

# Mercury Oxidation Across SCR Catalyst at LG&E's Trimble County Unit 1

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## ABSTRACT

In 2002, Louisville Gas & Electric installed a Selective Catalytic Reduction (SCR) system on Unit 1 at the Trimble County Power Plant in Bedford, Kentucky. The boiler fires high-sulfur eastern bituminous fuel and the SCR is equipped with Hitachi plate-type catalyst to achieve the required NO<sub>x</sub> reduction of 90%. In 2003, Hitachi and LG&E began a series of tests on the SCR catalyst and downstream equipment to determine the mercury speciation and removal from the system utilizing the Ontario Hydro Method. Testing was performed at the SCR inlet and outlet with both the initial charge of two catalyst layers and in 2005 with the third layer of catalyst installed. In addition to the SCR, mercury speciation tests were run at the air heater outlet, electrostatic precipitator (ESP) outlet and downstream of the wet flue gas desulphurization (WFGD) system. Results are provided showing the behavior of mercury oxidation across the catalyst both over time and with the new catalyst added. In addition, mercury speciation and removal at the downstream locations will be presented.

## INTRODUCTION

In March 2005, the U.S. Environmental Protection Agency (EPA) officially announced two final rules for air pollution control that apply to coal-fired power plants: the Clean Air Interstate Rule (CAIR) and the Clean Air Mercury Rule (CAMR). CAIR applies to states in which EPA atmospheric chemistry and transport models have demonstrated that nitrogen oxides (NO<sub>x</sub>) and sulfur oxides (SO<sub>x</sub>) emissions contribute to ground level ozone and PM<sub>2.5</sub>. The EPA has also estimated previously that mercury (Hg) emission from U.S. power plants is 48 tons per year. The

CAMR establishes a cap-and-trade program for national emissions of Hg, with national caps set in two phases: 38 tons per year starting in 2010 and 15 tons per year starting in 2018.

SCR technology has become a well-established method for controlling emissions of NO<sub>x</sub> from coal-fired power plants. In addition to NO<sub>x</sub> control, however, SCR catalyst has been found to affect the mercury speciation; the catalyst can change elemental mercury (Hg<sup>0</sup>) to Hg<sup>2+</sup> (oxidized mercury) in coal combustion flue gases. It is well known that increasing the emissions of Hg<sup>2+</sup>, which is present in the form of water-soluble mercuric chloride (HgCl<sub>2</sub>) allows for high Hg emission reduction because HgCl<sub>2</sub> can be removed in downstream equipment such as ESP and WFGD systems. Therefore the co-benefit of increased Hg<sup>2+</sup> through the SCR catalyst is very important to the overall control of mercury emissions from coal-fired power plants. However for plants firing bituminous coal, the oxidation of SO<sub>2</sub>, which forms SO<sub>3</sub>, can accelerate undesirable downstream impacts such as air heater fouling and flue corrosion and can result in visible stack plumes. Several downstream SO<sub>3</sub> mitigation technologies have become commercially available in recent years <sup>1</sup>, but these systems can have both high initial and operating costs, and maintenance concerns. Therefore advanced SCR catalyst, which maintains high Hg<sup>0</sup> oxidation with low SO<sub>2</sub> to SO<sub>3</sub> conversion, is being developed by Babcock-Hitachi<sup>2</sup>.

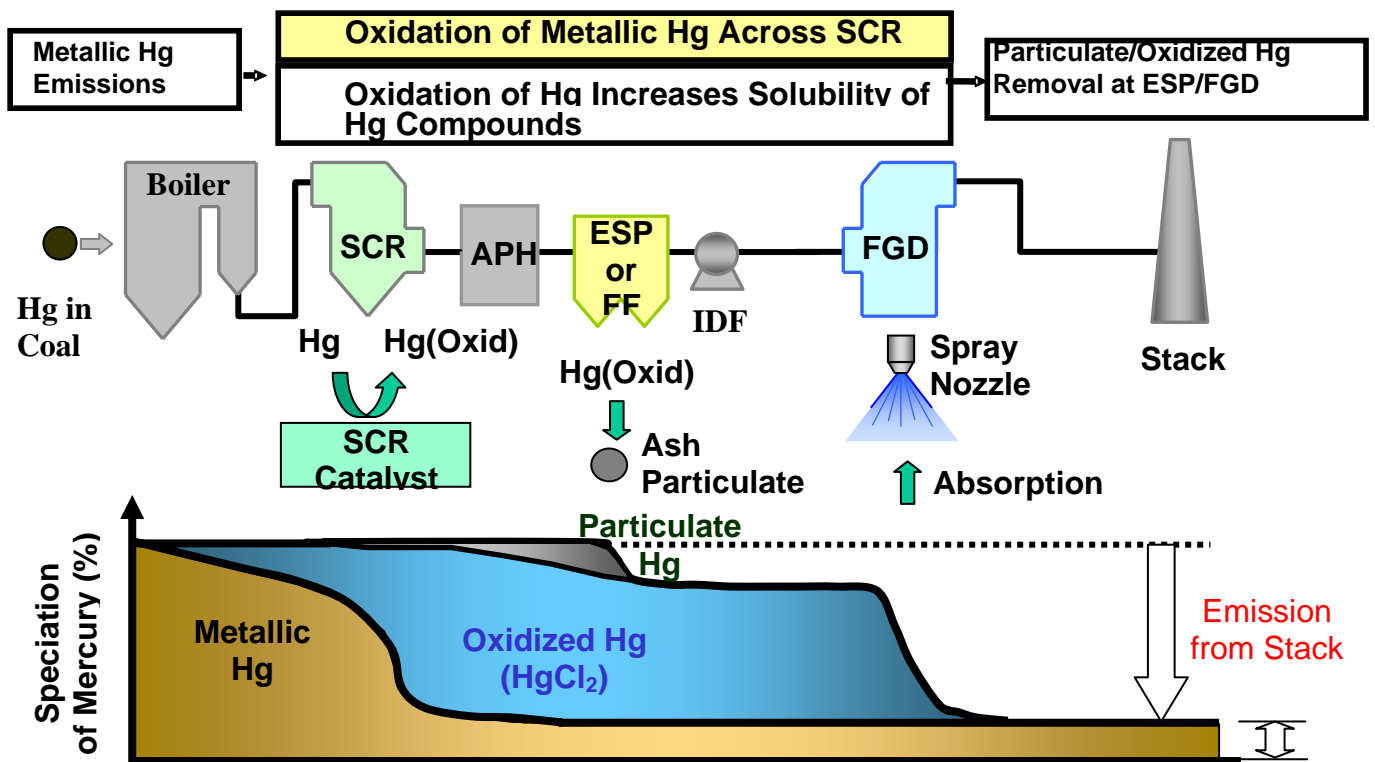
The effect of SCR catalyst on mercury speciation appears to be dependent on coal type. Power plants burning bituminous coals, which generally contain high amounts of chlorine (Cl) and sulfur (S), have shown high conversion of Hg<sup>0</sup> to Hg<sup>2+</sup> across the SCR catalyst. As shown in Table 1, the majority of US power plant installations burn eastern bituminous coal, and they produce a significant amount of the overall mercury emissions from US coal-fired power plants. Therefore an understanding of the mercury speciation through the flue gas stream of a typical eastern bituminous coal fired plant will be extremely valuable in determining the most economical means for reducing mercury emissions from these types of plants.

Table 1 – US Coal Speciation

	% Coal-Fired Installations	Relative Content		% Elemental Mercury in Flue Gas
		Cl	Hg	
<b>Lignite</b>	5	Low	High	>90
<b>Sub-bituminous</b>	38	Low	Low	80-90
<b>Bituminous (Western)</b>	7	Int	Low	NA
<b>Bituminous (Eastern)</b>	50	High	Int	30-40

Shown in Figure 1 is a schematic showing the fate of elemental or metallic mercury,  $Hg^0$ , as it passes through a typical eastern bituminous SCR-ESP-WFGD system. What is apparent is that the more elemental mercury that can be oxidized through the SCR catalyst, the higher the capture potential in the ESP and WFGD. Elemental mercury, if not oxidized somewhere in the flue gas system, will ultimately be emitted from the stack. Other mercury removal technologies, such as activated carbon injection (ACI), can be used for removal of elemental mercury. However these systems will typically require a downstream fabric filter (FF) to collect the mercury-laden particulate. Thus the capital cost of the ACI and FF are high, plus the operating costs (activated carbon, FF pressure drop, ash sales impacts, etc.) can be significantly high as well. Therefore, utilizing conventional AQCS equipment (SCR, ESP and WFGD) for mercury control has significant advantages since many U.S. plants that either have this equipment already in place, or will need to install these systems for future CAIR NO<sub>x</sub> and SO<sub>2</sub> control requirements. Utilizing the co-benefits of this equipment can result in significant capital and operating cost savings as compared to other mercury control technologies like ACI.

Figure 1 – Behavior of Mercury Through a Typical Eastern Bituminous SCR-ESP-WFGD System



## BACKGROUND ON TEST PLANT

In order to evaluate the effects of mercury oxidation through a typical SCR-ESP-WFGD plant arrangement, Babcock-Hitachi and LG&E agreed to conduct a series of tests at LG&E's Trimble County Unit 1 plant in Bedford, KY. Background information on Trimble County 1 (TC1) is shown in Table 2. In 2002, the retrofit SCR system began operation and was equipped with Babcock-Hitachi plate-type catalyst designed for 90% NO<sub>x</sub> removal.

Table 2 – Background on Trimble County Unit 1

Boiler Output	550 MWg
Placed in Service	1990
Manufacturer	Combustion Engineering
Fuel	High-Sulfur
Firing System	LNB with OFA
<b>SCR</b>	
SCR Placed in Service	2002
Catalyst Type	Plate
Catalyst Manufacturer	Babcock-Hitachi
Design DeNO <sub>x</sub>	90%
Design SO <sub>2</sub> Oxidation	1.5%
Guarantee Life	8,000 hours
<b>ESP</b>	
ESP Placed in Service	1990
Design Particulate Removal	99.6%
<b>WFGD</b>	
Wet FGD Placed in Service	1990
Design SO <sub>2</sub> Removal	97%

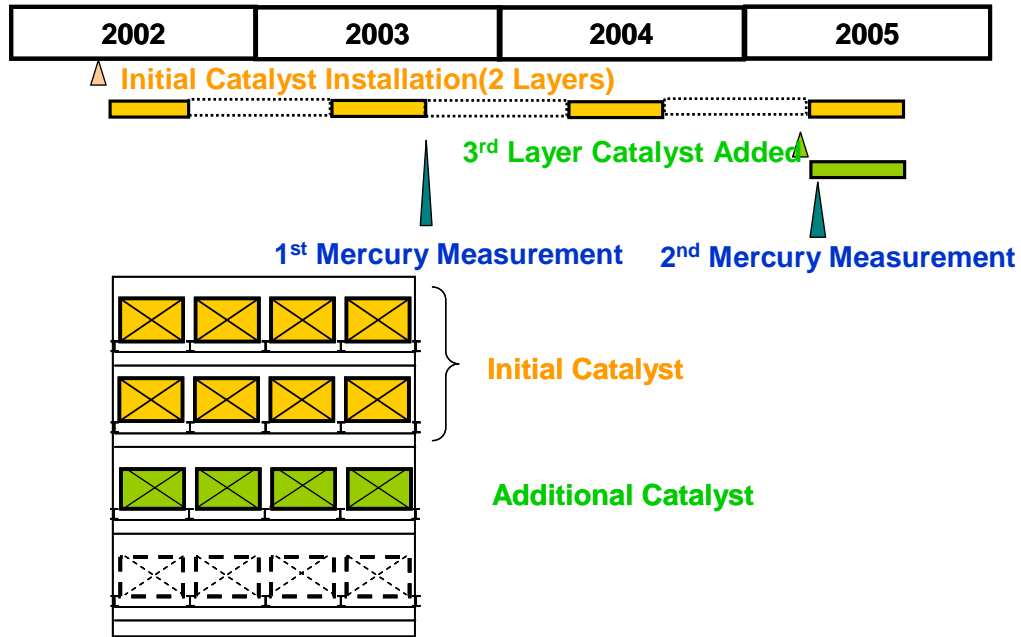
TC1 was equipped with two initial layers of catalyst when it began operation in 2002. After three ozone seasons (approximately 12,000 operating hours), a third layer of catalyst was added to the reactor in 2005, which was equipped with space for the addition of *two* future layers of catalyst. A graphical depiction of the catalyst management and mercury testing history is shown in Figure 2. Two mercury tests took place thus far:

Test #1 – September 2003

Test #2 – June 2005

As shown on Figure 2, both of these tests took place while the SCR was in operation during the ozone seasons.

Figure 2 – Catalyst Management and Mercury Testing Timeline

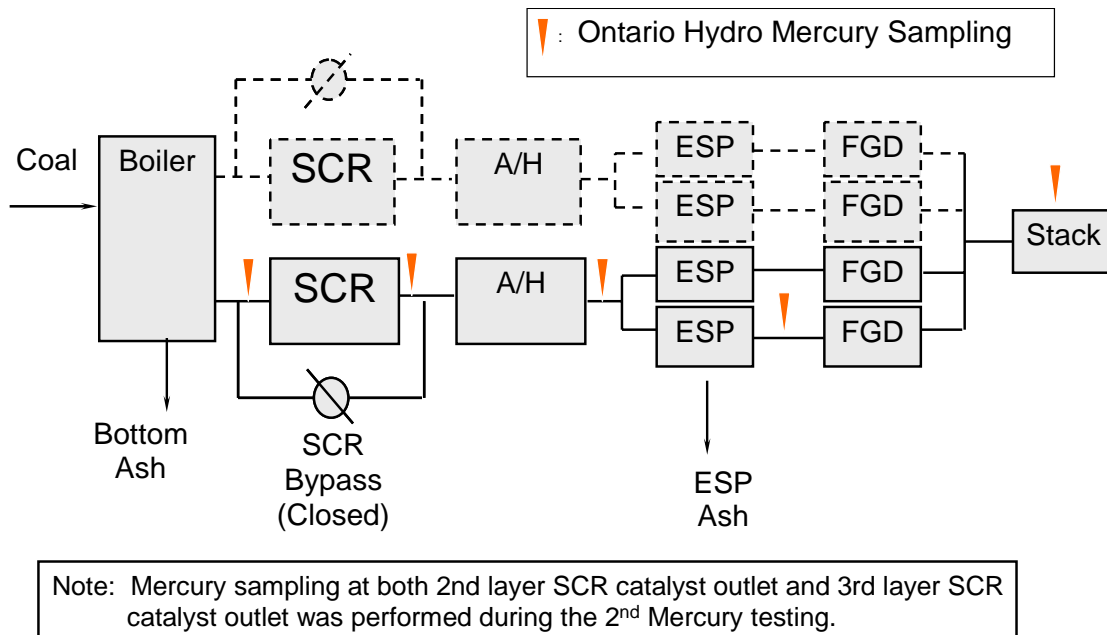


In order to ascertain the amount and speciation of mercury throughout the gas stream, the Ontario Hydro Method (OHM) was utilized. Table 3 shows the test conditions for the tests and Figure 3 shows the test locations throughout the flue gas stream. As noted above, the additional layer of catalyst was added in 2005 so Test #2 was conducted at the outlets of both the 2<sup>nd</sup> catalyst 3<sup>rd</sup> catalyst layers. This was done to evaluate the mercury oxidation potential of used and fresh catalyst.

Table 3 – Coal Analysis and Boiler Operating Conditions During Tests

	Test #1 (September 2003)	Test #2 (June 2005)
<b>Boiler Load (MWg)</b>	~540	~540
<b>Economizer Outlet Temp. (°F)</b>	688-716	688-716
<b>Coal Hg (mg/kg)</b>	0.125-0.212	0.1
<b>Coal Cl (mg/kg)</b>	450-550	~750

Figure 3 – Mercury Sampling Locations



## DISCUSSION OF TEST RESULTS

Shown in Figure 4 are the mercury oxidation results at key locations including the economizer outlet, SCR outlet (two locations) and the air heater outlet<sup>3</sup>. Because of the inherent variations of the OHM test method, results for each run of each test are shown. Figures 5 and 6 depict the  $Hg^0$  content before and after the SCR and APH, respectively. For reference, provided in Figures 5 and 6 are data from other US plants<sup>4,5</sup>. Since there is so much scatter in the US plant data, the solid and dashed lines are meant to bracket the  $Hg^0$  content at the SCR inlet and outlet, respectively. The solid lines in Figure 6 are curve fits of the data at the APH inlet and outlet.

Examining these three figures, several key elements are apparent:

- During both tests, there was a considerable amount of oxidized mercury already existing at the boiler exit. Figure 5 shows that depending on the test coal,  $Hg^0$  content varied from 15-45%; therefore oxidized mercury ranged from 55-85%.
- Mercury oxidation across the SCR ranged from 78-93%, depending on the  $Hg^0$  content at the SCR inlet, test location (2<sup>nd</sup> or 3<sup>rd</sup> layer) and Cl content in the coal.
- The added layer of catalyst contributes to increased mercury oxidation.
- As shown in Figure 5, the data obtained at TC1 fit reasonably well with data from other US plants. However the amount of scatter of  $Hg^0$  content at the economizer exit in other US plants is striking. Even with essentially the same amount of Cl content in the coal, the  $Hg^0$  content can vary from 40 to 80%.
- Mercury oxidation across the APH ranged anywhere from 10 to 70% depending on the Cl content in the coal and the test.

- As shown in Figure 4, particulate phase mercury was insignificant, regardless of test location.

Figure 4 – Mercury Oxidation at Test Locations

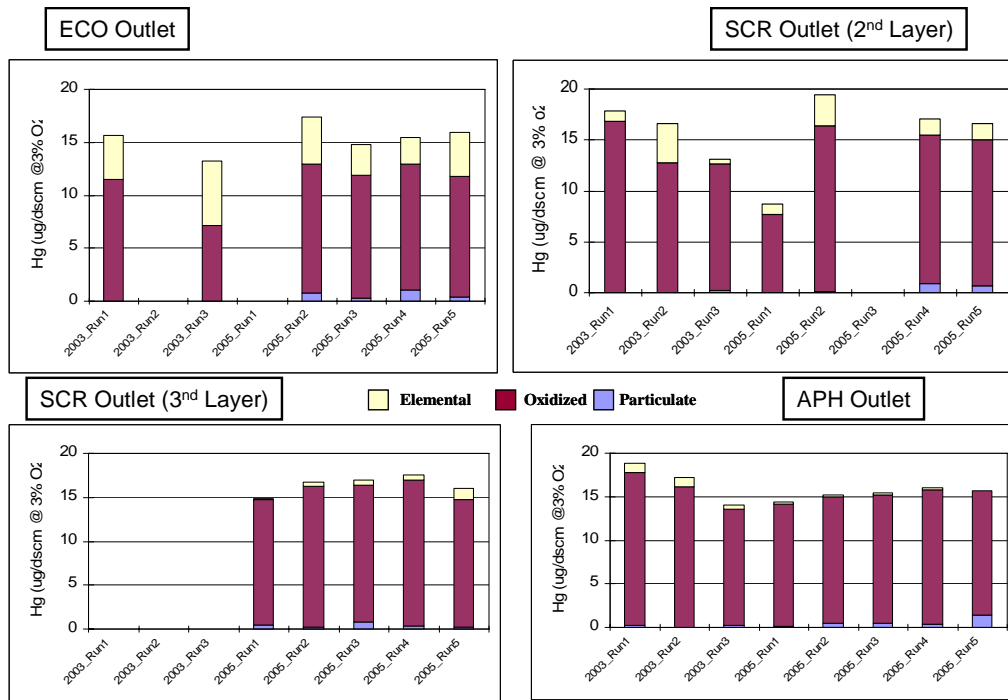


Figure 5 – Hg<sup>0</sup> Content Before and After SCR

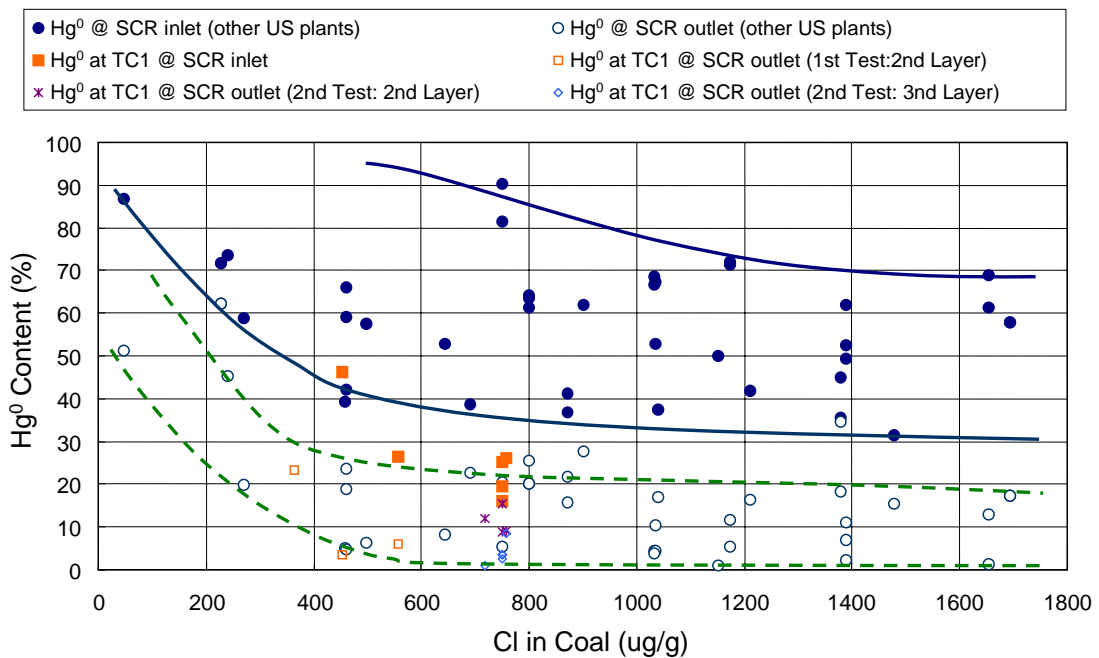
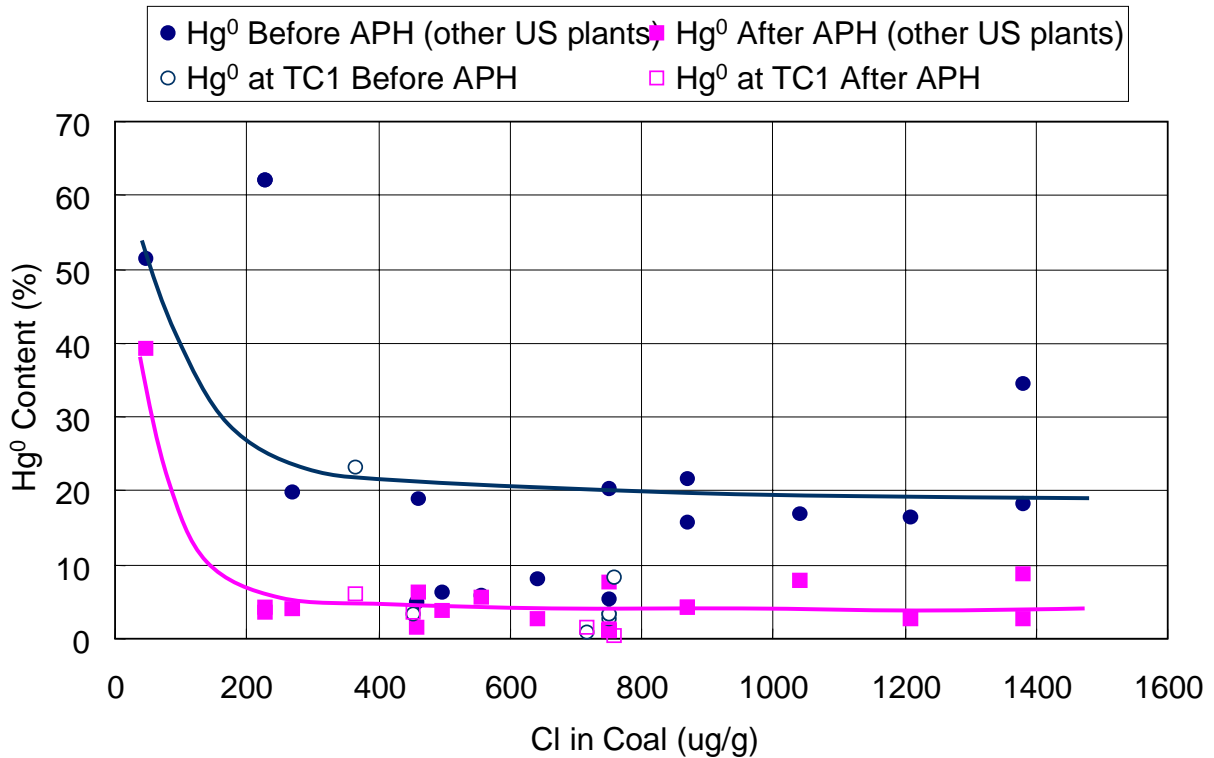


Figure 6 – Hg<sup>0</sup> Content Before and After Air Preheater



Although there are only two test periods to evaluate, Figure 7 shows the increase in Hg<sup>0</sup> content (decrease in mercury oxidation) over time and the impact of adding the 3<sup>rd</sup> layer of catalyst. As shown, the addition of the 3<sup>rd</sup> catalyst layer resulted in nearly 75% additional mercury oxidation from what existed at the 2<sup>nd</sup> catalyst layer outlet. The performance of the existing catalyst (1<sup>st</sup> and 2<sup>nd</sup> layer) shows a decrease in mercury oxidation over time. However it was not clear just how much the mercury oxidation potential diminished, so a laboratory test was conducted.

Figure 8 shows results from laboratory tests conducted at BHK's test facility at the Akitsu Works catalyst manufacturing facility in Japan. The purpose of these tests was to ascertain the reduction in mercury oxidation potential over time from catalyst pulled from the operating unit. The catalyst samples from TC1 were taken after approximately 2,400 5,200 and 9,000 hours of operating time. The results indicate a gradual decrease in mercury oxidation over time.



Figure 7 – Hg<sup>0</sup> Content Versus Operating Time at SCR Outlet (Field Tests)

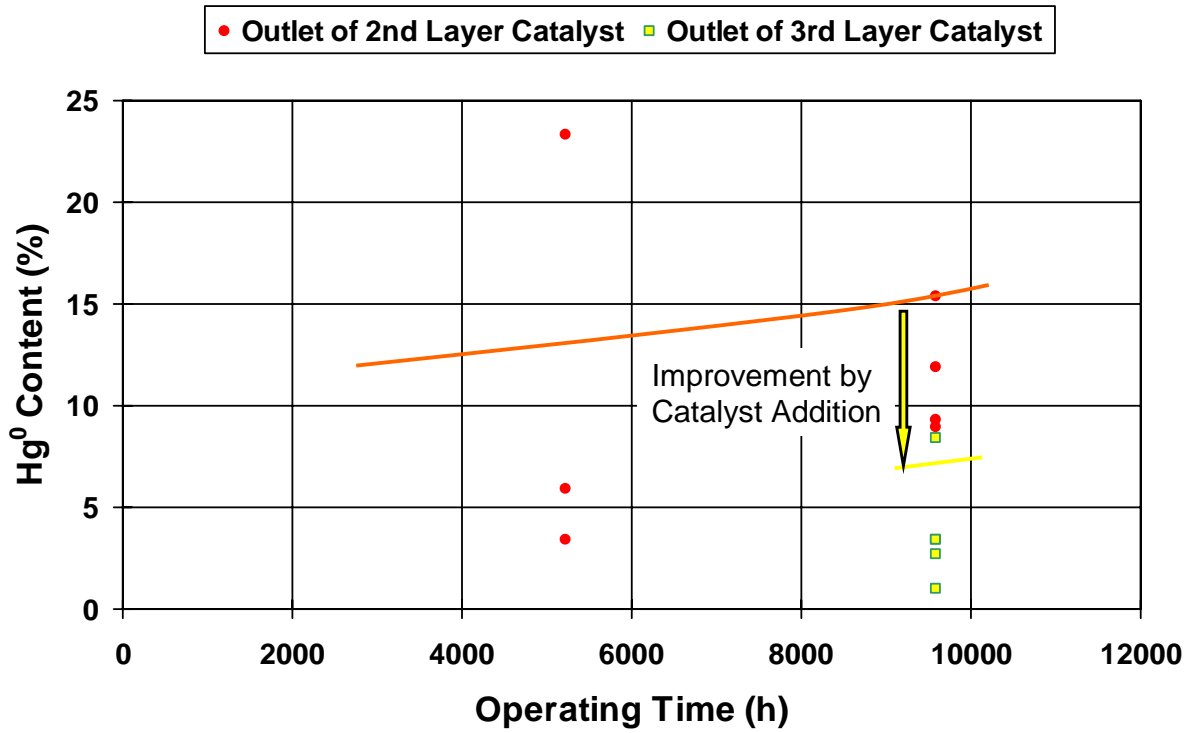
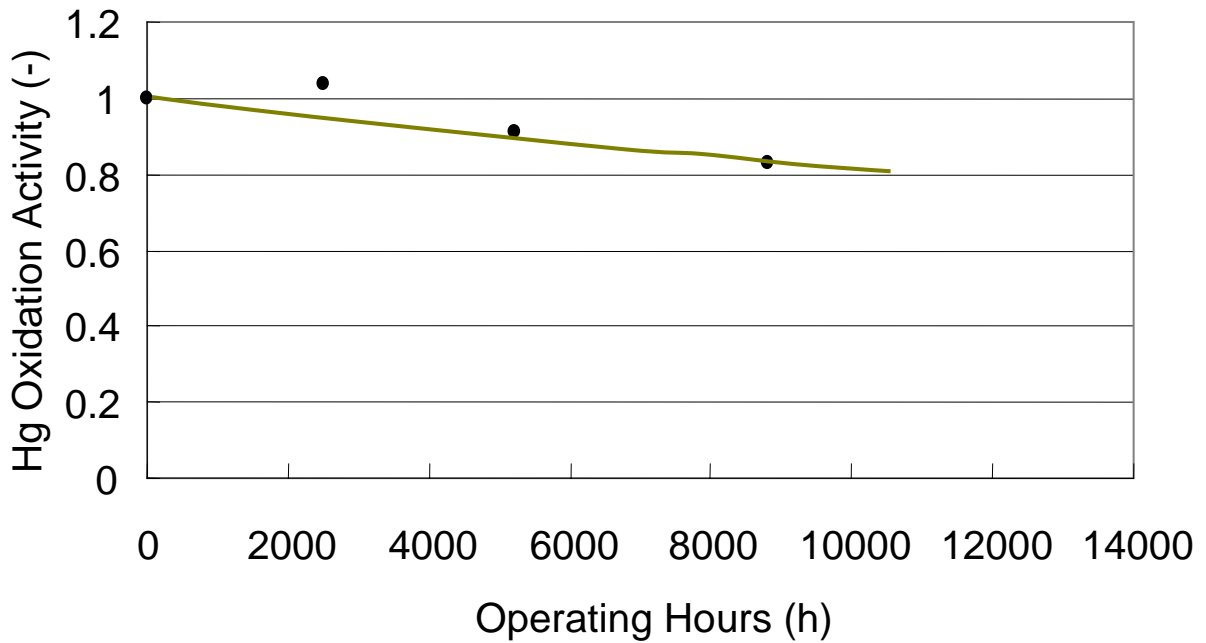
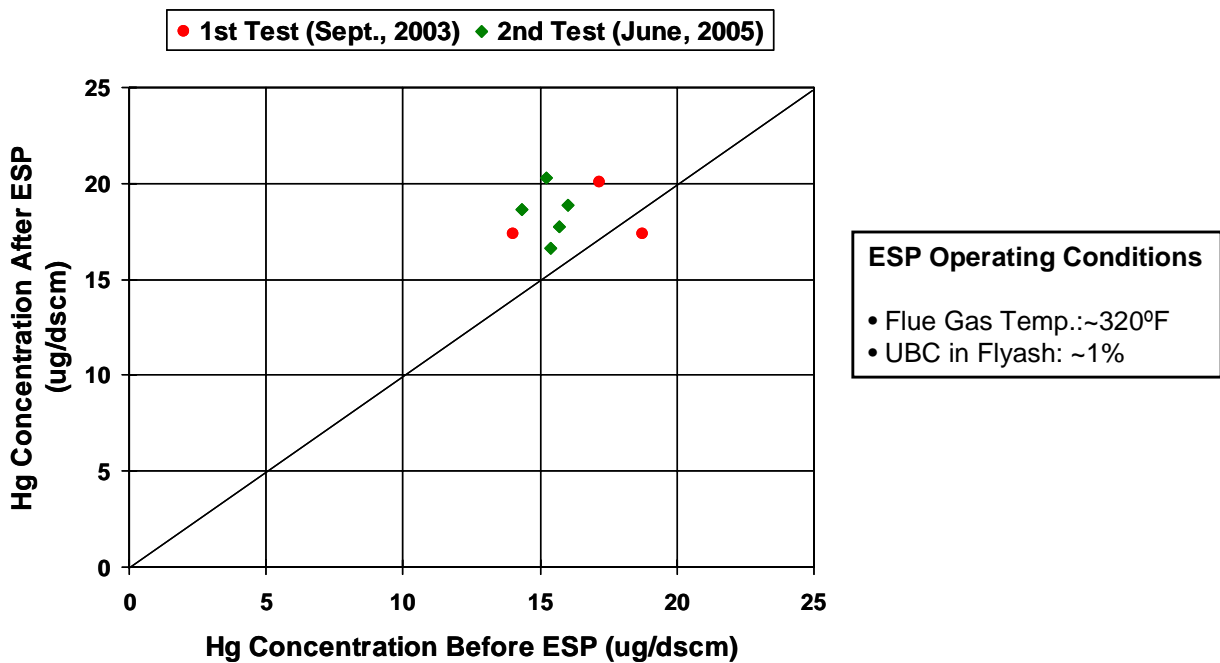


Figure 8 – Mercury Oxidation Activity Versus Operating Time (Lab Tests of Catalyst Samples)



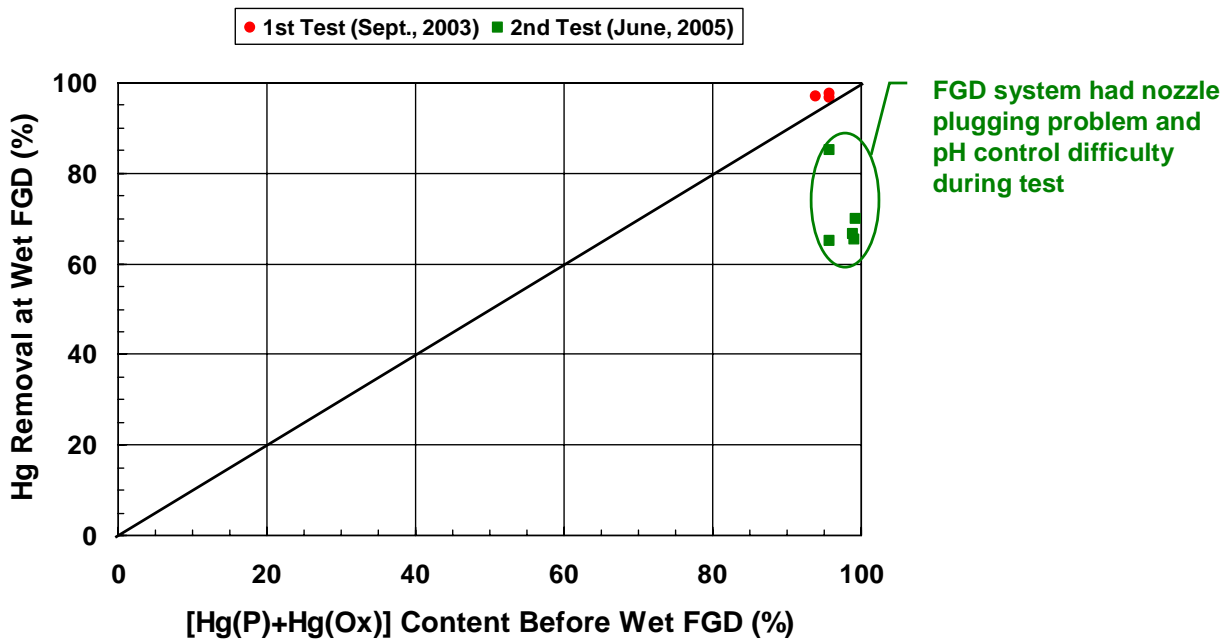
Mercury capture across the ESP was also evaluated (refer to Figure 3). The data is presented in Figure 9 and shows essentially no decrease in mercury concentration from the inlet to the outlet of the ESP. In fact there is a slight increase of mercury concentration for some cases. The data is not conclusive, but this low mercury removal across the ESP is likely due to very low unburned carbon in the ash (~1%) and a relatively high ESP operating temperatures (~320°F).

Figure 9 – Mercury Capture at ESP



Shown in Figure 10 is the resultant mercury removal across the WFGD system. The data for Test #1 (September 2003) shows very high mercury removal efficiency (~98%). However the mercury removal for Test #2 (June 2005) was considerably less (~65-85%). As noted in the figure, there were operational problems with the WFGD system during the tests and these resulted in lower SO<sub>2</sub> removal efficiency, and hence mercury removal efficiency. This confirms the importance of the WFGD system in acting as the final mercury cleanup mechanism.

Figure 10 – Mercury Capture by Wet FGD



## CONCUSIONS AND FUTURE TESTING

Mercury oxidation testing was conducted at the Trimble County Unit 1 plant. The following were the highlights of this test program:

1. Mercury oxidation across the SCR catalyst decreased gradually over time.
2. The addition of the third catalyst layer resulted in increased mercury oxidation. Overall mercury oxidation was on the order of 78-93%, depending on the fuel properties and the test location (2<sup>nd</sup> or 3<sup>rd</sup> layer).
3. Mercury oxidation across the APH varied from 10-70%.
4. Mercury removal from the ESP was very low. This appears to be due to the low unburned carbon in the ash and the ESP operating temperature.
5. Mercury removal after the WFGD was very high in the first test (~98%). However operational problems with the WFGD in the 2<sup>nd</sup> test decreased the mercury removal to approximately 65-85%.
6. The variability of data, both from the TC1 testing and from other US plants, indicates the difficulty in obtaining accurate measurements of mercury speciation with the OHM, particularly in high dust-conditions.

The data revealed in this test program provides considerable insight to the behavior of mercury in an actual operating plant. It also shows how parameters such as elemental mercury content, fuel properties, ash properties, operating temperatures and WFGD performance can have a significant impact on overall mercury removal.

Further testing at TC1 is planned for September 2006. The following are the objectives of this testing:

- Confirmation of mercury behavior along the flue gas path.
- Confirmation of the mercury removal across the WFGD system
- SO<sub>2</sub> to SO<sub>3</sub> conversion across the SCR and SO<sub>3</sub> behavior along the flue gas path.
- Confirmation of test methods and behavior of trace elements in the flue gas.

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