Mercury Removal Trends in Full-Scale ESPs and Fabric Filters

Abstract # 471

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INTRODUCTION

On December 14, 2000 the Environmental Protection Agency (EPA) announced their decision to regulate mercury emissions from the nation's coal-fired power plants. The decision was based on the risks associated with current emission levels and potential buildups of methylmercury in lakes and rivers. There will be a three-year period to develop proposed rules, followed by one year to finalize the regulation, with full compliance required in 2007.

In anticipation of potential regulations, a great deal of research has been conducted during the past decade to characterize the emission and control of mercury compounds from the combustion of coal. Much of this research was funded by the Department of Energy, EPA, and EPRI and results are summarized in the comprehensive AWMA Critical Review Article[1]. As a result of these efforts, the following was determined:

1. how to accurately measure trace concentrations of mercury,
2. that mercury is emitted in a variety of different forms,
3. that mercury species vary with fuel source and combustion conditions, and
4. that control of mercury 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. Initial estimates of emission costs were based on the experience gained from waste combustors in which mercury can be captured for a few hundred dollars per pound. However, because of the large volumes of gas to be treated, low concentrations of mercury, and presence of difficult to captures species such as elemental mercury, some estimates show that 90% mercury reduction for utilities could cost as much as $5 billion per year. Most of these costs will be borne by power plants that burn low-sulfur coal and do not have wet scrubbers as part of the 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 conventional particulate control devices (ESPs and fabric filters) represent the most mature and potentially most cost-effective control technology for utilities. However, all of the work to date has been conducted using bench-scale and pilot experiments. Although these reduced-scale programs provide valuable insight into many important issues, they cannot fully account for impacts of additional control technology on plant-wide equipment.

Therefore, it is necessary to scale-up the technology and perform full-scale field tests to document actual performance levels and determine accurate cost information. Under a DOE/NETL cooperative agreement, ADA-ES is working in partnership with PG&E National Energy Group, Wisconsin Electric, a subsidiary of Wisconsin Energy Corp., Alabama Power Company, a subsidiary of Southern Company, and EPRI on a field evaluation program of sorbents injection upstream of existing particulate control devices for mercury control[2]. This program is specific to units that do not have scrubbers for SO_2 control or hot-side ESPs. Organizations participating in this program as team members include EPRI, Apogee Scientific, URS Radian, Energy & Environmental Strategies, PSI Inc., Microbeam Technologies, EERC, EEC, Hamon Research-Cottrell, Norit Americas, and EnviroCare.

The objectives of this multifaceted program are to:

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

Testing will be conducted at four sites, shown below, that burn coal and have particulate control equipment that are representative of 75% of coal-fired generation.

Test Site	**Coal**	**Particulate Control**
PG&E NEG Salem Harbor	Low S. Bituminous	Cold Side ESP
PG&E NEG Brayton Point	Low S. Bituminous	Cold Side ESP
WEPCO Pleasant Prairie	PRB	Cold Side ESP
Alabama Power Gaston	Low S. Bituminous	Hot Side ESP COHPAC FF

One task in this program is to perform an integrated analysis of data gathered from the four sites with results from other test programs being conducted by EPRI and DOE and data collected in Phase III of the ICR. Key variables will be identified and their effect on mercury removal with and without dry sorbent injection will be quantified. This paper presents a summary of the initial efforts with the data integration.

REVIEW AND COMPILATION OF AVAILABLE DATA

Overall ICR Data Review

Phase III of EPA's Information Collection Request (ICR) identified a statistical sampling of plants for stack and waste measurements. Mercury was measured across the control devices using the modified Ontario Hydro method for total and speciated mercury. Analysis of the data by EPA, EPRI and others show general trends (for all coal types, boiler types, and emissions control configurations) that include[3]:

- Coal type and properties affect mercury speciation.
- Oxidized mercury (Hg II) is easier to absorb than elemental mercury (Hg^0)
- Ability to capture mercury increases with decreasing temperature.
- Absorption of mercury onto fly ash is thought to be related to fly ash carbon content.

Review of Mercury Data Relating to Non-Scrubbed, Cold-Side Units

Most of the reviews of the ICR data that have been published provide an overall interpretation of the data, including all configurations (coal types, boiler types, and emission control equipment). In this program it is of interest to analyze mercury capture in non-scrubbed units with ESPs or fabric filters for each of the major coal categories: bituminous, subbituminous and lignite. The analysis does not include units with fluidized bed combustors. In addition to the ICR data, the author's have collected data for mercury removal across full-scale ESPs and fabric filters from published EPRI and DOE reports to include in the database. The plant specific data was supplemented with parameters that contribute to mercury capture which have been identified during lab and pilot-scale studies conducted during the past ten years. These parameters include:

- the effect of temperature on mercury capture with flyash for some flyash types[1],
    - temperature plays a role in mercury removal both across the particulate collector and for any ash collected on a sampling filter
    - the potential impact of flyash on a sampling filter on measured mercury removal and oxidation
    - flyash captured on the sampling filter may alter the measured vapor phase mercury and oxidized/elemental ratio
- the difficulty of transporting mercuric chloride (reacts/"sticks" to flyash, tubing, etc.)

- the difference in mercury removal capabilities between a fabric filter, where a dustcake is present, and an ESP
- the impact of dustcake thickness and cleaning frequency on mercury removal in a fabric filter
  - pressure drop and cleaning frequency were not included in most ICR reports
- the effect of LOI carbon on mercury removal
  - LOI was not included in most ICR reports
- the importance of sorbent size distribution for overall mercury removal
  - LOI in flyash may be important but size distribution of the carbon may be a critical parameter
- the significance that residence time can influence mercury removal
  - units with long duct runs or large ESPs may have more mercury removal

A thorough review of the available full-scale data was conducted with special attention to parameters that could contribute to mercury removal as defined by the trends observed in laboratory and field research. For example, data collected at the inlet to the particulate collector is assumed to represent an accurate measure of the total mercury present at that location. However, since some flyash can remove and/or oxidize mercury, the mercury speciation measured at the inlet to the particulate collector does not necessarily accurately represent the speciation in the duct at that location. Also, mercury collected on the sampling filter with the flyash is considered to represent the affinity of the specific flyash to mercury but not necessarily the amount of mercury on the particulate at that location in the system. In other words, the mercury may have been captured on the flyash as the gas sample passed through the sampling filter.

To minimize discrepancies in the data, all mercury data from the draft Ontario Hydro tests were recorded from reports as micrograms of mercury collected in the specific impinger or particulate catch, to the total gas volume collected during the sample. Errors were noted in the summary sections of some ICR reports that resulted when converting the measured mercury concentration in $\mu g/m^3$ to lb/Tbtu. This error sometimes occurred when a portion of the flow at a unit was measured at one location (i.e. A or B-side) and compared to the combined flow at the other location. For each test, the volume collected for the sample was recorded as dry normal cubic meters corrected to 3% oxygen. Normal conditions for this paper are considered to be at a pressure of 29.92 inches Hg and a temperature of 68 ^oF. This definition was not consistent for all test contractors. Also, in some reports, the mercury concentrations presented in the test summary were corrected to 3% O_2 and others were reported as measured. For this paper, all concentrations were corrected to 3% O_2 to account for any air inleakage across the particulate collector that may contribute to an apparent mercury removal caused by a dilution of the gas.

The temperature of the sampling filter was also included in the database evaluated during this program to determine any correlation in the fraction of mercury collected on the sampling filter and the temperature of the filter. Other data included in the database were the SCA of the ESP[4], the type of fabric filter tested and average pressure drop across the filter if reported, and the estimated LOI carbon in the ash for the unit. The LOI values were obtained from plant engineers when possible and from combustion experts familiar with the plant when a direct value was not available.

Data Integration

The goal of this effort is to integrate available mercury measurement from full-scale units with results from the full-scale evaluations of PAC injection for mercury control to predict mercury removal and costs for a broad range of plants. However, as will be shown in the next section, the preliminary analysis conducted to-date for this program shows that general trends found in more comprehensive studies may not be applicable within a specific coal type. In addition, the limited data set available prevents a thorough survey of significant contributors to mercury removal.

During this program, baseline tests (no sorbent injection) will be conducted to better understand several factors that may affect mercury removal. These data will be added to the current database to better predict removal for units with ESPs and fabric filters. Tests have been planned to isolate likely contributors to removal and evaluate their specific effects. These contributors and the tests planned include:

- Duct temperature with PRB and bitumious flyash
  - Modify duct temperature by spray cooling or adjusting plant operation
- LOI in bituminous flyash
  - Adjust combustion characteristics to vary LOI
- Effect of SNCR
  - Turn urea injection on and off during semi-continuous mercury sampling
- Effect of residence time for in-flight mercury removal by particulate
  - Measure vapor-phase mercury at various points on a long duct run downstream of the air preheater
- Effect of SO_3 on mercury removal on PRB and bituminous flyash
  - Adjust the amount of SO_3 injected with a SO_3 conditioning system

DATA AND INTERPRETATION AND MERCURY REMOVAL TRENDS

The parameters that the authors chose to focus on in this analysis are:

- Percent of mercury measured on the inlet filter of the modified Ontario Hydro test and the temperature of the filter during testing as in indication of removal across the ESP or FF
- Inlet temperature
- Coal chloride concentration
- Specific Collection Area (SCA) of the ESP
- Carbon in the fly ash (LOI)
- Flue gas conditioning

Table 1 presents a summary of data from 19 units that have cold-side ESPs as the primary particulate control device. The majority of data in this table were taken from the ICR tests. Additional data were obtained from plants where either Ontario Hydro or R&D funded mercury measurements were made[5]. Specific names of plants are omitted at the request of some of the contributors. The data are organized by coal type with 7 units on bituminous coal, 4 units on lignite, 5 units on subbituminous, and 3 units firing a mix of bituminous, subbituminous and/or pet coke.

Similarly, Table 2 presents data from 10 units with fabric filters. This data set has 4 units on bituminous, 1 unit on lignite, 3 units on subbituminous and 1 unit with a mix of coals. No COHPAC units were included in this data set.

Table 1. Non-Scrubbed Units with Cold-Side ESPs

ID*	NOx Control	FGC	SCA	ESP Inlet Temp	Coal Chloride	Ash LOI	% Hg on Filter	% Hg Removal
B-1	LNB		290	289	882		0	8
B-2	LNB		550	310	575	5-10	36	26
B-3	LNB		550	245	966	3-7	30	23
B-4	LNB		252	322	2100	5-10	29	24
B-5	LNB		346	321	800	5-10	75	30
B-6	LNB&S NCR		475	262	264	25	84	88
B-7			323	320	333	3-6	60	46
L-1	LNB		599	368	18		0	7
L-2			267	395	115	1.4	17	-2
L-3				368	29		5	-1
L-4	LNB		470	329	74	1-5	1	-4
S-1		SO_3	468	291	100	<.5	2	-35
S-2	OFA	SO_3	686	306	57	0.09-0.18	1	-3
S-3	CC		213	317	133	1-2	16	10
S-4	LNB		279	322	76	1-2	0	8
S-5		SO_3	279					28
Mix-1	LNB		440	338	3620	<1	82	74
Mix-2			220	342	180	10-20	84	67
Mix-3			220	308	187	10-20	77	54

*B = bituminous, S = subbituminous, L = lignite, mix = blend

Table 2. Non-Scrubbed Units with Fabric Filters as Primary Particulate Collector

ID*	NOx Control	FF Inlet Temp	Coal Chloride	Ash LOI	% Hg on Filter	% Hg Removal
B-1	LNB	340	167	10-20	76	51
B-2	LNB	299	55		80	87
B-3	LNB	307	1233		100	100
B-4	LNB	290				99
L-1		358	167	2-4	14	-21
S-1	LNB	348	100	2-4	36	82
S-2	OFA	293	<10	1-2	16	57
S-3	LNB, OFA	342		<1		72
Mix-1	LNB	314	127	20-25	2	-4

*B = bituminous, S = subbituminous, L = lignite, mix = blend

The first comparison is the average mercury removal by subset group. These data are presented in Table 3. Data from Tables 1 and 2 that are negative for mercury removal are considered to have 0% removal. These data show that without additional sorbent injection, fabric filters have 70 to 84% mercury removal on bituminous and subbituminous coals. ESPs have removal efficiencies slightly lower than fabric filters, 66%, when a mixture of coals that include a bituminous is fired. Both ESPs and fabric filters have very poor removal on lignite coals, however all lignite units included in the analysis were operated at fairly high temperatures (330 – 395^{o}F). ESPs have poor mercury removal with subbituminous coals (290-322^{o}F).

Table 3. Summary of Average Mercury Removal in ESPs and Fabric Filters

Coal	ESPs (% Hg Removal)	Fabric Filters (% Hg Removal)
Bituminous	35	84
Subbituminous	9	70
Lignite	2	0
Bit/Sub/Pet Coke Mix	66	NA

Statistical analyses using the Pearson Product-Moment correlation were performed with respect to the primary variables of interest identified above, for each subset group with more than 3 units. The Pearson Product-Moment correlation between two variables reflects the degree of linear relationship between two variables, ranging from +1 to -1. A correlation of +1 means that there is a perfect positive linear relationship between variables and a correlation of –1 indicates a perfect inverse linear relationship. A correlation of 0 means there is no linear relationship between the two variables.

Table 4. Correlation with Mercury Removal (3% O_2)

	ESP				**FF***
	Bit	**Sub**	**Mix**	**Lig**	**Bit**
SCA (ft^2/1000cfm)	0.263	-0.908	0.539	0.795	NA
Inlet T (^oF)	-0.290	0.849	0.648	0.074	-0.385
Coal Chloride (µg/g)	-.515	0.552	0.654	-0.614	0.565
LOI (%)	0.908	0.965	-0.727	NA	NA
Hg on Sampling filter (%)	0.765	0.626	-0.011	-0.491	0.951

* Data included for categories with 4 or more data points (plants)

A summary of the analysis of several potential factors influencing mercury removal is presented in Table 4. The amount of mercury captured on the sampling filter at the inlet of the particulate collector is also included on this table. Trends, when choosing a value greater than 0.7 as significant, show:

- Mercury measured on the sampling filter of the Ontario Hydro test provides a good indication of mercury removal across the ESP or fabric filter for bituminous coals.

- Increased carbon in the fly ash correlates with higher mercury removal in ESPs for bituminous and subbituminous coals.

- There is a correlation between higher temperature and higher mercury removal with the subbituminous coals in ESPs, but this correlation is highly unlikely. There is a narrow data spread (0 to 10% removal at 291 to 322^{o}F) for this particular analysis.

- The size of the ESP, SCA, correlates with higher mercury removal in ESPs on lignite coals. Although this correlation appears to be significant, the highest level of mercury removal in this subset was 7%. For subbituminous coals, there appears to be an inverse correlation between SCA and mercury removal (the smaller the SCA, the higher the removal). It is expected that other factors are contributing because it is unlikely that this is a true correlation.

- No significant correlation with coal chloride level was found for any of the coal type subsets. However, the units burning bituminous coals have higher coal chloride on average and also have higher mercury removal on average.

- Flue gas conditioning with SO_3 was used on 3 of the 5 ESPs burning subbituminous coals. The use of SO_3 conditioning did not appear to influence mercury removal.

- No significant correlations with LOI, coal chloride or temperature were noted across the fabric filters.

A more detailed examination of the data available for the fabric filters suggests some additional trends. These trends are presented on Figure 1. For most of the plants burning bituminous coal, the mercury removal was fairly consistent until the temperature of the fabric filter outlet exceeded 305 ^oF. The fabric filter burning the blended coal showed virtually no mercury removal (temperature at the outlet was greater than 315 ^oF). For this particular plant, it is unlikely that operating at a slightly lower temperature would result in improved mercury removal because the inlet sampling filter, which was maintained near 230^oF for these tests, captured a maximum of 2.8% of the incoming mercury. This indicates that the ash has a very low affinity for mercury.

For the units burning subbituminous coals, good mercury removal was achieved at temperatures over 330 ^oF. This suggests that the collection mechanism for subbituminuos flyash is not as dependent on temperature as the bituminous flyash. Since the subbituminous coals produce primarily elemental mercury, this data may indicate that the reactivity of elemental mercury may not be as dependent on temperature as oxidized mercury.

The lignite site presents some very interesting results. The fabric filter outlet temperature at this site was nominally 330 ^oF for all three test runs. The mercury removal ranged from –51% to +28%. In addition, the highest fraction of mercury captured on the inlet sampling filter during testing at this site was 34%. The filter temperature during these tests was 260^oF. These two sets of data (the mercury removal across the fabric filter and the mercury capture on the sampling filter) suggest that the ash has an affinity for mercury at lower temperatures. However, at the fabric filter operating temperature, very small changes in temperature can account for either adsorption onto the filter dustcake, or desorption of mercury back into the flue gas.

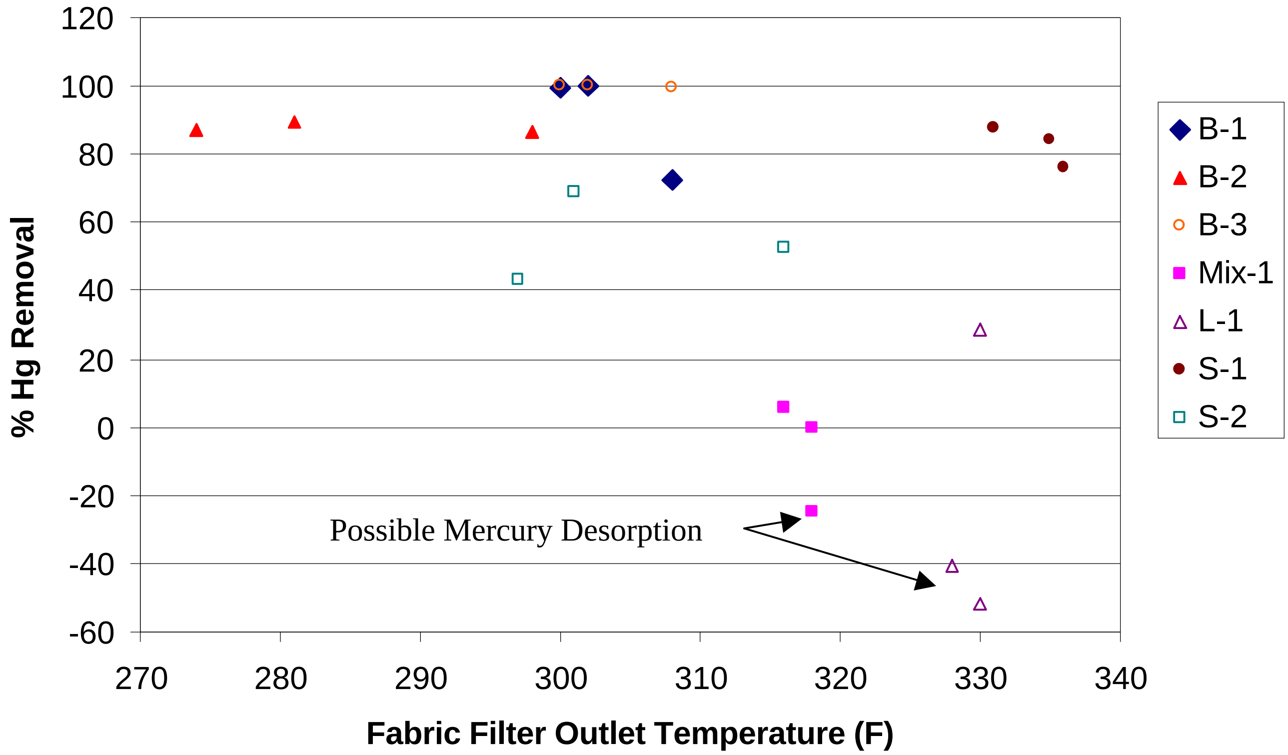

Figure 1. Mercury Removal Across Fabric Filters

CONCLUSIONS

Review of available data from full-scale coal-fired power generation facilities with cold-side ESPs and fabric filters suggest several important factors that influence mercury removal. These factors are listed below. There are other factors believed to contribute to mercury removal and many of these will be characterized during the next year under this program. Understanding parameters that influence mercury removal and characterizing the impact of sorbent injection on mercury removal will provide a method for plants to maximize baseline mercury removal and project costs for additional mercury removal with sorbent injection. Mercury removal trends identified thus far include:

ESPs:

Subbituminous Coal

Poor mercury removal (average 9%). Increased LOI carbon correlates with higher mercury removal.

Lignite Coal

Poor mercury removal (average 2% at temperatures above 330^{o}F).

Bituminous Coal

Fair mercury removal (average 35%) at temperatures below 325^{o}F. Increased LOI carbon correlates with higher mercury removal.

Mixed Coals

Good mercury removal (average 66% at 308 – 338^{o}F).

Fabric Filters:

Bituminous and Subbituminous Coals

Good mercury removal (average removal 84 and 70%) at temperatures below 310^{o}F.

Lignite Coal

Poor mercury removal (average 0%) near 330^{o}F. Based on mercury captured on the sampling filter (max 34% at 260^{o}F), it is possible this ash will remove some mercury at lower temperatures.

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