

Impact of SCR on Mercury Speciation and Removal

2004 Update

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Technical Update, December 2004

EPRI Project Manager

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ABSTRACT

The objective of this research study is to quantify the impact of selective catalytic reduction (SCR) on mercury speciation and its subsequent removal in the flue gas desulfurization (FGD) system. The intent of this technical update is to synthesize mercury measurements conducted at power plants with SCRs in several research studies that were sponsored by EPRI, Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and host utilities. The results indicate that SCRs may oxidize elemental mercury to oxidized mercury, which is more effectively captured in an FGD, if available. This SCR cobenefit is more likely to occur for bituminous coals, and appears to be much less likely and less significant for Powder River Basin (PRB) coals, and possibly low-chloride bituminous coals.

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1

INTRODUCTION

Selective catalytic reduction (SCR) technology, which can reduce NO_x emissions by up to 90%, is being installed on many power plants in the eastern US. SCR units achieve lower NO_x emissions by catalytically reducing NO_x to N_2 and H_2O . Ammonia (NH_3) is the reductant used for the SCR of NO_x . The SCR process is generally performed on metal oxide catalysts such as a titanium dioxide-supported vanadium pentoxide catalyst. The SCR catalysts may also promote $\text{Hg}(0)$ oxidation to $\text{Hg}(2)$, which is more effectively captured in the flue gas desulfurization (FGD) system, if available.

This technical update summarizes mercury measurements conducted at power plants with SCRs by EPRI, Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and host utilities under several research programs. These research studies varied in work scope, with some studies being more comprehensive and including measurements at the SCR inlet and outlet and FGD inlet and outlet, as well as with and without SCR operation. Other studies were limited to measurements with only SCR operation, and may not include measurements around the SCR and/or FGD. The intent of this report is to synthesize the results of these various studies and evaluate and quantify the impact of SCR on Hg speciation across the catalyst and downstream at the FGD inlet (ESP outlet), and its subsequent removal in the downstream FGD.

2

PROJECT GOALS AND OBJECTIVES

The goal of this research study is to characterize the effect of SCR operation on mercury speciation and removal. Specifically, the objectives included the following:

- Determine the change in mercury speciation across the SCR catalyst and in downstream mercury speciation at the FGD inlet (ESP outlet).
- Determine the effect SCR operation has on overall mercury removal across the electrostatic precipitator (ESP) and wet FGD.

The goal of this technical update is to synthesize the existing database of research results developed by EPRI, DOE, EPA, and various host utilities.

A significant number of measurements was conducted in the 2004 ozone season, especially in the August/September time frame. Thus many of those results have not been thoroughly reviewed and are still somewhat “preliminary”. In some instances, the laboratory analyses of solid samples (e.g. coal, fly ash, and FGD solids) have not been completed and material balance calculations have not been conducted. While the results are not likely to change significantly, additional data analyses may provide new perspectives. In addition, there are a number of research efforts still on-going, with more data expected in early 2005, as well as new field studies planned in the 2005 ozone season. Thus, the reader is encouraged to view this technical update as a report on work in progress, and read future reports and updates as they become available.

3

DESCRIPTION OF SITES TESTED

EPRI, DOE, EPA and Utility field tests (EERC) – Under this research program, EPRI, DOE, EPA, and a consortium of utilities cosponsored measurements at eight sites with SCRs, with EERC (Energy and Environmental Research Center) conducting the flue gas testing. Two of the sites were tested multiple times. Only three of these sites employed a wet FGD for SO₂ control, with one employing a lime combined particulate/SO₂ venturi scrubber. These studies were generally “comprehensive” and included mercury measurements at the inlet and outlet of the SCR, ESP, and the FGD. Where possible, measurements were conducted both with the SCR in operation and with the SCR bypassed or at a similar “sister” unit without an SCR. The results of these measurements are summarized in EPRI Reports 1008494, 1005558, and 1005400.

EPRI, Utility field tests (Western Kentucky University, URS, METCO) – EPRI and the host utilities conducted site-specific field testing at three additional sites with SCRs. All three plants employed an FGD – with one employing a spray dryer/fabric filter, the 2nd employed an ESP followed by a limestone wet FGD, and the 3rd a fabric filter followed by a limestone wet FGD. Measurements were conducted at the inlet and outlet of the various control devices. For the 2 sites with wet FGDs, measurements were conducted both with and without SCR operation.

Utility-sponsored field measurements – One utility conducted measurements at three sites with SCRs, and each site employed an ESP for particulate control, with SO₂ control by a low-sulfur compliance coal. Measurements were conducted at the SCR inlet/outlet and the stack.

DOE/Consol SCR project – DOE has an on-going research study with Consol to evaluate total mercury removal around 10 sites with SCRs and FGDs, including seven with wet FGDs and three with spray dryer/fabric filters. The focus of these studies was to characterize mercury removal and conduct an overall mass balance. Measurements included the SCR inlet, ESP inlet, and the stack. EPRI later offered DOE to expand the program by contracting with Consol to add measurements at the SCR outlet and the FGD inlet, as well as measurements without SCR at limited number of sites. Some of these field measurements were recently completed in the 2004 ozone season, and the results are still somewhat “preliminary”, awaiting completion of reviews and QA/QC. Additional studies are planned at 2 sites, and sampling under “no SCR” conditions was recently completed at two sites in November 2004, with these results still unavailable.

Table 3-1 summarize the available database and provides a description of the sites, including the coal type and air pollution control technologies. The FGD design is summarized per reagent type (limestone or magnesium-enhanced lime) and oxidation mode (inhibited, in-situ or ex-situ). The EERC and WKU sites are coded as “S”, the utility sites as “M”, and the Consol sites as “C”.

Site #	Coal Properties ¹		Boiler Type	Particulate Control	FGD Design ²	Catalyst Manufacturer	Space Velocity	
	Type	% S						ppm Cl
S1	PRB	0.2	60	Cyclone	ESP	Low-S coal	Cormetech	1800
S2- 1 ³	OH Bit	3.9	1250	Wall	ESP	Mg – Inhibit	Siemens	2125
S3	PA Bit	1.7	1100	Tangential	ESP	Low-S coal	KWH	3930
S4 – 1	KY Bit	~2.9	800	Cyclone	Venturi Scrubber	Venturi Scrubber ⁴	Cormetech	2330
S5	PA/WV Bit	3.6	415	Wall	ESP	Mg – Inhibit	Halder-Topsoe	~3750
S6	KY/WV Bit	1	1060	Tangential	ESP	Low-S coal	Cormetech	3800
S2 – 2	OH Bit	3.9	1330	Wall	ESP	Mg – Inhibited	Siemens	2125
S4 – 2	KY Bit	2.9	360	Cyclone	Venturi Scrubber	Venturi Scrubber	Cormetech	2330
S7	E. Bit 60/40	1	1190	Tangential	SD/FF	SD/FF	Siemens	~2750
S8	PRB/Bit	0.7	790	Wall	ESP	Low-S coal	Cormetech	3100
S9	PRB	0.4	10	Wall	ESP	Low-S coal	Cormetech	3000
S2 – 3	OH Bit	3.3	575	Wall	ESP	Mg – Inhibit	Siemens	2125
S4 – 3	KY Bit	2.8	410	Cyclone	Venturi Scrubber	Venturi Scrubber	Cormetech	2330
S10	IN Bit	3.6	110	Wall	ESP	LS - Inhibit	KWH	3400
S11	PRB 15/85	0.6	<50 ⁵	Tangential	FF	LS - Inhibit	Halder-Topsoe	~3700
M1 – 1	PRB/Bit 15/85	0.7	1400	Wall	ESP	Low-S coal	Siemens	2200
M1 – 2	PRB/Bit	0.7	870	Wall	ESP	Low-S coal	Siemens	2200
M2	Bit	0.9	1665	Wall	ESP	Low-S coal	Siemens	5250
M3	Bit	0.7	1080	Wall	ESP	Low-S coal	Siemens, Siemens,	2000
C1	Bit	1	1040	Wall	SD/FF	SD/FF	Hitachi	
C2	Bit	1.9	1000	Wall	SD/FF	SD/FF	NSKK	
C5	Bit	3.0	1360	Wall	ESP	LS – In-situ	Cormetech	2315
C6	Bit	3.6	130	Tangential	ESP	LS - Ex-situ	Hitachi	
C7	Bit	3.7	1100	Wall	ESP	LS - Ex-situ	Hitachi	
C8	Bit	4.7	460	Wall	ESP	Mg – Ex-situ	Halder-Topsoe	
C9	Bit	3.7	500	Wall	ESP	Mg – Inhibit	Halder-Topsoe	~3750
C10 ²	Bit	3.7	630	Wall	ESP	Mg – Inhibit	Siemens	2125

1 – Dry baiss

2 - FGD design by reagent and oxidation mode – LS – Limestone, Mg – Magnesium-enhanced lime. Inhibit, in-situ, and ex-situ refer to the oxidation approach

3 - Sites S2-1, S2-2, S2-3 (and S4, M1) were retested to evaluate catalyst aging. C10 is the same facility as S2.

4 - Site S4 – Combined particulate, SO₂ removal with limestone, forced oxidation

5 - Site S11 coal analyses – estimated from “no SCR” baseline measurements

**Table 3-1
Description of Site Tested**

Tables 3-2 and 3-3 provide a summary of the sites tested (as well as measurements) by coal type and control technology. The majority of the available database is for bituminous coals (16), and thus these results and conclusions have less uncertainty than the results for PRB sites (3) and PRB/bituminous blends (2). Of the 16 sites burning bituminous coal, 12 employed either a wet or dry FGD system.

Coal Type	Sites Tested	Total Number of Measurement Campaigns
Bituminous	16	21
PRB	3	3
PRB/Bituminous Blend	2	3

**Table 3-2
Distribution of Sites Tested by Coal Type**

Control Technology	All Coal Types		Bituminous Coal Only	
	Sites Tested	Total Number of Measurement Campaigns	Sites Tested	Total Number of Measurement Campaigns
ESP	8	9	4	4
ESP/FGD	8	13	8	13
Venturi Scrubber	1	3	1	3
SD/FF	3	3	3	3
FF/FGD	1	1	0	0

**Table 3-2
Distribution of Sites Tested by Air Pollution Controls**

4

SUMMARY OF RESULTS – SCR MERCURY OXIDATION

As described in Section 3, field results are available for 21 sites. Multiple measurements were conducted at 2 sites to evaluate the impact of catalyst aging, thus there are more measurements than sites tested.

Fifteen of the 21 sites included measurements at both the SCR inlet and outlet. The results presented in this Section are primarily based on Ontario Hydro measurements, generally conducted simultaneously at the SCR inlet and outlet. The difference between these two measurements of percent Hg(2) is believed to indicate the extent of the catalytic effect on mercury. As oxidation tends to continue as the flue gas flows through the air heater, the SCR may also have impact on mercury speciation, possibly due to the altered flue gas properties, e.g. much lower NO_x and higher SO₃ concentrations. The data are presented in 3 approaches to compare the results from site-to-site:

1. Percent (%) Hg(2) at the SCR outlet or FGD inlet,
2. Net increase in Hg(2),
3. % Hg(0) converted to Hg(2).

For simplicity in presenting the results in this report, Hg(2) is considered to be the mercury captured in the Ontario Hydro nitric acid and KCl impingers as well as the particulate filter. Hg(0) is the mercury captured in the permanganate impingers. The particulate mercury was generally not a factor, with the exception of Site S1 – cyclone boiler burning a PRB coal with high LOI fly ash.

Mercury Speciation at the SCR Outlet, FGD Inlet

The “bottom line” for power plants is the % Hg(2) at the FGD inlet, and hence the % of total mercury that could be captured by the FGD system. However, this adds an extra layer of uncertainty in using the data to understand the SCR/Hg mechanisms, since the change in Hg speciation across the air heater is difficult to compare among sites. Figure 4-1 compares these results at the FGD inlet (ESP outlet). Some sites included measurements only at the ESP (or particulate control) inlet, and these values are used for those sites.

For the bituminous sites, the measurements indicated that the mercury was primarily Hg(2), with the one exception being Site S10, which burned a low Cl coal. The average Hg(2) at the FGD inlet was 94% for bituminous coals. For the limited sites where baseline “no SCR” measurements were conducted, the Hg(2) at the FGD inlet (ESP outlet) was about 70%.

For the 3 PRB sites (shown in dark/red bars in Figure 3-1), Sites S9 and S11 measured primarily Hg(0) at the ESP/FF inlet. Sites S9 and S11 are more likely to represent traditional pulverized coal-fired boilers burning PRB coal, specifically with low levels of LOI. Site S1 is a cyclone boiler and observed very high levels of Hg(2). The ESP inlet results for S1 are shown in Figure 3-1 since most of the Hg was associated with particulate, possibly due to the high LOI (or unburned carbon) fly ash, and was captured in the ESP.

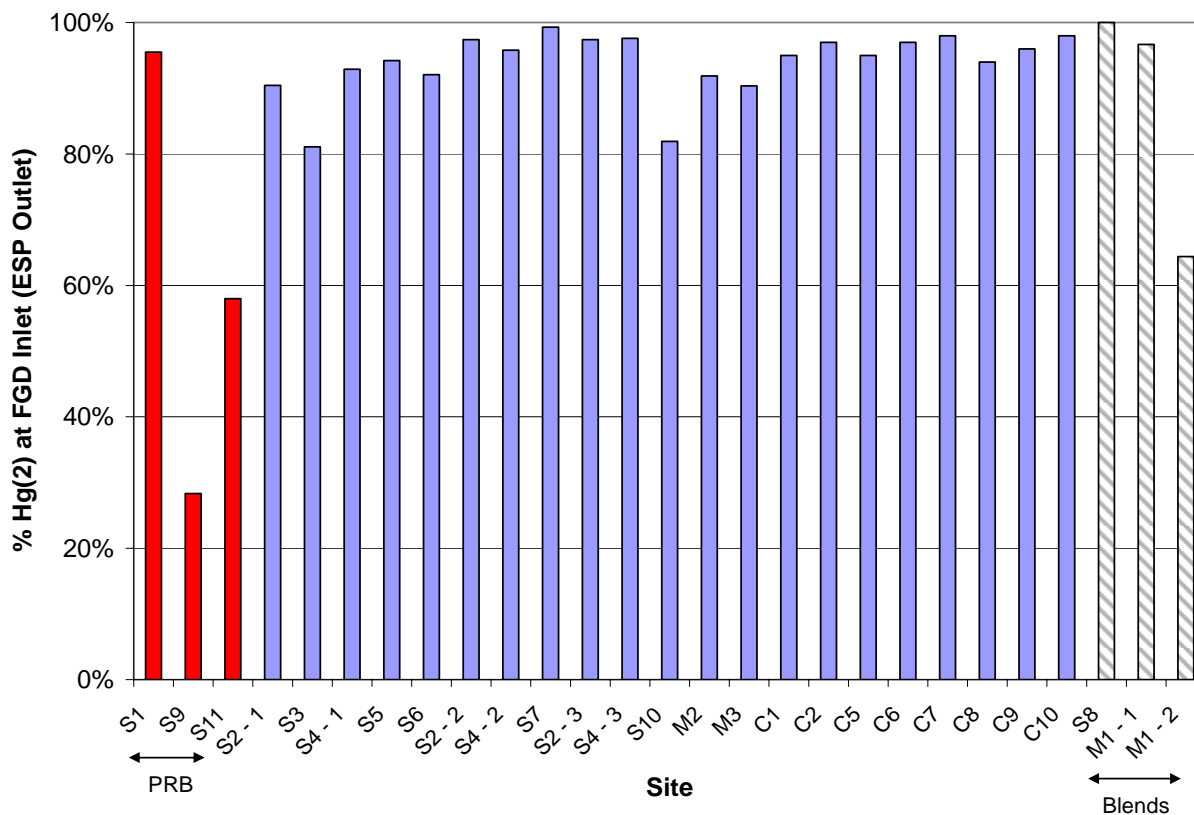


Figure 4-1
Mercury Speciation at the FGD Inlet

Two sites were tested that burned blends of PRB and bituminous coal. Sites S8 and M1 (tested twice) burned a ratio of 60/40 and 15/85, respectively, PRB/bituminous coals. Site S8 and M1-1 measured essentially all Hg(2) – but the follow on test at Site M1 measured a much lower level of Hg(2). The coal analyses for Sites S8 and M1 resemble analyses for a bituminous coal. The Cl in coal was 790 ppm for Site S8, and 1400 and 870 ppm for the two tests at M1. There is no clear explanation why the second test at Site M1 measured much less Hg(2) at the ESP outlet, 64% as compared to 97% during the first test. The tests were conducted five months apart, and it is unlikely that this represents catalyst deactivation. The coal Cl was somewhat lower, 870 compared with 1400 ppm, which may be a possible but unlikely factor since oxidation activity tends to be approximately the same for coals with chloride content greater than 100-200 ppm (discussed in more detail in “Effect of Coal Properties”). The host utility at Site M1 recently

conducted a third measurement, and the results indicate a level of oxidation consistent with the first measurement.

With at least 40% bituminous coal, a PRB/bituminous blend will behave like a bituminous coal. Additional measurements are needed to evaluate Hg speciation over a range of PRB/bituminous blend ratios in order to determine the level of bituminous coal necessary to achieve near complete Hg oxidation.

The more direct comparison among sites is to evaluate the % Hg(2) at the SCR outlet (Figure 4-2). This approach focuses only on the SCR catalyst and the variables related to the coal type. Note that Figure 4-2 includes different sites than Figure 4-1 because not all sites have SCR inlet and outlet measurements.

The average Hg(2) at the SCR outlet was 81% for bituminous coal (includes the PRB/bituminous blends – which impacts the average by less than one percentage point). Fourteen of these 20 measurements were greater than 80%. The one anomalous data point is Site S10, which measured only a minimal increase in Hg(2) across the SCR. For the PRB coals, all three sites observed little, if any, increase in Hg(2). These PRB sites as well Site S10 would suggest that the coal Cl content may be a key factor.

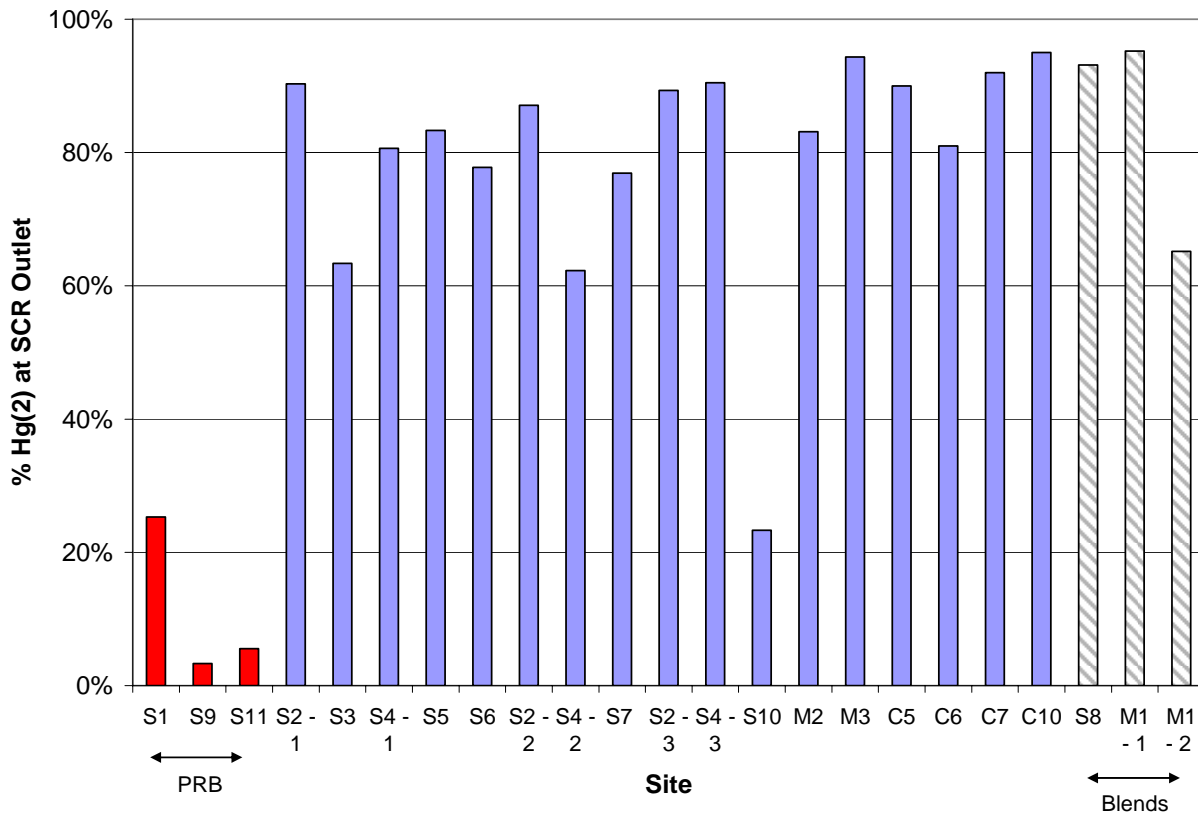


Figure 4-2
Mercury Speciation at the SCR Outlet

Net Increase in Hg(2)

Figure 4-3 summarizes the net percentage increase in Hg(2) across the SCR. As an example, if the SCR inlet Hg speciation was 30% Hg(2) and the SCR outlet Hg speciation was 70% Hg(2), then the net increase would be 40 percentage points. This approach is similar to the analysis of Hg(2) at the SCR outlet, but accounts for the variation in the inlet Hg(2) levels, which is generally affected by the coal CI level. For the bituminous coal plants (including the PRB/bituminous blends), the results vary from essentially no increase at two power plants to over 40 percentage points for about half of the measurements. The average increase is 35 percentage points for the bituminous coal and PRB/bituminous blends. Note that Site C6 measured 86% Hg(2) at the SCR inlet, so that there was little Hg(0) to be converted. This decrease in Hg(2) is likely within the sampling and analytical accuracy of the Ontario Hydro measurements.

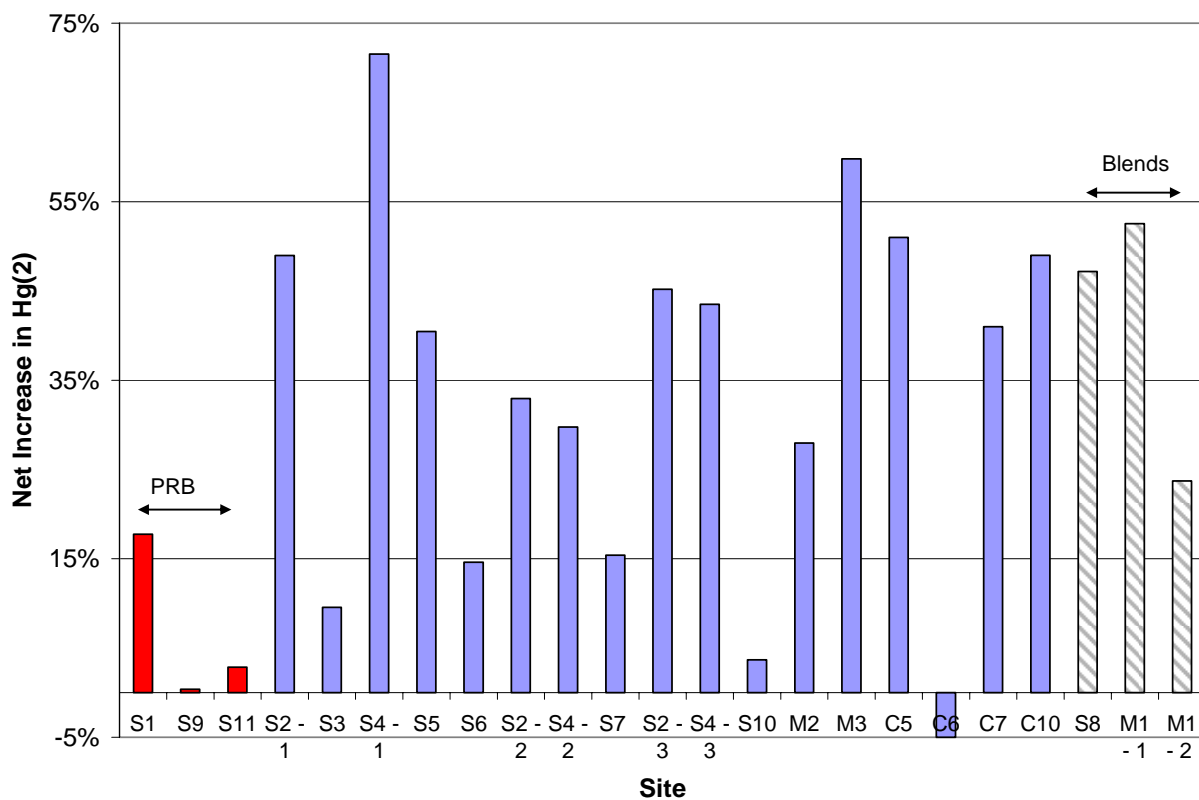


Figure 4-3
Net Increase (Percentage Points) in Oxidized Mercury Across the SCR

% Hg(0) Converted to Hg(2)

From an efficiency and chemical kinetic perspective, the percent Hg(0) oxidized or converted to Hg(2) is probably the best measure of the catalyst performance (Figure 4-4). The % Hg(0) converted was calculated as the % Hg(0) at the SCR inlet minus the % Hg(0) at the SCR outlet, divided by the % Hg(0) at the SCR inlet. This approach was necessary to normalize the total Hg concentrations at both locations.

For bituminous coals (including the PRB/bituminous blends), 61% of the Hg(0) was converted to Hg(2) across the SCR. The three PRB sites and three bituminous sites – Sites S3, S10, and C6 – measured little, if any, conversion of Hg(0). As noted earlier, the three PRB sites as well as Site S10 burn low Cl coals, which suggest that Cl may be necessary for significant oxidation. Site C6 measured only 1.7 $\mu\text{g}/\text{m}^3$ of Hg(0) at the SCR inlet and a small (0.8 $\mu\text{g}/\text{m}^3$) increase in Hg(0) at the SCR outlet, thus the high negative Hg(0) conversion.

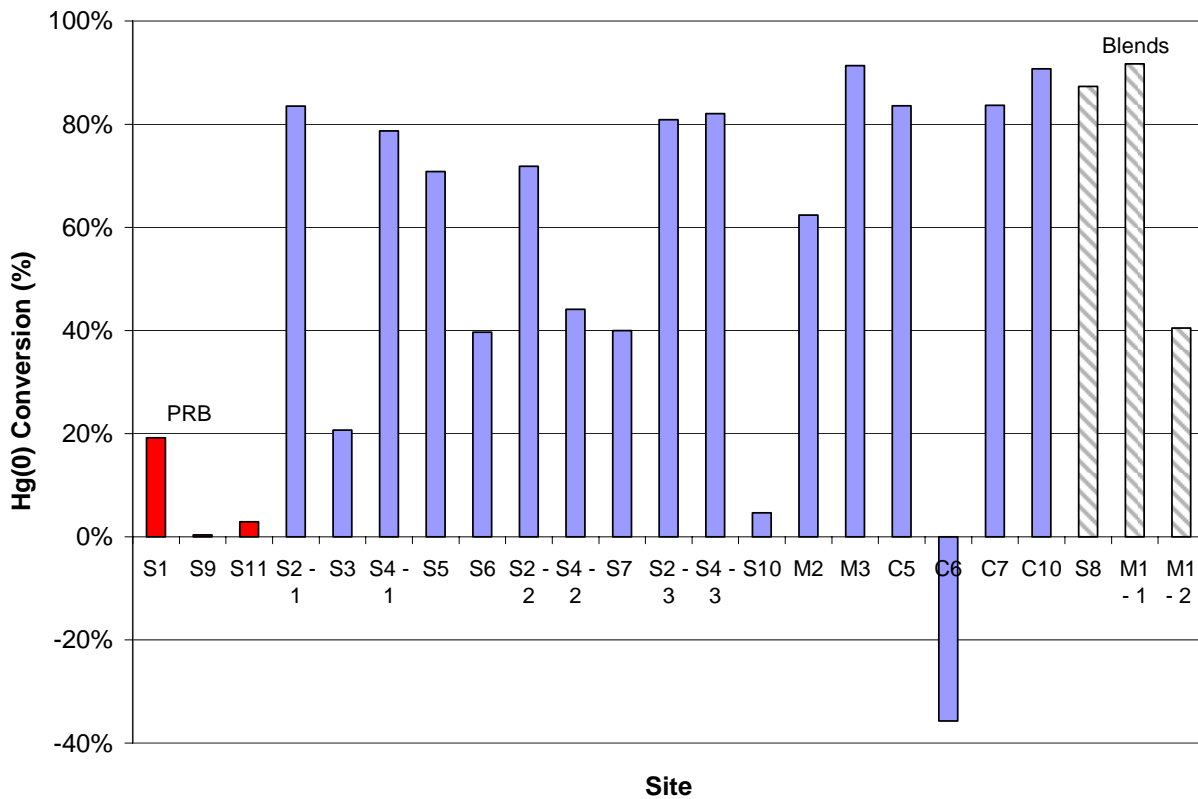


Figure 4-4
Elemental Mercury Oxidation/Conversion Across the SCR

Effect of Coal Properties

As discussed above, the coal Cl content appeared to be an important factor. Figure 4-5 illustrates the impact of Cl (ppm on a dry basis) on the Hg speciation at the SCR outlet. While there is considerable scatter in the data, the general trend is that coal Cl directly impacts the Hg/SCR reactions. Above about 100 to 200 ppm Cl in coal, tests at most sites observed high (>75%) levels of Hg(2) at the SCR outlet. Interestingly, two sites (S10 and C6) were tested which burned low Cl (~125 ppm) bituminous coals. Both sites did not measure a significant increase in Hg oxidation across the SCR. However, Site C6 observed much higher levels of Hg(2) at both the SCR inlet and outlet, as well as higher overall Hg removals. Thus while coal Cl appear to be a key factor, there appears to be other variables that affect the Hg chemistry.

Note that there is some uncertainty about coal Cl analyses at these low (<200-300 ppm) levels, especially using the “traditional” analytical methods such as ion selective electrode and ion chromatography (EPRI 1000287). The level of uncertainty for these low Cl coals would be significantly less using oxidative hydrolysis microcoulometry (EPRI 1000846).

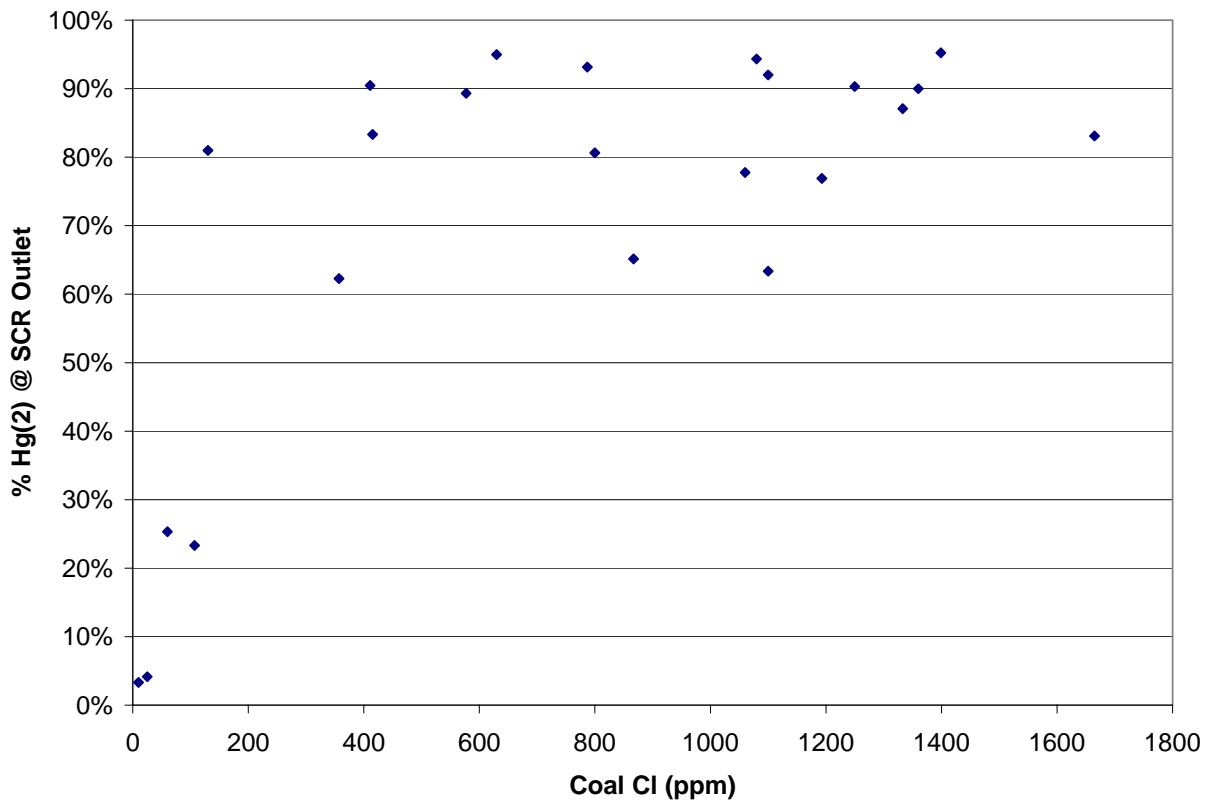


Figure 4-5
Effect of Coal Chloride on Oxidized Mercury at the SCR Outlet

Site S10

These measurements were recently completed in October 2004, and the results are still “preliminary”, with data evaluation still ongoing. Site S10 burned a bituminous coal and measured essentially no mercury oxidation directly across the SCR. This may be due to the low level of coal Cl (~110 ppm). While the Ontario Hydro measurements at the SCR inlet and outlet did not show catalytic oxidation of elemental mercury by the SCR, this site appears to have a cobenefit of the SCR on the downstream Hg speciation and removal in the FGD, when the measurements with SCR are compared with those without SCR. The % Hg(2) at the FGD inlet was 82% with SCR and only 57% without SCR; the Hg removal was 75% with SCR and only 58% without SCR. While there appears to be some SCR cobenefit, the % Hg(2) was only 82% as compared to 94% for all eastern bituminous sites tested, and the overall Hg removal was only 75% as compared to 86% for all eastern bituminous sites tested.

Catalyst Aging

Multi-year testing at Site S2 (which is the same facility as C10) was conducted near the end of each ozone season for four years. The results do not show any impact of catalyst aging after four ozone seasons of operation. The host utility at Site S4 has also retested after a fourth ozone season, and advises no degradation in mercury oxidation or removal. Thus for these two sites, no significant catalyst aging effects have been observed after four ozone seasons. While this suggests that catalyst aging may not be a significant concern for bituminous coals, four ozone seasons represents about 14,000 hours of operation; most catalyst guarantees for NO_x performance are for 24,000 hours. Furthermore, some users may recondition catalysts and not replace the catalyst. Mercury measurements have not been conducted on any catalyst after reconditioning.

5

EFFECT OF SCR ON MERCURY EMISSIONS AND REMOVAL

The proposed mercury MACT would set mercury emission limits at 2.0 and 0.6 lb/TBtu (pounds per trillion Btu) for existing and new bituminous-fueled units, respectively. Many power plants are considering SCR and FGD as a multipollutant control strategy for SO₂ and NO_x as well as for Hg. Thus the level of Hg emissions achievable for the SCR and FGD combination is of significant interest. Note that only 13 of the 21 SCR sites tested employed an FGD, with 10 being wet FGDs. Hence, this “database” is not identical to the one discussed in Section 4 which evaluated the impact of SCR on Hg speciation.

Mercury Emission Rates

Figure 5-1 summarizes the Hg emission rates (lb/TBtu) for the 12 sites with either a wet (shown in solid purple) or dry (green diagonals) FGD. **The results are the average of generally three or four Ontario Hydro two-hour measurements, and should be interpreted as only a snapshot of Hg emissions. These results do not represent a long-term average nor characterize any potential variability due to plant operation and coal variability.** The average Hg emission rate for the wet and dry FGD sites burning bituminous coals were 1.4 and 0.5 lb/TBtu, respectively. All the measurements conducted were below the proposed 2.0 lb/TBtu limit. Site C8 employed a flue gas bypass (~15%), and its emissions are very close to the proposed 2.0 lb/TBtu limit; if the bypass were not used, the measurement would be more comfortably under the proposed limit. Conversely, plants with higher percentage bypass would be expected to have higher mercury emissions. None of the wet FGD measurements were below the proposed standard of 0.6 lb/TBtu for new bituminous facilities.

Two of the three dry FGD sites were below the proposed 0.6 lb/TBtu standard. All three dry FGD sites burned relatively low-sulfur (1 – 1.8%) as well as high-Cl (1000-1200 ppm) coals. Note that dry FGD applications tend to be more common for low-sulfur coals. As the coal sulfur increases, dry FGDs become less cost-competitive with wet FGDs.

Site S11 was the only PRB site tested with an FGD, and the mercury emission rate was measured to be about 2.2 lb/TBtu, below the proposed MACT limit of 5.8 lb/TBtu for existing subbituminous facilities. Note that Site S11 employed a fabric filter, and much of the Hg oxidation occurred across the fabric filter, and not the SCR. Emissions for a PRB/SCR facility with an ESP and FGD may be higher, although additional measurements are needed to confirm this assessment.

Figure 5-1 also segregates the wet FGD results by FGD design – specifically reagent type and oxidation mode. There is no obvious impact of the FGD design that can be seen from the limited results. While the two sites with limestone inhibited oxidation FGDs have the highest emissions measured, this is likely due to the low coal Cl content at both sites.

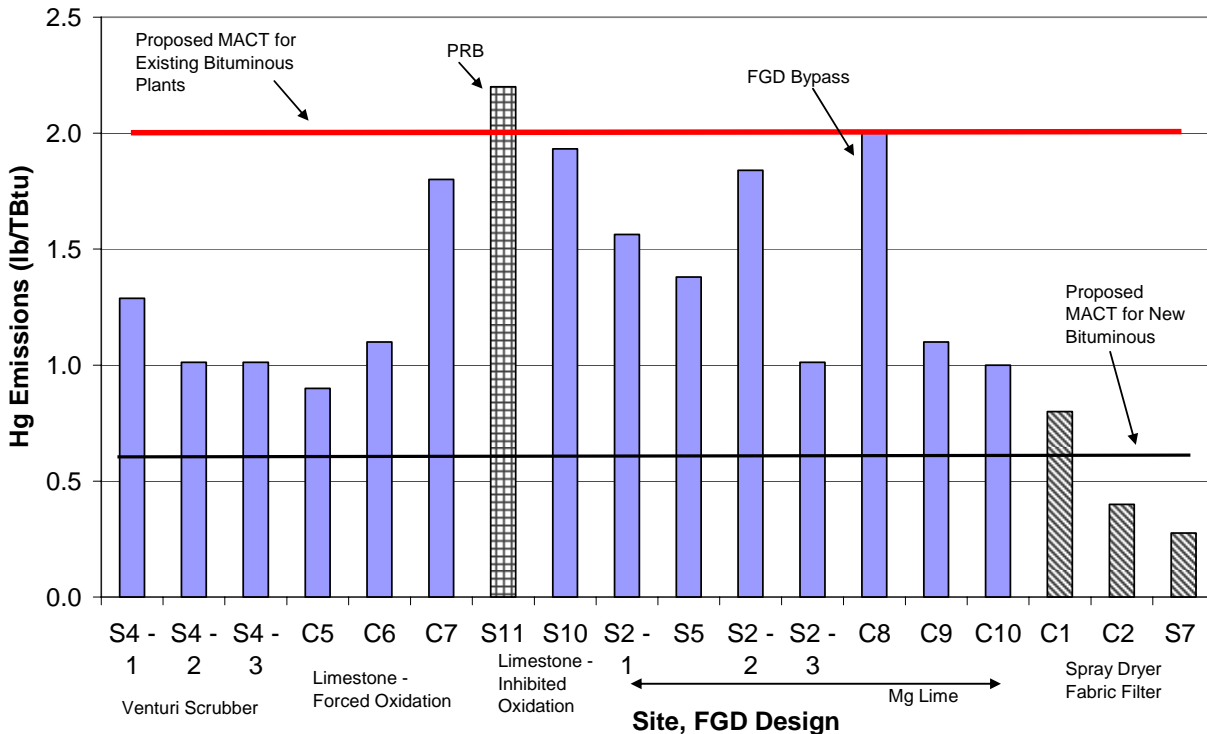


Figure 5-1
Summary of Mercury Stack Measurements for SCR/FGD Sites

Overall Mercury Removal

Figure 5-2 summarizes the overall Hg removals for those seven sites where data are available both with the SCR online and without SCR operation (in bypass or at a sister unit). For the bituminous coal sites with SCR and FGD, Hg removal averaged 88%, as compared to 55% without SCR operation. Assuming that the coal and other key plant operations are consistent, this is the best direct measure of the cobenefits of SCR and FGD. Note that Site S10 achieved only 75% removal. Site S11 which burned a PRB coal also measured about 75% removal.

The mercury removals for all the SCR/FGD measurements are summarized in Figure 5-3. Mercury removals were consistent whether the mercury content of the coal or the mercury concentration in flue gas at the ESP (particulate control) inlet were used to estimate the inlet Hg loading. The Hg removal was 87% based on the flue gas measurements at the particulate control inlet (gas-basis) and 86% based on the coal analyses (coal-basis). Because the coal- and gas-based removals are generally consistent, the coal-based removals are used in the remaining discussion to simplify the analyses.

Again, these results are the average of generally three or four Ontario Hydro measurements, and represent only a snapshot of Hg emissions; they do not represent a

long-term average. Note that, for this graph, the Site C8 results were adjusted to account for the ~15% flue gas bypass, and these results are estimated FGD removal efficiencies, i.e. as if the emission measurement had been made directly at the FGD outlet, before the bypassed gas was mixed with the cleaned gas from the FGD.

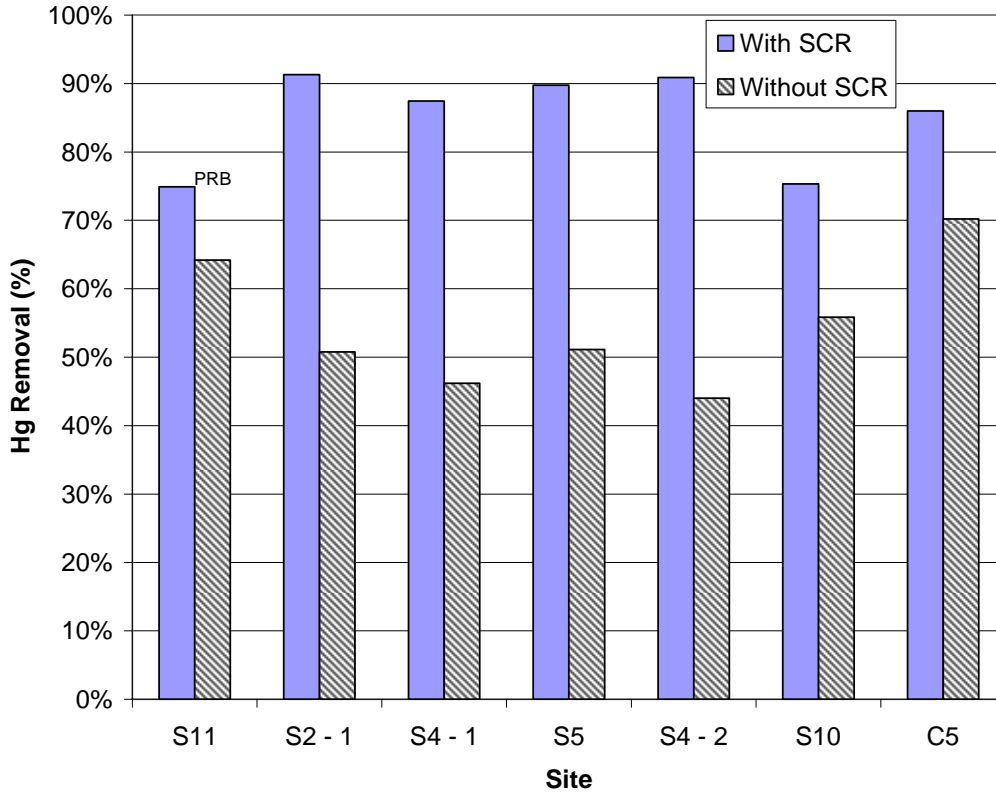


Figure 5-2
Comparison of Mercury Removals With and Without SCR

Site S11 is the only PRB site tested with an FGD and measured ~75% Hg removal. The results are still somewhat “preliminary” and have not been thoroughly reviewed. In addition, the coal analyses have not been finalized, and these removals are estimated based on the coal analyses from the “no SCR” tests. Interestingly, the mercury speciation measurements at the SCR inlet and outlet indicated essentially no increase in Hg(2) across the SCR. But the overall mercury removals are somewhat higher with SCR operation than without SCR, although the net difference is ~11 percentage points, while the other bituminous sites observed an average increase of 34 percentage points. It is important to note that Site S11 employs a fabric filter, and much of the Hg oxidation occurred across the fabric filter. Mercury removal for a similar PRB/SCR site employing an ESP and FGD would be expected to be lower.

As discussed in Section 4, Site S10 also observed a similar effect where an increase in Hg(2) across the SCR was not directly measured, but the overall mercury removals were higher with SCR operation than without SCR operation. There are two speculative theories. The first is that there may be intermediate chemical reactions in the mechanism for Hg(0) oxidation to Hg(2),

and in these instances, the SCR only facilitated a portion of the oxidation, with the remaining oxidation reactions occurring across the air heater and ESP. Another possible explanation is that the SCR impacts other flue gas constituents, i.e. SO₃ and NO_x, which may later have impacts on the downstream Hg speciation.

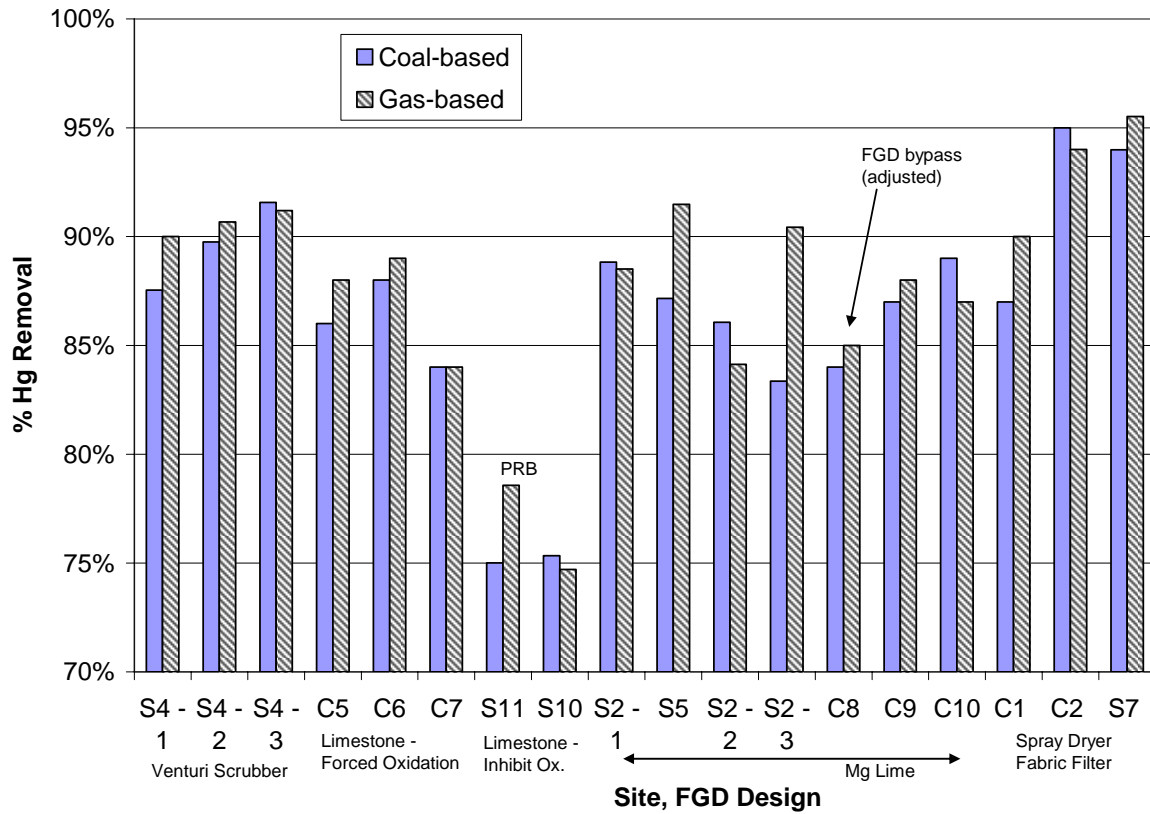


Figure 5-3
Summary of Mercury Removals for SCR/FGD Sites

ESP Mercury Removals

Figure 5-4 compares ESP gas-phase Hg removals with and without SCR operation. If SCR operations impact ESP removal, then the effect is not consistently observed from site-to-site. Very little particulate mercury was observed in nearly all of the test sites. One exception was Site S1, which employed a cyclone boiler and burned a PRB coal, and had high levels of LOI in the fly ash.

Three sites measured higher ESP removals with SCR and three sites measured lower removals with SCR. It is likely that SCR has no significant impact on ESP removals, and this scatter is primarily due to sampling and analytical errors. ESP removal efficiencies are generally low, i.e. less than 30%, with the exception of Site S1 with the high LOI fly ash. Thus uncertainties about the Ontario Hydro measurements (especially at the ESP inlet) as well as possible coal and plant variability make comparisons with and without SCR operations very difficult.

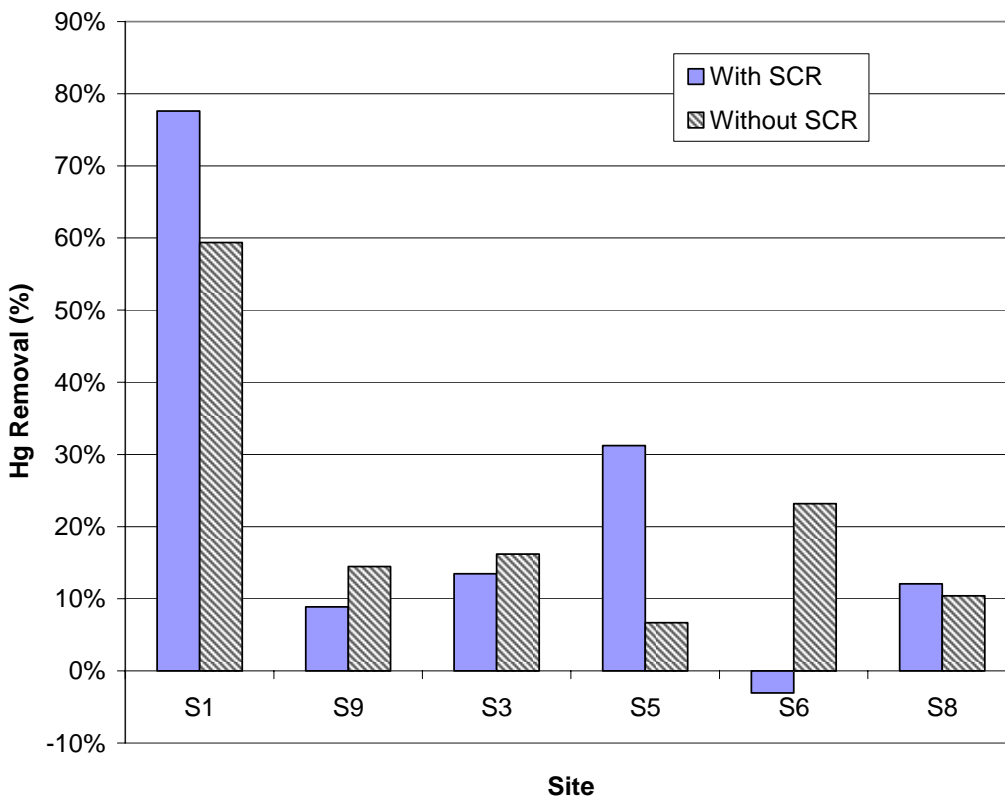


Figure 5-4
Comparison of ESP Mercury Removals with and without SCR

Impact of Coal Properties

In the analyses of SCR oxidation in Section 4, coal Cl levels greater than 100-200 ppm appeared to yield higher levels of Hg(2) at the SCR outlet. Thus one would assume that this would translate to higher overall Hg removals. Figure 5-5 indicates that Hg removals do increase significantly for coal Cl levels greater than ~100-200 ppm. At coal Cl levels above ~400 ppm, mercury removals appear to stabilize, ranging from ~83 to 92%. At quick glance, there may be a slight decrease at coal Cl levels greater than 1000 ppm, however several percentage points are likely within the measurement accuracy of the Ontario Hydro measurements.

Both Sites S10 and C6 burned bituminous coals with low (~125 ppm) Cl; however Site C6 achieved much higher levels of Hg removal. Thus there are likely other factors that significantly impact Hg removal.

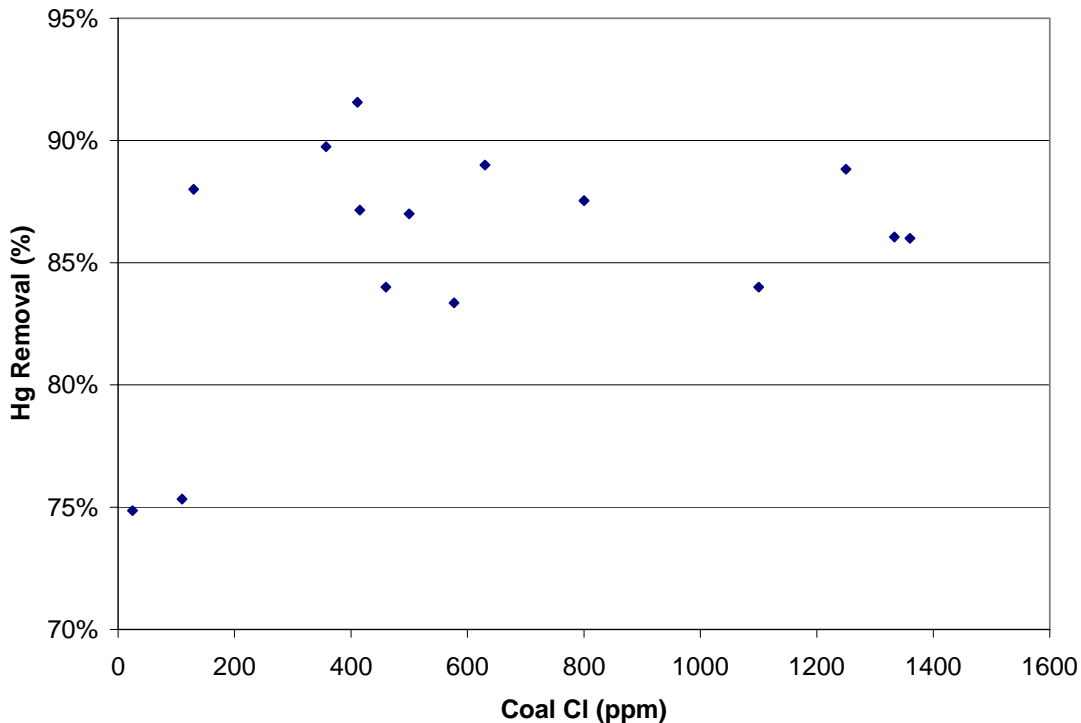


Figure 5-5
Effect of Coal Chloride on SCR/FGD Mercury Removal

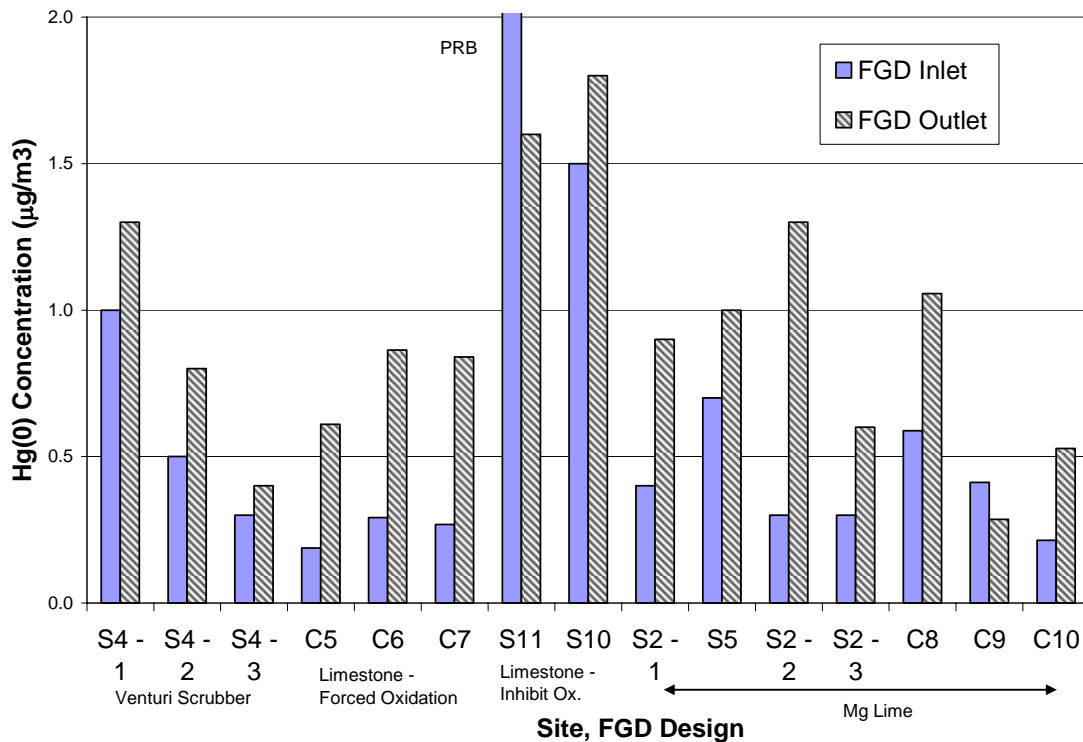
Mercury Re-emissions

A review of the Information Collection Request (ICR) Part III flue gas sampling data suggested that some sites may observe an increase in flue gas Hg(0) levels across the wet FGD systems. Researchers had hypothesized that the FGD systems may be converting some of the absorbed Hg(2) back to Hg(0), which is then re-emitted through the stack. The mechanism for these chemical reactions is not well understood, but speculation is that some Hg(2) captured in the FGD is not chemically stable and is then chemically reduced, possibly by the sulfites in the scrubber liquor.

Figure 5-6 compares the Hg(0) concentration at the FGD inlet and outlet for the tests with the SCR system operating. There are 15 measurements, of which 13 indicate an increase in Hg(0) concentration across the FGD. Only Sites S11 and C9 observe no increase in Hg(0) across the FGD. It is useful to understand the magnitude of these potential re-emissions. For Site C7, if the increase in Hg(0) of $0.5 \mu\text{g}/\text{m}^3$ were captured, the overall Hg removal would have increased from 84 to 88%.

For the 13 sites that measured an increase in Hg(0), the differences are generally less than $0.5 \mu\text{g}/\text{m}^3$, and easily within the measurement accuracy of three or four Ontario Hydro measurements conducted simultaneously at the FGD inlet and outlet. Thus it is difficult to conclude whether Hg re-emissions are occurring (or not occurring) at a given site, based on one “typical” Ontario Hydro sampling campaign. Interestingly, there is no clear difference in re-emissions across the various scrubber designs, which would suggest that sulfites alone is probably not be only key factors for re-emissions.

While the difference in Hg(0) for any one site would not be statistically significant, multiple measurements of this effect become a more reliable indicator. Hence, these results suggest that some conversion of Hg(2) to Hg(0) may occur across the FGD with the SCR system online. Another possible explanation is a potential bias in the Hg speciation measurements using the Ontario Hydro method at one of the sampling locations.



**Figure 5-6
Potential Mercury Re-emissions Across the FGD with SCR Operation**

Limited measurements at three power plants by EPRI et.al., suggested that mercury re-emissions could be less with the SCR system online than without the SCR system operating, i.e. bypassed or at a sister unit (EPRI 1008494). However, there were concerns about the limited number of measurements as well as the overall representativeness of the FGD designs.

Several additional SCR sites with FGDs have now been tested, yielding a total of seven measurements at 6 different power plants. The results comparing potential Hg(0) concentrations across the FGD, both with and without SCR online, are summarized in Figure 5-7. Five of the seven sites indicated an increase in Hg(0) across the FGD without SCR, with only Sites S10 and C5 not showing this increase, i.e. potential Hg(0) re-emission. With SCR operation, six of the seven sites measure some potential Hg(0) re-emission. However, the average increase in Hg(0) was 2.5 µg/m³ without SCR online compared with an average of 0.4 µg/m³ with SCR online.

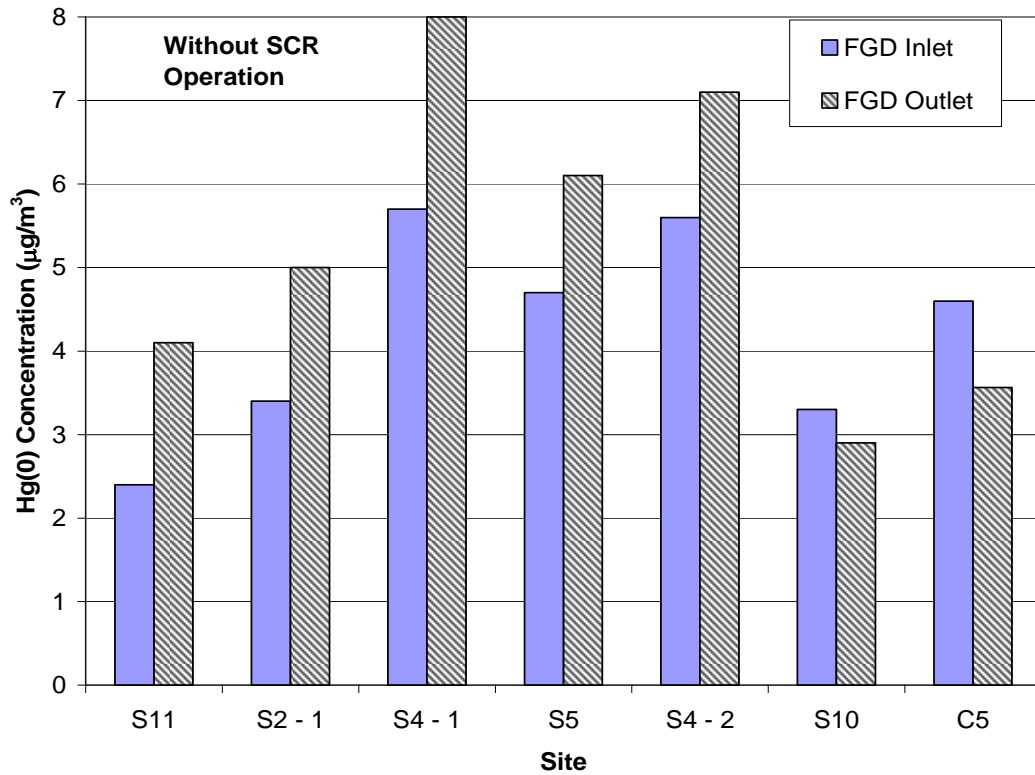
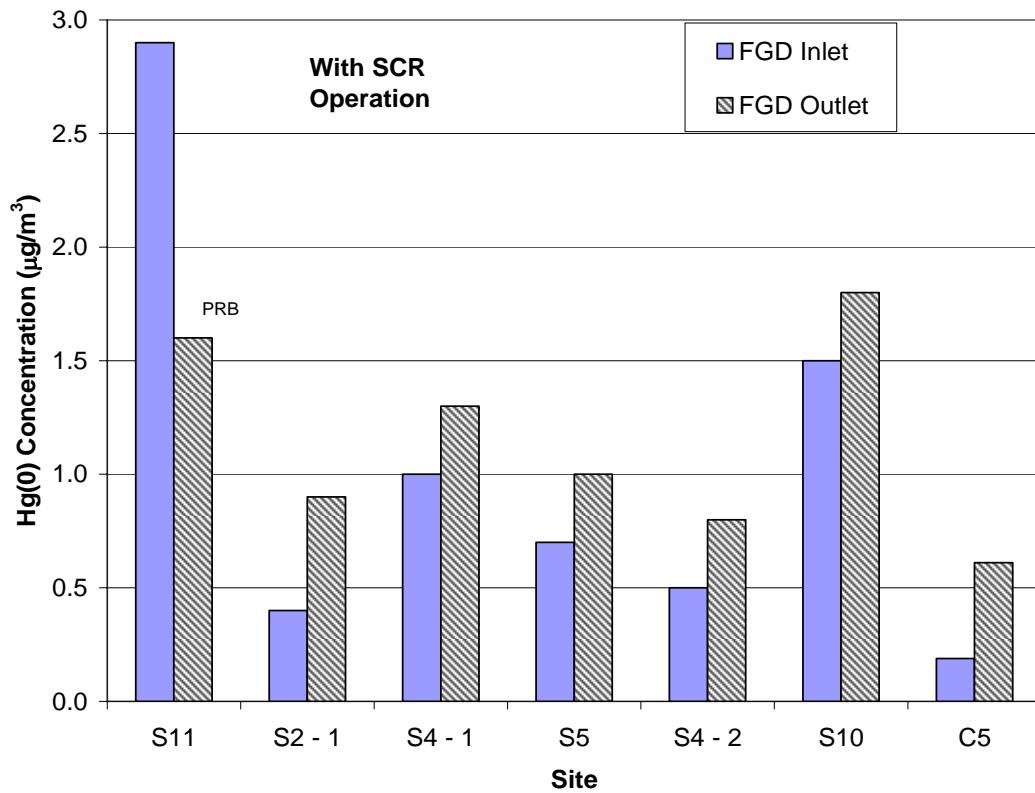


Figure 5-7
Impact of SCR on Potential FGD Mercury Re-emissions (Note the Difference in Scales)

Impact of Coal Properties

Because the chemistry of Hg re-emissions is not well understood, an attempt was made to see if re-emissions are affected by coal sulfur levels. Figure 5-8 illustrates the relationship between Hg re-emissions with coal sulfur. The appearance of a possible trend could be impacted by a few data points. Site S11 (PRB) measured a significant level of Hg(0) capture, thus the negative 1.3 $\mu\text{g}/\text{m}^3$ “re-emission”. Ignoring this data point, Figure 5-8 suggests that there may be a slight increase in Hg re-emissions with coal sulfur over the range of sulfur levels that reflect most medium to high-sulfur coals. This possible increase is quite small, approximately 0.3 to 0.5 $\mu\text{g}/\text{m}^3$ for most sites, which is within the measurement accuracy of the Ontario Hydro measurements. Given the wide scatter in the data and the small differences, it is not possible to draw any definitive conclusions from this graph.

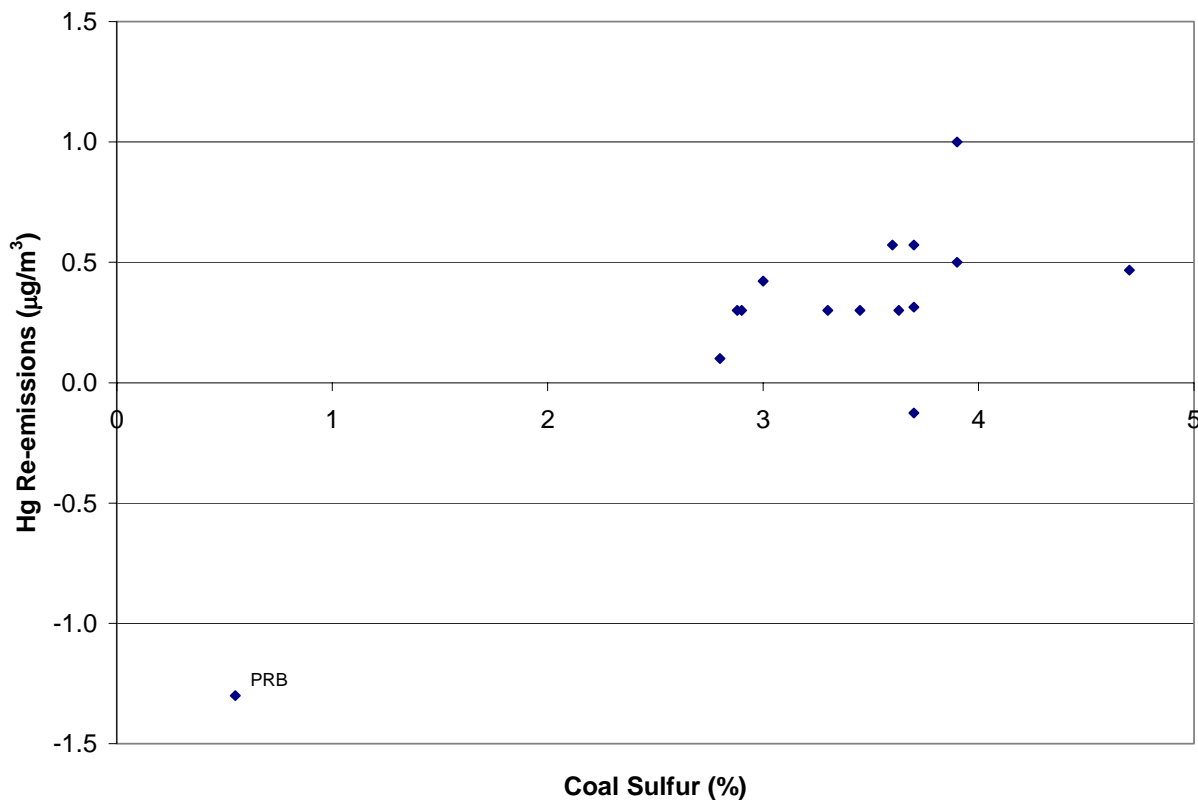


Figure 5-8
Possible Effect of Coal Sulfur on Mercury Re-emissions

Longer-Term Mercury Emission Measurements

As noted earlier, all the results presented in the previous discussions in Sections 4 and 5 are derived from generally three or four Ontario Hydro measurements. Earlier, EPRI conducted a significant number of longer-term (weeks to 1 month) mercury monitoring studies to characterize

mercury emission variability (EPRI Report 1005401). This work was limited to dry stacks, since at the time, operation of mercury continuous mercury monitors (CMM) in a wet stack environment was not feasible.

Mercury CMM measurements were conducted at two sites with SCR and FGD - Sites S7 (SD/FF) and S10 (wet FGD) with the SCR online. The Site S7 study is described in detail in EPRI Report 1009150. At Site S7, the CMM measurements indicated that Hg emissions were consistently low, probably less than $0.5 \mu\text{g}/\text{m}^3$, and possibly less than the detection limit.

A ten-day CMM test was recently completed at Site S10 with the SCR online; these results are still preliminary and have not been thoroughly reviewed. Figure 5-9 is a probability distribution function of the Hg CMM measurements at the stack with the SCR online. Figure 5-9 would suggest that Hg emissions could be greater than the proposed 2 lb/TBtu limit for about a third of this ten-day test period. For an eastern bituminous coal, $2.2 \mu\text{g}/\text{m}^3$ is approximately 2 lb/TBtu at 7% O_2 . The average total Hg emissions based on the CMM data was $\sim 2.1 \mu\text{g}/\text{m}^3$, with the median being $\sim 1.9 \mu\text{g}/\text{m}^3$. The CMM results were generally consistent with the Ontario Hydro measurements which measured $2.1 \mu\text{g}/\text{m}^3$ (1.9 lb/TBtu).

Additional measurements are needed to further evaluate longer term mercury emissions and removals with SCR and FGDs.

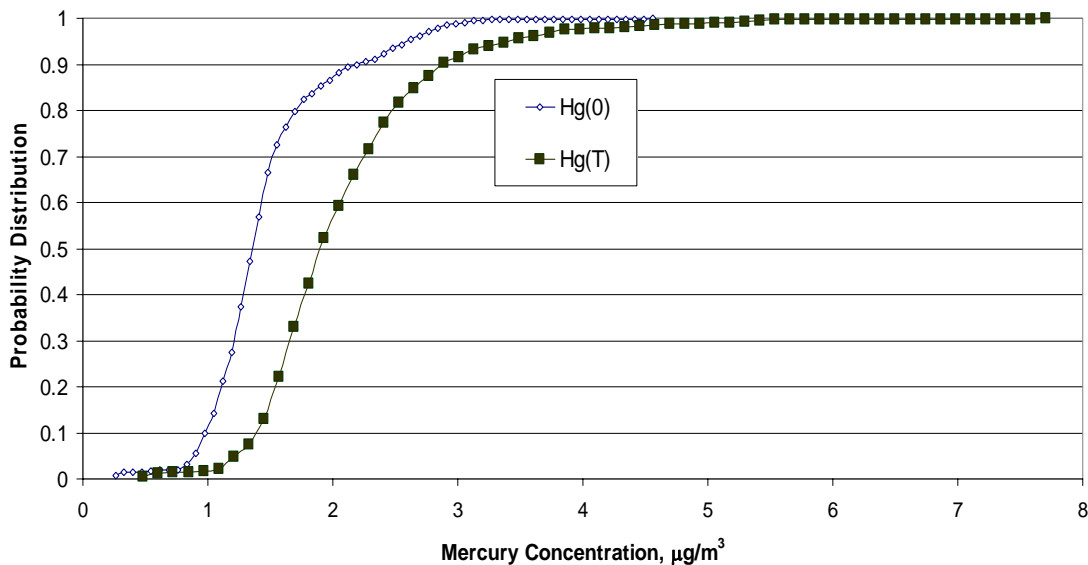


Figure 5-9
Mercury CMM Probability Distribution for Site S10, FGD Outlet with SCR - PRELIMINARY

6

CONCLUSIONS

Essentially all the data are two-hour mercury measurements using the Ontario Hydro method. These results should be considered as short-term snapshots, and do not account for potential variability due to coal and other process variations. The following conclusions were developed from the measurements at the 21 sites with SCR.

SCR Oxidation Summary

The SCR catalyst appears to increase mercury oxidation across the catalyst for bituminous coals as well as for PRB/bituminous blends. For most bituminous coals, the mercury was primarily Hg(2) at the SCR outlet, ranging from 60 to 90+%. While there is some variability among sites in the extent of mercury oxidation at the SCR outlet, most measurements indicated greater than 90% Hg(2) at the FGD inlet (ESP outlet).

There does not appear to any significant increase in Hg oxidation across the SCR for PRB coals, and possibly for low-Cl (less than 100-200 ppm) bituminous coals. The coal Cl levels appear to be a key factor affecting Hg oxidation across the SCR, however additional factors likely exist.

Blends of PRB and bituminous coals that contain at least 40% bituminous coal appear to behave as a bituminous coal, and not as a weighted average of the two parent coals.

FGD Mercury Emissions and Removal

Mercury measurements with combined SCR and wet FGD were generally less than the proposed 2.0 lb/TBtu MACT limit for existing bituminous power plants, but were consistently greater than the proposed 0.6 lb/TBtu limit for new facilities. Of the three facilities with SCR and dry FGDs, two of the sites were below the 0.6 lb/TBtu limit for new facilities.

For bituminous coals, overall mercury removals are significantly greater with SCR operation than without SCR operation. Higher overall mercury removals appeared to occur with coal Cl levels greater than 100-200 ppm; there are probably other factors in addition to coal Cl that impact removal.

Only one PRB/SCR/FGD site was tested. It employed a fabric filter and wet FGD, and achieved ~75% removal. However, much of the oxidation occurred across the fabric filter. Removals would likely be less with an ESP and wet FGD.

With SCR operation, the extent of measured “re-emissions” was generally less than $0.5 \mu\text{g}/\text{m}^3$, which is within the measurement accuracy of the Ontario Hydro method. However, most plants indicated re-emissions, so it is reasonable to believe that re-emissions occur to some extent - or that there is a sampling bias at one of the sampling locations. Re-emissions generally appeared to be less with SCR operation than without SCR operation.

7

PLANNED AND FUTURE R&D

Ongoing field studies are planned at 2 SCR power plants, including one PRB site employing a spray dryer/fabric filter. Additional studies were also conducted by the host utilities and Consol/DOE. Laboratory and data analyses are still ongoing, and the results will likely become available in early 2005.

Based on what is expected to be available, the following data gaps will still prevent the technical community from predicting with confidence the mercury performance of SCR and FGD on all fuels. Therefore, the following field measurements are needed to better quantify the impact of SCR and FGD on mercury:

PRB/Bituminous blends – The limited data suggest that a 40% bituminous blend still behaves like a bituminous coal, possibly because the coal Cl levels (~800 ppm) were above the 100-200 ppm level that appears to distinguish low- and high-Cl coal behavior. Additional studies are needed to evaluate varying blend ratios to determine what levels of coal Cl (or bituminous coal) are necessary to achieve sufficient Hg oxidation.

Longer-term mercury emissions characterization – Because the basis for all of the SCR/Hg results are generally three or four Ontario Hydro runs, a better characterization of the Hg emissions and removal variability is necessary. EPA plans to conduct one of its mercury CEMs evaluations at Site C6 in 2005. Several additional studies are still required to develop a more robust database of coal type and control technologies.

PRB coals with FGD – The only tested PRB/SCR/FGD site employed a fabric filter followed by a wet FGD. In addition to the planned test at a PRB site with a dry FGD, additional studies are needed to evaluate a PRB site with an ESP and wet FGD. However, we are not aware whether such a facility currently exists or will be operational in the 2005 time frame.

8

REFERENCES

1. *Power Plant Evaluation of the Effect of Selective Catalytic Reduction in Mercury*; EPRI, Palo Alto, CA, U.S. Department of Energy, Pittsburgh, PA, and U.S. Environmental Protection Agency, Research Triangle Park, NC, 2002; 1005400.
2. *Effect of Selective Catalytic Reduction on Mercury, 2002 Field Studies Update*; EPRI, Palo Alto, CA, U.S. Department of Energy, Pittsburgh, PA, and U.S. Environmental Protection Agency, Research Triangle Park, NC, 2003; 1005558.
3. *Effect of Selective Catalytic Reduction on Mercury, 2003 Summary Report*; EPRI, Palo Alto, CA, U.S. Department of Energy, Pittsburgh, PA, and U.S. Environmental Protection Agency, Research Triangle Park, NC, 2004; 1008494.
4. *Evaluation of Methods for Analysis of Mercury and Chlorine in Coal*, EPRI, Palo Alto, CA, 2000; 1000287.
5. *Technical Evaluation: Analysis of Chlorine in Coal by Oxidative Hydrolysis Microcoulometry*; EPRI, Palo Alto, CA, 2000; 1000846.
6. *Characterizing Variation in Mercury Emissions from Coal-Fired Power Plants*; EPRI, Palo Alto, CA, U.S. Department of Energy, Pittsburgh, PA, 2003; 1005401.
7. *Characterizing Coal-Fired Power Plant Mercury Emissions Variability at Low Concentrations*; EPRI, Palo Alto, CA, U.S. Department of Energy, Pittsburgh, PA, 2003; 1009150.

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