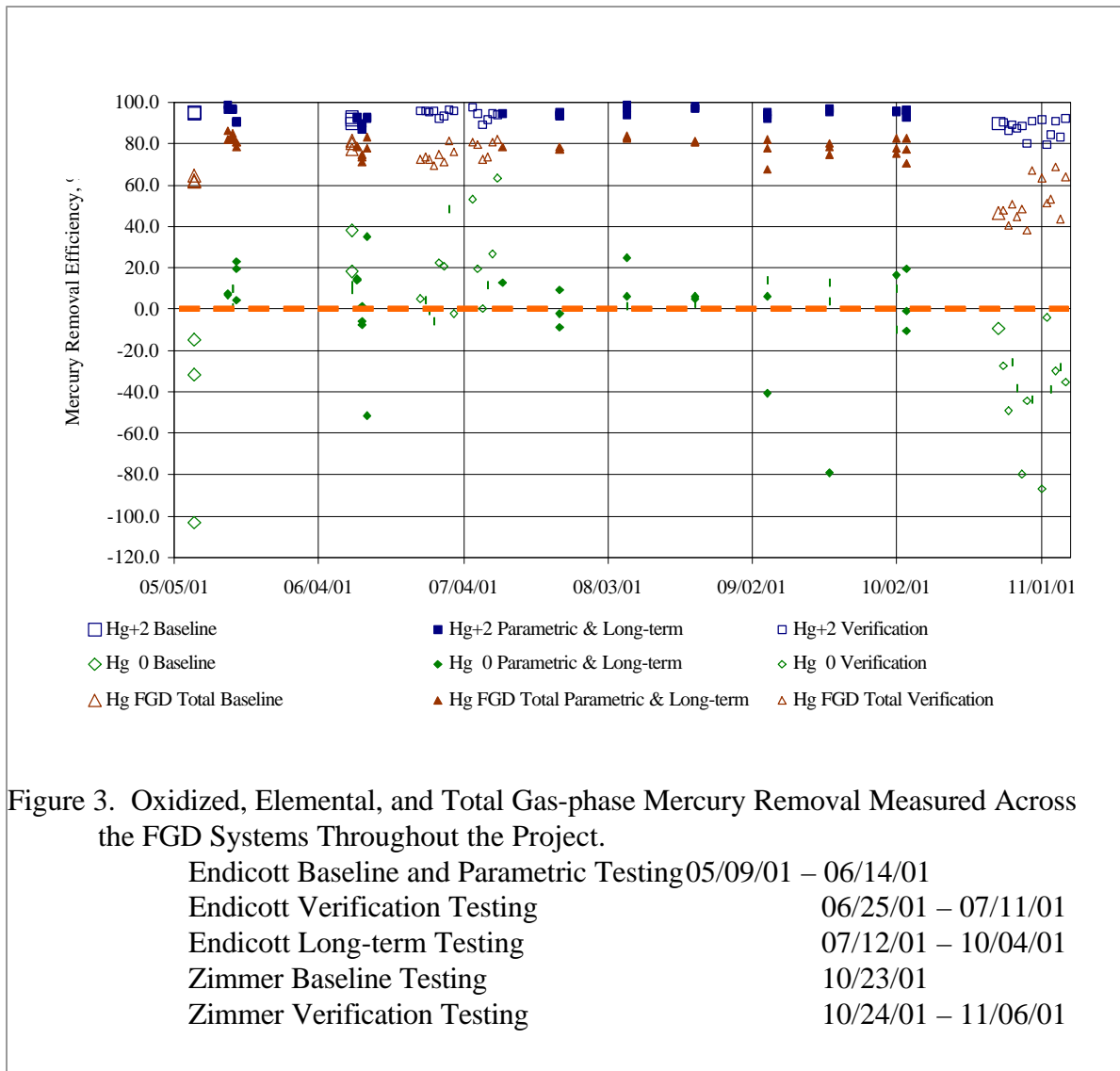


Figure 2. Effect of Additive Feed Rate on FGD Outlet Mercury Concentration at Endicott.

Testing then continued at the Zimmer Station. Figure 3 shows the individual removal efficiencies calculated from the mercury concentrations measured at the FGD inlet and outlet. Several major features are evident in the figure, the most striking of which is the difference between the consistently high total mercury removal obtained across the FGD system while additive was in use at Endicott, and the corresponding lower removal obtained at Zimmer. It has been known for some time that wet FGD systems are capable of generally high removal of oxidized mercury from flue gas, with little if any capture of elemental mercury due the metallic form being virtually completely insoluble. Whatever reduction in elemental mercury concentration may occur is generally ascribed to its “last minute” oxidation and removal. At Endicott, the data presented in the figure equate to a consistently high oxidized mercury removal efficiency of 95 percent, which, when coupled with the elemental mercury that passes through, equates to an overall removal of 77 percent for the combined Verification and Long-term Testing phases of the project. (Overall removal includes whatever particulate mercury values were determined in the work-up of the OH analyses. None of the particulate mercury values measured at the FGD system inlet accounted for more than 1 percent of the total mercury measured at that point.)

The results of the Verification Testing at Zimmer are in sharp contrast to those obtained at Endicott. Although the expectation had been that the additive would be about equally effective in the lime-based FGD system there, such was obviously not the case. Overall the mercury capture across the FGD system averaged 52 percent, with removal of the oxidized



fraction averaging 87 percent. The negative elemental mercury removal efficiencies calculated for each test are thought to reflect the conversion of oxidized mercury back to its elemental form in the Zimmer scrubber system. The fact that the Zimmer FGD system inlet mercury had a somewhat lower oxidized fraction (74 percent on average compared to Endicott’s 75 and 82 percent of the FGD system inlet mercury during the Verification and Long-term Testing, respectively) contributed to the lower overall mercury removal as well.

Over the years there have been occasional reports of low capture of total mercury, often coupled with the observation that the elemental mercury concentration exiting the scrubber is higher than that entering. Although they were first written off as anomalous, such observations at both full-scale installations and in early pilot tests conducted by B&W/MTI were part of the motivation that led to the development of the additive technology used in this project. As disappointing as it may be that the initial expectations for the Zimmer installation

were not realized, the fact that the Endicott system exhibited such behavior during the first baseline test, but then ran for about four months with virtually no significant recurrence suggests that the additive has been effective in allowing the limestone forced-oxidation FGD system at Endicott to retain the mercury captured there.

Chemical reduction of oxidized mercury back to the elemental form by the high level of sulfite present in the Zimmer scrubber is the most obvious potential explanation for such a phenomenon. However, the sulfite concentrations present in the scrubbing liquors in both the Endicott and Zimmer FGD systems are far in excess of the lower absorbed mercury concentration. Although it may be a contributing factor, other factors may come into play, the most obvious of which is the lower liquid-to-gas ratio (L/G) at Zimmer, as well as the higher ionic strength of the absorbing solution. Pilot studies that explored these variables to some extent did not produce the kind of results found at Zimmer, and differences arising from other trace metals and gases present at Zimmer or Endicott may also be involved.

As has been noted, performing a detailed material balance on mercury for each plant was well beyond the scope of the project. Nevertheless, there was a desire to develop at least some understanding of how the measured values may relate to the mercury content of the coal. To accomplish this, the mercury concentrations originally expressed in units of  $\mu\text{g}/\text{dscm}$  (dry standard cubic meter) at 3 volume percent  $\text{O}_2$  were converted to the equivalent units of  $\text{lb}/10^{12}$  Btu using the  $F_d$  factor derived from the ultimate coal analyses performed on samples generally collected on the same day as the test. When some samples could not be collected and analyzed for a specific day, average data for the day before and the day after was used if available, otherwise averages for all the coal samples for the appropriate site formed the basis. The results of this analysis is shown in Figure 4 where the large black squares represent coal mercury derived from specific analyses and the small squares those obtained from averaged values.

The data presented in Figure 4 illustrate several notable aspects of the considerations that must be taken into account in the design of strategies for mercury emission control. First, the variability in coal mercury content measured during the four months of operation at Endicott spans a range of about 8 to  $32 \text{ lb}/10^{12}$  Btu. Samples were collected as the coals were fed to the bunkers. The extent of variation was not entirely unexpected because the plant typically fires up to four different Ohio coals in varying percentages, primarily based on spot market availability. The coal used at Zimmer appears to reflect more consistent mercury content, though the number of samples available from this site was relatively small.

The figure also attempts to provide a perspective of how the data collected in this project compares with ICR data on the coals. The large vertical bar immediately to the right of the Endicott test data is based on an average of  $10.9 \pm 8.9 \text{ lb Hg}/10^{12}$  Btu calculated from the 32 analyses of coal in the fourth quarter of 1999 ICR analytical database for that plant, using twice the standard deviation to represent the 95 percent confidence interval. The vertical bar to the left of the Zimmer data offers a similar comparison with an average of  $9.7 \pm 5.8 \text{ lb Hg}/10^{12}$  Btu calculated from 77 analyses for that plant's coal. Here the ranges of data appear to be in better agreement, though the mercury concentrations during this project were perhaps

lightly higher than might have been expected from the ICR data.

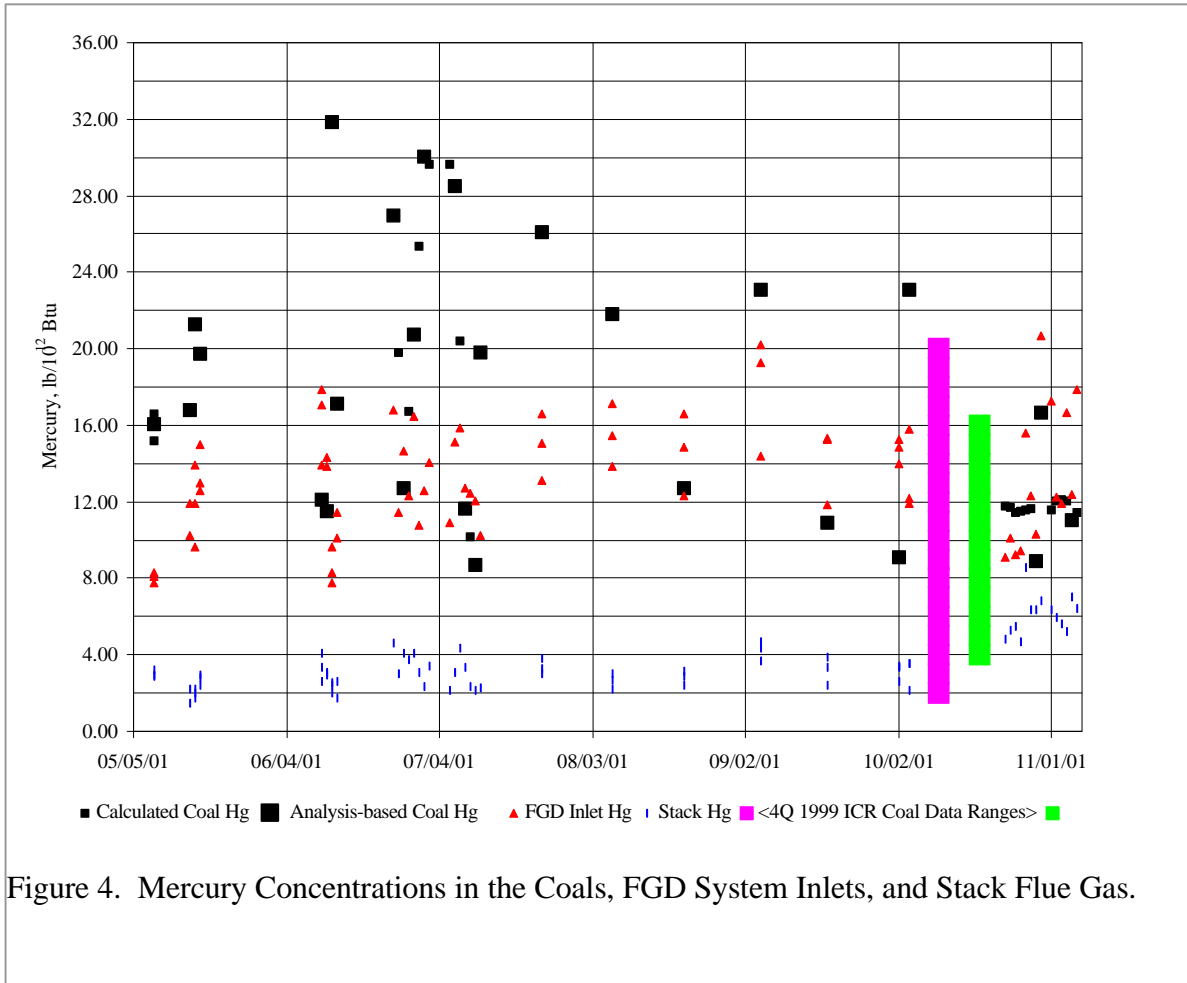


Figure 4. Mercury Concentrations in the Coals, FGD System Inlets, and Stack Flue Gas.

It is interesting to note as well that despite the apparent wide variation in coal mercury content, some of the variation disappears by the time the mercury enters the wet FGD system. Although there may still be as much as a twofold variation in the concentrations within a relatively short time frame, the wider swings evident in the coal mercury are much reduced by the time the flue gas enters the wet FGD system. Reasons for this include not only the obvious homogenization that may occur as the coal is pulverized and combusted, and whatever turbulence the flue gas flow imparts, but also the possible rejection of some of the mercury through the pulverizers' pyrite traps. The fact that some mercury associates with the pyritic material is not surprising, especially in light of the ICR data that showed that the highest mercury fuels were the waste bituminous coals that would be expected to have high pyritic content.

Finally, the mercury concentrations measured at the stack as shown in Figure 4 are of particular interest in that, by the time the mercury has reached this point in the gas path, most of what remains is predominantly elemental mercury that has either passed through

unoxidized, or has been chemically reduced by one or more of the active species present in either the flue gas or the scrubbing loop. The encouraging point to note is that the spread in the mercury concentration is now greatly reduced to on the order of a few lb/10<sup>12</sup> Btu. The fact that it has become more understandable and predictable offers reason to think that on-going development of reliable, lower cost control techniques for the elemental species will soon prove fruitful.

The significance of all of this comes to the forefront as one considers not only the methods that might be taken to control mercury emissions, but also how the control regulations might be structured to maximize mercury control given the development of sampling and analytical systems for mercury. The expectation is that a reliable continuous analyzer system will be available to identify in a timely manner the changes in mercury concentration and/or speciation that would require remedial action to keep a plant in compliance with whatever emission regulations eventually come to pass. Until such devices become accepted by the utilities and the regulatory agencies, periodic, manual OH sampling and analysis or some future equivalent will be the basis for determining compliance. As a result, longer averaging periods will be necessary to accommodate a reasonable number of analyses to assure representative analytical data upon which compliance/noncompliance decisions will be made.

### **Economic Considerations**

As noted at the beginning of the paper, the most extensive mercury emissions control research has been directed toward mercury capture with sorbent, primarily PAC, injection. This section presents the preliminary results of the economic evaluation currently in progress as B&W and MTI examine the implications of the demonstration project. The analysis includes some comparison of recently published mercury removal and cost information for the PAC technology.<sup>4,7,8</sup> Cost estimate modeling for enhancement of mercury emissions control with a wet FGD system calculates the annual levelized costs following the basic methodology of EPRI's *TAG™ Technical Assessment Guide*.<sup>9</sup> This entails determination of the total capital requirement, distributed over a 20-year life, plus yearly operating and maintenance costs. Because the feed system for the additive consists of a small tank and metering pump, the additional cost for labor and administration/overhead is considered to be covered within basic plant operating labor and maintenance activity and is not broken out separately.

The cost model is intended to represent the most likely application of enhanced mercury capture for a unit equipped with a wet limestone force-oxidized FGD system. The calculations include the following operational assumptions:

Unit generation:	500 MW
Combined capacity and availability factor:	65 %*
Coal sulfur:	3 %
Coal mercury:	0.23 ppm
Cost of additive, dry basis:	\$0.21/lb
Enhanced mercury removal:	80 %
Base wet FGD mercury removal	70 %

\* For the purpose of a simple comparison, the same factor was used for the new installation, though in a more rigorous analysis, a higher figure would normally be used.

Table 3 summarizes the results of the analysis and provides the estimated capital, operating and maintenance (O&M) costs both for applying B&W/MTI's enhancement process to an existing wet FGD system, and for installing a new wet FGD system with the enhancement process. The table also includes what might be considered an equivalent evaluation using PAC technology solely for mercury capture at the 60 and 70 percent removal levels. Direct comparison of enhancement in an FGD system with PAC technology is difficult to establish given the fact that potential applications for each do not lend themselves to an apples-to-apples comparison. Nevertheless, the incremental cost difference between the 60 and 70 percent removals with PAC may establish a better way to evaluate the relative cost benefit associated with improving mercury capture with the additive enhancement in a wet FGD system. Although it is highly unlikely that PAC would be used in a situation where the existing wet FGD system is already providing 70 percent removal, the 0.18 mil/kWh annual levelized cost of improving this to 80 percent with the additive technology is substantially below the 0.80 mil/kWh cost differential between achieving 60 and 70 percent removal with PAC injection. This is thought to illustrate the fact that enhanced mercury capture on its own represents minimal additional expense for scrubber-equipped utilities interested in reducing their mercury emissions and assuring that the mercury captured will be retained within the system rather than being re-emitted in the elemental form.

**Table 3. Costs of Mercury Removal Processes**

<b>ENHANCED MERCURY CAPTURE IN A WET FGD SYSTEM</b>	<b>Existing 500 MW Installation</b>	<b>New 500 MW Installation</b>
<b>Total Capital Requirement, \$</b>	3,000,000	63,000,000
<b>Total System O&amp;M Costs, \$/yr</b>	125,000	3,200,000
<b>Annual Levelized Cost, \$/yr</b>	500,000	12,000,000
<b>Annual Levelized Cost, mil/kWh</b>	0.18	4.23
<b>MERCURY CAPTURE WITH PAC TECHNOLOGY</b>	<b>@ 60 % Removal</b>	<b>@ 70 % Removal</b>
<b>Annual Levelized Cost, \$/yr</b>	2,400,000	4,700,000
<b>Annual Levelized Cost, mil/kWh</b>	0.85	1.65

While the values presented for PAC technology are based on B&W/MTI's own analysis of the cost of providing and operating an injection system, there are both positive and negative differences between the relative costs of capital and operating costs when compared to some of those reported by others. Because these differences are still being reconciled, no breakdown is provided on the capital and operating costs at this time. There is general agreement however between the costs developed here and the \$2 – 5 million/yr range of

overall annual levelized costs being reported by those working more directly on the PAC technology.<sup>4,8</sup>

The application of the B&W/MTI enhanced mercury capture process with a wet FGD system has the additional benefit of having virtually no impact on scrubber operation and gypsum quality. Moreover, it does not adversely affect the acceptability of fly ash for disposal/sale, a potential drawback PAC may have if it is not practical or economically attractive to separate by-product fly ash from the spent activated carbon. This aspect came to light in the demonstration of PAC technology at Wisconsin Electric's Pleasant Prairie Power Plant where the carbon appeared to negate its use as a cement admixture. The economic impact in this case was estimated to be \$12 to \$15 million/yr due to lost fly ash sale revenue and increased landfill disposal costs.<sup>7</sup>

## **CONCLUSIONS**

The challenge presented by the forthcoming regulations on mercury emissions from coal-fired power plants is one that is transforming the industry into examining multipollutant control methods that take advantage of the capabilities of existing particulate and gaseous emission devices in order to achieve economically viable solutions. The test program conducted sought to demonstrate the effectiveness of an additive that was expected to enhance mercury capture in both lime and limestone wet scrubbers.

Test results indicated that the additive indeed was effective in maintaining high removal efficiency at an overall average of 77 percent over approximately four months of continuous operation at MSCPA's Endicott Station by virtue of preventing the chemical reduction of oxidized mercury with re-emission in its elemental form. Unfortunately, while corresponding effectiveness had been expected in two weeks of operation at Cinergy's Zimmer Station, the results showed that chemical reduction was taking place within the scrubber, leading to an overall removal efficiency of approximately 50 percent for the wet FGD system alone. The mercury capture that does occur is ascribed to absorption of the oxidized mercury species. The reduction in oxidized mercury species averaged 95 and 87 percent at Endicott and Zimmer for the individual tests, respectively. Limited impact on elemental mercury or an increase in elemental mercury emissions reduced the overall mercury emissions reduction performance to the levels noted above.

The results point to the need for further research and development of methods to effect oxidation of the elemental mercury fraction in the flue gas and improved means of preventing the reduction of captured oxidized mercury species in lime-based wet FGD systems. Coupled with this, the results also describe to some degree the limitations on interpretation of data obtained by manual methods, and point to the need for further development of reliable continuous sampling and analytical systems that will permit more effective responsiveness to the variations in the mercury loading and speciation present in a flue gas.

## ACKNOWLEDGMENTS

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