ALBEMARLE® | Environmental Division

Mercury Control for Taconite Plants Using Gas-Phase Brominated Sorbents

Final Report

CFMS Contract No. B50921
T-Number 1029E

Prepared by J. Miller, M. Zerangue, Z. Tang and R. Landreth

Edited by R. Landreth

7/9/2012

Table of Contents

Abstract

In 2011, Albemarle Environmental Division personnel conducted a field trial at Hibbing Taconite to demonstrate the effectiveness of gas-phase brominated sorbents in controlling mercury emissions from taconite facilities. There was a preliminary site visit in March 2011 followed by pre-trial testing in early June 2011. The pre-trial testing determined that the mercury sorbent would have to be injected into both the Windox Exhaust flue gas stream and the Hood Exhaust flue gas stream in order to achieve the desired result of 75% mercury removal from the baseline condition.

The equipment was prepared for the trial and the demonstration conducted in September and October 2011. The parametric testing demonstrated that the 75% Hg removal target could be achieved with a gas-phase brominated sorbent injection rate of about 3 lb/MMacf (126 lb/hr). It was demonstrated in a two-week long continuous injection run that this removal rate could be achieved over time. This injection rate is higher than expected to achieve the 75% mercury removal but it does not appear to be a problem of the control technique. Rather, the sorbent distribution was sub-optimal due to project limitations. The better the sorbent distribution, the better the mercury removal results.

Grab samples of green balls, multiclone dust and scrubber water were taken to identify any trends. The green ball mercury content averaged about 15 ng/g and varied randomly by nearly a factor of two from high to low concentration measured. Sorbent was injected before the multiclone and there was a concern that some sorbent would be captured there and decrease the overall Hg removal rate. It was discovered that some sorbent was captured by the multiclone but that its impact on the mercury removal rate was probably small. The Hg content of the scrubber water did not increase during the trial and varied between the high and low levels observed in the baseline testing. Filtering the scrubber water greatly reduced the mercury content since the sorbent contained in the scrubber solids still had Hg capacity.

Project Purpose

The purpose of this effort is to demonstrate that the Minnesota Department of Natural Resources (MN DNR) goal of reducing taconite flue gas mercury emissions by 75% from current levels can be achieved by the use of gas-phase brominated mercury sorbents. Gas-phase brominated sorbents have been proven very effective in mercury capture in similar applications.

Project Scope

In order to achieve this task, Albemarle Environmental Division conducted a six-task trial. Task 1 was the preliminary site visit to Hibbing Taconite, which was conducted on March 1, 2011. Hibbing Taconite was selected by the MN DNR as the host for the trial. Task 2 involved pre-trial testing, which was conducted at Hibbing Taconite between May 30 and June 4, 2011. Pre-trial testing determined the sources of Hg generation, as well as the sorbent injection and Hg measurement locations.

Task 3 of the project was for equipment preparation while Task 4 was the field trial, which began on 9/13/2011 and ended on 10/22/2011. Task 5 was the analysis of the samples and data collected during the field trial while Task 6 was final report preparation.

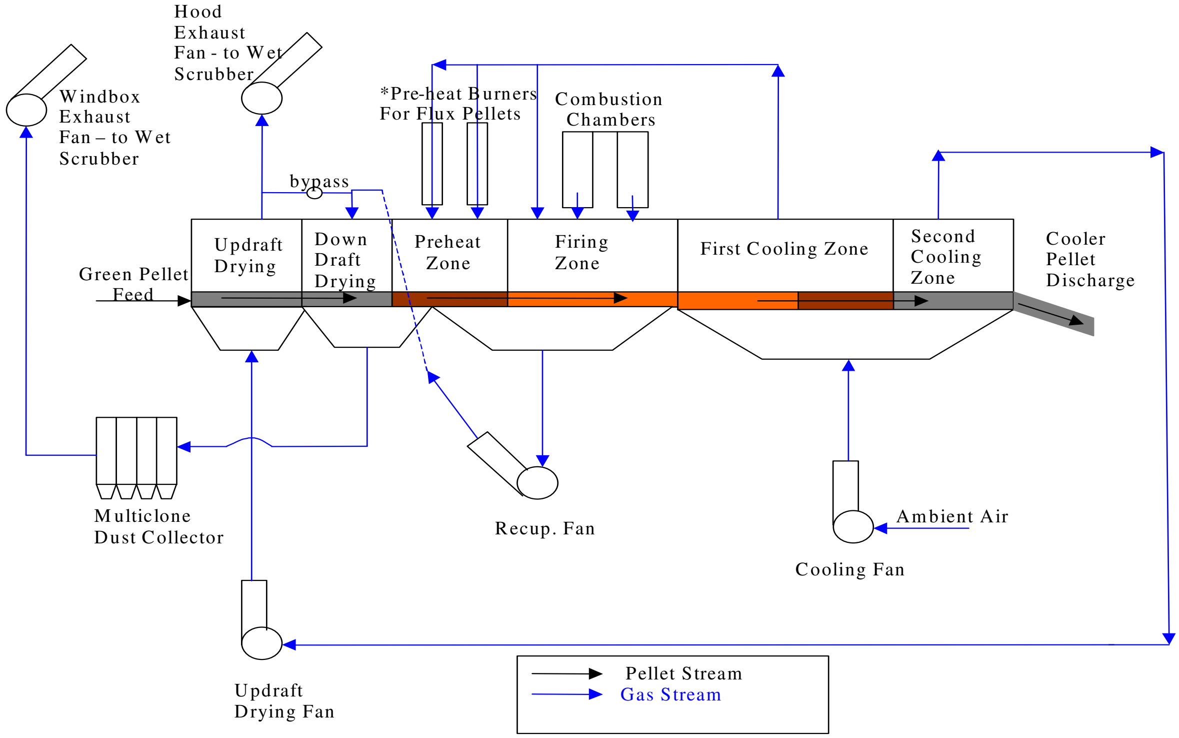
Hibbing Taconite Process Description

Hibbing Taconite, located near Hibbing, MN, fires greenballs made of taconite in straight-grate furnaces. Large combustion chambers firing natural gas, located in the center of each furnace, provide heat to pellets that move past the firing zone on a large grate. Outside air, heated as it cools the fired pellets in the second cooling zone, dries and heats fresh greenballs in the up-draft drying zone. Meanwhile, air introduced in the combustion chambers and/or in the first cooling zone passes through the pellet bed in the firing and preheat zones, and then again in the down-draft drying zone. Operation in this manner provides for thermal efficiency.

The drying, heating, and firing procedures are all performed on the grate in a straight-grate facility, however, a “hearth layer” consisting of pre-fired pellets is added beneath fresh greenballs to protect the grate from the intense heat used in the firing zones.

A schematic of the Hibbing Taconite pellet firing equipment is shown in Figure 1.

Figure 1. Diagram of the Hibbing Taconite Pellet Firing Equipment



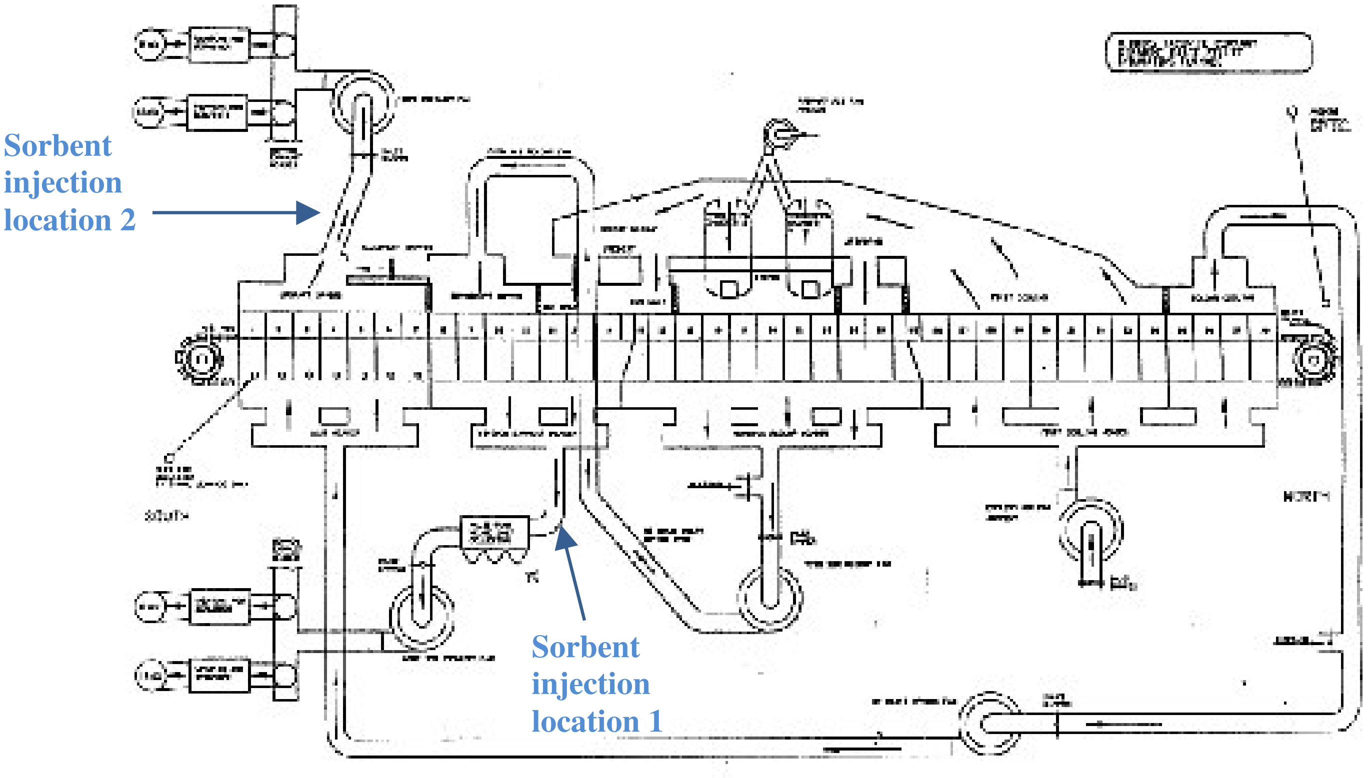
The furnace has two flue gas streams (Windbox and Hood Exhaust). Four single-pass scrubbers connected by a common duct are used for particulate control. The flue gas flow through each stack is 350-400 KSCFM.

Production Line 1 was used for this demonstration test. Injection ports were installed upstream and downstream of the multiclones in the Windbox Exhaust ductwork prior to the test since it was unclear which location would provide the best results. Unfortunately, it was discovered during equipment set up that the ports after the multiclones in the Windbox Exhaust ductwork were not usable due to obstructions in the ductwork. Therefore, only the injection ports upstream of the multiclone were utilized.

The injection locations in the Hood Exhaust ductwork were more straight forward to define.

The injection locations used during the trial are shown in Figure 2.

Figure 2. Sorbent Injection Locations



Sorbent injection location 2

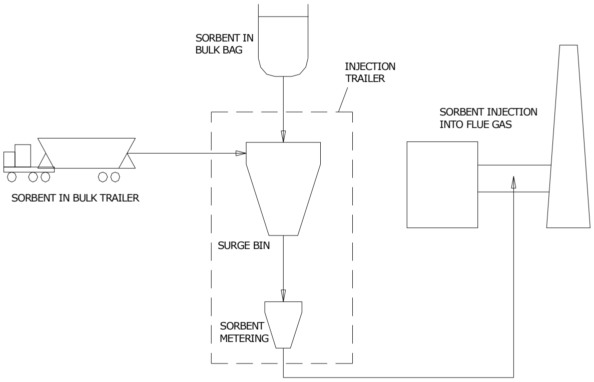
Sorbent injection location 1

Experimental

Albemarle Mobile Demonstration Unit

The sorbent injection system design took into consideration both the desires of our host sites and the Albemarle's Environmental Division previous full-scale mercury testing experience. Customer sites typically have space constraints. Thus, the testing design incorporated the use of pneumatic tankers for the storage of large quantities of sorbent. The difficulty of building an injection system on site had been clearly demonstrated in the previous full-scale tests at other locations. The need for gravimetric control rather than volumetric control had also been demonstrated. The injection system was design to fit inside a trailer and be fully mobile. A diagram of the mobile demonstration unit appears in Figure 3.

Figure 3. Diagram of the Mobile Demonstration Unit



The functions of the sorbent injection system are as follows:

1. To provide for sorbent loading to a day storage hopper from either super sacks or pneumatic trucks.
2. To deliver the sorbent from the day storage hopper to a feeder system hopper.
3. To gravimetrically feed sorbent at selected rates into an eductor injection system.
4. To provide dilute phase conveying of the sorbent through the sorbent distributor and to the injection lances.

The day storage hopper, feeder hopper, gravimetric feeder and eductor are all enclosed in a trailer. A bin vent filter is provided to capture any dust generated by material handling. This filter is located on top of the day hopper. Blowers are used to provide the air flow necessary to convey the sorbent from a tanker to the day storage hopper and to convey the sorbent from the feeder to the injection lances. The first of these blowers is located outside of the trailer while the other in located inside. All controls for the operation of the injection system are in an isolated area within the trailer. The injection trailer is shown in below in Photograph 1.

Photograph 1. Albemarle Mobile Demonstration Unit

The injection system has a PLC based control system, which controls all of the injection system operations. The control system monitors the amount of sorbent in the feeder system hopper and activates the screw feed system associated with the day storage hopper to provide refills as necessary. The control system can also refill the day storage hopper from the tanker.

The injection system was designed with the ease of installation and disassembly in mind. Only electricity and injection ports are required by the host site to support its operation.

The injection system was designed to have a sorbent injection rate range from as low as 15 lb/hr to a high of over 500 lb/hr. This range was selected in order to be able to provide testing at a variety of size systems and applications. For tests requiring a significant amount of sorbent, as was this one, the sorbent is provided by tanker truck. Only the plain powdered activated carbon (PAC) was fed to the day hopper from a super sack.

Sorbent Distribution and Lance System

The sorbent distribution and lance system designed for the Hibbing Taconite trial was based on injection into multiple ducts using a single sorbent feeder and a pneumatic conveyance system. Each of the ducts had multiple injection locations and two injection lances at each injection location. The control of material flow to the multiple injection lances was controlled by orifices.

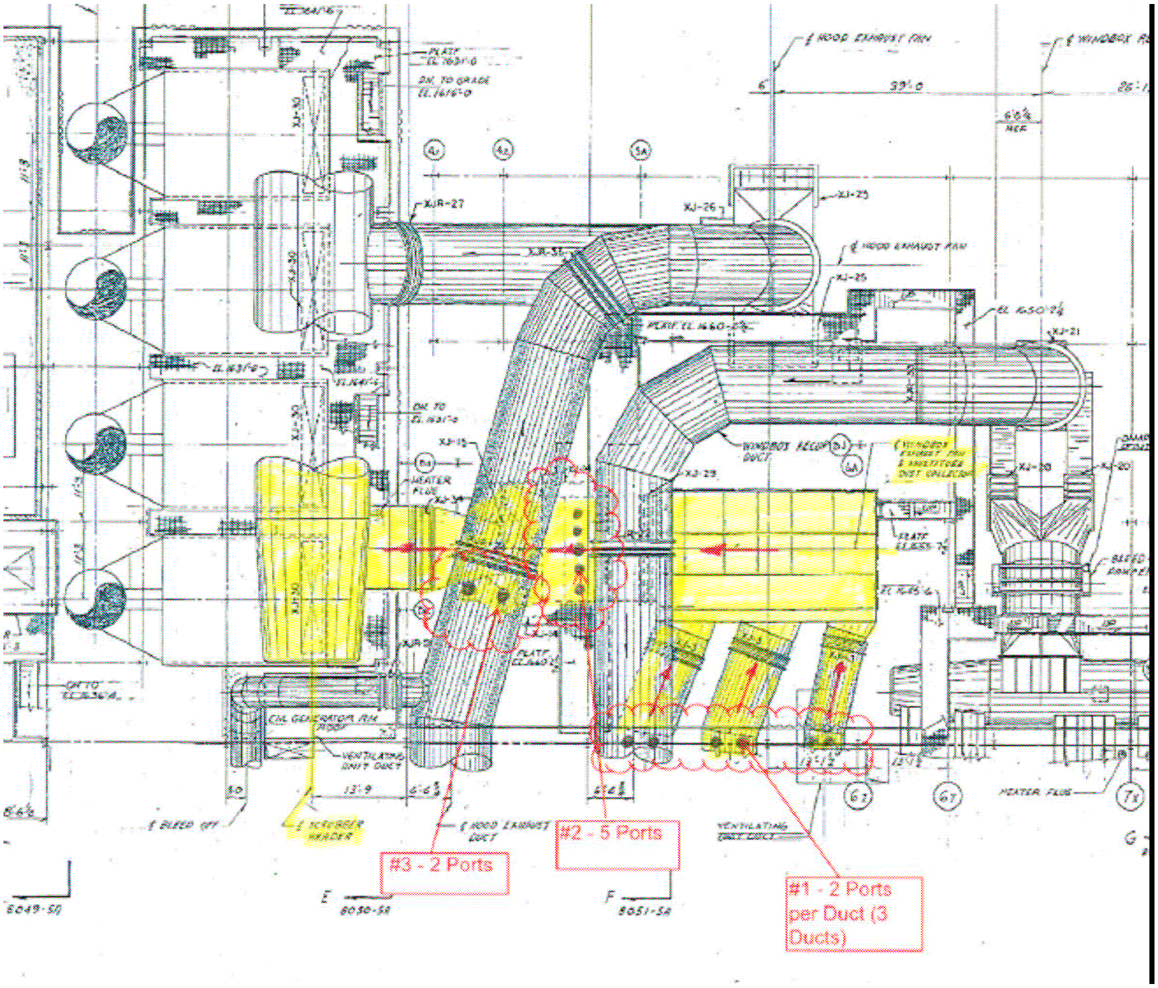
The injection lances are incorporated into injection modules, which bolt onto 4" flanged injection ports. Each injection port establishes an injection point in the exhaust gas. Two (2) lance testing modules were used at Hibbing Taconite. Testing modules are intended for short term applications but are designed with the same features as Albemarle's permanent injection modules. The main features of these systems are:

1. Multiple lances per injection module.
2. An orifice for each lance to control sorbent flow to the lance.
3. One port for each lance to allow installation of a PACFlow™ flow measurement probe.
4. Modules installed in series across a duct with spool pieces creating a manifold.
5. An inlet wye, two 180° bends, and connecting lines to create an equalization loop which delivers the sorbent to lances through the manifold.

In most applications Albemarle uses its proprietary X-a-Lance™ technology to increase the distribution of sorbent in the treated gas. The X-a-Lance™ design is an open ended, non-plugging lance design which uses specially designed exit holes to increase the dispersion of sorbent particles within the gas stream. The injection modules at Hibbing Taconite were equipped with X-a-Lances™.

Sorbent injection locations at three different areas on the furnace exhaust ducts were used at Hibbing Taconite as shown in Figure 4. Location #1 is on the Windbox Exhaust ducts immediately downstream of the furnace windbox. At this location three (3) ducts carry the hot gas and two (2) injection points per duct are identified. Each of these six (6) points is supplied with four (4) inch ports into which two (2) injection lances of different lengths are inserted. Therefore, at injection Location #1, twelve (12) injection lances deliver sorbent into the gas stream.

Figure 4. Injection Locations



Location #2 is on the Windbox Exhaust duct also but on the outlet of the multiclone particulate collection device. This device is designed to collect larger particles of iron compounds but should not remove particles of sorbent, which have a d50 particle size of 20 µm. However, due to the uncertainty of sorbent removal in the multiclone collector, injection Location #2 was designed as an alternative to Location #1. At Location #2, five (5) injection ports, or points, were designed and spaced across the duct perpendicular to the gas flow. Each of these ports is designed for two (2) injection lances of different lengths.

Unfortunately, during the lance installation period it was discovered that turning vanes exist inside the duct at Location #2, which was not known and did not appear on the drawings. Therefore Location #2 could not be used for sorbent injection testing.

Location #3 is on the Hood Exhaust duct after the duct exits the building but before the ID fan. At this location two (2) injection ports were installed in the ductwork and each port was designed to receive two (2) injection lances.

Due to plant outage scheduling constraints, the injection ports at Hibbing Taconite were chosen and installed before the pre-trial testing was conducted. At the time of the injection location design, it was believed that little mercury would be present in the Hood Exhaust gas. The reasoning was that the low temperature of 550° F present in the Hood Exhaust would not be expected to cause mercury to release from the green balls. Therefore, only two sorbent injection points were designed for the Hood Exhaust duct. However, the data gathered in the pre-trial testing proved the assumption concerning the mercury release from the green balls was incorrect in that more than 25% of the total gas phase mercury was in the Hood Exhaust gas. Unfortunately, it was not possible to put more injection points into the Hood Exhaust duct after the pretrial testing, so the control testing was performed with just two injection points in the hood exhaust duct.

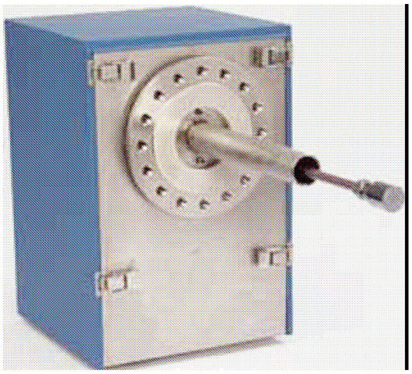
Additionally, due to ductwork constraints, the orientation of the installed injection ports on the hood exhaust duct was suboptimal. Both of the injection ports were installed on the centerline of the duct instead of across the duct as was done on all other ducts.

It is believed that fewer injection points and the suboptimal port orientation could have contributed to lower mercury capture in the Hood Exhaust gas than what was observed in the Windbox Exhaust gas.

Mercury Monitors

The latest version of the Tekran mercury monitoring equipment was used for this test program. Two types of particulate separator probes were utilized in this trial. One is a simple filter designed for use after wet scrubbers while the second is an inertial separator. A photograph of the filter probe is shown in below.

Photograph 2. Filter Probe



In an inertial separator, flue gas is drawn into the system by means of an eductor. The flow rate is measured by a Venturi meter and adjusted to provide an axial gas flow through the inertial separator of 70 – 100 feet per second. A gas sample is extracted at a low inertial filter face velocity of 0.006 feet per second. The particulate matter follows the gas stream and is thus separated from the gas sample. The gas removed from the duct is returned after use. The entire inertial separator is in an enclosure and maintained at 400^{O}F to avoid any condensation issues. The gas sample is conveyed through a heated line to the conversion module where the oxidized mercury is either converted to elemental mercury in order to provide a total gas phase mercury measurement or removed from the gas to allow for the measurement of elemental mercury.

The gas from the mercury conversion module is directed to a mercury analyzer. The gas sample is drawn across a gold trap in which the mercury is collected. After a prescribed sampling time, the trap is heated in order to release the mercury, which is measured by atomic fluorescence. The system was calibrated at least once per day using mercury standards. The analyzer provides one mercury measurement every two and one half (2.5) minutes, thus the name semi-continuous emission monitor. If both elemental and oxidized mercury are being analyzed, the measurements are five (5) minutes apart. The Tekran mercury conversion module and mercury CEM is shown in Photograph 3.

Photograph 3. Tekran Mercury Conversion Module and CEM

An Appendix K Mercury sorbent trap system was also used in this trial to measure the total mercury content of the flue gas. Albemarle manufactures its own Appendix K traps using our brominated sorbents. These traps are easier to analyze than those made using iodinated carbon. These traps are used to verify the mercury readings obtained by the Tekran Analyzer. A photo of a trap and the Appendix K controller appear below in Photograph 4.

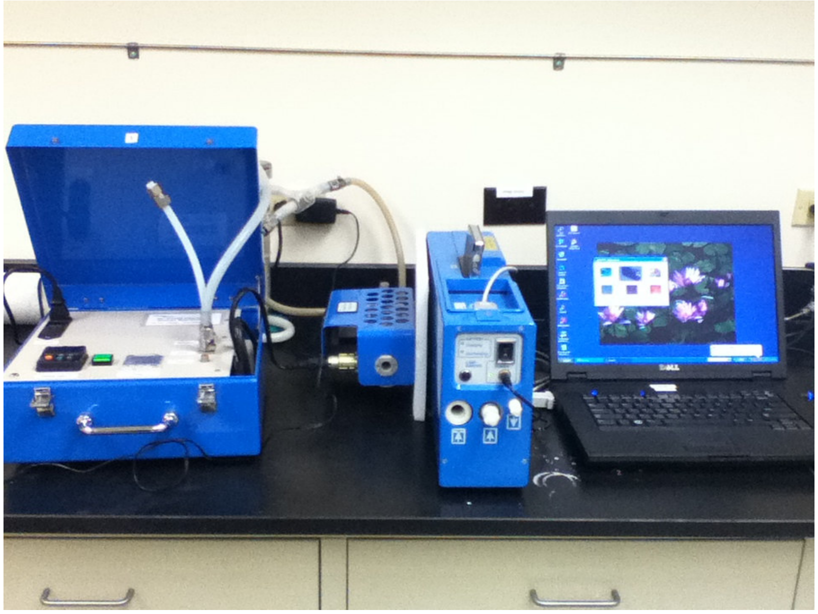
Photograph 4. Appendix K Mercury Trap

The Appendix K samples were taken from all four stacks during the trial but mostly from Stacks 1 and 4, since they provided the extremes in the mercury concentration.

Solid Sample Mercury Analysis

The Appendix K traps, greenballs, and dust were analyzed for mercury content using an Ohio Lumex carbon trap Mercury Analyzer. The Ohio Lumex mercury analyzer is an atomic absorption spectrometer with Zeeman background correction. The Zeeman background correction eliminates the need for gold traps to concentrate the mercury. The instrument is calibrated with NIST standards. The detection limit is 50 µg/g. The Ohio Lumex unit is shown in Photograph 5.

Photograph 5. Ohio Lumex Carbon Trap Mercury Analyzer



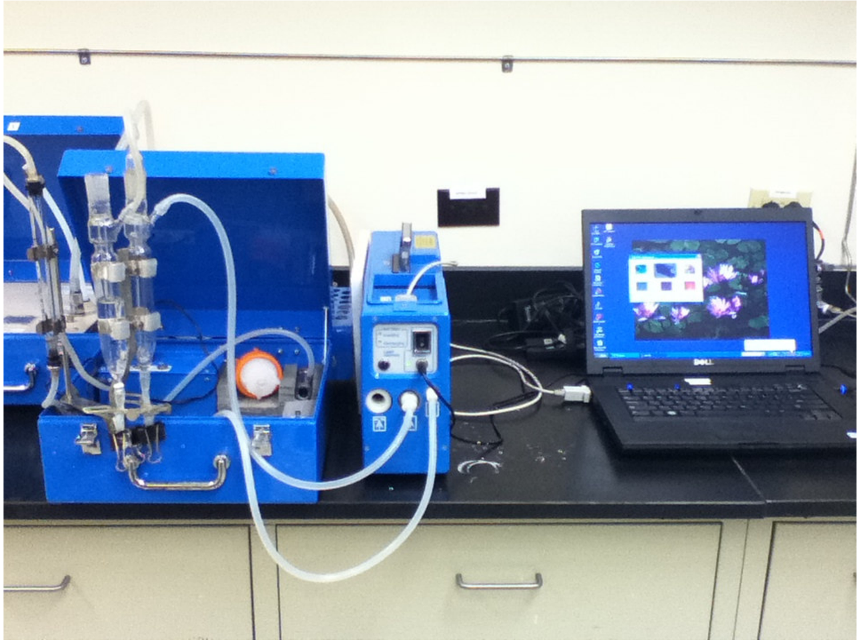
Water Sample Mercury Analysis

The water samples were analyzed using Ohio Lumex RA-915+ mercury analyzer. The analytical system consists of the RA-915+ analyzer itself, the RP-91 attachment for determination of mercury content in aqueous solutions using the "cold vapor" technique, and the RP-91C attachment for measuring mercury concentration in liquid and solid samples with a complex composition using the pyrolysis technique. Basic analytical characteristics of the system are given in the Table 1. The filtering of the water samples was performed at the Albemarle PDC using a 0.4 µm glass filter.

Table 1. Ohio Lumex Aqueous Sample Detection Limits

Subject	Detection limit	Sample parameters (flow rate, volume, weight)	Detection technique	Complete set
Ambient air	2 ng/m^3	20 l/min	Direct	RA-915+
Natural and industrial gases	2 - 500 ng/m^3	1 - 20 l/min		
Water	0.5 ng/l	20 ml	"Cold vapor" technique	RA-915+ RP-91
Urine	5 ng/l	1 ml		
Solid samples (soils, rocks)	0.5 µg/kg	0.2 g	Pyrolysis technique	RP-91C RA-915+
Biological samples (tissues, liver, etc.)	5 µg/kg	0.02 g		
Hair	20 µg/kg	0.01 g		
Oil and oil products	50 µg/kg	0.01 g		
Plants	2 µg/kg	0.05g		
Foodstuff	2 - 10 µg/kg	0.005 - 0.05 g		

Photograph 6. Ohio Lumex Model RA-915+ Mercury Analyzer with Liquid Sample Analysis Attachment



LOI Analysis

LOI analysis was performed on all dust samples taken from the multiclone. This was done to determine the carbon content present within the dust and whether any of the injected sorbent was captured.

All dust samples were individually weighed and placed into a crucible. Seven random samples were dried for 3 hours in an oven at 120°C. After drying the samples were weighed and the average weight variation calculated. The average weight variation for all seven samples was 0.00076%. It was therefore determined that the moisture content was extremely low, and drying before the actual LOI analysis would not be needed.

The dust samples were then placed into an oven at 800°C for 2 hours. The samples were weighed before and after being placed in the oven. The sample LOI was calculated by taking the percentage weight loss or gain of the sample after exiting the oven.

Hg Removal Calculation Method

Mercury removal is the key parameter to be calculated in this trial. The calculation is complicated by the fact that there are significant emissions from both the Windbox Exhaust and the Hood Exhaust, which report to four stacks. Fortunately, the four stacks are connected by a common duct, causing nearly identical flue gas flow through each stack.

The baseline and parametric testing was conducted by measuring the mercury emissions in two of these stacks (#1and #4), which had the most divergent Hg emissions. The Hg concentrations were then averaged to provide the average Hg emission for the time period.

The following equation was used to calculate the Hg removal percentage:

$$Hg \quad removal(\%) = \left(1 - \frac{Controlled \quad gas \quad mercury \quad concentration}{Uncontrolled \quad gas \quad mercury \quad concentration}\right) \times 100$$

The uncontrolled gas mercury concentration was the average mercury emission rate derived from the baseline testing data.

The controlled gas mercury concentrations for the parametric tests were the average for the period after injection began once the Hg level reached a near stable level.

The mercury emission concentration was established in the parametric tests below which both stacks being monitored would have to be maintained in order to reach 75% mercury control. Thus, it was only necessary to monitor one stack during the continuous two-week run and make sure that a Hg emission level below the desired was maintained.

Field Trial Test Plan - Final

The field trial was divided into three phases: Baseline Measurements, Parametric Testing and Continuous Injection Run.

Baseline Measurements

Baseline flue gas mercury emissions from the facility were measured after the monitoring equipment was installed. The data from this period was used as a basis for determining the mercury reduction percentages achieved in the next phases of the project.

Parametric Testing

Both plain PAC and gas-phase brominated PACs were utilized during the parametric testing. A parametric injection test lasted for up to 6 hours at one or more injection rates. The injection was then terminated to allow the mercury to return to baseline levels. The injection runs with the brominated sorbents were usually shorter due to the high mercury capacity of these sorbents, which precludes returning to baseline mercury levels if injected for too long a period of time.

The sorbent injection trials started at an injection rate of 1 lb/MMacf on the first day that each sorbent was used and was increased as needed to achieve the mercury target. Plain PAC was not expected to be able to achieve the target and its injection rate was limited to a maximum of 5 lb/MMacf. There was a lay day between the plain PAC and brominated PAC runs.

Continuous Run

After the parametric testing, there was a continuous injection run with the gas-phase brominated sorbent at a selected rate for a two-week time period. This run was to approximate the results that might be achieved in continuous commercial operation.

Schedule

The schedule for the field test conducted at Hibbing Taconite is presented In Table 2.

Table 2. Schedule for Testing at Hibbing Taconite

Schedule for Albemarle Project Entitled
"Mercury Control for Taconite Plants Using Gas-Phase Brominated Sorbents"

Activity	**Date**
Travel to Hibbing Taconite	September 13, 2011
Equipment Installation	September 14-17, 2011
Baseline Measurements	September 17-21, 2011
Parametric Testing	September 22-26, 2011
Test Break/Plant Down	September 27 – October 6, 2011
Continuous Run	October 7 - October 22, 2011
Equipment Disassembly	October 22, 2011
Personnel Leave Site	October 23, 2011

Results and Discussion

Pre-Trial Testing

From May 30 through June 4, 2011, members of the Albemarle field testing team visited the Hibbing Taconite plant in order to define the mercury split between the two primary exhaust gas streams (Windbox and Hood) and determine where it would be best to install the injection ports. Sorbents traps were collected from the flue gas in both the Windbox and Hood Exhaust streams as well as from the flue gas in each of the four interconnected stacks. This testing would help determine if it would be necessary to inject into both the Windbox and Hood Exhaust gas ductwork in order to achieve the 75% mercury reduction target.

The data from the sorbent traps collected in Production Line 1 are presented in Table 3. All concentration data presented is in μg/Nm^3.

Table 3. Hg Test at HibTac Line 1 May-June, 2011

Location	Gaseous Hg	Particulate Hg	Total Hg	% Particulate
Windbox	3.59	0.00	3.59	0.0%
Hood	2.20	0.47	2.67	17.7%
	2.24	0.34	2.57	13.1%
	2.40	0.15	2.54	5.7%
Stack 1	1.45	0.32	1.76	17.9%
Stack 2	2.65	0.13	2.77	4.5%
Stack 3	3.49	0.34	3.83	9.0%
Stack 4	3.63	0.42	4.05	10.3%
	4.34	0.45	4.80	9.4%

In these tests, the front wool section of the sorbent trap was analyzed separately and designated as particulate mercury. It is known that fine iron oxide can act as a sorbent to capture mercury, and, thus, it is expected that some of the mercury captured on the filter was really gaseous mercury captured on the wool by iron oxide. The particulate mercury levels varied from 0.0% to 17.9% and averaged nearly 10 %. In a typical application the naturally occurring particulate mercury is less than 1%.

The stack flue gas flow rates are nearly the same since there is a common duct connecting them. The flue gas from the Hood Exhaust reports to Stacks 1 and 2, while that from the Windbox Exhaust reports to Stacks 3 and 4. From the data in Table 3, it can be seen that the mercury content in Stacks 1 and 2 are similar as is the mercury content in Stacks 3 and 4. It was expected that most of the mercury would be in the Windbox Exhaust gas. While the Windbox Exhaust gas does contain more mercury than the Hood Exhaust gas, it only contains 70% of the mercury. Thus, injecting sorbent only into the Window Exhaust gas stream could not achieve the mercury reduction target of 75%.

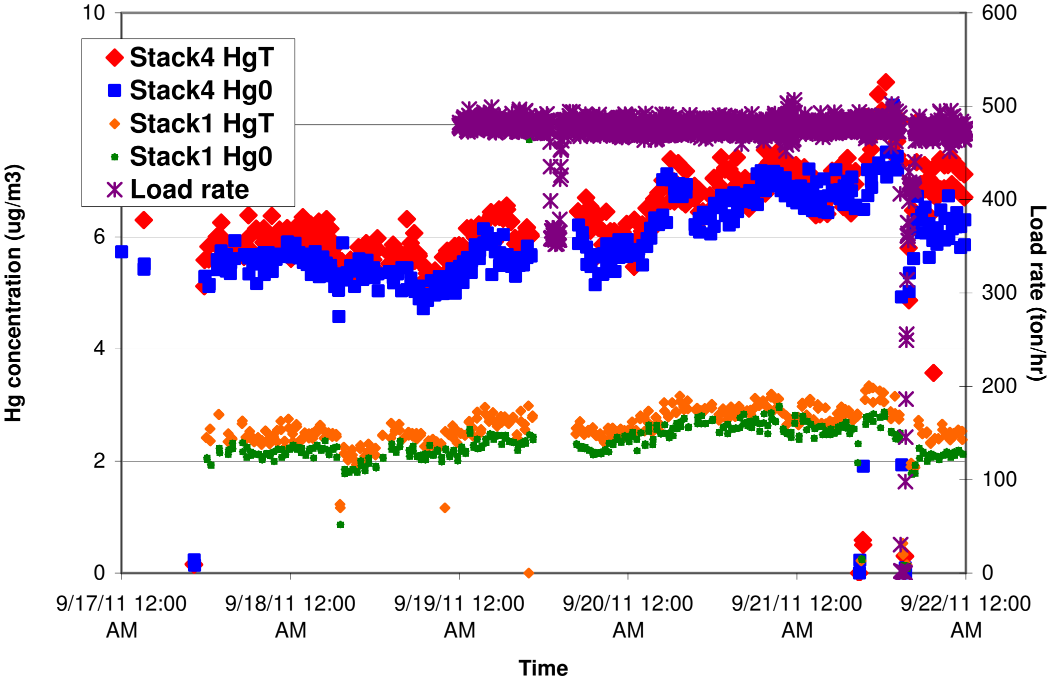
The preferred injection locations were also selected during the pre-trial testing and these were discussed previously in the section on sorbent distribution and lance system.

Baseline Measurements

Baseline measurements were conducted on Line 1 from Sept. 17 through end of day Sept. 21, 2011. The Tekran CEM was used for analyzing Stacks 1 & 4. The purpose of the baseline period was to analyze mercury emissions and establish the average mercury content of the flue gas without sorbent injection in both the Windbox and Hood Exhaust flue gas streams. These baseline mercury content values would then be used to judge the effectiveness of B-PAC^{TM} once it was introduced into the gas stream during the parametric testing.

Figure 5 shows the baseline mercury emissions data from Line 1. The load rate data provided by Hibbing Taconite was also included.

Figure 5. Stacks 1 & 4 Baseline Mercury Data with Load Rate



As seen in the pre-trial testing, the mercury content of the flue gas was less in Stack 1 (Hood Exhaust) than in Stack 4 (Windbox Exhaust). The average total mercury concentration in Stack 4 over the 5-day baseline period was 6.32 µg/Nm^3 while the average concentration in Stack 1 was 2.58 µg/Nm^3. The combined average mercury concentration for the two stacks was 4.45 µg/Nm^3. For all subsequent calculations contained in this report, this average mercury concentration will represent baseline conditions and will be referred to as 0% Hg removal.

It should be noted that there was a problem with the Hg CEM equipment on September 19 (10:25-16:35) during a plant slowdown, which caused the loss of 6 hours of data. The missing data was not used to compute the average mercury content over the baseline period. There were two periods on September 21 when there was a reduction in total mercury measured. The first was likely due to completion of the sorbent injection system set-up. Residual sorbent present in the distribution hoses was probably pulled into the flue gas stream by the negative pressure Windbox and Hood Exhaust ducts causing the slight drop in mercury levels. The second drop in mercury concentration on that day was caused by a brief shutdown of the plant. The mercury emissions followed the production rate down to zero during this time. The mercury data exhibits the typical meander in mercury emissions caused by variation in the raw material mercury concentration.

Sorbent traps were taken from all four stacks during the baseline period. The results were very consistent with the Hg concentration in Stacks 1 and 2 being nearly identical as were the concentrations in Stacks 3 and 4. This is the same as the data shown in Table 3.

The results from the sorbent traps taken on Stacks 2 and 3 during the baseline period are presented in Table 4 relative to results from Stacks 1 and 4, respectively. The results for Stack 3 are very close to the results obtained by the CEM on Stack 4 during the sampling time. There was some variability in the traps taken on Stack 2 compared to the CEM data for Stack 1.

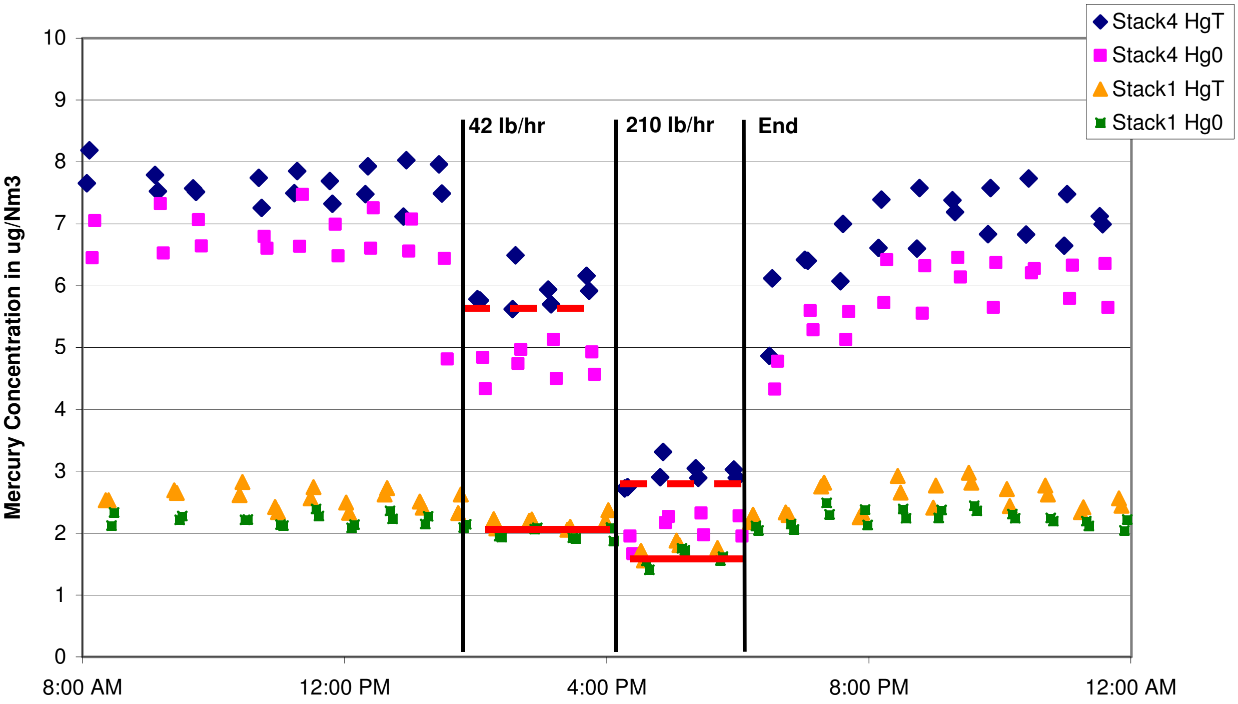
Table 4. Baseline Sorbent Traps, Stacks 2 & 3

Baseline Sorbent Trap Results				
Date	**Stack 2 (Using Stack 1 Baseline)**		**Stack 3 (Using Stack 4 Baseline)**	
	Analyzed w/ Filter	Analyzed w/o Filter	Analyzed w/ Filter	Analyzed w/o Filter
9/18/2011 15:07-16:07			+4%	+1%
9/19/2011 11:32-14:05	+53%	+46%		
9/20/2011 10:51-13:41	+77%	+71%		

Parametric Tests

The parametric testing began on 9/22/2011 with the injection of plain PAC. Two injection rates were utilized: 42 and 210 lb/hr. This translates into approximately 1 and 5 lb/MMacf, respectively. Injection rates are typically shown in lb/MMacf, since sorbent distribution is a primary factor controlling Hg removal. The mercury monitor data for this day is presented in Figure 6.

Figure 6. Injection of Plain PAC on 9/22/2011



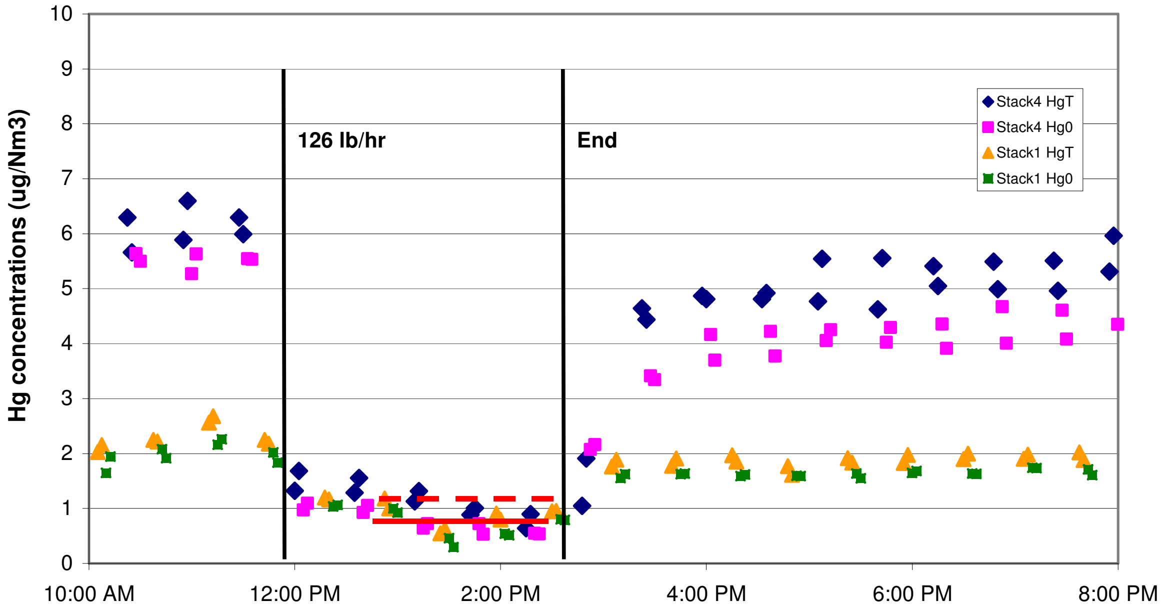
The mercury concentration in both stacks 1 and 4 are shown since the mercury emissions from both must be controlled in order to meet the 75% mercury reduction target. The combined average is used in the mercury reduction calculations since the stack flows are the same. It should be noted that a very high percentage of the Hg emissions is in elemental form. This is not surprising due the lack of acid gases in the taconite flue gases. The primary acid gases in flue gas are SO_3 and HCl. The acid gases are formed by converting SO_2 and NaCl, respectively, that are present in fuels and raw materials. Since taconite plants are natural gas fired and since the raw materials are low in sulfur and chloride impurities, very low levels of acid gases are expected in the flue gas.

Once injection began, the mercury emissions were very rapidly reduced. The red lines are shown as the average Hg levels for a given injection rates. After the injection stopped, the Hg emissions did not recover immediately to the baseline mercury level. This is due to sorbent on the walls continuing to remove mercury.

In fact, in trials using B-PAC, which has a much higher mercury capacity than plain PAC, the impact can be seen for a longer period.

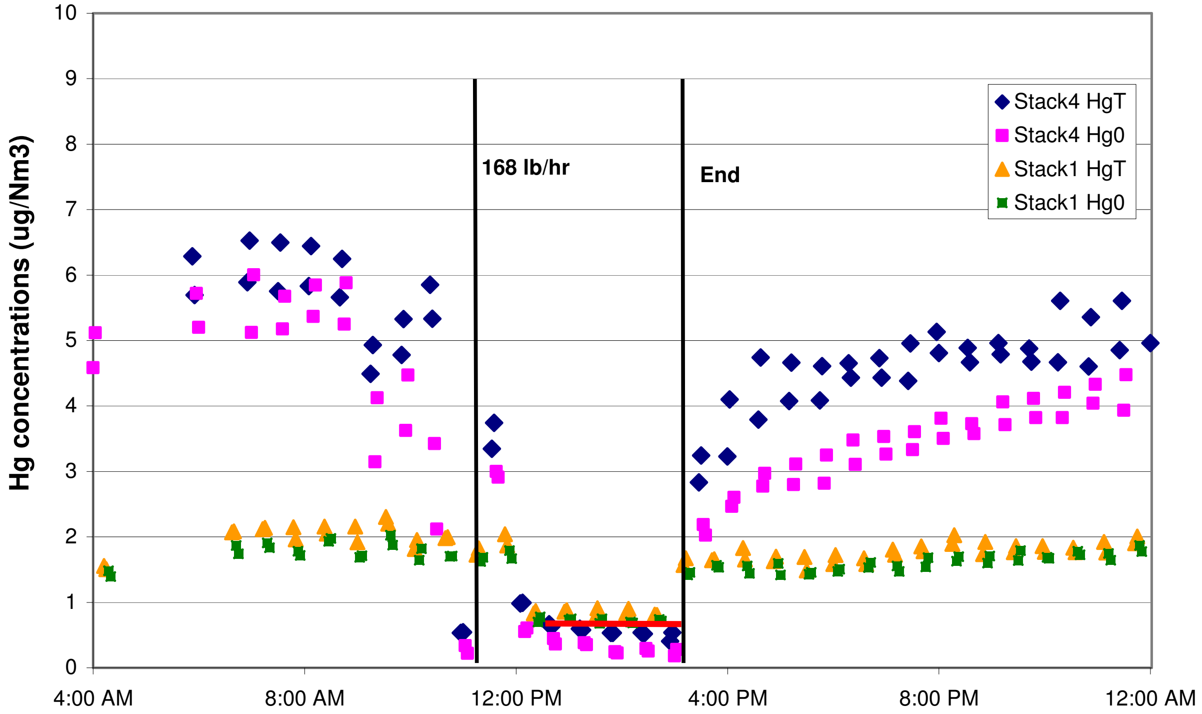
Several more days of parametric injection tests were conducted using B-PAC. The Hg monitor data for those days is presented in Figure 7 to 9.

Figure 7. Injection of B-PAC^{TM} on 9/24/2011



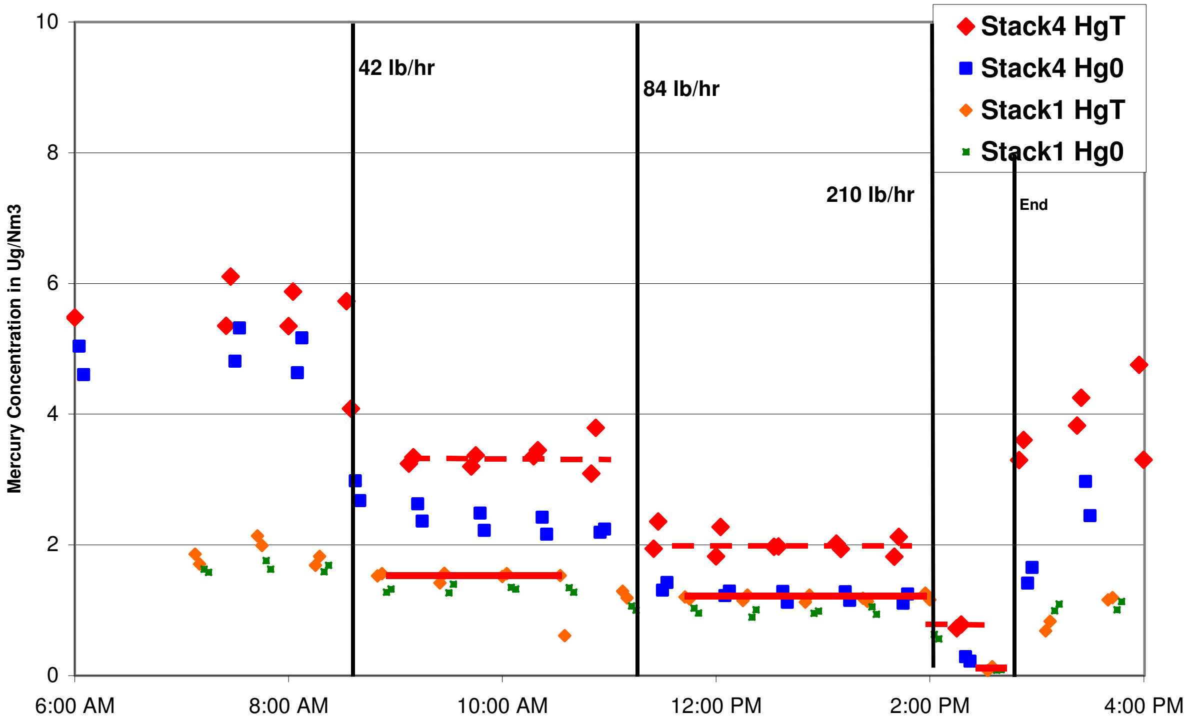
The mercury reduction is very rapid when the injection of B-PAC begins on September 24, 2011 at a rate of 126 lb/hr. The mercury recovery after the injection ceased is not rapid.

Figure 8. Injection of B-PAC^{TM} on 9/25/2011



The B-PAC injection rate on September 25, 2011 was 168 lb/hr or approximately 4 lb/MMacf. Again the recover to baseline after the test is slow.

Figure 9. Injection of B-PAC^{TM} on 9/26/2011



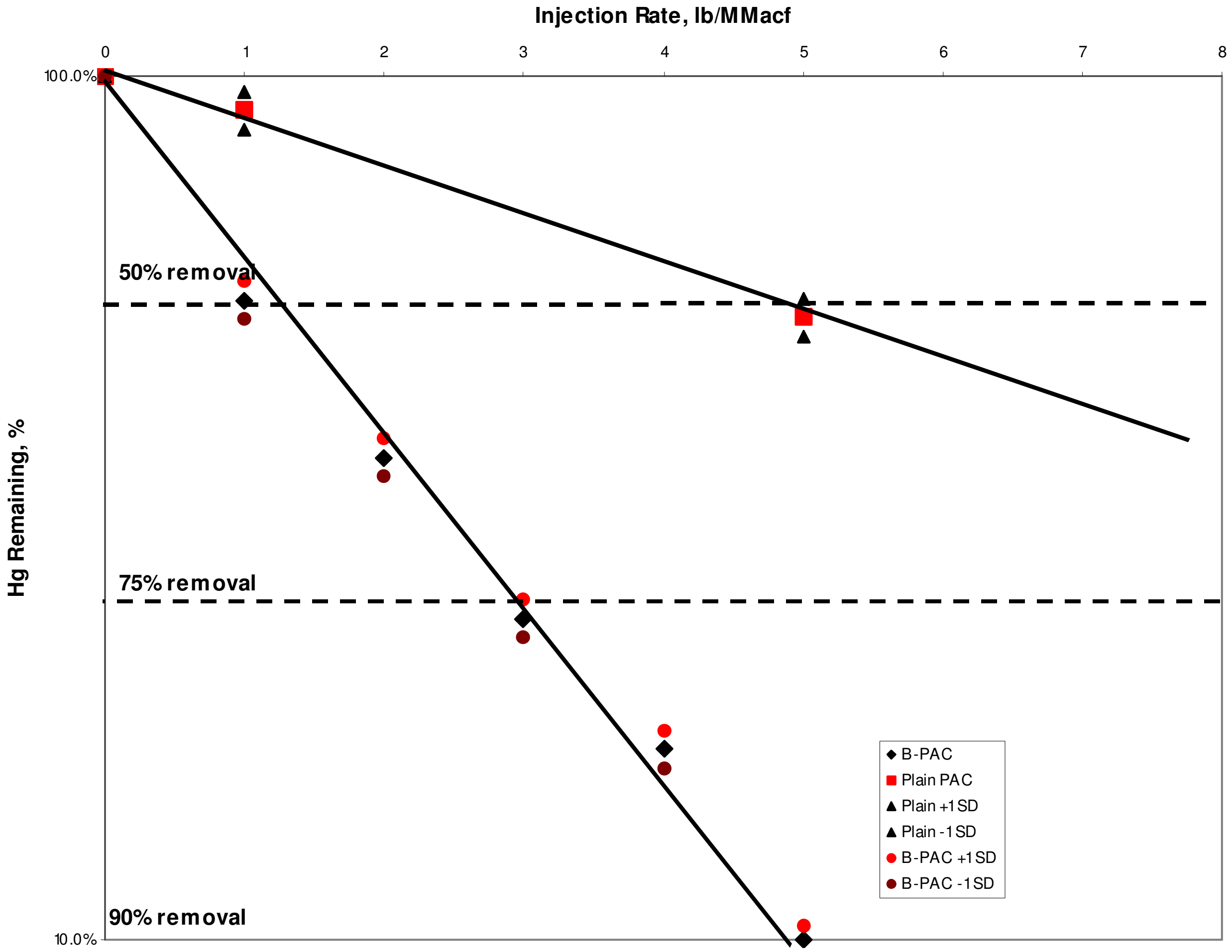
There were three injection rates tested on September 26, 2011: 42, 84 and 210 lb/hr. The highest of these injection rates provided a mercury removal rate in excess of the 75% mercury reduction target.

The results from all of the parametric sorbent injection tests are presented graphically in Figure 10.

The results are presented on a semi-log plot with the percent mercury remaining shown on the y-axis and the injection rate in terms of lb/MMacf shown on the x-axis. Shown in this manner, the results form straight lines since removal is a first order rate. The lines are trend lines and not regression lines. Both lines start at the origin: 100% Hg remaining (zero mercury reduction) and 0 lb/MMacf injection. Thus, mercury removal solely due to the sorbent is being presented. In addition to the measured mercury removal, values for ± 1 standard deviation of the mercury data is also presented. The data fits the trend lines fairly well.

The plain PAC performed as expected. The 75% removal target was not achieved even at the highest injection rate attempted. It is projected that a plain PAC injection rate >10 lb/MMacf would have been required to reach the target reduction, if at all possible. The B-PAC was able to achieve the 75% Hg reduction rate at about 3 lb/MMacf (126 lb/hr) or less than a third that of plain PAC. This is typical of the difference in performance of plain PAC and gas-phase brominated B-PAC in other applications. Mercury removal rates higher than 75% were achievable. Based upon these results, an injection rate of 3 lb/MMacf was selected for use in the continuous run.

Figure 10. Parametric Injection Test Results



The Hg removal results from all of the parametric tests are presented in Table 5.

Table 5. Parametric Test Results

	Injection Rate		Hg Remaining		
Sorbent	lb/hr	lb/MMacf	%	+1 SD	-1 SD
Plain PAC	42	1	91.2%	95.8%	86.7%
Plain PAC	210	5	52.5%	55.2%	50.0%
B-PAC	126	3	23.5%	24.8%	22.4%
B-PAC	168	4	16.6%	17.5%	15.8%
B-PAC	42	1	54.9%	57.8%	52.3%
B-PAC	84	2	36.2%	38.0%	34.4%
B-PAC	210	5	10.0%	10.4%	9.6%

The mercury data used to make these calculations is shown in Table 6.

Table 6. Parametric Testing CEM Hg Data

	Injection Rate		Level Stack 1	Level Stack 4	Average	Baseline	Hg
Sorbent	**lb/hr**	**lb/MMacf**	**$\mu g/Nm^3$**	**$\mu g/Nm^3$**	**$\mu g/Nm^3$**	**$\mu g/Nm^3$**	**Remaining**
Plain PAC	42	1	5.94	2.18	4.06	4.45	91.2%
Plain PAC	210	5	2.94	1.73	2.34	4.45	52.5%
B-PAC	126	3	0.93	1.16	1.05	4.45	23.5%
B-PAC	168	4	0.85	0.63	0.74	4.45	16.6%
B-PAC	42	1	1.53	3.36	2.45	4.45	54.9%
B-PAC	84	2	1.19	2.03	1.61	4.45	36.2%
B-PAC	210	5	0.11	0.75	0.43	4.45	9.7%

Appendix K sorbent traps were collected during the parametric testing. The data from these traps was also used to calculate the mercury removal rate at each injection rate. The calculated mercury removal rates for these two measurement methods are shown in Table 7.

Table 7. CEM and Appendix K Trap Hg Removal Data

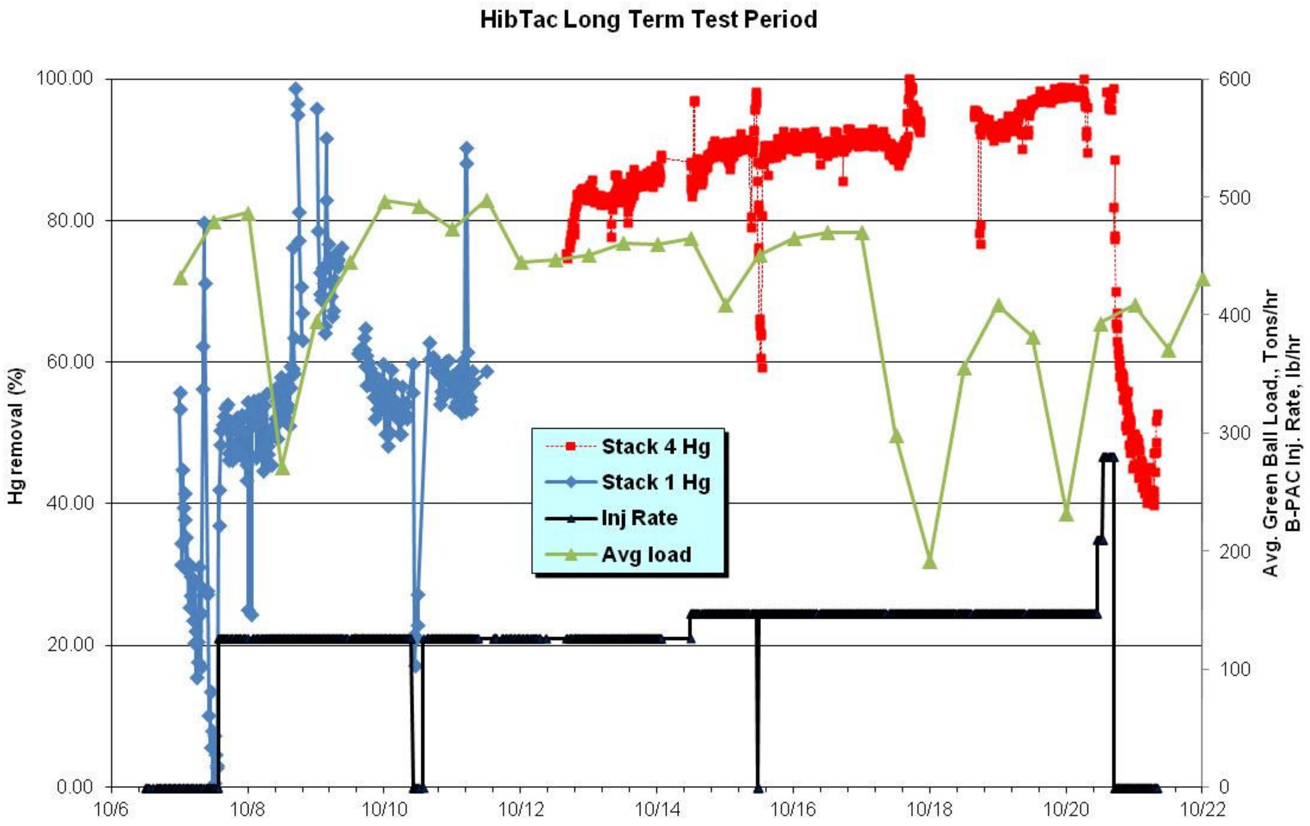
	Injection Rate		Hg Remaining	
Sorbent	**lb/hr**	**lb/MMacf**	**CEM**	**Trap**
Plain PAC	42	1	91.2%	81.5%
Plain PAC	210	5	52.5%	55.5%
B-PAC	126	3	23.5%	14.5%
B-PAC	168	4	16.6%	21.5%
B-PAC	42	1	54.9%	49.2%
B-PAC	84	2	36.2%	36.2%
B-PAC	210	5	10.0%	16.7%

The comparison of the mercury removal data is fairly good considering the difficulties associated with collecting sorbent traps in a wet stack. All of the removals appear to be in line except for the B-PAC injection rates of 3 and 4 lb/MMacf, but even these are within 10% of each other.

Continuous Run

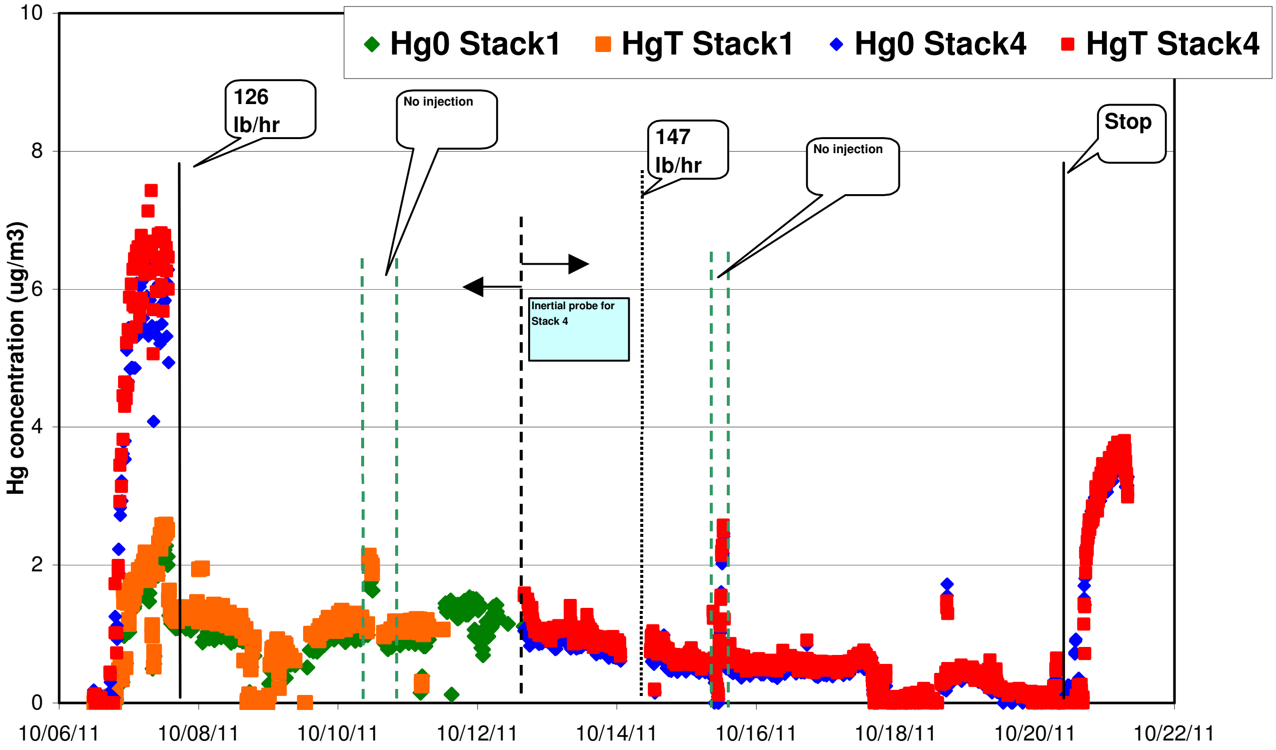
Albemarle began the long term testing at Hibbing Taconite on October 7 following a one-week break from sorbent injection. Like the other tests, the continuous run was on Line 1. The test period began with the CEM wet stack probe in Stack 4 and the CEM inertial filter probe in Stack 1. The CEM analyzer took alternating total and elemental mercury measurements from Stack 1 and Stack 4. The cycle time for each measurement is 2.5 minutes. Each stack was sampled for 30 minutes before switching to sample from the other stack. In Figure 11 below, the reduction of total mercury, as measured by the Hg CEM, is plotted along with the B-PAC™ injection rates, and the twelve-hour average green ball Hg load.

Figure 11. Continuous Run Mercury Removal



Both inertial and wet stack CEM probes were inserted into the emission gas stream on different stacks and used for drawing filtered gas samples for measurement in the CEM. In Figure 11 above, the percent mercury removal data gathered by only the inertial filter probe is plotted. No data collected by the wet probe is shown.

Figure 12. Continuous Run Mercury Concentrations



At the beginning of the continuous run, the wet probe was inserted into Stack 4 and the inertial probe into Stack 1. However, after day two of the long term test program, it was determined that the sample gas supplied by the wet stack probe had a negative mercury bias, meaning the probe was absorbing some of the mercury carried by the sample furnace gas to the CEM.

The bias of the sampling probes is determined by a calibration procedure called mercury recovery. In this procedure, the CEM monitor sends a known concentration of elemental mercury calibration gas to the intake portion of the sampling probe. From here it is drawn through the probe and back to the CEM for measurement. In a probe with no bias toward mercury absorption or mercury release, the CEM will measure 100% of the mercury supplied by the CEM with an accuracy of +/- 5%.

During the early part of the continuous run, the wet stack probe on Stack 4 began to show a steady increase of negative bias during mercury recovery calibrations. This probe uses an inline particle filter with blowback cleaning to separate solid particles from the sampling gas. As evidenced by the filter media color change, fine particles were accumulating on the filter and the blowback cleaning option was not able to dislodge these particles from the filter media. The mercury recovery procedure verified that during the first two days of long term testing, the particles captured on the filter media were increasingly absorbing mercury from out of the sampling gas. This situation is consistent with the theory that some B-

PAC™ particles were escaping from the scrubber collector and depositing on the wet probe filter media. While this negative bias was not seen on the wet probe during the short parametric tests, the continuous injection of B-PAC™ during long term testing overwhelmed the wet stack filter cleaning capability. Therefore, the data collected with the wet stack during the long term testing was not used in the data set of this report. The inertial filter probe was used to collect data on Stack 1 from October 7 – 11 and then physically moved to Stack 4 for the remainder of the long term test period. A mercury bias was not seen while sampling gas with the inertial filter probe.

The injection of B-PAC™ was started at 13:30 on October 7 at a rate of 126 lb/hr. This rate is equivalent to 3 lb B-PAC™/MMacf of furnace gas. The reduction of mercury was measured on Stack 1 by the CEM. The beginning of B-PAC™ injection is clearly visible in Figure 11 on October 7 as the mercury removal quickly jumped to 50%. The average removal measured on Stack 1 from October 7 to October 11 was 57%. The average Hg removal was 74% during the 24 hour period from 16:00 on October 8 to 16:00 on October 9. It should be noted that a higher mercury removal was always observed in Stack 4 as compared to Stack 1 due to the reduced number of lances and, subsequently sorbent delivered to that side. As can be seen by the Stack 4 data in Figure 11, a much higher mercury removal was achieved there and the combined removal would exceed 75%.

On October 10, the data set in Figure 11 switches to mercury removal on Stack 4. Removal on Stack 4 is significantly higher than removal on Stack 1 which is caused by a lower B-PAC™ mass injection rate in the Hood Exhaust stream as compared with the Windbox Exhaust stream. Mercury removal on Stack 4 is shown to increase steadily through the continuous run test period. An increase in mercury reduction over time has often been observed in mercury control tests and generally attributed to a build-up of mercury sorbent particles on surfaces within the gas flow path.

The average mercury removal on Stack 4 with 126 lb/hr (3 lb/MMacf) of B-PAC™ was 84%. This rate of injection was maintained until October 14 at 12:00.

In order to compensate for the lower removal rates measured on Stack 1, the injection rate of B-PAC™ was increased to 147 lb/hr, or 3.5 lb/MMacf, on October 14 at 12:00. The increase in injection rate resulted in an immediate increase in the mercury removal rate. The average mercury removal rate at 147 lb/hr was 92% in Stack 4. The Line 1 furnace was stopped unexpectedly for repairs on October 20 at 7:00 and this ended the 147 lb/hr test period.

Because October 20 was the last scheduled continuous run test day, the B-PAC™ injection rate was increased in increments from 210 lb/hr to 280 lb/hr to empty the MDU storage bin. The time weighted average injection rate during this 6-hour period, ending at 17:00 on October 20, was 255 lb/hr. The average mercury removal during the high injection rate period far exceeded the 75% target.

B-PAC™ injection was stopped at 17:00 on October 20 but the mercury CEM continued to collect data from Stack 4 until October 21 at 8:00. The change in mercury removal due to the end of B-PAC™ injection is clearly seen in the data set in Figure 11 as the mercury removal drops sharply to as low as 40%. However, the mercury does not recover to the low removal level seen at the start of the continuous run test period. This is often observed in B-PAC™ injection tests and can be contributed to the presence of still active B-PAC™ collected in the ductwork and scrubber.

Green Ball Analysis

Green ball samples were taken during the test and analyzed for Hg. The samples were all grab samples and, thus, any conclusions made based upon the analysis are tentative. The results are shown in are Table 8. The Hg content of the green balls was measured at Albemarle's Hg R&D lab, which is located at Process Development Center (PDC) in Baton Rouge, LA using the Ohio Lumex analyzer.

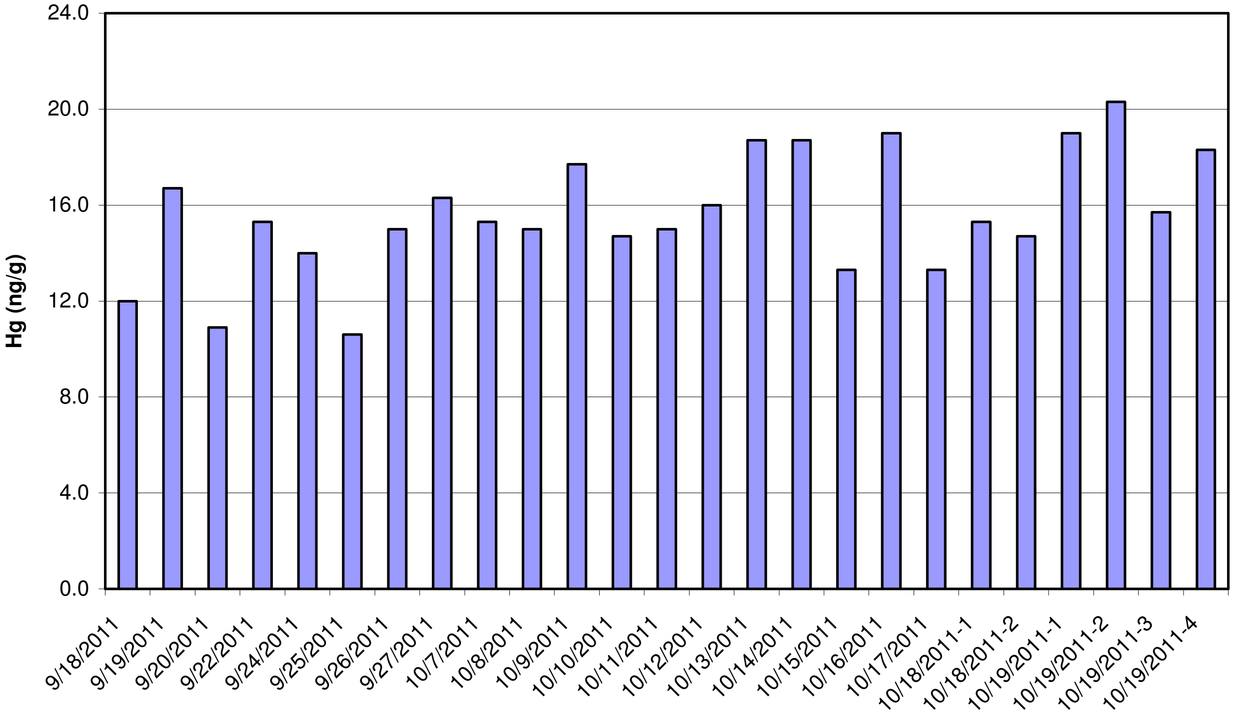
Table 8. Green Ball Hg Analyses

Date	Time	Operation	Result (ng/g)
9/18/2011	2:00pm	Baseline	12.0
9/19/2011	4:00pm	Baseline	16.7
9/20/2011	8:40am	Baseline	10.9
9/22/2011	5:10pm	Plain AC (5lb/MMacfm)	15.3
9/24/2011	1:40pm	Parametric (2lb/MMacfm)	14.0
9/25/2011	2:20pm	Parametric (4lb/MMacfm)	10.6
9/26/2011	12:30pm	Parametric (2lb/MMacfm)	15.0
9/27/2011	9:35am	Parametric (5lb/MMacfm)	16.3
10/7/2011	2:40pm	Long term (3lb/MMacfm)	15.3
10/8/2011	12:40pm	Long term (3lb/MMacfm)	15.0
10/9/2011	4:30pm	Long term (3lb/MMacfm)	17.7
10/10/2011	5:00pm	Long term (3lb/MMacfm)	14.7
10/11/2011	3:50pm	Long term (3lb/MMacfm)	15.0
10/12/2011	3:45pm	Long term (3lb/MMacfm)	16.0
10/13/2011	3:15pm	Long term (3lb/MMacfm)	18.7
10/14/2011	2:50pm	Long term (3.5lb/MMacfm)	18.7
10/15/2011	2:15pm	Long term (3.5lb/MMacfm)	13.3
10/16/2011	4:15pm	Long term (3.5lb/MMacfm)	19.0
10/17/2011	4:20pm	Long term (3.5lb/MMacfm)	13.3
10/18/2011-1	4:40pm	Long term (3.5lb/MMacfm)	15.3
10/18/2011-2	4:40pm	Long term (3.5lb/MMacfm)	14.7
10/19/2011-1	10:45am	Long term (3.5lb/MMacfm)	19.0
10/19/2011-2	10:45am	Long term (3.5lb/MMacfm)	20.3
10/19/2011-3	3:30pm	Long term (3.5lb/MMacfm)	15.7
10/19/2011-4	3:30pm	Long term (3.5lb/MMacfm)	18.3

The green ball Hg content varied from a low of 10.6 ng/g to a high of 20.3 ng/g, or nearly by a factor of two.

The data is presented graphically in Figure 13. The variation in green ball mercury level is easier to observe in this format.

Figure 13. Hg Content in Green Ball Samples



Multiclone Dust Analysis

The multiclone dust samples collected during the trial are listed in Table 9.

Table 9. Multiclone Dust Samples Collected during the Trial

Date	Time	Operation	Analysis
9/18/2011	2:15pm	Baseline	Hg, LOI
9/19/2011	3:30pm	Baseline	Hg, LOI
9/20/2011	9:00am	Baseline	Hg, LOI
9/22/2011	5:20pm	Plain AC (5lb/MMacfm)	Hg, LOI
9/24/2011	1:45pm	Parametric (2lb/MMacfm)	Hg, LOI
9/25/2011	2:20pm	Parametric (4lb/MMacfm)	Hg, LOI
9/26/2011	12:30pm	Parametric (2lb/MMacfm)	Hg, LOI
9/27/2011	9:45am	Parametric (5lb/MMacfm)	Hg, LOI
10/7/2011	2:30pm	Long term (3lb/MMacfm)	Hg, LOI
10/8/2011	12:45pm	Long term (3lb/MMacfm)	Hg, LOI
10/9/2011	4:25pm	Long term (3lb/MMacfm)	Hg, LOI
10/10/2011	5:00pm	Long term (3lb/MMacfm)	Hg, LOI
10/11/2011	3:45pm	Long term (3lb/MMacfm)	Hg, LOI
10/12/2011	3:45pm	Long term (3lb/MMacfm)	Hg, LOI
10/13/2011	3:15pm	Long term (3lb/MMacfm)	Hg, LOI
10/14/2011	2:30pm	Long term (3.5lb/MMacfm)	Hg, LOI
10/15/2011	2:15pm	Long term (3.5lb/MMacfm)	Hg, LOI
10/16/2011	4:15pm	Long term (3.5lb/MMacfm)	Hg, LOI
10/17/2011	4:20pm	Long term (3.5lb/MMacfm)	Hg, LOI
10/18/2011	4:40pm	Long term (3.5lb/MMacfm)	Hg, LOI
10/18/2011	4:40pm	Long term (3.5lb/MMacfm)	Hg, LOI
10/19/2011	10:45am	Long term (3.5lb/MMacfm)	Hg, LOI
10/19/2011	10:45am	Long term (3.5lb/MMacfm)	Hg, LOI
10/19/2011	3:30pm	Long term (3.5lb/MMacfm)	Hg, LOI
10/19/2011	3:30pm	Long term (3.5lb/MMacfm)	Hg, LOI

The LOI values should be a negative number since weight is expected to be lost during the heating process. However, the multiclone dust is composed primarily of various forms of iron oxide as can be seen in Table 10.

Table 10. XRD Analysis of Multiclone Dust

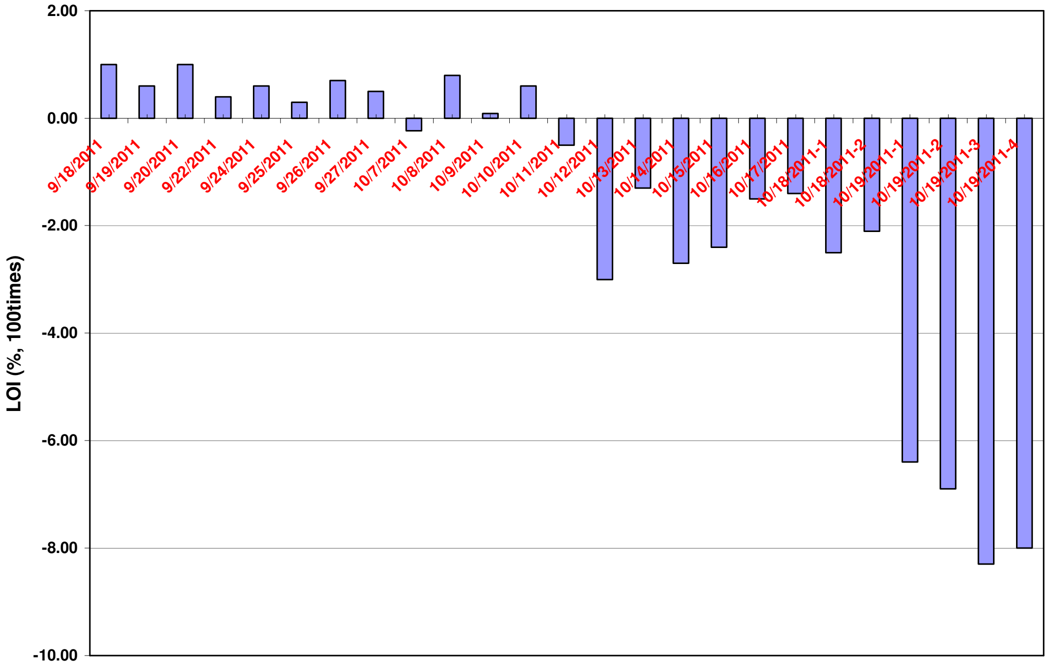
Sample	Magnetite (wt%)	Hematite (wt%)	Silicon Oxide (wt%)
9-19 sample	62.6	30.8	6.6
9-23 sample	58.4	33.3	8.4
10-13 sample	53.0	40.7	6.3
10-16 sample	53.6	39.4	7.0

At the high temperature conditions present in LOI analyses, magnetite (Fe3O4) can be converted to hematite (Fe2O3) as by Equation 1 to cause a weight gain of 3.5% for each magnetite particle oxidized.

$$2Fe_3O_4 + 1/2\,O_2 \rightarrow 3(\alpha - Fe_2O_3) \qquad (1)$$

It can be seen from Table 8 that the multiclone dust has a high percentage of magnetite and, thus, a weight gain in the analysis might be expected. The LOI results for the mulitclone dust samples are presented in Figure 14.

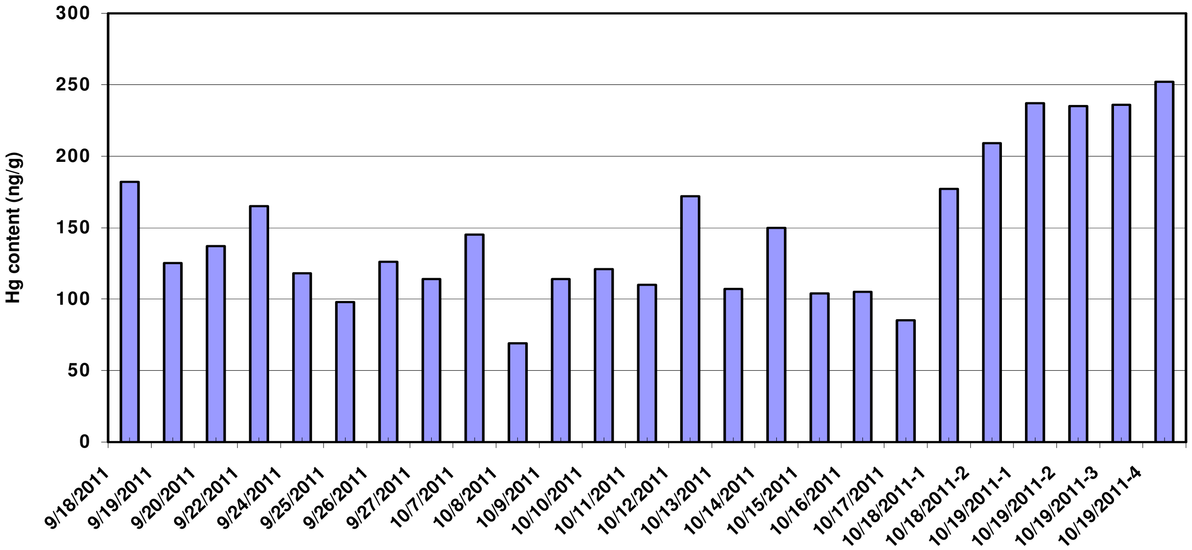
Figure 14. LOI Results for Multiclone Dust Samples



The LOI analyses of the dust samples did provide positive values up until the time of the continuous run when sorbent injection was around the clock. At that point, the LOI turned negative indicating that some of the B-PAC™ sorbent was being collected in the multiclone. This probably had a detrimental impact upon mercury removal since some of the sorbent was removed after a very short residence time and did not have an opportunity to fully capture mercury.

The mercury data from the multiclone samples is shown in Figure 15. The mercury content of the multiclone dust samples bounced around the average of all samples until the LOI content jumped well into the continuous run. Then the mercury content of the multiclone dust jumped to as high as 70% above the average mercury content of all samples. Thus, the sorbent being captured in the multiclone was capturing mercury but not as effectively as if it had more residence time in the ductwork. The overall impact on the mercury removal rate was probably small.

Figure 15. Hg Content of Multiclone Dust Samples



Scrubber Water Analysis

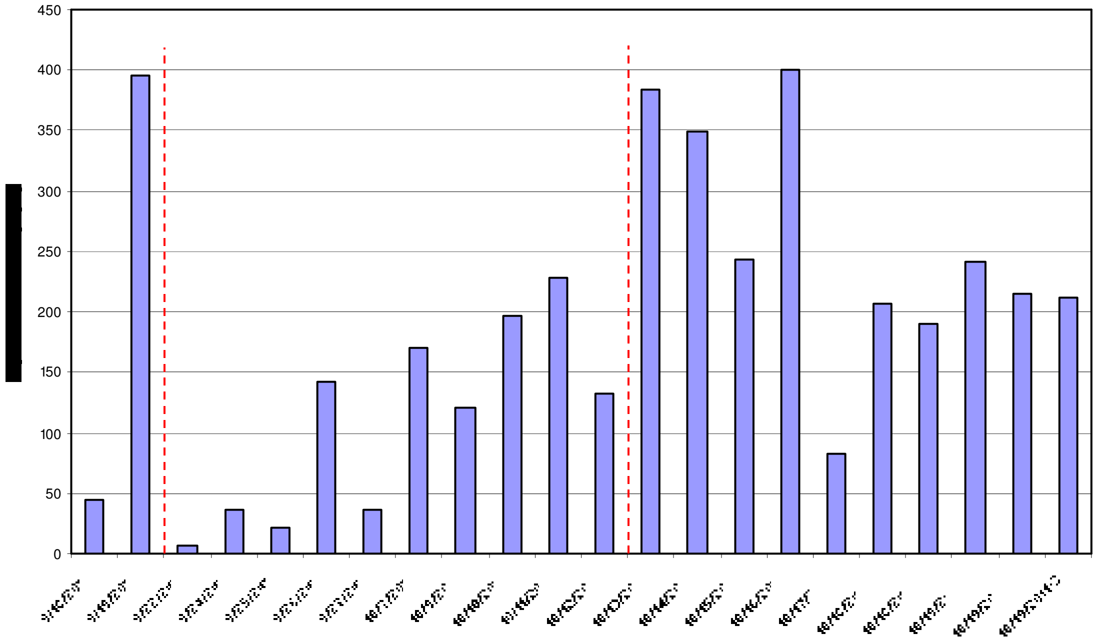
All of the scrubber water samples that were collected during the test period are listed in Table 11. In the last days of the trial, additional samples were taken in order to evaluate the impact of different treatment and storage methods. It should be noted that all samples are grab samples since representative sampling was not possible nor in the scope of the project.

Table 11. List of Scrubber Water samples

Date	Time	Storage Temperature	Operation	Analysis
9/18/2011	2:15pm	Room	Baseline	Hg
9/19/2011	3:30pm	Room	Baseline	Hg
9/22/2011	5:15pm	Room	Plain AC (5lb/MMacfm)	Hg
9/24/2011	1:40pm	Room	Parametric (2lb/MMacfm)	Hg
9/25/2011	2:20pm	Room	Parametric (4lb/MMacfm)	Hg
9/26/2011	12:30pm	Room	Parametric (2lb/MMacfm)	Hg
9/27/2011	9:35am	Room	Parametric (5lb/MMacfm)	Hg
10/7/2011	2:35pm	Room	Long term (3lb/MMacfm)	Hg
10/9/2011	4:30pm	Room	Long term (3lb/MMacfm)	Hg
10/10/2011	5:00pm	Room	Long term (3lb/MMacfm)	Hg
10/11/2011	3:50pm	Room	Long term (3lb/MMacfm)	Hg
10/12/2011	3:45pm	Room	Long term (3lb/MMacfm)	Hg
10/13/2011	3:15pm	Room	Long term (3lb/MMacfm)	Hg
10/14/2011	2:50pm	Room	Long term (3.5lb/MMacfm)	Hg
10/15/2011	2:15pm	Room	Long term (3.5lb/MMacfm)	Hg
10/16/2011	4:15pm	Room	Long term (3.5lb/MMacfm)	Hg
10/17/2011	4:20pm	Room	Long term (3.5lb/MMacfm)	Hg
10/18/2011	4:30pm	4^{o}C	DI water	Hg
10/18/2011	4:30pm	4^{o}C, w/HNO3	DI water	Hg
10/18/2011	4:30pm	Room	DI water	Hg
10/18/2011	4:50pm	4oC	Long term (3.5lb/MMacfm)	Hg
10/18/2011	4:50pm	4^{o}C, w/HNO3	Long term (3.5lb/MMacfm)	Hg
10/18/2011	4:50pm	Room	Long term (3.5lb/MMacfm)	Hg
10/18/2011	4:50pm	Room	Long term (3.5lb/MMacfm)	Hg
10/19/2011	10:45am	4^{o}C, w/HNO3	Long term (3.5lb/MMacfm)	Hg
10/19/2011	10:45am	4oC	Long term (3.5lb/MMacfm)	Hg
10/19/2011	10:45am	Room	Long term (3.5lb/MMacfm)	Hg
10/19/2011	10:45am	Room, w/HNO3	Long term (3.5lb/MMacfm)	Hg
10/19/2011	3:30pm	4^{o}C, w/HNO3	Long term (3.5lb/MMacfm)	Hg
10/19/2011	3:30pm	4oC	Long term (3.5lb/MMacfm)	Hg
10/19/2011	3:30pm	Room	Long term (3.5lb/MMacfm)	Hg
10/19/2011	3:30pm	Room	Long term (3.5lb/MMacfm)	Hg

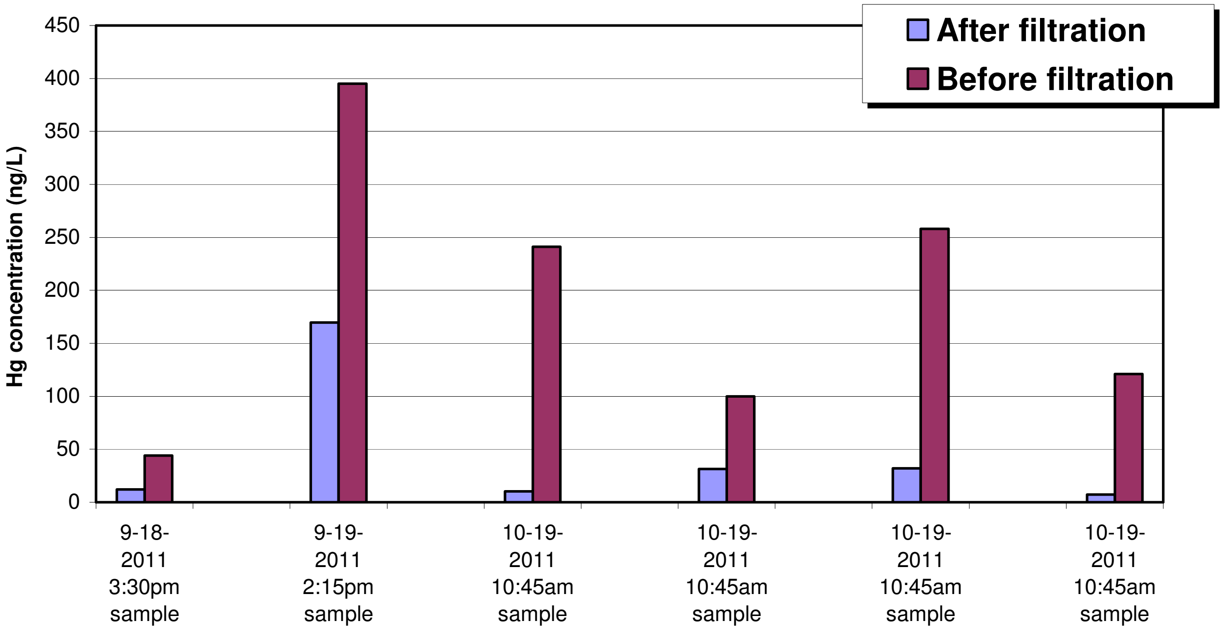
The mercury content of the water samples is presented in Figure 16.

Figure 16. Hg Content in Scrubber Water Samples



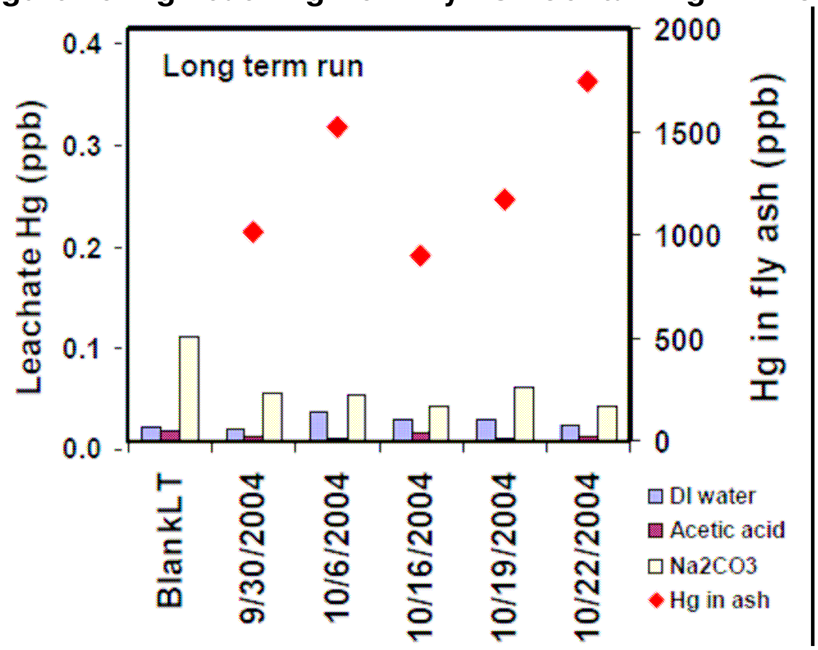
The mercury content of the scrubber water varied between the baseline low value and the baseline high value. The lack of mercury in the scrubber water is not surprising. B-PAC™ is a sorbent that can also capture mercury from water. The impact of filtration on the water samples can be seen in Figure 17.

Figure 17. The Impact of Filtration on Scrubber Water Hg Concentration



The samples were all filtered after the trial using a 0.4 mm glass filter. Filtration greatly reduced the scrubber water mercury concentration. This could be expected since the sorbent had additional capacity onto which the mercury could be captured. This is very similar to the results found when fly ash containing B-PAC™ is put through the U.S. EPA leachate tests. The results from one such series of tests are presented in Figure 18.(1)

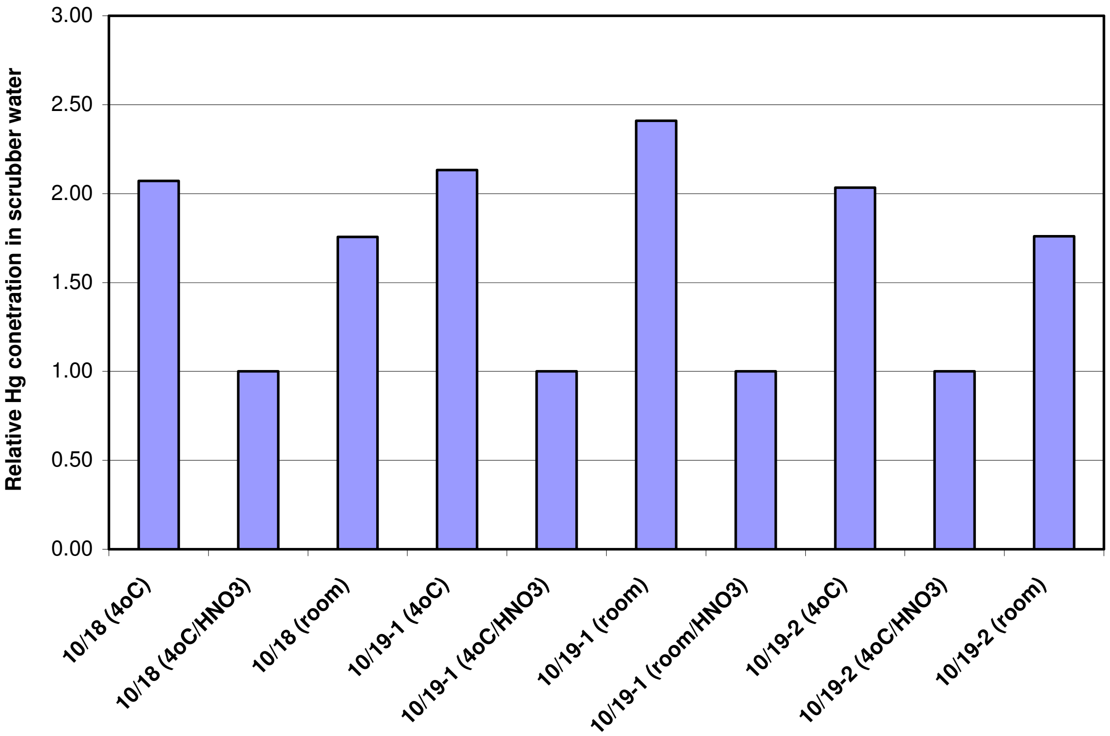
Figure 18. Hg Leaching from Fly Ash Containing B-PAC™



The mercury content of the leachates was below that of the blank in this test series since the sorbent had available mercury capacity and used it on the mercury in the water.

One last evaluation was performed with water samples. The mercury content of samples that had been stored at room temperature were compared to those stored at 4°C. In addition, the mercury content of samples that had been acidified with nitric acid was compared to those that had not. The results of these analyses are presented in Figure 19. There does not appear to be any difference in mercury content of samples stored at room temperature versus those stored at 4°C. This was expected. What was not expected was the impact of acidification. It was thought that acidification would stabilize any mercury in the liquid yielding higher mercury values. Just the opposite was the case. Acidification appears to have driven the mercury into the solids contained in the liquid.

Figure 19. Hg Content of Scrubber Water Treated in Different Manners



Summary and Conclusions

Sorbent testing using both plain and gas-phase brominated B-PAC™ was conducted in 2011 at Hibbing Taconite Line 1. The test program was divided into six tasks. Task 1 was the preliminary site visit to Hibbing Taconite, which was conducted on March 1, 2011. Hibbing Taconite had been selected by MN DNR as the host for the trial. Task 2 of the project was the pre-trial testing which was conducted at Hibbing Taconite from May 30 through June 4, 2011. Task 3 of the project was for equipment preparation while Task 4 was the field trial, which began on 9/13/2011 and ended on 10/22/2011. Task 5 was the analysis of the samples and data collected during the field trial while Task 6 was final report preparation of this report.

The following conclusions were made:

1. It was necessary to inject sorbent into both the Windbox and Hood Exhaust gas streams in order to achieve the target of 75% mercury removal.
2. The target of 75% mercury removal was achieved with an injection rate of about 3 lb/MMacf of B-PAC™.
3. It is believed that even better performance would have been achieved if the desired injection locations could have been utilized, since some sorbent was captured in the multiclone.
4. The 75% mercury reduction target was achieved throughout the two-week continuous run.
5. The scrubber water mercury content did not increase during sorbent injection but the mercury content in the scrubber solids did increase.
6. Storage temperature had no impact on the measured mercury concentration in the scrubber liquor samples but acidification did.
7. The four stacks at Hibbing Taconite Line 1 were very wet making mercury analysis a challenge, especially for sorbent traps and for some particulate separators associated with Hg CEMs.

Recommendations

The trial discussed in this report had limitations which should be addressed in a future trial. The next trial should address the following:

1. The current trial had a continuous run of only two weeks at one plant. A trial lasting several months should be conducted to further verify the long-term performance of the gas phase brominated sorbent at a different taconite facility.
2. Representative green ball and scrubber liquor samples should be collected in order to complete a mercury balance of the system.
3. Better sampling techniques should be developed for sorbent traps.
4. Better injection locations should be utilized in order to obtain better sorbent distribution and, thus, better mercury removal.

References

1. Landreth, R.R., “Advanced Utility Mercury-Sorbent Field-Testing Program”, Final Report to the United States Department of Energy, September 15, 2011.

APPENDICES

A. List of Figures

B. List of Tables

C. List of Photographs

D. DQAW

Appendix A

List of Figures

List of Figures

Appendix B

List of Tables

List of Table

Appendix C

List of Photographs

List of Photographs

Appendix D

DQAW

Title of Project: Mercury Control for Taconite Plants Using Gas-Phase Brominated Sorbents
Project Leader: Ron Landreth
Date Submitted: May 10, 2011, Rev 5 Final

(1) Method Description/Key Parameters:

a. For which taconite plants are the test results from this study most applicable?
   i. Testing will be performed on the Hibbing Taconite Plant but it is believed that this B-PAC™ technology may be viable for all the plants in this project.
   ii. Provide an explanation.
      1. Brominated powdered activated carbon, B-PAC™, has been injected into wet and dry scrubbers to successfully control mercury emissions in the utility industry. It has been shown that the mercury captured on the carbon does not leach in wet environments such as scrubbers. It is believed that the B-PAC™ can work similarly in the exhaust gas scrubbing systems of taconite plants.

b. What specific equations are being used to evaluate Hg removal efficiency from the process stream in your experiment or test?

i. Percent reduction basis – for a single pellet product and each B-PAC injection rate, establish percent mercury reduction of stack emissions as measured by a mercury CEM, continuous emission monitor. Uncontrolled mercury emission concentration is measured in a pre-injection test period.

$$Hg \quad removal(\%) = \left(1 - \frac{Controlled \quad gas \quad mercury \quad concentration}{Uncontrolled \quad gas \quad mercury \quad concentration}\right) \times 100$$

(2) Data Quality Assessment for key variables:

a. For all variables in the equation for 1(b), what are the baseline values for these parameters in the uncontrolled process stream? Provide an estimate of the uncertainty in these variables (1 SD) and describe how this uncertainly was obtained or estimated.
   i. The uncontrolled mercury concentration will be measured during a period before injection of B-PAC™. This pre-injection concentration will be used for calculating the percent reduction of mercury during sorbent injection.
   ii. Uncertainty :

CEM accuracy: 5% uncertainty (1SD) (provided by instrument vendor)

b. For all variables in the equation for 1(c), what are the baseline values for these parameters in the uncontrolled process stream? Provide an estimate of the uncertainty in these variables (1 SD) and describe how this uncertainly was obtained or estimated.

c. For each variable in 2a and 2b provide the location of raw data and field logs. These records will be kept for a period of at least three years following acceptance of the final report. See section D in this QAPP for information on how these files will be used.
    i. Raw data and field logs to be kept electronically in Baton Rouge at Albemarle Corporation’s Product Development Center.

(3) <u>Mercury Removal Estimates</u>:

a. <u>Quantitative estimates:</u> For a taconite plant currently emitting 100 units of mercury per unit time, what do the test results suggest mercury emission rates would be with application of the technology? Using the values in (2), calculate the error (1 SD) in this estimate. As an example, a value of “25 +/- 5” implies 25 units of mercury would be emitted per unit time and that the error in this estimate is 5 units (1 SD) of mercury per unit time).
    i. Estimated mercury reduction based on utility plant testing, >75% with B-PAC™ injection rate of 2 to 4 lb/MMacf of exhaust gas
    ii. The uncertainty (1SD) of the Tekran Hg CEM measurement is 5%. For a taconite plant currently emitting 100 units of mercury per unit time, to reach 75% Hg removal, the final stack hg emission is 25 unit+/-1.25 unit, the estimated measurement error is 1.25 units.

b. <u>Qualitative Factors:</u> For the tests being considered, list critical components of experimental design that were not quantified but which may affect mercury removal in the actual process. For example, if certain components are known to contaminate or interfere with chemical additives, these should be listed.
    i. Sulfur trioxide, SO_3, in the Windbox exhaust gas could compete with mercury for capture sites on the B-PAC™. SO_3 will be measured in the Windbox exhaust gas during the testing.
    ii. Iron oxide interactions with mercury vapor could affect mercury speciation in sampling gas stream.