Developing Cost-Effective Solutions to Reduce Mercury Emissions from Minnesota Taconite Plants

United Taconite Plant

Final Report

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DISCLAIMER

Summary of Acronyms, Abbreviations, and Chemical Symbols

AC	Activated Carbon
ADA-ES or ADA	ADA Environmental Solutions
EPA	Environmental Protection Agency
Hg	Mercury
H_r	Relative Humidity
KT	Kepner-Tregoe
MnDNR	Minnesota Department of Natural Resources
MIM	Mercury Index Method
MTMCAC	Minnesota Taconite Mercury Control Advisory Committee
RPD	Relative Percent Difference
STM	Sorbent Trap Method, modified EPA Method 30B
TMDL	Total Maximum Daily Load

Executive Summary

In 2009, the Minnesota Pollution Control Board developed an Implementation Plan to reduce Minnesota's statewide mercury Total Maximum Daily Load (TMDL). As part of this plan, the taconite industry set a target of 75% reduction in the 2010 mercury air emissions by 2025[1]. ADA Environmental Solutions (ADA) proposed a project to The Minnesota Department of Natural Resources (MnDNR) to develop cost-effective solutions to meet the industry goal by reducing mercury emissions from taconite plants by 75%. ADA was contracted to determine if activated carbon (AC) was a viable sorbent to control mercury in process gas from taconite plants when used in a fixed-bed application. The project was funded by the United States Environmental Pollution Agency (US-EPA), facilitated by the MnDNR, and coordinated by the Minnesota Taconite Mercury Control Advisory Committee (MTMCAC). Field testing was conducted at three taconite plants. This report applies specifically to United Taconite (UTac), Eveleth, Minnesota.

There were four main tasks defined in the Work Scope for Part 1. The four tasks are listed below.

Task 1. Slipstream Testing. Screening tests included the relative performance of test materials in actual process gas, impact of relative humidity on performance, and impact of process gas on mercury capture performance compared to controlled laboratory conditions.
Task 2. Develop a Full-Scale, Integrated Fixed-Bed Process Concept
Task 3. Techno-Economic Analysis of Mercury Control Options
Task 4. Pilot-Scale Fixed-Bed Design

Task 1 - Sorbent Screening Slipstream Testing

Screening was conducted using the Mercury Index Method (MIM), a tool based on EPA Reference Method 30B that was developed by ADA for the project. Stack gas from a taconite process was drawn through tubes containing AC sorbents. Each tube contained two sections, the first containing the AC under evaluation mixed with sand, and the second containing a standard EPA Method 30B AC. The Method 30B AC was sufficient to capture all the mercury contained in the sample gas for several days to weeks. The effectiveness of the test AC was determined by measuring the mercury captured in both sections and determining the fraction that passed through the first section into the section containing the Method 30B AC.

Results from Task 1 indicate that all test AC sorbents were effective for mercury removal at UTac. Test sorbents included a sulfonated, granular, coconut shell-based carbon; an untreated, pelletized, anthracite-coal based carbon; and a sulfonated, pelletized, anthracite-coal based carbon. The material that comparatively captured the most mercury was the sulfur-treated coconut-shell (CR612C-Hg). Performance sensitivity to changes in process conditions will affect the full-scale design. Therefore, CR612C-Hg was tested in process gas with relative humidity between 50% and 67%. There was no significant impact in mercury capture performance as a result of changes to the relative humidity. Also, mercury removal results

from laboratory testing in dry nitrogen were very similar to results from slipstream tests at UTac, indicating that nothing in the process gas at UTac during the test period negatively impacted the mercury removal effectiveness. These results are consistent with results from testing conducted at the other two taconite plants.

Task 2 - Develop a Full-Scale, Integrated Fixed-Bed Process Concept

Task 1 screening results and full-scale design criteria were used by activated carbon applications expert Ray Johnson, PhD, to develop a full-scale fixed-bed conceptual design for UTac using a design flow of 493,000 ACFM, which represents one line at UTac. The design incorporates 11 vessels containing beds of carbon that are each 47 feet long and 12-feet wide and 3 feet deep. An estimated 813,850 lbs of AC are required to fill the beds. The estimated pressure drop across is 6 to 12 inches of water. The amount of carbon that would be used per year to maintain 100% mercury capture was projected to be 138,108 lbs. The estimated requirements for both lines at Utac are 22 vessels, 1,627,700 lbs of carbon to load the beds, and 276,216 lbs of replacement carbon per year. This initial concept design would need to be validated through longer-term pilot testing.

Task 3 - Techno-Economic Analysis

The relative technical and economic characteristics of seven mercury control technologies were compared using a Kepner-Tregoe (KT) decision-making approach by Stantec Consulting Ltd. The fixed-bed method to control mercury was determined to provide good performance but at relatively high cost compared to other options. The high cost was a result of several factors including the number of vessels required and the associated plant integration, and the expected pressure drop across the beds. AC injection was identified as the most promising technology using this approach.

Task 4 - Pilot Plant Design

The estimated cost of a pilot-scale fixed-bed system appropriate to collect detailed information required for a robust full-scale design is $50,000. All testing costs would be in addition to the cost of the equipment.

Task 1 results indicate fixed-beds of activated carbon can reliably achieve the taconite industry's goal of 75% mercury control. However, based on the Task 2 concept design and the Task 3 relative comparison of technical and economic factors, a fixed-bed approach to control mercury from the process gas at UTac is expected to be more costly than other approaches and require multiple, large, interconnected vessels. Therefore, ADA does not recommend continued development and testing of fixed-bed technologies for mercury control from the process gas at UTac. Based on results from Task 3, ADA recommends consideration of AC injection as a lower cost option to apply AC to meet the industry goal of 75% mercury control.

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1. Project Overview

In 2009, the Minnesota Pollution Control Board developed an Implementation Plan to reduce Minnesota's statewide mercury Total Maximum Daily Load (TMDL). As part of this plan, the taconite industry set a target of 75% reduction in the 2010 mercury air emissions by 2025[1]. ADA Environmental Solutions (ADA) proposed a project to The Minnesota Department of Natural Resources (MnDNR) to develop cost-effective solutions to reduce meet the industry goal by reducing mercury emissions from taconite plants by 75%. The ADA proposal was a three-part study to assess the use of activated carbon based technologies. The first part of the study (Part 1) was to determine if activated carbon (AC) was a viable sorbent to control mercury in process gas from taconite plants. Part 2 was pilot-scale testing, and Part 3 was full-scale validation. Only Part 1 of ADA's proposal was approved, and ADA was contracted to focus on fixed-bed applications of AC. The project was funded by the United States Environmental Pollution Agency (US-EPA), facilitated by the MnDNR, and coordinated by the Minnesota Taconite Mercury Control Advisory Committee (MTMCAC). Field testing was conducted at three taconite plants. This report applies specifically to United Taconite (UTac), Eveleth, Minnesota.

There were four main tasks defined in the Work Scope for this project, and the key Task 1 objectives, are listed below.

Task 1. Sorbent Screening Tests

- Compare the performance of different AC and select the best performer based on mercury adsorption capacity and break through.
- Study the effects of relative humidity (H_r) on the performance of AC.
- Determine if any constituent in taconite process gas negatively impacts mercury capture.

Task 2. Develop a Full-Scale, Integrated Fixed-Bed Process Concept

Task 3. Techno-Economic Analysis of Mercury Control Options

Task 4. Pilot-Scale Fixed-Bed Design

2. Technical Approach

Task 1. Sorbent Screening

ADA developed the Mercury Index Method (MIM) and performed sorbent screening tests on commercially available AC on Stack 2A at Utac's production line. The MIM is a derivative of EPA Method 30B[2], an industry standard for measuring mercury in a process gas. During MIM testing, stack gas from a taconite process was drawn through tubes containing AC sorbents. Each tube contained two sections, the first containing the AC under evaluation mixed with sand, and the second containing a standard EPA Method 30B AC. The Method 30B AC was sufficient to capture all the mercury contained in the sample gas for several days to weeks. The effectiveness of the test AC was determined by measuring the mercury captured in both sections and determining the fraction that passed through the first section into the section containing the Method 30B AC. The percent mercury contained in the second section is classified as the percent breakthrough from the first trap to the second trap. No breakthrough (0%) indicates all mercury was captured in the section of test AC. Full breakthrough (100%) indicates that the test AC did not capture any mercury and it all passed to the section containing the Method 30B carbon. A description of the MIM method is included in Section 4, Test Methods and Materials.

In the MIM trap, the first section AC is replaced with a mixture of inert material and small amounts of the powdered AC under evaluation. Although granular or pelletized carbon is typically used in a full-scale fixed-bed system, powdered AC is used for screening tests so that the mass of AC used can be limited to manage the test duration to hours rather than weeks or months. Screening tests to determine viability and relative performance are often conducted prior to investing resources into long-term field testing. A typical fixed-bed pilot-scale test would be designed so that breakthrough on a single carbon may take weeks or months, which can add unnecessary time and costs when the goal is initial screening. While long-duration tests are not appropriate for a screening tool, these are required to collect the information required for a robust and detailed full-scale design and would be appropriate if the project progressed to Part 2, pilot testing.

Task 1 included three objectives. The Task 3 activities were divided into three phases to address the three objectives. These phases are described below.

<u>Phase 1: Relative Efficacy of Various AC Types</u>

To achieve the first Task 1 objective, ADA tested four carbons at one, three, and ten hour periods to determine the relative performance of the materials. The criteria established compare relative performance was breakthrough from the section of test AC to the section of Method 30B AC. Percent breakthrough is defined as the mass of mercury in the second trap section divided by the total collected in both sections. It was determined in the lab before the test that a ten hour period was sufficient to assure significant breakthrough. Tests were repeated on separate days as a quality assurance measure. For all tests in Phase 1, the relative humidity, H_r, was maintained at 50%, and each trap was sampled at the same gas extraction rate. Once sampling was complete, the traps were returned to ADA's laboratory in Littleton, CO and analyzed with the Ohio Lumex analyzer.

Phase 2: Evaluate the Effect of Relative Humidity

The second Task 1 objective was to determine the effect of H_r on carbon performance in fixed beds. High H_r is known in the industry to negatively impact performance. The effect of H_r may have important ramifications on the design of a full-scale fixed-bed system. If high humidity reduces mercury adsorption, a costly preheating or drying system may be required upstream of the fixed bed system.

The best performing sorbent from Phase 1 testing and the standard were tested simultaneously at each H_r levels for one, three, and ten hour periods. The stack gas at HibTac was measured (wet bulb/dry bulb method) at an H_r of 67%. Therefore, tests were conducted at 67%, and 50% H_r. H_r was easily adjusted by changing the operating temperature of the aluminum heating block at the tip of the MIM probe containing the sorbent traps. The traps were returned to ADA for analysis.

Phase 3: Impacts of Process Gas Constituents

The final Task 1 objective was to determine if any constituent in taconite process gas could negatively impact carbon performance. Constituents such as sulfur trioxide have been shown to impact the effectiveness of AC for mercury capture in the utility industry[3].

Performance data from MIM testing at UTac was compared to similar tests performed at ADA under ideal lab conditions using mercury in dry nitrogen. Nine traps were run and the results averaged. These results were then compared to MIM field data collected at UTac. Any significant decrease in sorbent screening performance could then be attributed to a constituent in the gas that prevented or decreased mercury capture on the carbon. The laboratory test apparatus consisted of standard Method 30B equipment, and a Thermo Fisher 81i Mercury Calibrator to generate a gas stream with a steady mercury concentration of $10 \mu g/m^3$. This mercury concentration was selected based on prior discussions with the plant and was decided to be a safe, high-end representative of the expected mercury emissions. The same type of MIM traps were used in the laboratory and in the field.

STM Sampling

ADA also performed sorbent trap method (STM) measurements on the stack not used for MIM testing, Stacks 2B. The test was done to determine the mercury variability between stacks. A description of the STM is included in Section 4 Test Methods and Materials.

Although the MIM results provide valuable insights, it should be stressed that the results do not provide all the information needed to design a full-scale fixed-bed system, nor can they be used to directly predict full-scale fixed-bed performance. For example, 100% mercury capture cannot be definitively demonstrated using the MIM technique because the calculated breakthrough will always be > 0% due to the trace levels of mercury present in the section 2 trap prior to exposure to process gas.

Task 2. Integrated Full-Scale Fixed-Bed Process Concept

ADA contracted with Ray Johnson, PhD, the principal consultant with Activated Carbon Technologies, LLC, to develop a full-scale integrated fixed-bed process concept based on results from screening tests from UTac in combination with other data available in the industry, and a Design Guide developed by the U. S. Army Corps of Engineers[4]. Dr. Johnson has been in the activated carbon industry for 40 years, and he has first-hand knowledge of the two primary carbon production processes, chemical and thermal activation, plus thermal reactivation/recycle of previously used carbon.

Screening tests, such as those conducted during Task 1, can and are utilized to identify gas streams unsuitable for mercury removal by AC. For gas streams where AC is suitable, industry standard design criteria provides for excess mercury removal capacity so that for a well-designed fixed-bed system, 100% mercury removal is achieved until initial breakthrough occurs. Commercial fixed-bed systems are designed to assure that beds are replaced or recharged well before initial mercury breakthrough is expected. Pilot tests are typically conducted to collect the data necessary, including breakthrough characterization, to complete the design engineering of the full-scale systems.

Task 3. Techno-Economic Assessment

ADA subcontracted Stantec Consulting Ltd. to compare the different technical and economic aspects of seven mercury control technologies using a Kepner-Tregoe (KT) decision-making approach[5]. The selected control technologies were identified by ADA as options for mercury control at taconite facilities and presented to the industry for approval during an industry update meeting on April 2, 2012. This presentation is included in Appendix D for reference. The selected technologies were: 1) monolithic polymer resin adsorber, 2) AC injection, 3) oxidant chemical addition, 4) AC injection + fabric filter; 4) AC fixed-bed adsorber, 5) AC fixed-bed adsorber + fabric filter, and 6) AC monolith.

Task 4. Pilot-Scale Design

Dr. Johnson prepared a design and parts list for a pilot system to complete the obligations of this project.

3. United Taconite Plant System Description

The UTac Plant processes iron ore and is located along the Mesabi Iron Range near the town of Eveleth, Minnesota. The plant uses a grate and kiln furnace type for its indurating process and burns a combination of fuels including natural gas, fuel oil, petroleum coke and Eastern coal. Line 2 at the UTac plant has two stacks, 2A and 2B. Figure 1 is a flow diagram of the UTac processing plant.

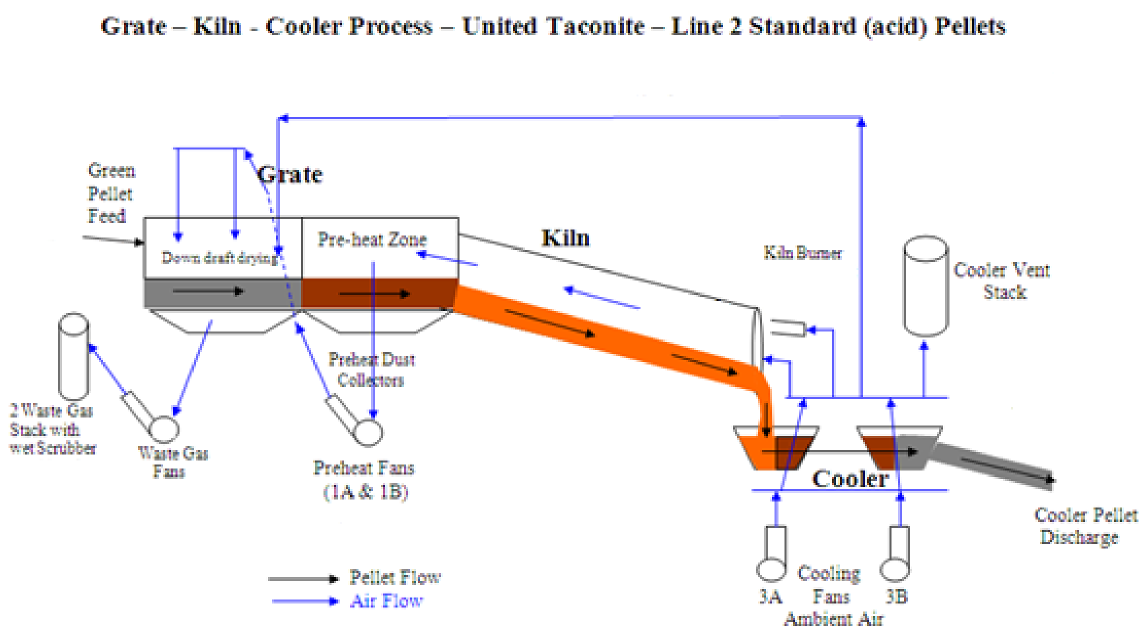

Figure 1: UTac Process Flow Diagram

ADA performed all testing on the Line 2 stacks downstream of the venturi wet scrubber. This was determined by the MnDNR, UTac and ADA to be the best test location because it typically has the highest Hg concentration and is most representative of the gas stream that would be routed to a retrofitted fixed-bed treatment system. Test equipment was installed at existing sample ports on Stack 2A. Two sample ports were used on Stack 2A so that four sorbents could be run simultaneously. STM measurements were also performed on Stack 2B to confirm that this stack had the highest Hg concentration.

4. Test Methods and Materials

This section describes the testing methods that were used by ADA, including the Quality Assurance (QA) Program, and descriptions of the selected sorbents.

EPA Method 30B and Sorbent Trap Method

EPA Reference Method 30B[2] is commonly used in the electric utility industry to measure gas-phase mercury in flue gas. ADA's Sorbent Trap Method (STM) is Method 30B with slight modifications to some of the quality assurance criteria.

Both methods utilize two sections of 10 mm diameter glass tubes loaded with AC (trap) to capture mercury. Two carbon-filled glass tubes are inserted into the tip of the sampling probe which is then inserted directly into the gas stream. A measured volume of gas is drawn through the glass tubes, or mercury traps, at a constant flow rate. Mercury is captured by the AC. The traps are then analyzed for mercury in the laboratory using standard analytical techniques that meet specifications described Method 30B. For the traps used in this program, the carbon was heated to thermally desorb the mercury and the mercury was measured using atomic absorption spectroscopy. The concentration of mercury in the gas is calculated by dividing the mass captured by the gas volume drawn through the trap.

Each trap section normally contains enough carbon to adsorb several weeks of mercury. The second section of AC is used as a back-up for the first trap to capture any mercury that breaks through. If more than 10% of the total mercury is measured in the second section, the trap does not pass the quality assurance criteria. This is an EPA Method 30B criterion and effectively sets the upper limit for the relative amount of mercury that can be present in the "blank" carbon used to fill the traps. A more detailed description of the STM technique and a table showing the differences between the STM and Method 30B is included in Appendix E.

Mercury Index Method

ADA developed the Mercury Index Method (MIM) as a relatively simple method to quickly compare the mercury capture characteristics of various sorbents under a variety of process conditions. The MIM is a derivative of EPA Method 30B where the Method 30B AC in first section of the sampling tube is replaced with a very small amount of test AC mixed with an inert medium. The second section of the glass tube is the standard Method 30B AC-filled tube. The amount of test AC in the first section is limited so that the test AC will become completely saturated with mercury within a few hours. Any mercury that passes through the first section is captured by the AC in the second section. Figure 2 shows a MIM sorbent trap with the sections labeled.

The goal of the MIM screening tests is to achieve typically more than 20% and less than 80% breakthrough from the first (test) trap to the second (Method 30B AC) trap so that the relative performance of different test AC materials can be compared. Other key operating procedures are similar to the EPA Method 30B testing protocol.

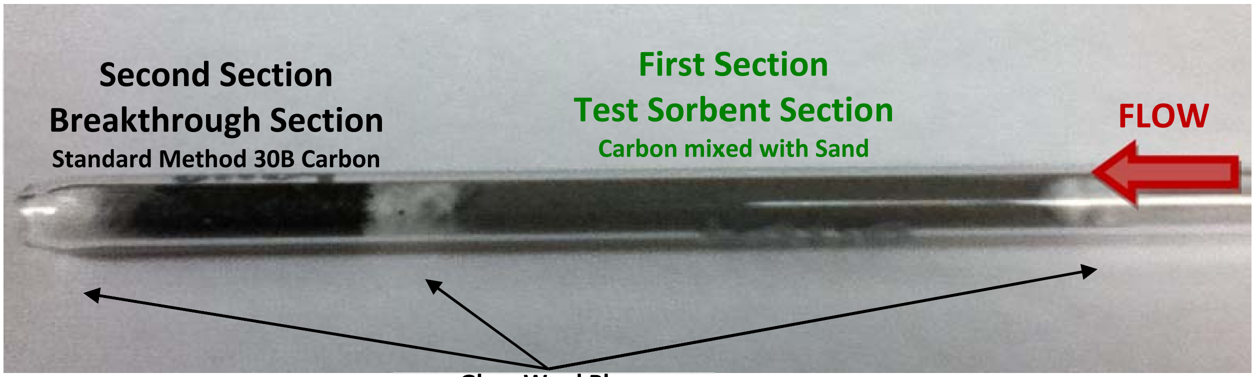

Figure 2: MIM Sorbent Trap

ADA assembled each of the test traps in a clean lab, beginning with empty, 10 mm diameter, standard, Method 30B glass tubes. The four sorbents were each ground and sieved until 95% by weight passed through a 325 mesh (45μm) screen and then mixed with an inert medium. The mixture was put into separate traps and backed up with a standard carbon section. Sections of the trap were separated by glass wool plugs.

Standard Method 30B sampling systems, model Hg-324K by the Environmental Supply Company, were used for the MIM tests. These systems consist of a probe, sample line, water knock outs and gas measurement and control console. Two MIM sorbent traps were inserted into the tip of each of two probes so that four sorbents could be tested simultaneously. Test duration, sample flow rate, and test bed temperature were controlled independently for each pair of traps.

Using the MIM test, the relative performance of a variety of AC samples under various operating conditions can be quickly determined. This allows the researchers to accurately determine the overall suitability of AC for mercury control with actual process gas conditions. Performance can also be compared to results in a controlled laboratory environment with mercury-laden laboratory gas to determine if the actual process gas introduces any trace elements that may interfere with mercury capture by the AC.

Mercury Analysis

Mercury captured in the AC traps was analyzed using an Ohio Lumex RA-915+ mercury analyzer. The procedure meets the requirements of EPA Method 30B and is the typical analytical technique used for this method. The principle of operation is atomic adsorption spectrometry. The two sections of each test trap were analyzed separately in the RP-C91 furnace attachment. The glass wool plugs and any ash drawn into the trap were analyzed with the subsequent trap section. In the RP-C91 furnace attachment, mercury is vaporized and the gas passes through the RA-915+ analyzer. The RA-915+ produces a desorption curve and the mass of mercury emitted from the sample is determine by comparing the area under the curve to a calibration curve created using NIST traceable mercury standards.

Quality Assurance

ADA's Quality Assurance (QA) Program focused on maintaining consistency and accuracy of the sorbent screening and laboratory sampling equipment, the procedures used to collect the samples, and the laboratory equipment and procedures used to analyze the samples. The QA/QC Criteria for this program along with the corresponding corrective action is shown in Table 1. The Data Quality Assessment Worksheet (DQAW) for this program and additional QA information and records are included in Appendix F.

Table 1: Key STM QA/QC Criteria and Corrective Action

	QA/QC Specification (performed by)	Acceptance Criteria	Frequency and Requirement	Corrective Action
STM	Pre-test Leak-check (ADA-ES)	≤4% of target sampling rate	Prior to sampling, sampling lines and probe with sorbent traps in place and capped	Repair Leak. Do not start test unitl leak check is passed
STM	Post-test Leak-check (ADA-ES)	≤4% of average sampling rate	After sampling, sampling lines and probe with sorbent traps in place and capped	Flag data repeat run if necessary
STM	Dry Gas Meter Calibration (Environmental Supply)	Calibration factor (Y) within ±5% of average value from initial (3-point)	Prior to Initial Use: at 3 orifice settings; then Quarterly: at 1 setting	Recalibrate the meter at 3 orifice settings to determine new value of Y.
STM	Temperature Sensor Calibration (Environmental Supply)	Absolute temperature from sensor within ±1.5% of a reference sensor	Prior to Initial Use: then Quarterly	Recalibrate. Sensor not to be used until criteria is met.
STM	Barometer Calibration (Environmental Supply)	Absolute pressure by instrument within ±10mm Hg or reading with a mercury barometer	Prior to Initial Use: then Quarterly	Recalibrate. Intrument not to be used until criteria is met.
STM	Flowmeter Calibration (Environmental Supply)	Calibrate instrument voltage to reference flow until linear	Prior to Initial Use: then Quarterly	Recalibrate. Intrument not to be used until criteria is met.
STM	Flowmeter check (ADA-ES)	Total flow by instrument ±10% of a reference flowmeter	After Initial Use; then after each testing period, not to exceed Quarterly.	Recalibrate. Intrument not to be used until criteria is met.
Lab	Ohio Lumex Calibration (ADA-ES)	Mass of mercury measured within ±10% of mercury standard (≥3 point)	Prior to Initial Use; then daily	Recalibrate. Intrument not to be used until criteria is met.
Lab	Ohio Lumex check (ADA-ES)	Mass of mercury measured within ±10% of mercury standard	After every 10-15 testing runs	Recalibrate. Intrument not to be used until criteria is met.

Note: Additional steps were taken while handling the traps to eliminate possible contamination. The sorbent traps were sealed at both ends with a tight cap and kept inside a sealed plastic bag until ready for use, at which time a clean pair of sampling gloves was worn during handling. The caps were not removed until the last possible moment before inserting the trap in the probe or the stack.

Sorbent Descriptions

Four different sorbents obtained from Carbon Resources, an industry provider of carbon for fixed-bed systems, were selected for Task 1 sorbent screening.

- Sabre 8% Br: Fine-grain, brominated, lignite-based. This sorbent was selected by ADA as the standard sorbent because it is known by ADA to have excellent mercury absorption capacity. However, fine grain material is not appropriate for fixed-bed applications because of the high pressure drop associated with beds of fine material and the likelihood that fine material will be carried out of the bed. Bromination enhances mercury capture of gaseous elemental mercury and may provide better performance at higher temperatures (>325°F) than untreated sorbents. It was ground and sieved for use in the MIM traps.

- CR4AN: Pelletized, untreated, anthracite-based. This carbon is pelletized for use in full-scale applications to provide a large surface area and high mechanical hardness. CR4AN is also noted to have excellent pore volume and chemical stability. It was ground and sieved for use in the MIM traps.

- CR4AN-Hg: Pelletized, sulfonated, anthracite-based. Similar to CR4AN but impregnated with sulfur to react with mercury to form mercuric sulfide. It was ground and sieved for use in the MIM traps.

- CR612C-Hg: Coarse-grained, sulfonated, coconut shell-based. This carbon is also designed to react with mercury to form mercuric sulfide. It was chosen as being different from the other two in that it is granular and coconut shell based. It was ground and sieved for use in the MIM traps.

5. Results and Discussion

Task 1: Screening Tests

Table 2 shows the project schedule for Task 1 as it was actually conducted.

Table 2: Sorbent Screening Test Schedule

United Taconite Test Schedule		8/1/2011	8/2/2011	8/3/2011	8/4/2011	8/5/2011	8/6/2011	8/7/2011	8/8/2011
		M	T	W	Th	F	S	S	M
Test Description									
1	Arrive/Site Safety Orientation (7:00)	X							
2	Install Test Equipment	X	X						
3	Phase 1 - AC Comparison Test on Stack 2A		X	X					
4	Send traps to ADA for analysis			X					
5	Conduct STM Tests on Stack 2B				X			X	
6	Phase 2 - Relative Humidity Test on 2A						X	X	
7	Demobilization								X
8	Phase 3 - Gas Contaminate Study at ADA Lab								

<u>Phase 1: Relative Efficacy of Various AC Types</u>

Phase 1 testing occurred from August 2, 2011 until August 3, 2011 on Line 2 at UTac. The results of Phase 1, shown Figures 3 through 5, are the percent breakthrough (mass of mercury in the second trap section divided by the total mass in both sections) for each of the test runs and duplicate tests (Run 1 and 2, respectively). The "best" performer is defined as the sorbent with the lowest percent breakthrough. The results from Phase 1 were also used to determine which sorbents to use in Phase 2. The AC sorbents are identified as follows: 1) Sabre 8% Br, 2) CR4AN, 3) CR4AN-Hg, 4) CR612C-Hg.

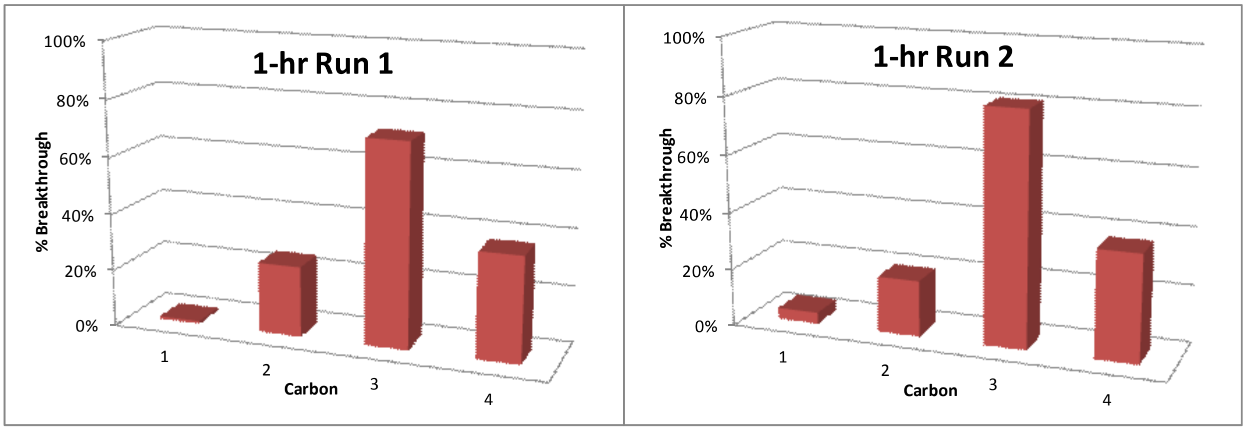

Figure 3: Breakthrough after 1-Hour

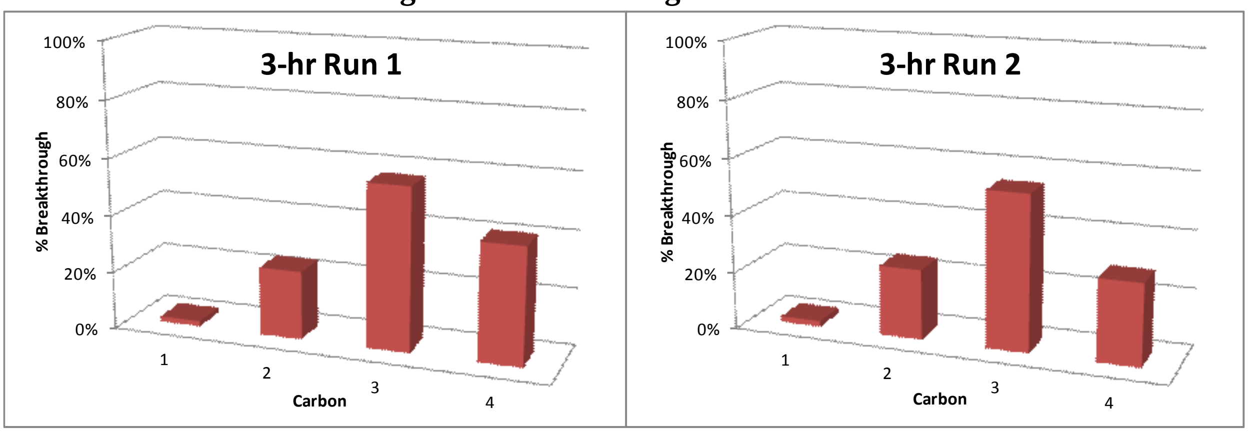

Figure 4: Breakthrough after 3-Hours

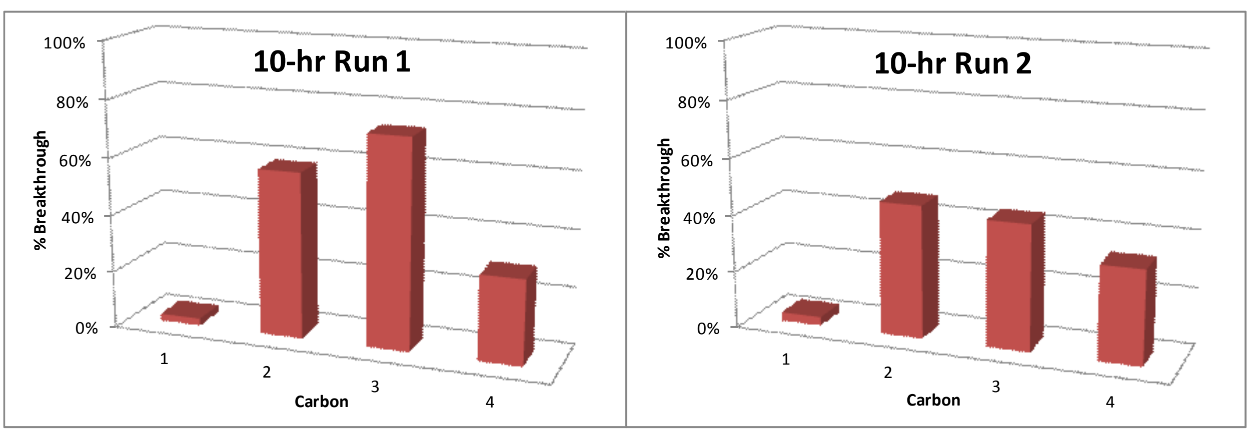

Figure 5: Breakthrough after 10-Hours

The Sabre 8% Br standard carbon had low percent breakthrough, which was expected because it was the benchmark standard chosen for the test. However this product is only offered commercially in powdered form and is therefore not appropriate for use in fixed beds unless it was pelletized. Carbon 3 (CR4AN-Hg) demonstrated the highest mercury breakthrough for all exposure periods.

A decision matrix was developed to rank the performance of the three remaining fixed-bed test sorbents. In Table 3, results from each test run were analyzed separately and each of the three test ACs was given a score based on its comparative performance to the other two ACs. If the AC had the lowest percent breakthrough it was given a score of 3, the median percent breakthrough scored 2, and the highest percent breakthrough scored 1. These scores were then weighted by multiplying them by the test length hours. Weighting was deemed necessary because the ten hour tests are comparatively more important than the shorter tests. The scores for each carbon were then summed, and CR612C-Hg (Carbon 4) was identified as the best performer.

Table 3: Sorbent Performance Decision Matrix

	RUN 1			
	Weighted Multiplier (hrs)			
CARBON	1	3	10	SCORE
2	3	9	20	32
3	1	3	10	14
4	2	6	30	38

	RUN 2			
	Weighted Multiplier (hrs)			
CARBON	1	3	10	SCORE
2	3	9	10	22
3	1	3	20	24
4	2	6	30	38

CARBON	TOTAL SCORE
2	54
3	38
4	76

2: CR4AN, 3: CR4AN-Hg, 4: CR612C-Hg

Similar results were obtained at the two other taconite plants tested by ADA confirming that CR612C-Hg was the best performer. CR612C-Hg was used in Phase 2.

Phase 2: Effect of Relative Humidity

Phase 2 testing occurred from August 6, 2011 to August 7, 2011 on United Taconite's Line 2. Figures 6 and 7 show the mercury capture (the mass of mercury in each section divided by the total mass of mercury in the trap) at 67 and 50% H_r for the standard sorbent and for CR612C-Hg. The figures show that there is no significant decrease in performance for increased H_r.

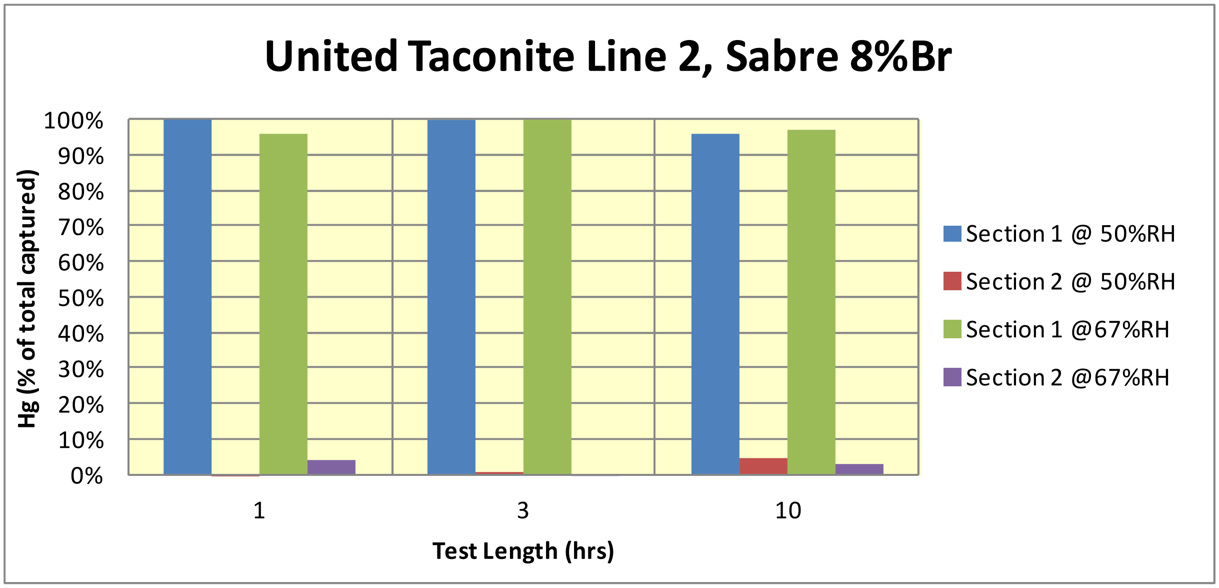

Figure 6: Relative Humidity Comparison for Sabre 8% Br Standard

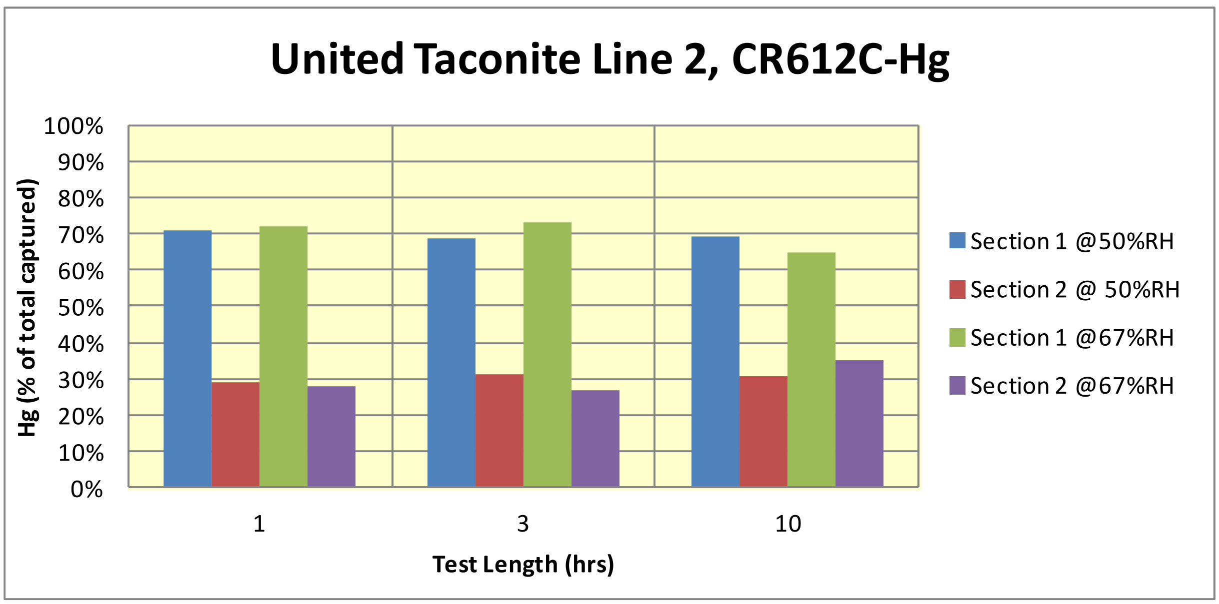

Figure 7: Relative Humidity Comparison for CR612C-Hg Test AC

<u>Phase 3: Impacts of Process Gas Constituents</u>

Figure 8 shows the average mercury capture of the lab tests compared to the MIM field tests. The data indicates that mercury capture was not significantly reduced in the actual process gas compared to laboratory gas. This indicates that there was no contaminating constituent in the taconite process gas that affected the mercury capture performance of the AC during the testing period.

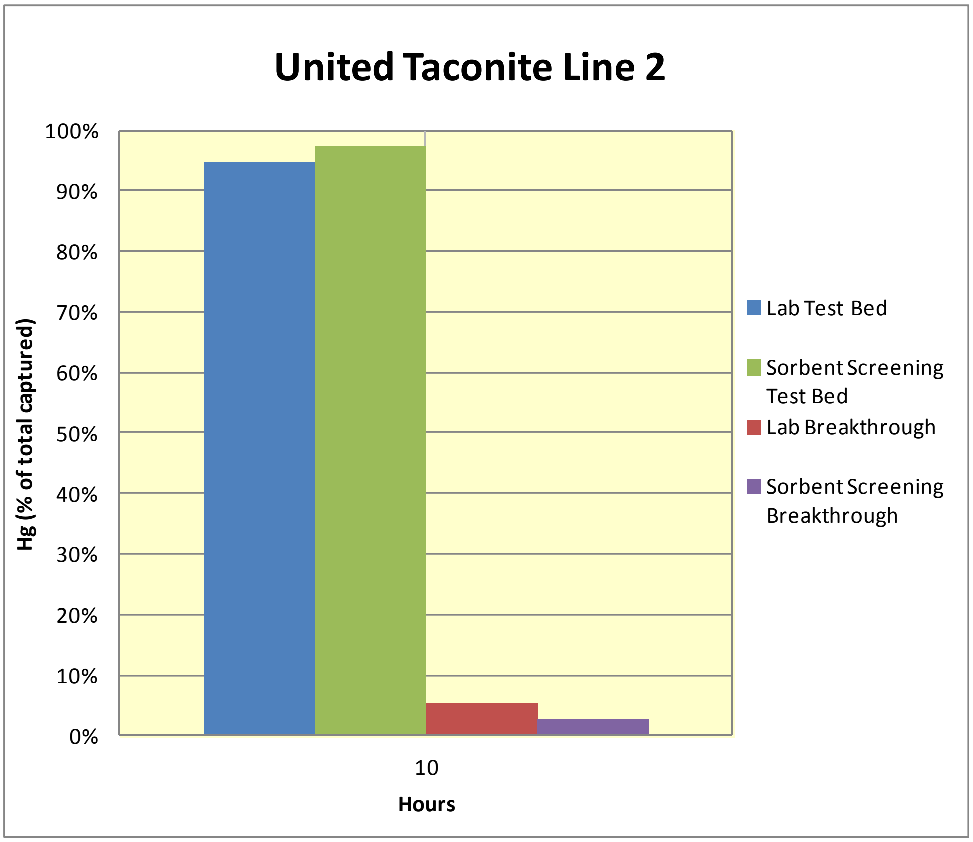

Figure 8: Comparison of Field (Sorbent Screening) and Lab MIM Results

STM Stack Sampling Results

On August 4 and 7, 2011, ADA performed STM measurements on the stack which was not used for MIM testing, Stack 2B. These measurements were done to determine if there was mercury variability between stacks. Three STM pairs were collected during one-hour runs (raw data presented in Appendix E). The average mercury concentration of each stack is summarized in Table 4. Calculated total mercury from CR612C-Hg (Carbon 4) testing in Phases 1 and 2 is included in the average for Stack 2A and shown in Table 4. Note that the units $[ng/l]_{dry}$ are identical to µg/dscm.

Table 4: Average Mercury Concentration of UTac's Line 2 Stacks

Stack	Hg_{AVG} $[ng/L]_{dry}$
2B	6.72
2A	7.86

Note: Hg concentrations may not be representative of long term operation.

Task 2. Integrated Full-Scale Fixed-Bed Process Concept

Based on an operating process gas flow of of 493,000 ACFM, which represents one line at UTac, Dr. Johnson recommended 11 fixed-beds of carbon with dimensions of 47-feet long, 12-feet wide, and 3 feet deep in separate cylindrical vessels, as shown in Figure 9. Approximately 813,850 lbs of carbon would be required to fill the beds. The estimated pressure drop across the beds is 6 to 12 inches of water. The amount of carbon that would be used per year, based on results from the Task 1 screening tests, is projected to be 138,108 lbs. This would need to be validated through pilot testing. The estimated requirements for both lines at Utac are 22 vessels, 1,627,700 lbs of carbon to load the bed, and 276,216 lbs of replacement carbon per year. For an actual full-scale design, UTac would need to specify the desired design flow condition. Dr. Johnson's design report is included as Appendix A.

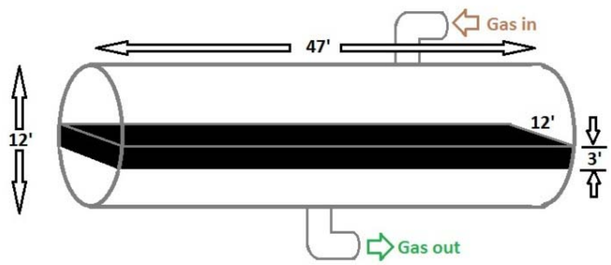

Figure 9: Sketch of Full-Scale Fixed-Bed Module

Task 3. Techno-Economic Summary

Stantec compared the technologies for both a general straight-grate taconite process and a grate kiln process and ranked them using a Kepner-Tregoe decision-making approach. Rankings were based on various technical and economic factors. The results of the assessment are summarized in Table 5, where the maximum possible score for any technology option is 1000. There was no difference in the score for the straight grate or grate kiln process. Two technology options, the polymer monolith and the AC monolith, are not included in the table because neither is currently offered commercially.

Based on this assessment and comparison to other technology options, the fixed-bed was determined to provide good performance but was expected to have a relatively high cost. The high cost was a result of several factors including the number of vessels required and the associated plant integration, and the expected pressure drop across the beds. The Stantec report is included as Appendix C.

Table 5: Kepner-Tregoe Decision Matrix

Technology	Grand Total	Positive Attributes	Negative Attributes
ACI Injection	713	Reasonable performance at very low cost.	Questionable performance, limited specific experience.
Oxidant Chemical Addition	716-706	Reasonable performance at very low cost. Has been trialed on actual waste gas.	Mixed results with many difference oxidants.
ACI + Fabric Filter	686	Good performance. Good co-benefits.	Large footprint, high pressure drop.
Fixed-bed Adsorber	587	Good performance.	Very large footprint, high pressure drop. Very high capital cost.
Fixed-bed Adsorber + Fabric Filter	515.5	Good performance. Good co-benefits.	Largest footprint, highest pressure drop. Very high capital cost.

Task 4. Pilot-Scale Design

Dr. Johnson prepared a design and parts list for a pilot system to complete the obligations of Task 4 of this project. He estimated the parts could be purchased for less than $20,000. Although not included in Dr. Johnson's estimate, it is reasonable to assume that the labor to assemble the parts and check-out the operation will result in a multiplier of 2 to 2.5, resulting in an overall cost of nominally $50,000. This estimate only included the pilot-scale equipment. Therefore, all testing costs would be in addition to the cost of the equipment. The pilot-scale design report is included as Appendix B.

6. Conclusions and Recommendations

Results from Task 1 indicate fixed-beds of activated carbon can achieve the taconite industry's goal of 75% mercury control, with the caveat that these results were obtained from short-duration screening tests. Specific objectives from Task 1: Slipstream Testing and the related observations are shown below:

Objective 1: Relative differences in sorbent performance:

- All test samples showed some initial calculated breakthrough at one hour. This may have been a result of mercury present on the carbon in the second section trap prior to exposure to process gas.
- The sulfur-treated coconut-shell (CR612C-Hg) performed best of all fixed-bed candidates.
- The sulfur-treated anthracite carbon (CR4AN-Hg) demonstrated the highest mercury breakthrough for all exposure periods.

Objective 2: Effects of Relative Humidity

- No significant reduction in mercury capacity of the best-performing AC (CR612C-Hg) was observed when changing the relative humidity between 67% and 50%. This is consistent with the results from the test standard AC (Sabre 8% Br). Pilot-scale testing is recommended to confirm this result.

Objective 3: Process Gas Impacts

- MIM evaluations conducted using a slipstream of gas from UTac compared well to MIM tests conducted using mercury in dry nitrogen in the laboratory. This indicates that nothing in the process gas at UTac during the test period negatively impacted the mercury removal effectiveness of the activated carbons included in the test program.

Analysis of test results for Tasks 2 and 3 show that a fixed-bed approach is not the most cost-effective application of activated carbon. Based on the findings in Task 2 and 3, ADA does not recommend continued development and testing of fixed-bed technologies for mercury control from taconite plants. Based on results from Task 3, ADA recommends industry consideration of activated carbon injection as a lower cost option to apply AC to meet the industry mercury control goals.

7. References

1) Implementation Plan of Minnesota's Statewide Mercury Total Maximum Daily Load. Minnesota Pollution Control Agency Publication wq-iw4-01p. October 2009.

2) METHOD 30B – DETERMINATION OF TOTAL VAPOR PHASE MERCURY EMISSIONS FROM COAL-FIRED COMBUSTION SOURCES USING CARBON SORBENT TRAPS - http://www.epa.gov/ttn/emc/promgate/Meth30B.pdf accessed 8/2/2012.

3) Campbell et al. "Mercury Control with Activated Carbon: Results from Plants with High SO3" Paper #08-A-174. Presented at the Power Plant Air Pollutant Control "Mega" Symposium, Baltimore, MD, August 25-28, 2008.

4) Adsorption Design Guide, Design Guide No. 1110-1-2, Department of the Army U. S. Army Corps of Engineers, 2001.

5) *The Rational Manager: A Systematic Approach to Problem Solving and Decision-Making* Charles H. Kepner, Benjamin B. Tregoe June 1965.

8. Appendices

Appendix A: Full-Scale Design Proposal

Appendix B: Fixed-bed Pilot-Scale Cost Estimate

Appendix C: Techno-Economic Analysis

Appendix D: Slides from April 2, 2012 Industry Meeting

Appendix E: Sorbent Trap Method Testing

Appendix F: Quality Assurance Program

9. Appendix A: Full-Scale Design Proposal

FIXED BED/ACTIVATED CARBON MERCURY REMOVAL-CONCEPTUAL DESIGN

FOR: UNITED TACONITE

FORBES, MINNESOTA

PREPARED BY: ACTIVATED CARBON TECHNOLOGIES, LLC

209 Clearwater Drive

Covington, VA 24426

H. Ray Johnson, PhD

CONSULTANT

SUMMARY AND RECOMMENDATION

Fixed bed/activated carbon technology has been successfully used for over 80 years to capture compounds from gas streams. Based on the information presented below and my 40+ years experience in the activated carbon field, it is my professional opinion that fixed bed/activated carbon technology can be successfully implemented and used to remove mercury from taconite process off-gases. It is recommended that the fixed bed carbon technology investigation move to the next stage; an activated carbon pilot system test.

BACKGROUND-FIXED BED/ACTIVATED CARBON SYSTEMS

Activated Carbon has been applied in Fixed Bed Adsorption Equipment for many years, beginning in the 1920's in Europe for recovery of organic solvents according to some historical information presented by Donau Carbon (1). The recovery of solvents by activated carbon also began in the U.S. in 1925 according to a historical timeline from Barnebey Sutcliffe (2), now part of Calgon Carbon. Thus, activated carbon has been successfully used in fixed bed, gas phase applications for over 80 years.

As a more recent example of fixed bed activated carbon technology, MeadWestvaco (MWV) commercialized a fixed bed system around 1980 for capture of corrosive gases such as H_2S. The initial fixed bed systems treated air flows up to 3,000 SCFM and utilized a 3 foot deep bed of impregnated, 3 or 4 mm pellet carbon or large granular carbon, such as 4 X 10 mesh size. The capture of H_2S and other sulfur gases occurred through chemical reaction with the impregnant material resulting in a high capacity for H_2S adsorption and carbon service life up to several years, 3-5 years in many cases. Based on experience and a review of published literature, there seem to be several similarities between fixed bed/activated carbon performance for capture of H_2S and for capture of mercury. These similarities could potentially be exploited to increase the probability of commercial success for fixed bed/activated carbon capture of mercury from taconite process off gases.

Another example of fixed bed/activated carbon processes dates to the late 1980's when MWV commercialized unique pelletized carbons, 3 and 4 mm diameter, for organic solvent recovery applications. These products were used worldwide in solvent recovery systems designed and built by several different equipment manufacturers. These fixed bed systems typical employed a carbon bed that was also about 3 feet deep but in many cases a single vessel was sized to treat up to about 40-50,000 SCFM solvent laden air. After the carbon became saturated with adsorbed solvent in a matter of a few hours, the solvent is then removed by steaming and another adsorption cycle can begin. In most cases the carbon remains in service in the fixed bed for a period of years. Many features of the fixed bed design and operating features that have evolved over decades in the solvent recovery application can be applied in designing and operating a fixed bed/activated carbon system for mercury removal.

A more recent fixed bed type technology, developed within the past 5-10 years, uses an impregnated honeycomb carbon matrix; in place of carbon pellets or carbon granules, to capture corrosive gases such as H2S (3). MeadWestvaco has commercialized systems utilizing the honeycomb technology treating gas flows up to about 30-40,000 SCFM. The honeycomb systems have faster removal kinetics, lower pressure drop, and operate at superficial velocities of 500 ft. /min., 5 times higher velocity compared to the typical 100 ft. /min. maximum for conventional activated carbon fixed beds for gas purification.

MeadWestvaco has provided systems with the honeycomb technology for corrosion control to the Flint Hills Resources Pine Bend Refinery in Rosemount, Minnesota. This installation would seem to offer a convenient site to gain more insight into the potential of mercury capture from taconite process off-gases using impregnated carbon technology.

Corning, Incorporated is also developing an impregnated honeycomb type filter to remove mercury from flue gas (4). Additional information on the development program for the Corning technology is described in a National Energy Technology Laboratory publication (5).

DESIGN CONSIDERATIONS-FIXED BED/ACTIVATED CARBON SYSTEM FOR MERCURY REMOVAL

United Taconite

The following design information will in general follow the steps presented in Appendix B-2-English Units of the ADSORPTION DESIGN GUIDE, Design Guide No. 1110-1-2 by the U. S. Army Corps of Engineers (6).

a. Parameters

* Flow Rate of Gas to be treated: 493,000 ACFM

* Temperature of Gas to Fixed Bed: 140 F°

* Run Time between carbon changes: (See design calculations below)

* Number of Carbon Vessels: (See design calculations below)

* Atmospheric Pressure: 14.7 psia

*Moisture content in gas: 15.27%

* Mercury Concentration: 10 μg/m^3

***** Total Mercury per Year: 140.87 lb Hg/yr

* Carbon Capacity for Mercury Adsorption (X/M): 0.00102 lb Hg/lb C

Other carbon capacity data for mercury capture can be found in several publications including the following data.

(7) "Carbon Bed Mercury Emissions Control for Mixed Waste Treatment": 0.19 lb Hg/lb C, and

(8) "Long-Term Performance of Sulfur-Impregnated, Granulated Activated Carbon (GAC) for Mercury Removal from NWCF Off-Gas": .035 to .072 lb Hg/Lb C based on analysis of carbon samples.

(9) Mersorb carbon containing impregnated sulfur was used for the studies in both publications. The carbon manufacturer, Nucon, predicts Mersorb to have capacity of about 0.20 lb Hg/lb C.

b. Design Steps

(1) Determine the amount of carbon needed.

Considering several factors including:

- CR612C-HG, a sulfonated coconut shell carbon, performed best of the 3 carbons used during sorbent screening tests by ADA Environmental Solutions. The supplier, Carbon Resources, has a specification for 12% minimum sulfur content for the CR612C-HG. The measured Mercury Index Method adsorption capacity (X/M) for this carbon was 0.00102 lb Hg/lb carbon.

- Relevant publications and another sulfur impregnated carbon supplier, Nucon, indicate sulfur impregnated carbon capacity of about 0.2 lb Hg/lb Carbon.

- The carbon is in a fixed bed, expected to be exposed to the off gas containing mercury for extended time period, and under conditions that allow for the carbon in the upstream part of the bed to at least approach its saturation capacity for adsorbing mercury, 0.20 lb Hg/lb Carbon.

Potential carbon usage rates, based only on potential mercury adsorption capacity, could be:

Mercury Adsorbed, lb/yr	Assumed Carbon Capacity, lb Hg/lb C	Carbon Useage, lb/yr
140.87	**0.00102**	**138,108**
222.32	0.035	6,352
222.32	0.100	2,223

222.32	0.200	1,112

These calculated carbon usage numbers based on literature values are very minimal, but based on a somewhat similar type of process using impregnated carbon for removal of H2S through reaction with an impregnant; the usage numbers could be reasonable and expected based on broad experience with H2S removal over several thousand different installations.

However, it should also be noted that contaminants, adsorption of other compounds, temperature, relative humidity, etc. could very significantly impact the carbon usage rate. Larger scale pilot tests could provide more definitive information on the potential effects of these parameters.

(2)Determine the size of the carbon adsorption vessels

Relatively large fixed bed carbon adsorption systems/vessels have been used in solvent recovery applications for many years. Based on the extensive design/operating experience in this application area and my knowledge of this area, I will base the vessel sizing and number of vessels on solvent recovery experience.

One solvent recovery equipment manufacturer with decades of experience is AMCEC, Inc. located in Lisle, Illinois. One of the case studies listed on AMCEC's web site is "Pollution Control That Pays Its Way" covering a system installed in 1982 and still in operation (10).

The system includes 4 fixed bed carbon vessels with each adsorption vessel having a diameter of 12 feet and a length of 47 feet. Each vessel contains 43,000 pounds of CECA-AC35 activated carbon pellets. Assuming a cross-sectional area for the carbon bed of 12 feet X 47 feet or 564 ft², the carbon bed depth is in the range of 2.5 to 3 feet depending on the packing density of the carbon. See Figure 1 below

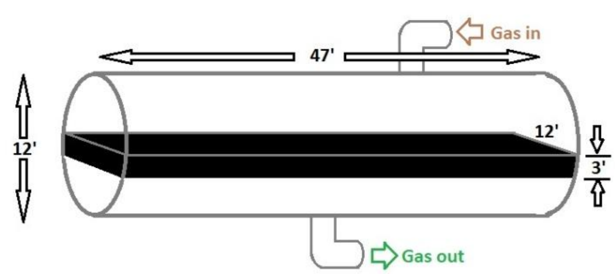

Figure 1: Carbon Vessel Design

In my experience this size vessel , up to about 12 feet diameter and 45-50 feet long, can be shop fabricated and transported to the job site by special tractor/trailer. There are many advantages to using a cylindrical vessel design and shop fabrication.

For subsequent calculations, I will assume a vessel size of 12 feet diameter, 47 feet long, and carbon bed cross sectional/bed surface area of 564 feet².

(3) Number of Adsorption Vessels

The typical range for gas flow velocities in fixed bed applications is on the order of 50-100 feet per minute. At this point, I would suggest a superficial gas velocity of 75 ft/minute and I will assume a bed cross sectional area of 564 ft² from above.

Each vessel will then treat 75 ft/minute times 564 ft² equals 42,300 ACFM.

Number of vessels on line at one time = 493,000 ACFM/ 43,200 ACFM/Vessel = ~11 Vessels.

An additional 1 or 2 vessels would be needed to provide back-up for maintenance, etc.

(4) Total Amount of Carbon

A typical carbon bed depth for a fixed bed application of this type is about 3 feet and I will use this depth.

Carbon bed volume/vessel = 564 ft² X 3 ft = 1692 ft³

Calgon gives an Apparent Density of 37 lb/ft³ for sulfur impregnated HGR grade carbon.

Carbon amount per vessel = 1692 ft³ X 37 lb /ft³ = 62,604 pounds.

Total installed carbon (13 vessels) = 813,850 pounds.

(5) Pressure Drop Across Carbon Bed

Pressure drop for gas flow through a packed bed of carbon is dependent on the packing characteristics; and the limiting pressure drop curves are measured by many manufacturers for "dense pack" (maximum pressure drop for a given superficial velocity) and for "loose pack "(minimum pressure for a given superficial velocity). In some cases the "loose pack pressure drop is only about ½ the "dense pack" pressure drop. As an example Calgon's data (11) for BPL 4 X 10 Mesh product shows a pressure drop of ~ 1.5 inches water/foot bed at a superficial velocity of 75 ft./min for "loose pack" while the pressure drop is ~ 3.5 inches water/ft. bed at the same velocity for "dense pack."

In NUCON MERSORB BULLETIN 11B28-2010 (12), Nucon does not indicate the packing characteristic but gives a pressure drop of ~ 2 inches water/ft.bed at 75 ft./min for 4 mm pellet and ~ 4 inches water/ft.bed for 3 mm pellet.

At this conceptual stage, it seems appropriate to assume that the pressure drop for the fixed bed of carbon will be in the range of 2-4 inches water/ft bed.

Assuming a 3 foot deep bed from section (4) above, the total pressure drop for the carbon bed is expected to be 6 to 12 inches of water.

(6) Other Pressure Drops

Pressure drop across other parts of the system such as flow control valves ductwork, inlet/exit flow losses, etc. will not be evaluated at this stage of the conceptual design.

(7) Blower

Pressure drop, horsepower and other characteristics of the blower will not be evaluated at this stage of the conceptual design.

POTENTIAL ALTERNATE DESIGN CONSIDERATIONS-HONEYCOMB MODULE/ACTIVATED CARBON SYSTEM FOR MERCURY REMOVAL

MeadWestvaco Corporation

MeadWestvaco (MWV) Corporation has provided deep bed (~ 3 feet nominal depth) carbon pellet systems for over 30 years and installed over 3,000 of these systems in industrial and municipal applications (13). The impregnated carbon systems are designed primarily for removal of corrosive acid gases, such as H2S, from air/gas streams. The process of removing of H2S by impregnated carbons seems to have many similarities to the process for removing Mercury using impregnated carbons.

Within about the past 5 years, MWV has developed and commercially introduced a new impregnated Honeycomb Matrix (HM®) Media to replace the traditional carbon pellet media. According to MWV, the Honeycomb Media Has several advantages when compared to traditional pellet media. These advantages include:

1) Superficial velocities of air can be 500 ft./min. for the honeycomb system compared to 100 ft./min. for pellet systems
2) Even with higher velocities, honeycomb media achieves higher removal efficiencies with lower bed depths.
3) Improved performance with lower maintenance and cost.

More details on the honeycomb matrix systems are available in the following documents that can be downloaded from the MWV web site, MWV.com under the Specialty Chemicals, Air Purification Section.

* Clean Air Update March 2010 (PDF)

* Clean Air Update January 2010 (PDF)

* Air Purifications Brochure

MWV does not currently provide the honeycomb matrix system for air purification applications to remove Mercury but I recommend that this technology be considered as the evaluation of fixed bed carbon technology evolves.

MWV does have the honeycomb matrix technology installed and operating for corrosion control at Flint Hills Resources Pine Bend Refinery in Rosemount, Minnesota. I would expect that a site visit to view this installation could be arranged for ADA-ES and Minnesota DNR representatives.

Corning Incorporated

Corning Incorporated is also developing honeycomb media and has several U. S. patents and patent applications on the use of sulfur-impregnated honeycomb media for mercury capture . Corning patents in this general area include U. S. Patents 6, 136,749; 6,187,713; 6,258,334; 6,372,289 and others. Some recent patent application numbers by Corning relative to mercury removal include 20080207443; 20110020202 and others.

Corning's development of this media is mentioned in a Chemical and Engineering News article titled "Getting Rid of Mercury" dated November 24, 2008 (4).

According to a National Energy Technology Laboratory (NETL) project fact sheet the Corning honeycomb media is undergoing development in an integrated system to remove trace metals including mercury (5).

CONCLUSION

Conventional fixed bed/activated carbon systems have been used for over 80 years to remove target compounds from gas streams including off-gases from many types of processes. Systems employing impregnated carbons, as an example, have been utilized in many thousands of installations to remove corrosive gases, such as H2S, employing 3 foot deep beds of carbon pellets or large carbon granules. Pilot studies utilizing impregnated carbon pellets/granular particles have demonstrated the potential for using deep fixed carbon beds for capture of mercury from different types of process off gases. There seems to be many similarities between the removal of H2S employing impregnated carbons and the capture of mercury by impregnated carbons.

In view of the historical success using impregnated carbons in fixed bed systems and based on my broad experience in activated carbon technology, it is my professional opinion that fixed bed activated carbon technology can be successfully applied to mercury capture from taconite process off gases. Furthermore, I recommend that a pilot system investigation be performed to demonstrate the performance of this technology and develop additional information for design and installation of full scale systems.

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11. BPL 4X10 Granular Activated Carbon, Product Data Sheet, Pressure Drop Curve, Calgon Carbon Corporation
12. Nucon Mersorb Bulletin 11B28-2010, Nucon International, Inc.
13. www.mwv.com, MWV Specialty Chemicals Division, Air Purification Group,Vol. 1,Issue 1,January 2010"

FIXED BED/ACTIVATED CARBON MERCURY REMOVAL

INTEGRAL PROCESS DESIGN CONCEPT

FOR: UNITED TACONITE

FORBES, MINNESOTA

PREPARED BY: ACTIVATED CARBON TECHNOLOGIES, LLC

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DESCRIPTION OF PROCESS DESIGN CONCEPT

The attached block diagram presents a concept for integrating the new fixed bed carbon adsorption system into the existing plant process. The design concept includes two separate, but identical lines to treat a total waste gas flow of 493,000 ACFM at 140 F° with 15.27 % moisture.

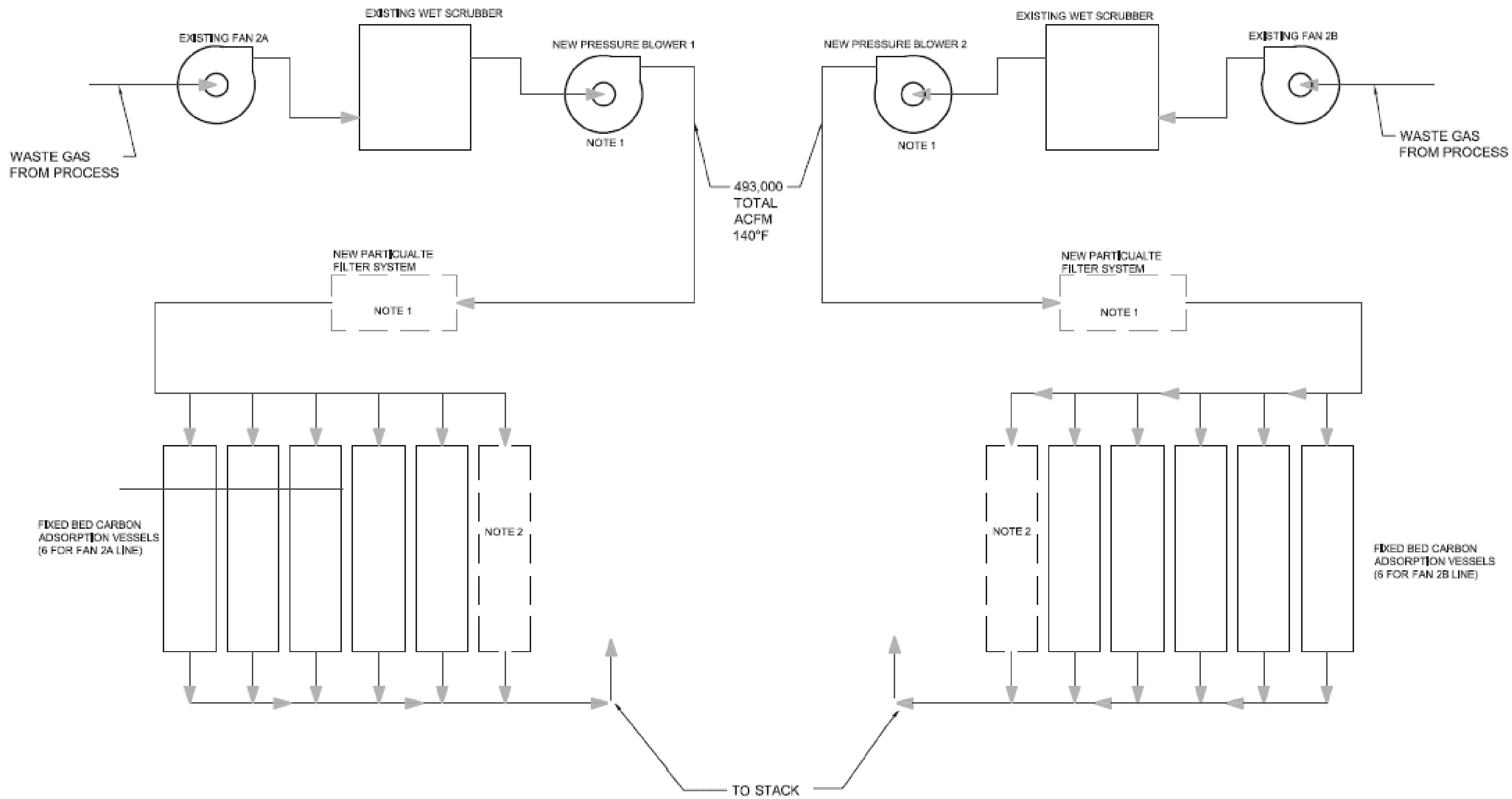
For each line, waste gas from an existing wet scrubber will be diverted prior to exiting the existing stack to a new pressure blower. Although the proposed design concept includes only one large pressure blower, United's operating philosophy and strategy may favor more than one pressure blower for each line.

The design concept presented includes a new particulate filter system downstream of the pressure blower to remove particulate matter to a level that eliminates potential problems with particulates clogging the fixed carbon beds and increasing pressure drop above maximum design level. Design information for the particulate filter system and level of particulate removal required should be developed during a pilot system test program. Although the concept includes a new filter system, the potential for increasing the efficiency of the existing wet scrubber should be evaluated as a possible means of eliminating the need for a new filter. Also, the carbon adsorption vessels might include the potential for filtering particulates with periodic removal of the captured particulate matter.

The filtered waste gas is then treated in the fixed bed carbon adsorption vessels. The design concept includes multiple carbon adsorption vessels, 6 vessels for each of the two lines. Depending on United's operating strategy, one of the six vessels could be typically off-line and designated as a spare vessel, to be used as needed for maintenance purposes, reduce blower pressure requirements, etc. It is also possible that the sixth vessel in each line could be eliminated leaving only five vessels and reducing operating margins from some standpoints. The design concept includes adsorption vessels of a size that can be shop fabricated, however, the potential for on-site fabrication of larger, but fewer number adsorption vessels can be considered by United.

The cleaned off-gas from the carbon adsorption vessels is routed to the existing stacks and emitted to the atmosphere.

UNITED TACONITE
CARBON FIXED BED ADSORPTION
PROCESS DESIGN CONCEPT



NOTE 1: REQUIRENMENT AND DESIGN PARAMETERS TO BE DEFINED DURING PILOT TESTING PAHSE.

NOTE 2: ONE ADSORPTION VESSEL CAN NORMALLY BE KEPT OFF LINE AS A SPARE.

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10. Appendix B: Fixed Bed Pilot-Scale Cost Estimate

ADA-ES PROJECT-MERCURY REMOVAL FROM TACONITE OFF GAS

PILOT SYSTEM DESIGN AND COST ESTIMATION

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DESCRIPTION OF PILOT SYSTEM

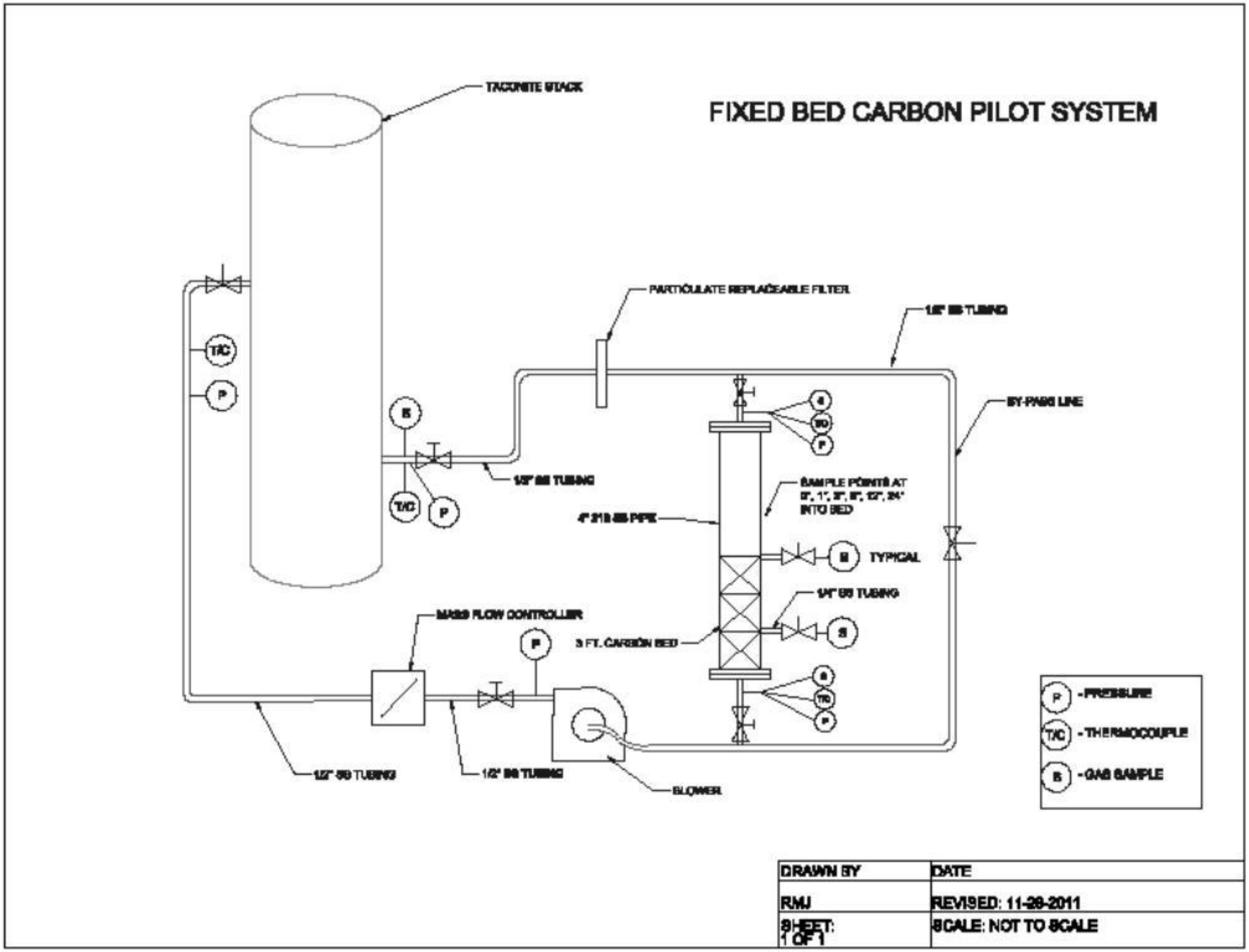
The fixed bed, activated carbon pilot system will include a 4 inch nominal, 316 SS pipe, 5 feet long to serve as the column or vessel for the fixed bed of carbon particles. The design basis will provide for carbon bed depths of 3 feet with provisions made to withdraw gas samples at bed depths of 0,1,3,6,12, and 24 inches to monitor the mercury adsorption wave front. Superficial gas velocities through the 4 inch column will be in the range of 50-100 ft./minute for a flow of about 5-10 ACFM. Provisions for filtering particulate matter from the inlet gas, monitoring and controlling total gas flow through the column. Measuring temperatures and pressures will be included. A pressure blower rated for a static pressure of 50 inches water and flows up to several hundred ACFM is included. Provisions for mounting, weatherizing and other installation details can be included as more details on the actual site for the pilot system becomes available.

The present pilot system proposed design can be easily modified/added to by adding one or more adsorber vessels (4 inch pipe) to evaluate more than one carbon grade at the same time, as an example. Since plugging of a carbon bed with particulates in an unfiltered off-gas can be a concern, modification of the system to include another carbon column receiving unfiltered off-gas can be easily accomplished. Other modifications can be considered.

The estimated cost to date for a single column system is in the range of about 14,000 to 19,000 dollars not including a contingency estimate. The major components and their cost estimate are listed on the following page. Manufacturers spec sheets for some of the major components are attached. Other suppliers' information is available as needed. A simple drawing of a single column pilot system is provided in the attachment.

PILOT SYSTEM COMPONENTS/COST ESTIMATE

COMPONENT	BRIEF DESCRPTION		ESTIMATED COST Dollars Low	High	SOURCE OF ESTIMATE
1. Column ,	4 inch, sch.40 ,316 SS pipe,5 feet long, inlet,outlet flanges ,6 sampling connections		750	850	Creative Fab., Covington,VA
2. Flow Controller	Sierra Max-Trak Model 180M (See Spec Sheet)		2800	3500	JOBE & Company,Richmond,VA
3. Pressure Blower	Cincinnati Fan Model HP-6E26 (See Spec Sheet) 10 HP Motor		3000	3200	Prime Air Products,Lynchburg,VA
4. Swagelok Tubing Fittings	1/2 inch,316 SS, ball valves	6@ 211.10 each	1267	1300	Diebert Valve,Richmond,VA
	1/4 inch,316 SS, ball valves	10@ 174.60 each	1746	1800	
	1/2 inch, 316 SS tubing tees	8@ 44.90 each	359	375	
	1/4 inch,316 SS male to tubing fittings	8@ 7.10 each	57	70	
	1/2 inch,316 SS tubing	40 ft.@ 10.69/ft	428	450	
	1/4 inch, 316 SS tubing	40 ft@ 6.00/ft	240	250	
5. Magnehelic Pressure Gages	Series 2000 for P/DP	6@ 70 each	420	450	Dwyer Web Site
6. Thermocouples	Type J	4@ 22 each	88	100	Omega Web Site
7 Temperature Data Logger		1 @ 999 each	999	1000	Omega Web Site
8. Insulation-4 inch column		2-3ft lengths @ 26.05 each	52	60	Granger Web Site
9. Cartridge Filter	Compressed air filter 55 SCFM Max Flow		200	300	Filtersource Web Site
10. Assembly,Enclosure, Weather Protection as needed.			2000	5000	HRJ Estimate
			14406	18705	


FIXED BED CARBON PILOT SYSTEM
TACONITE STACK
PARTICULATE REPLACEABLE FILTER
BY-PASS LINE
T/C
P
B
SAMPLE POINTS AT
INTO BED
TYPICAL
MASS FLOW CONTROLLER
3 FT. CARBON BED
BLOWER
P - PRESSURE
T/C - THERMOCOUPLE
B - GAS SAMPLE
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1 OF 1
SCALE: NOT TO SCALE

Appendix C: Techno-Economic Analysis

EVALUATION OF MERCURY CONTROL OPTIONS TACONITE INDUSTRY

Revision F

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1.0 Introduction

Stantec Consulting Ltd. has been tasked by ADA Environmental Solutions (ADA-ES) to assist them in a high-level evaluation of technologies that show potential for controlling mercury emissions from taconite processing facilities as listed below:

- Keewatin Taconite (Keetac) - located near Keewatin, Minnesota
- Hibbing Taconite (Hibtac) - located near Hibbing, Minnesota
- ArcelorMittal - located near Virginia, Minnesota
- USS Minntac (Minntac) - located near Mountain Iron, Minnesota
- United Taconite (U-Tac) - located near Eveleth, Minnesota

Stantec has elected to use a Kepner-Tregoe style qualitative analysis to rank the technologies being considered. The details of this method are expanded upon within this report.

2.0 Technologies Considered

Seven mercury control technologies, as provided by ADA-ES, were to be assessed using the Kepner-Tregoe technique. ADA conducted fixed bed screening tests to determine the relative performance of activated carbon for mercury control on process gas slipstreams from three taconite plants. The other technologies were considered options because of their application for mercury control in other industries.

Activated Carbon Injection (ACI)

Powdered Activated Carbon (PAC) is used as a sorbent to adsorb the mercury. It is injected and mixed with the waste gas in the duct prior to the existing wet scrubber. Since it is in-duct capture, residence time of the AC will depend upon the configuration of the plant and distance from the injection points to the particulate control device as well as the type of particulate control device. The spent AC is removed from the treated gas in the wet scrubber by scrubbing water and discharged with scrubber blowdown.

Activated Carbon Injection with Fabric Filter

PAC is used as a sorbent to adsorb the mercury. It is injected and mixed with the waste gas in new ductwork leading to the fabric filter, which is used for filtering the spent carbon out of the system. In this evaluation, the fabric filter will replace the existing wet scrubber.

Fixed Bed Adsorption

PAC is packed in a fixed bed adsorption vessel. The waste gas leaves the wet scrubber and passes through a series of horizontally cylindrical vessels where the fixed carbon beds remove the mercury from the waste gas. The spent beds will be removed for potential off-site regeneration.

Fixed Bed Adsorption with Fabric Filter

Waste gas passes through a fabric filter to remove particulate matter to a level that eliminates potential problems with clogging the fixed carbon beds. The dedusted waste gas will be introduced to a series of fixed bed carbon adsorption vessels, which will remove the mercury from the waste gas. The spent beds will be removed for off-site regeneration. Functionally no different from the fixed bed application; the fabric filter only serves to protect the fixed beds. The fabric filter allows the existing scrubber to be eliminated.

Monolithic Honeycomb Adsorption

Activated carbon is mechanically fixed into a honeycomb structure that may include additives to enhance mercury capture. The cells of the monolith are plugged at their ends intermittently to force gas flow through the walls of the structure.

Evaluation of this technology was halted, but a data sheet for it can be found in the appendices of this report. During the course of the evaluation, the monolithic honeycomb adsorption technology was found to be no longer in commercial development.

Monolithic Polymer Resin Adsorption

Activated Carbon Fluoropolymer Composite (CFC) materials are used to chemically adsorb mercury from the flue gas stream. The treated activated carbon powder is combined with chemicals, such as elemental sulfur or alkaline metal iodides, to enhance the mercury removal efficiency and the fluoropolymer. The mixture is then calendered into CFC sheets under elevated temperature. The CFC sheet is stretched extensively to develop the microporous structure that will allow rapid chemical oxidation of Hg^0 and binding of Hg^{2+} to the active sites of the fibre. This technology is evaluated as contained within a stand-alone adsorber tower but can also be retrofitted into an existing wet scrubber.

Oxidative Chemical Addition

A chemical additive is added in the waste gas to enhance mercury oxidization converting Hg^0 (insoluble) to Hg^{2+} (water-soluble). An increase in the percentage of Hg^{2+} or particulate-bound mercury at the inlet of the wet scrubber will improve the mercury removal from the process. The oxidant can be added into the process gas during the induration or into the scrubber water at the wet scrubber. This evaluation assumes induration injection, and we have selected calcium bromide as the oxidant.

3.0 Evaluation Technique

The technique used in this evaluation is a modified, high-level Kepner-Tregoe style WANTS analysis, which can be found in full in their book "The New Rational Manager." The process involves a decision analysis that uses a scoring technique to apply a series of qualitative assessments of an option to arrive at a more quantitative score. The technologies for mercury control will be assessed individually using this technique, then ranked to determine which ones show the most promise.

The process typically begins with establishing criteria of importance. These criteria are generally divided into two categories, MUSTS and WANTS. MUSTS represent features that must be achievable by the technology. For this specific evaluation, there were no clear MUSTS as any technology that does not meet the MUSTS list is discounted immediately, and there was a desire for all technologies to make it forward to the more detailed WANTS analysis. Still, the following MUSTS were generally followed:

- Technology MUST be capable of 75% mercury capture or better.
- Technology MUST be commercially available in 2012 or on track for commercial availability before 2014.

Between these two MUSTS, the polymer resin monolith and honeycomb monolith technologies did not pass. Although the monolithic polymer resin adsorption technology has been successfully piloted and scheduled for a larger scale pilot testing in 2013, it may not be commercially ready before 2014. Unlike the polymer resin monolith technology, an attempt to commercially develop the honeycomb monolith technology for mercury removal application for utility flue gases was terminated, since it was most likely not cost-effective.

The remaining technologies then proceed to the WANTS analysis. Here the technology is given a score in several different categories, grouped as follows:

- Economic

  These criteria are related to the capital and operating costs of the systems, as assessed from the high-level aspect of this study.

  1. *Capital Cost* - Systems with the highest capital costs were given the worst score and the lowest the best; all systems in-between were scored relatively between them.
  2. *Operating Cost* - Similar to capital cost, the highest and lowest yearly operating costs were given the worst and best scores, respectively, with technologies in-between scored relatively.

- Risk

  These criteria are related to the apparent risk of retrofitting the technologies to an existing facility.

  1. *Turndown* - This criterion assesses the technologies capability to load follow downward while maintaining performance. Technologies that feature multiple parallel reactors score well because as gas flow is reduced, modules can be shutdown. Technologies that depend on the existing scrubber depend on its turndown capabilities to maintain particulate control, which is likely unique to each scrubber.
  2. *Availability/Reliability* - This criterion assesses the uptime of a given system. Systems with many moving parts or unreliable components score poorly.
  3. *Erosion/Corrosion/Plugging/Scaling* - This criterion assigns a score based on how susceptible the system is to attack from the harshness of the flow or chemicals used. A high score is impervious to these issues, while a low one may be at risk.
  4. *Simplicity* - Generally, a simplified system will be more successful in long-term performance and ease of operability. High scoring systems would have relatively simple flow sheets.
  5. *Modularization* - To minimize system costs, in-shop fabrication of modularized gas treatment equipment is often beneficial. High scoring systems would have systems delivered to site ready for installation; low scoring systems will require much more field work.
  6. *Technology Maturity* - A mature technology scores high as the long operation history increases the likelihood of avoiding design or operational problems.
  7. *Commercial Scale* - Systems available today, at the scale required, score high in this category. If significant scale-up is required from systems readily available today, then a low score will result.
  8. *Construction Schedule* - Technologies with fewer pieces of equipment (e.g., injection lances or chemical silo) are likely to meet the construction schedule and keep the schedule short. These technologies will score higher than those requiring multiple parallel trains of vessels.
  9. *Retrofit Integration* - The ease of integrating new equipment is assessed in this category. Equipment that can be installed in the gas path with minimal impact to the operating plant scores high, while systems needing significant shutdowns for integration score low.
  10. *Safety* - Systems using dangerous, toxic chemicals with many confined spaces, excessive temperatures, and pressures would score poorly here.

11. *Materials of Construction* - Systems that feature high steel alloys score poorly here. Due to being installed after existing wet scrubbers, some systems will have to be constructed of corrosion-resistant material (e.g., stainless steel) as the waste gas would be near saturated conditions.
12. *Maintenance* - Systems requiring frequent maintenance, adsorbent change outs, and bag replacements score lower here.

- Performance

  The performance section seeks to rank the technologies on how well they will accomplish their primary function to control mercury in waste gas. It also assesses how susceptible they are to performance hindrance, due to expected upset conditions that will undoubtedly arise.

1. *Scrubber Compatible* - If the technology has a limited impact to the scrubber, it scores well in this category. If it changes how the existing scrubber works or performs, it scores progressively worse as impact increases.
2. *ΔP* - The pressure drop of the technology is assessed here. Higher pressure drops require more fan power than lower pressure drops, and score worse than technologies with relatively lower resistance to gas flow.
3. *Footprint* - Systems with large footprints score poor in this category, as it is our understanding that space limitations may be present at many of the possible host plants.
4. *Suitability to Induration Type* - If the technology performance depends on the induration type present at the host plant, it will be scored well or poorly based on information available thus far. Specific analysis is included for the two induration types considered in this study.
5. *Sensitivity to Flue Gas Compositions* - Flue gas compositions (e.g., SO_x, NO_x and moisture) can reduce the mercury removal efficiency by reducing the adsorption capacity of adsorbents or reacting with oxidative chemicals directly. Technologies with adsorbents/chemicals insensitive to these flue gas compositions score well here.
6. *Regeneration Capability* - Technologies with regenerable adsorbents score well here as they typically have lower operation costs.
7. *Impact on Scrubber Solid Recycle* - Adding adsorbents/chemicals at or before the existing wet scrubber or the new fabric filter can contaminate scrubber solid recycling to the green ball feed with mercury. Technologies that remove mercury downstream of the wet scrubber tend to avoid solid contamination and score well.

8. *Impact on Iron Chemistry During Induration Process* - If the technology interacts or interferes with iron chemistry during the induration process, it is scored poorly here.
9. *Possibility of Mercury Re-emission/Desorption* - Based on information provided on the technologies considered, some display a risk of re-emission of mercury. Technologies that feature this risk to performance are scored poorer than those that feature robust and stable adsorbents.

- Environmental

  While the whole analysis focuses on the technologies capabilities with regards to mercury, the environmental category looks at co-benefits or waste emission increased due to the incorporation of new emission control equipment.

  1. *Particulate Co-Benefits/Fugitive Emissions* - Technologies that may increase the emission of particulate by increased loading on the existing scrubber, or introduce new emissions to the gas path, are scored lower than technologies that do not increase emissions or assist in controlling existing emissions even further.
  2. *Waste Quantity* - Technologies that produce waste streams that must be handled score poorer than those that either have regenerable adsorbents or do not produce significant wastes.

Each category is subdivided into further individual criteria, each of which is given a weight. The weight, a value between 1 and 10, indicates the relative importance of each criteria (10 being of high importance; 1 being of minimal importance). When the technology is evaluated, it is given a score from 1 to 10 for each criteria (10 being an excellent score; 1 being a poor score). The weight and the score are multiplied to arrive at a weighted score, and then all weighted scores are tallied to give a grand total. The highest grand totals are then recommended as attractive technologies for further study.

4.0 Generic Plant

In order to calculate some rough sizing and costs for the technologies to evaluate, it was necessary to develop generic plants that could represent the actual plant data provided.

As shown in Table 4-1, two generic plants, Plant 1 (Straight Grate) and Plant 2 (Grate Kiln), are established to represent the taconite facilities in Minnesota for evaluation. Based on process data received from five taconite plants, both generic plants are co-fire natural gas and coal with a recirculating wet venturi-type scrubber, as an existing particulate matter control device. Scrubber solids are recycled back to the process at the green ball feed. Other process parameters of the generic plants (e.g., waste gas flow rate, SO_x/NO_x stack emission rate) are selected to represent the worst-case scenario of the process. However, the generic plants do not cover the differences between each plant such as pre-heat burners. A full process description of these generic plants can be found in Appendix B. As can be seen in the end, the generic plants are very similar, differing only in induration type. At this high-level it was not necessary to delve any deeper into the unique features of each individual processing line. All other factors of the plants did not play a role in determining the scoring of the technologies evaluated.

Table 4-1 Generic Taconite Plant

Parameter		Unit	Generic Taconite Plant 1 Straight Grate	Generic Taconite Plant 2 Grate Kiln
Induration Type		(-)	Straight Grate	Grate Kiln
Existing PM Control Device		(-)	Wet Venturi-Type Scrubber	Wet Venturi-Type Scrubber
Scrubber Type		(-)	Recirculating	Recirculating
Solid Recycle to the Process		(-)	Yes	Yes
Recycle Location		(-)	Green Ball Feed	Green Ball Feed
Fuel Type		(-)	Coal/Natural Gas	Coal/Natural Gas
Waste Gas After Scrubber		(scfm)	854000	854000
Gaseous Composition After Scrubber	• Moisture	(%)	15.27	15.27
	• Mercury	($\mu g/m^3$)	10	10
SO_2 Emission Rate		(lb/hr)	272	272
NO_x Emission Rate		(lb/hr)	311	311

5.0 Evaluation Results

Table 5.1 is generated from the generic plants and demonstrates the ranking and general appraisal of the technologies after completion of scoring. The ranges reflect the subtle variants in scoring due to the separate analysis for the two induration types from the generic plants, which in the end were not substantial.

Table 5-1 Ranking and General Appraisal for Generic Plants

Technology	Grand Total	Positive Attributes	Negative Attributes
ACI Injection	713	Reasonable performance at very low cost.	Limited specific experience.
Oxidant Chemical Addition	716-706	Reasonable performance at very low cost. Has been trialed on actual waste gas.	Mixed results with many difference oxidants.
ACI + Fabric Filter	640	Good performance. Good co-benefits.	Large footprint, high pressure drop.
Fixed Bed Adsorption	597	Good performance.	Very large footprint, high pressure drop. Very high capital cost.
Fixed Bed Adsorption + Fabric Filter	475.5	Good performance. Good co-benefits.	Largest footprint, highest pressure drop. Highest capital cost.

The full scoring can be found in the appendices of this report along with notes explaining the scores.

A high-level appraisal of costs was conducted for these systems as applied to the generic plant. Cost estimation accounted for the cost of equipment, material, labour, engineering and construction management, project contingency and Operational & Maintenance (O&M). It excluded the demolition cost of the existing equipment and other owner's costs, such as commissioning and start-up costs. The following figures demonstrate the relative results of this analysis:

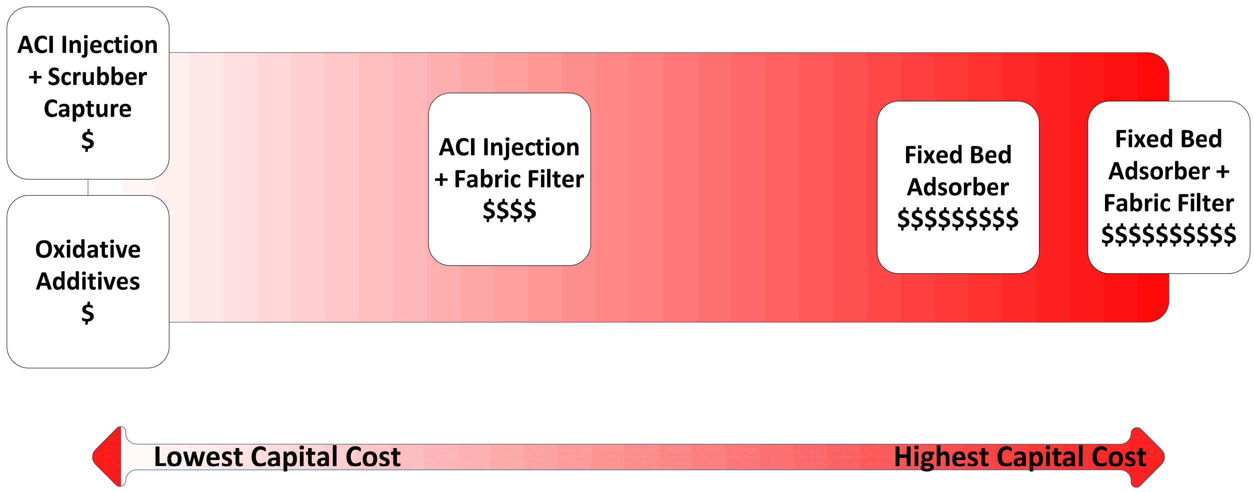


Figure 1 Relative Capital Costs

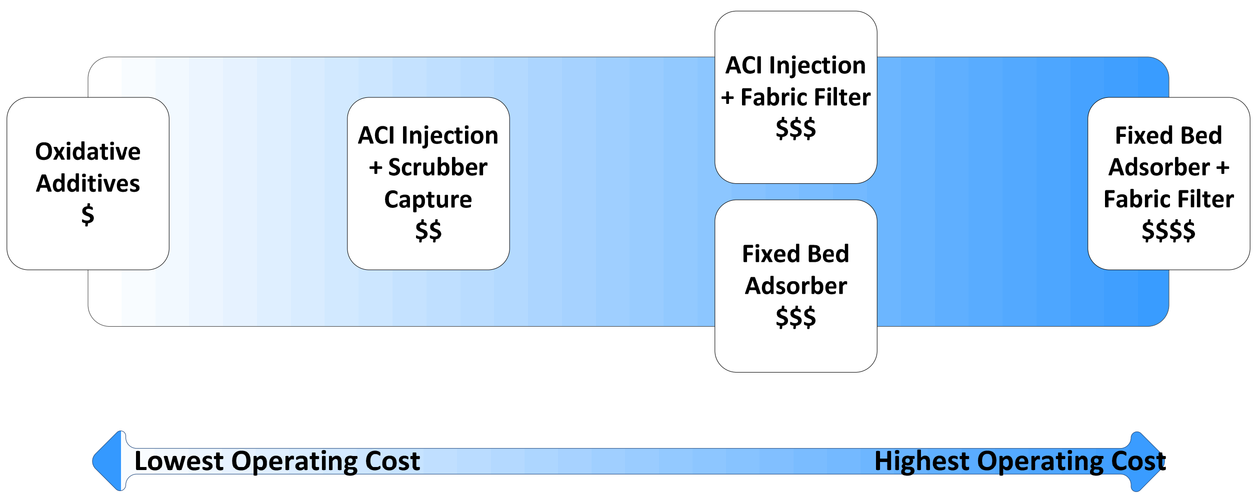


Figure 2 Relative Operating Costs

6.0 Discussion

Based on this high-level screening, the most attractive technologies are the simplified injection technologies, be they activated carbon injection into the existing scrubber or with a new fabric filter, or the special oxidant additives. However, the spent AC, or the chemical additives, can contaminate the recycle solids allowing mercury to be re-emitted back to the atmosphere. Some possible solutions are proposed to reduce the impact of these sorbents on the recycle solids:

- Sending the recycle solids to the grinding mill, instead of the green ball feed, may help reduce the mercury concentration in the solids, since only the magnetic fraction of these solids are recovered, and mercury, which tends to adsorb to the non-magnetic fraction of the solids, will be disposed.
- Proper separation techniques should be used to separate the sorbents from the scrubber solid prior to recycle.

The fixed bed options, while offering predictable performance, have high capital cost, due to the large number of parallel trains required to treat a waste gas volume of this size, and high quality materials of construction to withstand any potential corrosion environment in the process. However, it is possible to lower the cost by reducing the quality of materials if selected for this analysis, which can be confirmed in detailed design. If the waste gas from kilns is not corrosive, carbon steel can be used at a significant savings.

7.0 Appendices

Appendix A Technology Data Sheets

Appendix B Evaluation Backup Information

APPENDIX A

Technology Data Sheets

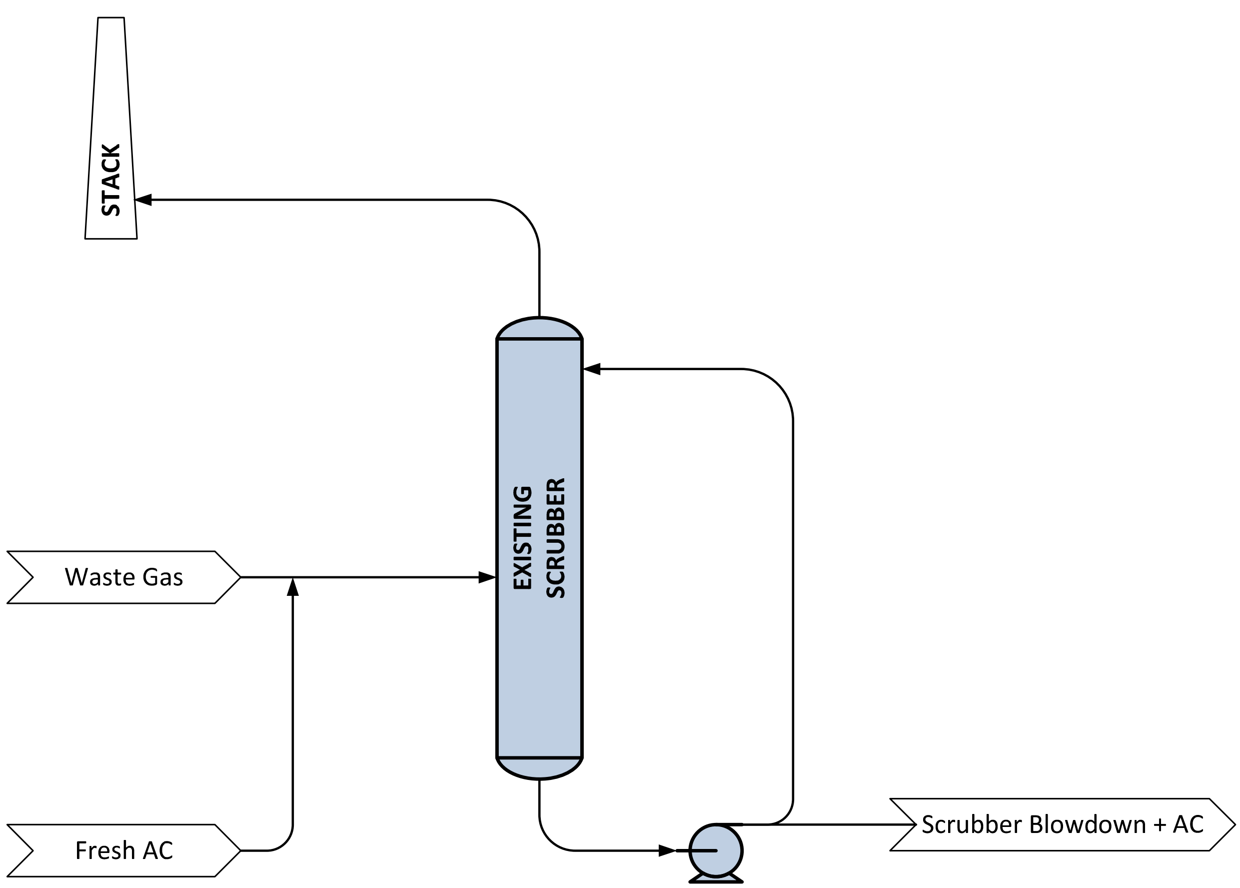
APPENDIX B

Evaluation Backup Information

APPENDIX A

Technology Data Sheets

Technology Survey: Activated Carbon Injection (ACI) and Wet Scrubber
Date of Technology Assessment: May 08, 2012
Equipment Summary: 1. Activated Carbon (AC) 2. AC silo 3. Feeder 4. Injection lance
Detailed Description: Powdered activated carbon is used as a sorbent to adsorb the mercury. It is injected and mixed with the waste gas in the duct prior to the wet scrubber. Residence time varies with the configuration of the plant and distance to the particulate control device, as well as the type of particulate control device. In this technology, the existing wet scrubber is used for removing the spent carbon, which will be taken out of the treated gas by scrubbing water and discharged from the scrubber with scrubber blowdown. Note that the results referenced in this datasheet were obtained from pilot testings at coal-fired power plants where an electrostatic precipitator or a fabric filter was used as a particulate control device. Unlike the utility sector, the wet scrubber was a primary particulate control device in the taconite processing plants and was not designed to handle additional AC injected to the system. As a result, any introduced AC could likely result in an increase in particulate emissions and actual mercury removal may differ.
Potential for Use with Generic Taconite Plant: Injection lance prior to existing scrubbers. Lances for individual scrubbers or for the entire waste gas duct to be determined in detail design.
Flow Sheet:



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Technology Survey: Activated Carbon Injection (ACI) and Wet Scrubber

- Scrubber Compatible: No. The spent AC can increase particulate loading of the scrubber. A further evaluation on particulate removal efficiencies required.
- Pressure Drop: Small
- Footprint: 2500 ft^2 for one processing line (756000 acfm flue gas)
- Size: Small
- Power Usage: Small. No additional fan power is required.
- Suitability for Induration Type: Straight Grate/Grate Kiln
- Suitability for Fuel Type: High-rank coal (e.g., bituminous coals); the mercury control can be increased if brominated (treated) AC is used.
- Susceptibility to Flue Gas Compositions: (i) Water vapor; SO_3; SO_2/NO_2 (reduce the equilibrium sorption capacity) (ii) Cl; NO_x; NO_x/NO_2 and HCl (increase the equilibrium sorption capacity)
- Regeneration Capability: No
- Chemistry b/w Mercury and Additives or Sorbents: Well-understood since it has been extensively tested in coal-fired systems.
- Possibility of Mercury Re-emission/Desorption: Possible if a very high level of SO_x, NO_x, and HCl control is not obtained.

Maturity/Risk Comments:
Mature technology in coal-fired utility applications, commercially available.

State of Development:
☐ Conceptual ☐ Bench Scale ☐ Pilot Scale ☐ Full Scale ☒ Commercially Available & Performance Guaranteed

List of Users/Pilot Sites (include size of plant and type of fuel):

Power Plant	Fuel Type	ACI Rate (lb/hr)
1. E.C. Gaston	Low sulfur bituminous	750
2. Pleasant Prairie	Powder River Basin (PRB) subbituminous	750
3. Brayton Point	Low sulfur bituminous	750
4. Salem Harbor	Low sulfur bituminous	750

Projected to be Commercially Available on:
ACI technology is currently commercially available for utility industries.

Path to Commercial Availability:
Multiple ACI technology providers for utility industry as listed below;

Company	% Mercury removal	Experience	ACI system
1. ADA Environmental Solutions (CO, USA)	+90%	10+ years with >60 full-scale demonstrations (>16,000 MW of ACI systems under contract)	Standard and custom designed ACI systems
2. Norit Americas Inc (TX, USA)	+90%	15+ year	Standard and custom designed ACI systems
3. Dustex Cooperation (GA, USA)	+90%	Not given	Standard and custom designed ACI systems
4. APC Technologies Inc. (PA, USA)	+90%	Not given	Not given

Other suppliers include Clyde Bergemann Delta Ducon, Inc. (PA, USA) and FLSmidth (PA, USA).

Technology Survey: Activated Carbon Injection (ACI) and Wet Scrubber

Cost Summary:

Cap	Staffing	Maint.	Aux. Power	Disposal	By Product	Reagent	Fuel	Total O&M Cost

Total Installed Cost: **Total Annual O&M:**

Source(s) of Cost Data:

Comments on Costs:
Low cost option. Impact of scrubber waste water contamination not considered.

Integration Potential:
Integrates easily, except for impacts to scrubber waste water/solid reuse.

Imposed Operational Limitations/Plant Impact:

- Impact on Scrubber Solid Recycle: Yes, the spent AC can contaminate the scrubber solid. Therefore, recycling these solids could result in very high (and increasing) levels of mercury being recycled. However, it is possible to minimize this impact if the scrubber solids are recycled to the grinding mill rather than the green ball feed. Since mercury tends to absorb to the nonmagnetic fraction of the scrubber solids, it will be discarded at the grinding mill where only the magnetic fraction of these solids are recovered. Or, other separation techninques (e.g. magnetic separation) may be used to separate the spent AC from the scrubber solids before recycling to the green ball feed.

- Impact on Iron Chemistry During the Induration Process: No, the activated carbon is added after induration.

- Others: the long-term balance-of-plant impacts is unknown when more expensive treated (brominated) AC is used to achieve desired mercury control, especially when high elemental Hg concentration is generated at taconite plants.

Other Technologies:
ACI technologies can be used with other particulate control devices (e.g., fabric filter) to help remove spent AC from the gas stream.

Materials of Construction (erosion, corrosion, etc.):
Corrosion resistant lances required due to presence of acidic species and humidity, although waste gas is not saturated.

Safety Comments:
Entry into AC silo requires assurance of breathable atmosphere. Entry will be rare.

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Technology Survey: Activated Carbon Injection (ACI) and Wet Scrubber
General Comments: ACI technology is a commercially proven technology for coal-fired power plants (>90% mercury removal) and has been tested for mercury control in the taconite facilities. Integration of the ACI technology to the taconite process is straightforward due to small footprint and small pressure drop (no need for additional fan power). Among other technologies, it is considered a low-cost option even though it is a throwaway process. However, spent AC can possibly impact the scrubber solid and wastewater and may worsen particulate emission of poorly functioning scrubbers.
Benefits and Drawbacks: Benefits • No additional duckwork is required, except for the injection lances. Equipment such as AC silo and feeder can be placed outside the process building. • All equipment can be purchased directly from vendors and is very reliable. • Depending on the amount of AC used, the annual labour cost for operating and maintaining the equipment is quite low. Drawbacks • Since mercury removal by the ACI technology is in-duct capture, optimization of the injection location is required to maximize the residence time. In addition, a flow profile and simulation of the duct may be necessary to ensure good distribution of AC and to determine the proper location of the lances. • The amount of AC must be increased in order to achieve the same mercury removal level as would be when an electrostatic precipitator or a fabric filter is present. • Additional AC could potentially increase particulate emissions. • It can impact scrubber solids recycling and/or chemistry.
References: 1. Laudal, D.L., Dunham, G.E. Mercury Control Technologies for the Taconite Industry (2007). 2. Sjostrom, A.; Durham, M.; Bustard, C.J. Activated Carbon Injection for Mercury Control: Overview. Fuel 89 (2010), pp.1320 – 1322.

Technology Survey: Activated Carbon Injection (ACI) and Fabric Filter

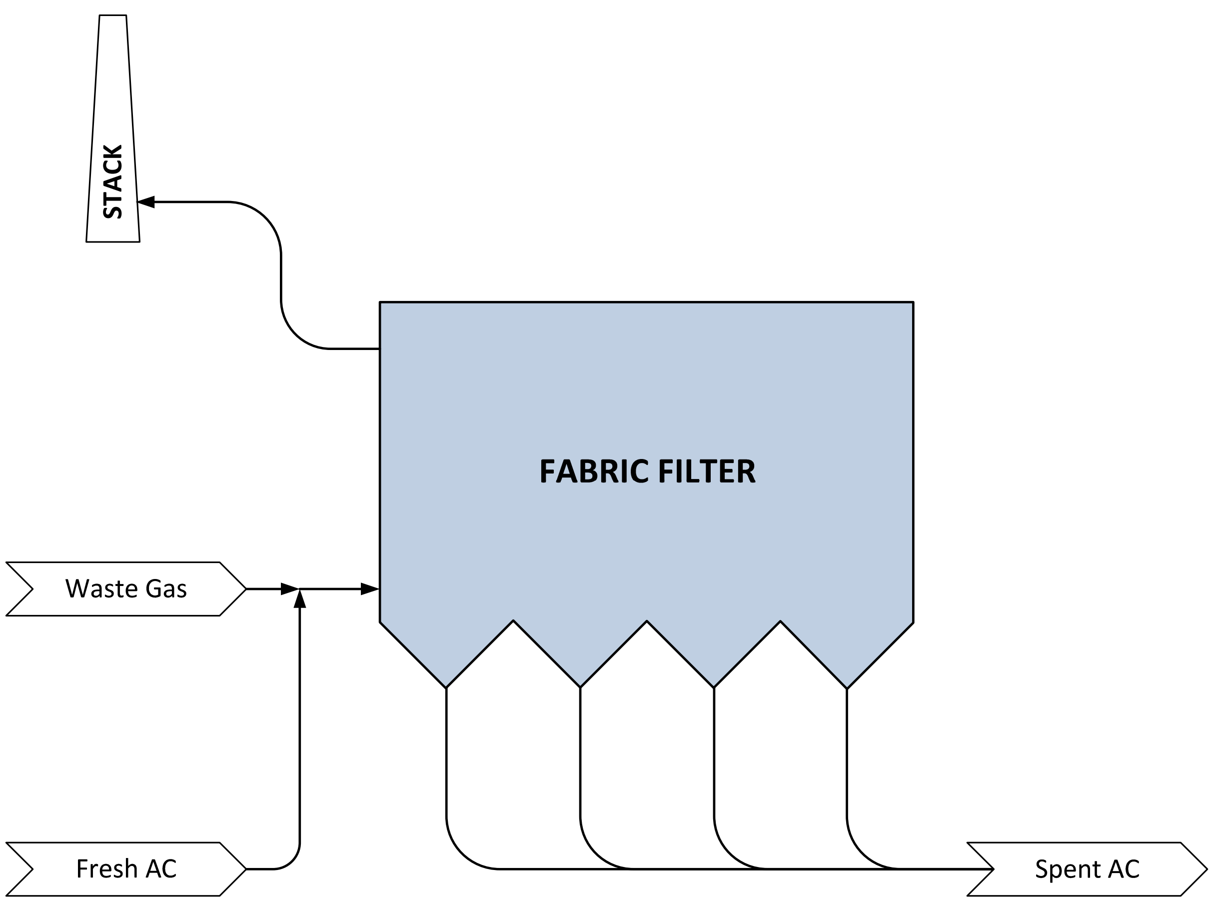
Date of Technology Assessment: May 08, 2012

Equipment Summary:
1. Activated Carbon (AC)
2. AC silo
3. Feeder
4. Injection lance
5. Fabric filter

Detailed Description:
Powdered activated carbon is used as a sorbent to adsorb the mercury. It is injected and mixed with the waste gas in new ductwork leading to a fabric filter that will replace the existing wet scrubber. The fabric filter is used to filter the spent carbon out of the system.

Potential for Use with Generic Taconite Plant:
Injection lance prior to a new fabric filter. Lances for the entire waste gas duct and a specification of a fabric filter to be determined in detail design.

Flow Sheet:



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Technology Survey: Activated Carbon Injection (ACI) and Fabric Filter

- Scrubber Compatible: No. The fabric filter replaces the existing wet scrubber.
- Pressure Drop: High
- Footprint: 4500 ft^2 for one processing line (756000 acfm flue gas)
- Size: Small ACI system and 75 ft by 60 ft for fabric filter
- Power Usage: 3000 hp
- Suitability for IndurationType: Straight Grate/Grate Kiln
- Suitability for Fuel Type: See ACI technology
- Susceptibility to Flue Gas Compositions: See ACI technology
- Regeneration Capability: No
- Chemistry Between Mercury and Chemical Additive or Sorbents: See ACI technology
- Possibility of Mercury Re-emission/Desorption: Possible if a very high level of SO_2, NO_x, and HCl control is not obtained.

Maturity/Risk Comments:
Mature technology, commercially available.

State of Development:
☐ Conceptual ☐ Bench Scale ☐ Pilot Scale ☐ Full Scale ☒ Commercially Available & Performance Guaranteed

List of Users/Pilot Sites (include size of plant and type of fuel):
Multiple utility + industrial applications.

Projected to be Commercially Available on:
Both ACI technology and fabric filter are currently commercially available.

Path to Commercial Availability:
Multiple ACI technology providers (See ACI technology) and fabric filter suppliers.

Cost Summary:

Cap	Staffing	Maint.	Aux. Power	Disposal	By Product	Reagent	Fuel	Total O&M Cost

Total Installed Cost: **Total Annual O&M:**

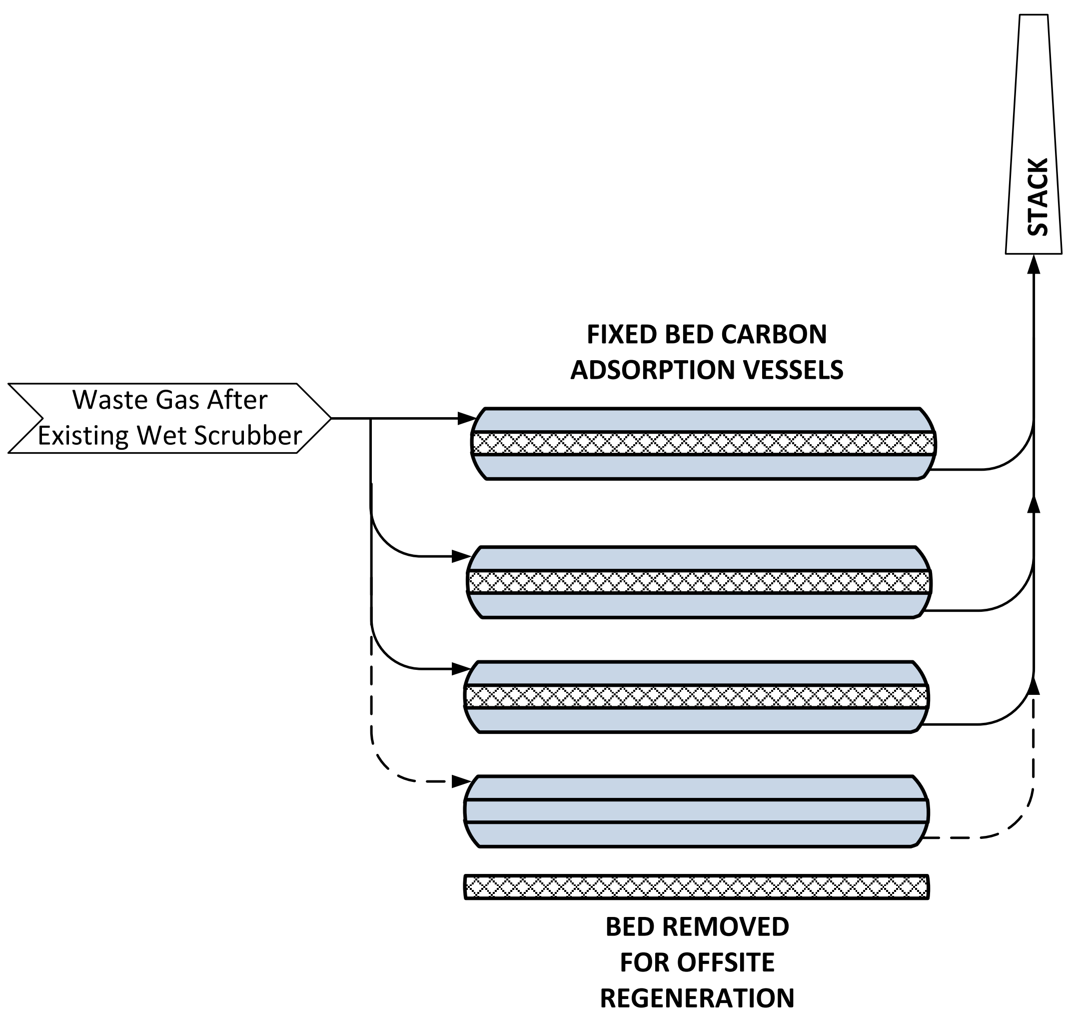
Source(s) of Cost Data:

Comments on Costs:
Middle cost option.

Integration Potential:
Medium integration potential. Replacing the existing scrubber involves substantial duct work rearrangement.

Technology Survey: Activated Carbon Injection (ACI) and Fabric Filter
Imposed Operational Limitations/Plant Impact: • Impact on Scrubber Solid Recycle: Yes, recycling solids will be mixed with the spent AC. To minimize the impact, the mixture should be recycled to the grinding mill, instead of the green ball feed, or it must be separated before recycle. • Impact on Iron Chemistry During the Induration Process: No, the activated carbon is added after induration. • Others: the long-term balance-of-plant impacts is unknown when more expensive treated (brominated) AC is used to achieve the desired mercury control, especially when high elemental Hg concentration is generated at taconite plants.
Other Technologies:
Materials of Construction (erosion, corrosion, etc.): Corrosion resistant lances required due to presence of acidic species and humidity, although waste gas is not saturated. Stainless steel assumed for a fabric filter. However, the quality of materials may be reduced, which can be confirmed in detail design. If the waste gas from kilns is not corrosive, carbon steel can be used at a significant savings.
Safety Comments: Entry into AC silo requires assurance of breathable atmosphere. Entry will be rare.
General Comments: Each individual technology is a commercially proven technology for coal-fired power plants. In this particular application, the ACI technology removes mercury from the waste gas whereas the fabric filter filters spent AC out of the system, mitigating the particulate stack emission problem. Integration to the taconite process has a medium potential considering extra space, ductwork and fan power to accommodate the fabric filter in addition to the ACI system. Among other technologies, it is considered a middle-cost option due to additional equipment costs.
Benefits and Drawbacks: <u>Benefits</u> • It increases particulate control. • It can achieve a high mercury control level with a relatively low amount of sorbents compared to the ACI technology. <u>Drawbacks</u> • Since mercury removal by the ACI technology is in-duct capture, optimization of the injection location is required to maximize the residence time. In addition, a flow profile and simulation of the duct may be necessary to ensure good distribution of AC and to determine the proper location of the lances. • Required space is large. • It can impact scrubber solids recycling and/or chemistry • Increased fan power is required.
References: 1. Laudal, D.L., Dunham, G.E. Mercury Control Technologies for the Taconite Industry (2007).

Technology Survey: Fixed Bed Adsorption
Date of Technology Assessment: May 08, 2012
Equipment Summary: 1. Activated Carbon (AC) 2. Carbon adsorption vessels
Detailed Description: Powdered activated carbon is packed in a fixed-bed adsorption vessel. The waste gas leaving the wet scrubber passes through a series of these vessels where the fixed-carbon beds will remove the mercury from the waste gas. The spent beds will be removed for potential off-site regeneration.
Potential for Use with Generic Taconite Plant: A series of adsorption vessels after existing wet scrubbers. Extensive amount of ductwork required. The number and size of vessels, the amount of AC initial fill and off-site regeneration to be determined in detail design.
Flow Sheet:



Technology Survey: Fixed Bed Adsorption

- Scrubber Compatible: Yes
- Pressure Drop: 6 – 12 in H_2O[(2-4)] for one adsorption vessel (42300 acfm)
- Footprint: 42900 ft^2 for one processing line (756000 acfm flue gas)
- Size: 12 ft dia. and 47 ft long for one adsorption vessel (42300 acfm) (Require multiple vessels)
- Power Usage: 3000 hp (756000 acfm flue gas)
- Suitability for Induration Type: Straight Grate/Grate Kiln
- Suitability for Fuel Type: See ACI technology
- Susceptibility to Flue Gas Compositions: See ACI technology / Post scrubber corrosion concern due to wet gas
- Regeneration Capability: Yes
- Chemistry b/w Mercury and Additives or Sorbents: See ACI technology
- Possibility of Mercury Re-emission/Desorption: Possible if a very high level of SO_2, NO_x, and HCl control is not obtained or bed is replaced.

Maturity/Risk Comments:
Used in other industries. Piloting recommended.

State of Development:
☐ Conceptual ☐ Bench Scale ☐ Pilot Scale ☒ Full Scale ☐ Commercially Available & Performance Guaranteed

List of Users/Pilot Sites (include size of plant and type of fuel):

Plant	Application	Waste gas flow rate
1. Armak (MI, USA)	Solvent recovery system	125,000 scfm

Projected to be Commercially Available on:
The fixed-carbon bed technology is currently commercially available for several industries such as solvent recovery systems and waste-to-energy plants. A full-scale conceptual design for a taconite processing plant was performed in 2012 by ADAES.

Path to Commercial Availability:
Multiple fixed-bed adsorption technology providers as listed below;

Company	% Removal	Application
1. APC Technologies Inc. (PA, USA)	99% (mercury)	Wastewater treatment plants (sludge incinerators), hospital waste incinerators, municipal waste incinerators, waste-to-energy plants, fossil fuel fired boilers, taconite plants, retort furnaces, fluorescent bulb manufacturing, chlor-alkali plants, chemical plants and specialty refineries
2. AMCEC Inc. (IL, USA)	+99% (Organic solvents)	Solvent recovery systems
3. MEGTEC System Inc. (WI, USA)	+99% (Organic solvents)	Solvent recovery systems
4. Fusion Environmental Corporation (GA, USA)	+99% (Organic solvents, e.g., VOCs)	Solvent recovery systems

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Technology Survey: Fixed Bed Adsorption

Cost Summary:

Cap	Staffing	Maint.	Aux. Power	Disposal	By Product	Reagent	Fuel	Total O&M Cost

Total Installed Cost: **Total Annual O&M:**

Source(s) of Cost Data:

Comments on Costs:
High cost option due to large number of parallel trains, extensive ductwork and additional fan power to overcome back pressure exerted by the fixed bed. Cost can be decreased if the lower quality of materials of construction than stainless steel (assumed in this evaluation) is used.

Integration Potential:
Difficult, much ductwork rerouting required, and high space requirement.

Imposed Operational Limitations/Plant Impact:

- Impact on Scrubber Solid Recycle: No, the fixed carbon adsorption technology is applied after the scrubber. Therefore, the scrubber solid recycle is not affected.
- Impact on Iron Chemistry During the Induration Process: No, there is no need for the fixed bed technology to add any AC or additives during the induration process.
- Others: Very high pressure drop

Other Technologies:
In case of poor-efficiency wet scrubbers, installing particulate control devices (e.g., fabric filter) upstream of the adsorption vessel help reduce particulate clogging the fixed beds, but increase system pressure drop at the same time. Additional fan power is needed.

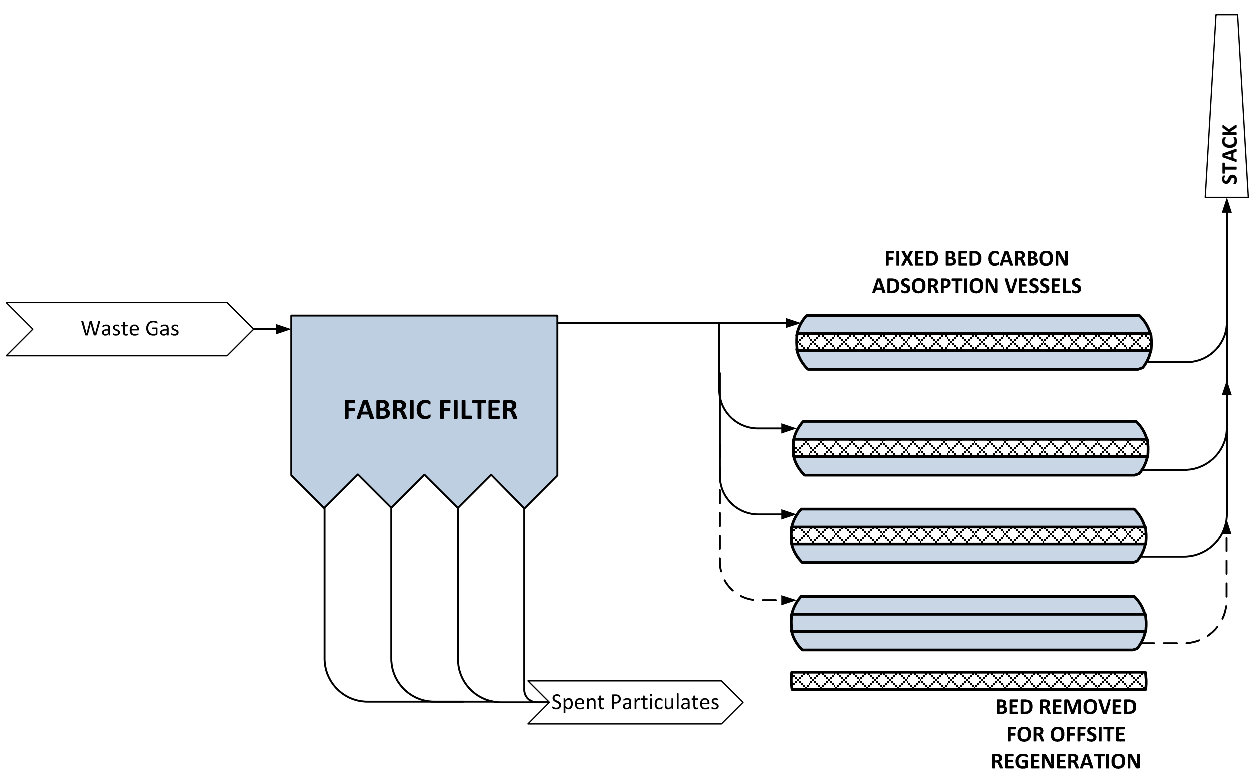
Materials of Construction (erosion, corrosion, etc.):
Post scrubber installation has acid dew point corrosion concerns. Stainless steel assumed in this evaluation. However, the quality of materials to resist corrosion may be reduced, which can be comfirmed in detail design.

Safety Comments:
Entry to the fixed bed vessels is moderately frequent since entry is required each time the top layer of the bed needed to be changed, but manually entering the confined space may not be necessary depending on techniques used.

General Comments:
Although the fixed-carbon bed adsorption technology has been used in several industries (e.g., chlor-alkali plants and solvent recovery systems) to remove organic solvents from the gaseous streams with >99% removal, pilot testing with waste gas from the taconite processing plants is recommened. Since this technology requires large space to house several parallel trains, extensive ductwork and extra fan power, it makes the integration to the taconite process relatively difficult and expensive. However, this technology will not impact the existing wet scrubber.

Technology Survey: Fixed Bed Adsorption
Benefits and Drawbacks: Benefits • Increased particulate emissions can be avoided. • Impact to scrubber solids recycling can be avoided since the technology is installed after the wet scrubber. Drawbacks • Additional fan power is required to overcome the pressure drop across the fixed-bed reactor. • Required footprint is substantially large. • Due to space limitation, the fixed-bed reactor would have be located outside the process plant. Therefore, duct modification is required to direct the waste gas from the wet scrubber and back to the stack. • High relative humidity can impact the carbon performance in fixed beds. A waste gas pretreatment may be required to get rid of excess water vapor. • Material disposal (e.g., spent AC bed) should be taken into consideration.
References: 1. Laudal, D.L., Dunham, G.E. Mercury Control Technologies for the Taconite Industry (2007). 2. ADA Environmental Solutions (ADA-ES), Developing Cost-Effective Solutions to Reduce Mercury Emissions from Minnesota Taconite Plants: United Taconite Plant (2012). 3. ADA Environmental Solutions (ADA-ES), Developing Cost-Effective Solutions to Reduce Mercury Emissions from Minnesota Taconite Plants: Hibbing Taconite Plant (2012). 4. ADA Environmental Solutions (ADA-ES), Developing Cost-Effective Solutions to Reduce Mercury Emissions from Minnesota Taconite Plants: ArcelorMittal Minorca Mine Inc. Plant (2012).

Technology Survey: Fixed Bed Adsorption and Fabric Filter
Date of Technology Assessment: May 08, 2012
Equipment Summary: 1. Activated Carbon (AC) 2. Carbon adsorption vessels 3. Fabric Filter
Detailed Description: Waste gas passes through a fabric filter, which replaces the existing wet scrubber, to remove particulate matter to a level that eliminates potential problems with clogging the fixed carbon beds. The dedusted waste gas is then introduced to a series of fixed-bed carbon adsorption vessels, which will remove the mercury from the waste gas. The spent beds will be removed for off-site regeneration.
Potential for Use with Generic Taconite Plant: Fabric filter and a series of adsorption vessels. Extensive amount of ductwork required. The number and size of vessels, the amount of AC initial fill and off-site regeneration as well as fabric filter sizing to be determined in detail design.
Flow Sheet:



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Technology Survey: Fixed Bed Adsorption and Fabric Filter

- Scrubber Compatible: No. The fabric filter replaces the existing wet scrubber.
- Pressure Drop: Greater than the fixed bed technology (>6 – 12 in H_2O)
- Footprint: 47400 ft^2 for one processing line (756000 acfm flue gas)
- Size: 12 ft dia. and 47 ft long for one adsorption vessel (42300 acfm) (Require multiple vessels) and 75 ft by 60 ft for fabric filter
- Power Usage: 3900 hp (756000 acfm flue gas)
- Suitability for IndurationType: Straight Grate/Grate Kiln
- Suitability for Fuel Type: See ACI technology
- Susceptibility to Flue Gas Compositions: See ACI technology
- Regeneration Capability: Yes
- Chemistry Between Mercury and Chemical Additive or Sorbents: See ACI technology
- Possibility of Mercury Re-emission/Desorption: Possible if a very high level of SO_2, NO_x, and HCl control is not obtained or bed is replaced.

Maturity/Risk Comments:
Similar to the fixed-bed technology.

State of Development:
☐ Conceptual ☐ Bench Scale ☐ Pilot Scale ☒ Full Scale ☐ Commercially Available & Performance Guaranteed

List of Users/Pilot Sites (include size of plant and type of fuel):
Similar to the fixed-bed technology.

Projected to be Commercially Available on:
Similar to the fixed-bed technology.

Path to Commercial Availability:
Multiple fixed-carbon bed technology providers (see the fixed-bed technology) and fabric filter suppliers.

Cost Summary:

Cap	Staffing	Maint.	Aux. Power	Disposal	By Product	Reagent	Fuel	Total O&M Cost

Total Installed Cost: **Total Annual O&M:**

Source(s) of Cost Data:

Comments on Costs:
Highest cost option due to large number of parallel trains, the fabric filter, extensive ductwork and additional fan power to overcome back pressure exerted by the fixed bed and the fabric filter. Cost can be decreased if the lower quality of materials of construction than stainless steel (assumed in this evaluation) is used.

Technology Survey: Fixed Bed Adsorption and Fabric Filter

Integration Potential:
Difficult, extensive space and ductwork modification required.

Imposed Operational Limitations/Plant Impact:

- Impact on Scrubber Solid Recycle: Yes, recycling solids will be mixed with the spent AC. To minimize the impact, the mixture should be recycled to the grinding mill, instead of the green ball feed, or it must be separated before recycle.
- Impact on Iron Chemistry During the Induration Process: No, there is no need for the fixed bed technology to add any AC or additives during the induration process.
- Others: Very high pressure drop.

Other Technologies:

Materials of Construction (erosion, corrosion, etc.):
Stainless steel assumed. However, the quality of materials may be reduced, which can be confirmed in detail design. If the waste gas from kilns is not corrosive, carbon steel can be used at a significant savings.

Safety Comments:
Entry to fixed bed vessels is moderately frequent since the entry is required each time the top layer of the bed needed to be changed, but manually entering the confined space may not be necessary depending on techniques used.

General Comments:
Similar to the fixed-bed technology. With an addition of the fabric filter, particulate clogging of the fixed carbon bed is eliminated but difficulty in process integration and cost is increased.

Benefits and Drawbacks:

Benefits

- Increased particulate emissions can be avoided.
- Clogging in the fixed-bed carbon vessel due to particulate matter is reduced.

Drawbacks

- Higher fan power than the fixed-bed technology to overcome the pressure drop across both fabric filter and fixed-bed reactors.
- Required footprint is substantially larger than the fixed-bed technology.
- Due to space limitation, both fabric filter and fixed-bed reactors would have be located outside the process plant. Therefore, duct modification is required to direct the waste gas from the wet scrubber and back to the stack.
- High relative humidity can impact the carbon performance in fixed beds. A waste gas pretreatment may be required to get rid of excess water vapor.
- It can impact scrubber solids recycling and/or chemistry.
- Material disposal (e.g., spent AC bed) should be taken into consideration.

References:

1. Laudal, D.L., Dunham, G.E. Mercury Control Technologies for the Taconite Industry (2007).

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Technology Survey: Monolithic Polymer Resin Adsorption

Date of Technology Assessment: May 08, 2012

Equipment Summary:
- Adsorption vessels
- Activated-carbon polymer resin monoliths

Detailed Description:

Activated carbon fluoropolymer composite (CFC) materials are used to chemically adsorb mercury from the flue gas stream. The treated activated carbon powder is combined with chemicals such as elemental sulfur or alkaline metal iodides to enhance the mercury efficiency and the fluoropolymer (e.g., polymertetrafluoroethylene - PTFE). The mixture is then calendered into CFC sheets under elevated temperature. The CFC sheet is stretched extensively to develop the microporous structure that will allow rapid chemical oxidation of Hg^0 and binding of Hg^{2+} to the active sites of the fiber. Fig. 1 shows the microscopic structure of the CFC material where the solid nodes represent the activated carbon and the lines represent PTFE polymer fibrils. The mercury molecules in the flue gas will be chemically adsorbed on the activated carbon active sites. These sites do not saturate with SO_2 since SO_2 molecules adsorbed on the activated carbon are converted to H_2SO_4 with the presence of O_2 and H_2O, expelled from the activated carbon through the polymer fibril networks due to a high water repellency of PTFE and then collected at the outlet. Without SO_2 saturating the acitive sites, it is possible to achieve long-term operation before the activated carbon becomes saturated by mercury and sorbent regeneration may not be required in the lifetime of the adsorbent. When interviewed, the vendor indicates that adsorbent removal and replacement can be built into the supply contract and will be carried out periodically and automatically. The limited commercial experience with this technology does not allow prediction of service life at this time.

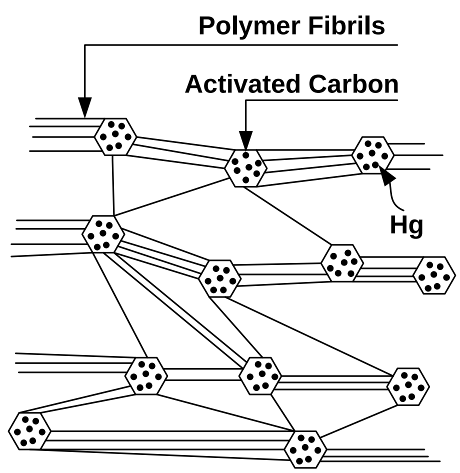


Figure 1. Microscopic structure of a CFC material

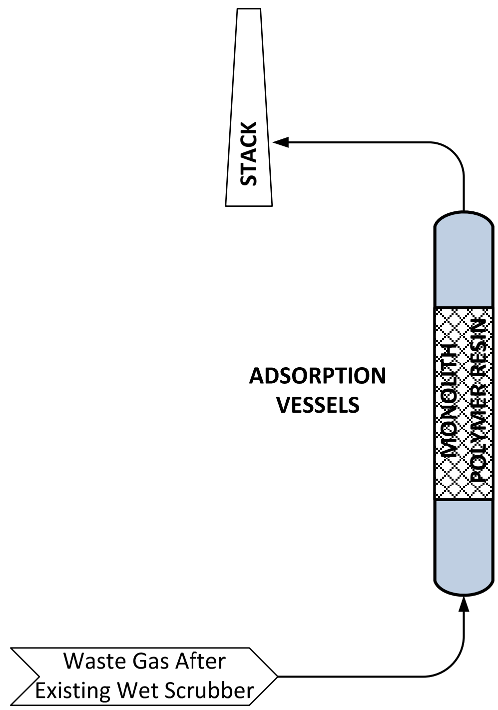
Both sides of the CFC surface can be laminated with extra porous membranes to enhance the PM2.5 filtration capability. The CFC sheets can be fixed on a solid frame in parallel with the same distance between the sheets to form a sorbent module, which will be stacked in the sorbent house. Alternatively, the CFC materials made into granular, rod or other shapes can be used as a packing material to form a packed-bed system [1,2]. Pressure drop created by this technology is expected to be lower than the fixed-bed technology since CFC sheets can be made into various shapes and forms, including an open-channel design.

Potential for Use with Generic Taconite Plant:

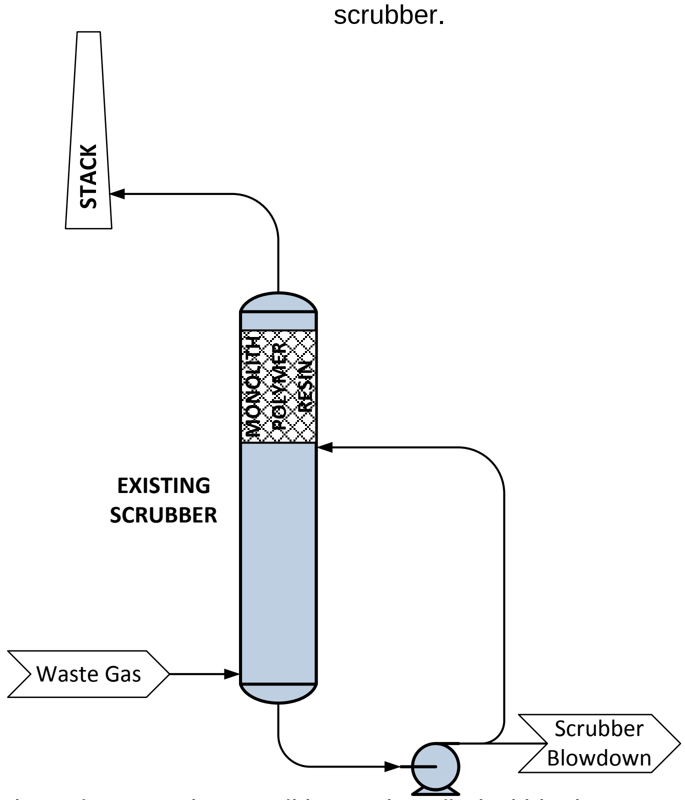
The monolith may be installed in a new adsorber vessel, or possibly integrated directly into the existing scrubber. In this evaluation, an installation of a new adsorber vessel is assumed.

Technology Survey: Monolithic Polymer Resin Adsorption

Flow Sheet:



(a) Adsorption vessels packed with the polymer resin monoliths is used to treat the waste gas after wet scrubber.



(b) the polymer resin monoliths are installed within the wet scrubber.

Technology Survey: Monolithic Polymer Resin Adsorption

- Scrubber Compatible: Yes
- Pressure Drop: Expected to have lower pressure drop than the fixed bed design due to open-channel Design (based on preliminary vendor commentary).
- Footprint: 6400 ft^2 for post scrubber installation. The foot print can be reduced if the monoliths are installed in the scrubber.
- Size: A single vessel with 32 ft by 32 ft square by 30 ft tall
- Power Usage: Fan power required
- Suitability for IndurationType: Unknown. Never been tested in the taconite processing plants.
- Suitability for Fuel Type: Need further testing
- Susceptibility to Flue Gas Compositions: No
- Regeneration Capability: No need for regeneration
- Chemistry Between Mercury and Chemical Additive or Sorbents: Need further testing
- Possibility of Mercury Re-emission/Desorption: No

Maturity/Risk Comments:
Immature technology has been piloted successfully, larger scale pilot planned for 2013. The site has not been announced.

State of Development:
☐ Conceptual ☐ Bench Scale ☒ Pilot Scale (small) ☐ Full Scale ☐ Commercially Available & Performance Guaranteed

List of Users/Pilot Sites (include size of plant and type of fuel):

Power Plant	Coal Type	Flue Gas	CPC Tape	%Hg Removal	Ref
1. Plant Yates	low sulfur, eastern bituminous coal	Slip stream after wet scrubber			3-5
		• 5.0 acfm, 100% humidity and 123°F	Four 5" wide, 5' long strips	~60% for 60 days	
		• 13.0 and 24.7 acfm, 100% humidity and 123°F	Eight 6" deep, 3.8" diameter cylindrical modules	>90% for 120 days	

Projected to be Commercially Available on:
Full-scale demonstration is proposed in 2013 [5].

Path to Commercial Availability:

Company	% Mercury Removal	Application
1. W. L. Gore & Associates, Inc. (DE, USA)	Up to 95%	Coal-fired power plants

Cost Summary:

Cap	Staffing	Maint.	Aux. Power	Disposal	By Product	Reagent	Fuel	Total O&M Cost

Total Installed Cost: **Total Annual O&M:**

Technology Survey: Monolithic Polymer Resin Adsorption

Source(s) of Cost Data:

Comments on Costs:
It offers low operating cost due to long module life time (very high mercury storage capacity) and simple operation (no adjustments needed to account for changes in mercury concentration or speciation, little to no maintenance or energy required to operate, no regeneration).

Integration Potential:
Extra space to install a single adsorption vessel and ductwork modification required unless the in-scrubber installation is considered.

Imposed Operational Limitations/Plant Impact:

- Impact on Scrubber Solid Recycle: No, the polymer resin monolith is applied after the scrubber. Therefore, the scrubber solid recycle is not affected.
- Impact on Iron Chemistry During the Induration Process: No, there is no need for the monolithic polymer resin adsorption technology to add any additives during the induration process.
- Others: May adsorb SO_2 as H_2SO_4, and add this acid to the scrubber water. It is unclear if this waste stream is already acidic, and if a lower pH is an issue.

Other Technologies:

Materials of Construction (erosion, corrosion, etc.):
Must be constructed of corrosion resistant materials.

Safety Comments:
Minimal.

General Comments:
This developing technology requires further testing with the taconite waste gas. Data from pilot testing with coal-fired flue gases showed positive results of up to 95% mercury removal without sorbent regeneration. It is considered a low cost option compared with other technologies.

Benefits and Drawbacks:

Benefits

- No frequent regeneration required since the bed is not deactivated by SO_x or other acid gases [3].
- It offers co-benefit of SO_2 and PM2.5 reduction since most of SO_2 will be converted to H_2SO_4 (aq) (~37%wt) and PM2.5 can be filtered out [1].
- The pressure drop due to the CPC sheet or CPC in modular forms is reasonably low [3].
- The CPC sheet can be used to capture PM2.5 by surface filtration mechanism, and SO_x and other acid gases by converting them into aqueous acid solutions and expelled to the outer surfaces of the CPC sheet [1,3]
- The peripherial equipment such as silos and lances and procedures associated with PAC injection, collection, and disposal not required [2].
- It is insensitive to flue gas compositions (SO_3, halogen content, VOCs) [5].
- It is possible to use within a wet scrubber to prevent mercury re-emissions from the scrubber and provide

Technology Survey: Monolithic Polymer Resin Adsorption

SO_x polishing [5].

- Since mercury reduction is determined by the number of the CPC modules, it allows a flexibility to meet future regulations or process changes by simply adding additional layer of modules.

Drawbacks

- The technology is immature and requires full-scale demonstration.
- Impact of condensing acids on scrubber water is unknown.

References:

1. Lu, X-C; Wu, X. Flue Gas Purification Process Using a Sorbent Polymer Composite Material. U.S. Patent No. 7,442,352 B2 (2008).
2. Durante, V.A.; Stark, S.; Gebert, R.; Xu, Z.; Bucher, R., Keeney, R.; Ghorishi, B. A Novel Technology to Immobilize Mercury from Flue Gases. Paper # 232 (2003).
3. Darrow, J.R. Options for PM, Dioxin/Furan and Mercury Control Using ePTFE Technologies. Presentation (2011).
4. Lu, X.S.; Xu, Z.; Stark, S.; Gebert, R.; Machalek, T.; Richardson, C.; Paradis, J.; Chang, R.; Looney, B. Matthews, M. Flue Gas Merury Removal Using Carbon Polymer Composite Material. Presented at EUEC, Jan 31 – Feb 2, 2011.
5. Darrow, J.; Kolde, J. Gore ® Mercury Control System. Presentation (2012).

Technology Survey: Oxidative Chemical Addition
Date of Technology Assessment: May 08, 2012

Equipment Summary:

1. Chemical additives – Several potential chemical additives were considered as listed below;
   - Sodium and calcium chloride (NaCl and $CaCl_2$)
   - Sodium and calcium bromide (NaBr and $CaBr_2$)
   - Hydrogen peroxide (H_2O_2)
   - EPA's proprietary oxidant
   - EERC's proprietary additive
   - Ozone
   - Sodium bicarbonate ($NaHCO_3$)

Note that an H_2O_2 solution can capture about 10 – 15% of the mercury in the process gas. It is not a likely candidate for taconite processing plants and it even interferes with the background mercury oxidation process that takes place when no oxidant is added to the water. However, the proprietary EPA oxidant achieved above 80% removal.

2. Chemical silo

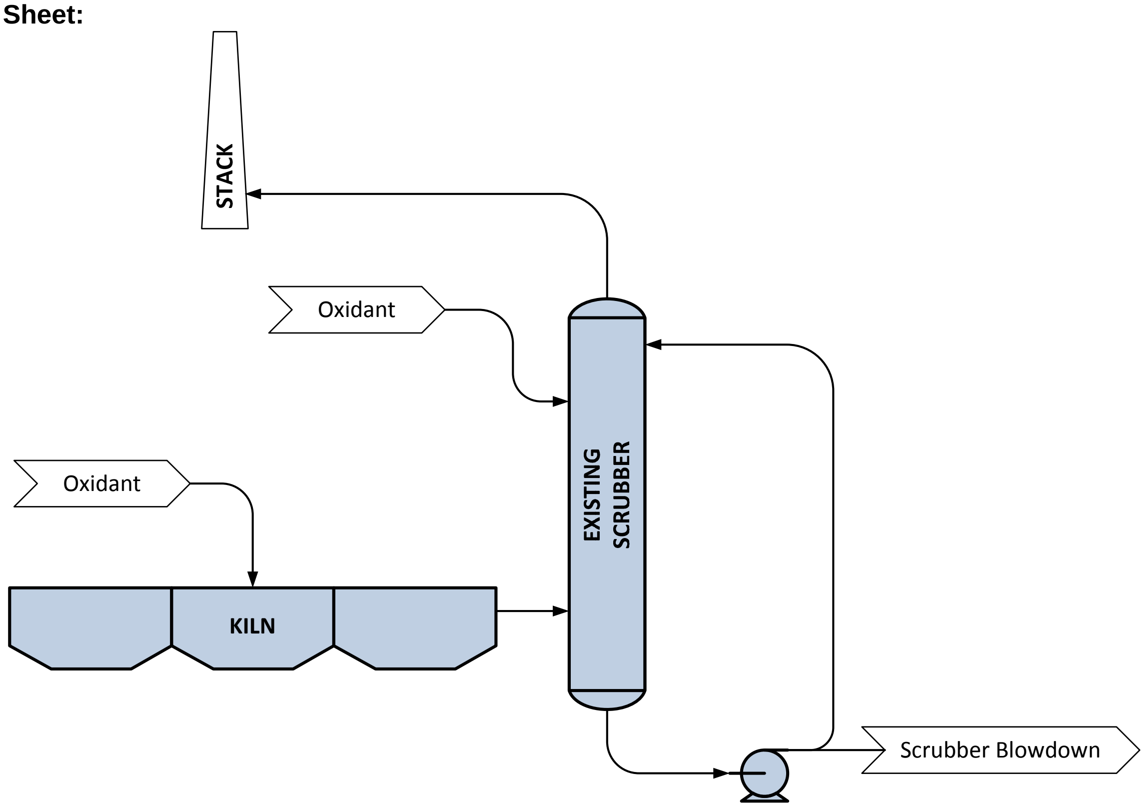
Detailed Description:

A chemical additive is added in the waste gas to enhance mercury oxidization converting Hg^0 (insoluble) to Hg^{2+} (water-soluble). An increase in the percentage of Hg^{2+} or particulate-bound mercury at the inlet of the wet scrubber will improve the mercury removal from the process.

Potential for Use with Taconite Plant:

Short-term tests has been conducted at the taconite plants for mercury reduction from stack emissions in 2007. A series of experiments was performed on slipstream gases from an operating taconite facility to investigate the effect of chemical oxidants on capture efficiency for elemental mercury. $CaBr_2$ is assumed as the oxidant for this analysis.

Flow Sheet:



Technology Survey: Oxidative Chemical Addition

- Scrubber Compatible: No. Oxidants will impact scrubber solid recycle/effluent.
- Pressure Drop: No change to current pressure drop.
- Footprint: 2500 ft^2 for one processing line (756000 acfm flue gas)
- Size: Small
- Power Usage: Small. No additional fan power is required.
- Suitability for Induration Type: Grate Kiln
- Suitability for Fuel Type: Need further testing
- Susceptibility to Flue Gas Compositions: EPA_{ox} reacts extensively with SO_x and NO_x.
- Regeneration Capability: No
- Chemistry b/w Mercury and Additive or Sorbents: Partially studied
- Possibility of Mercury Re-emission/Desorption: Yes

Maturity/Risk Comments:
Commercially emerging technology has been tested in the coal-fired power plants. Pilot testing is recommended. High potential for corrosion and erosion when the halogenated additives are used.

State of Development:
☐ Conceptual ☐ Bench Scale ☐ Pilot Scale ☒ Full Scale ☐ Commercially Available & Performance Guaranteed

List of Users/Pilot Sites (include size of plant and type of fuel):

Taconite Plant	Fuel Type	Production Rate (Lt/hr)	Induration Type	Pellet	Scrubber Type	Chemical Additive
1. U-Tac	Natural gas /Coal	200 - 450	Grate Kiln	Standard	Recirculating	NaCl to greenball
2. Hibtac	Natural gas	300 - 350	Straight Grate	Standard	Once through	NaCl, NaBr, $CaCl_2$ and $CaBr_2$ to greenball and process gas
3.KeeTac	Natural gas /Coal	700	Grate Kiln	Standard	Recirculating	H_2O_2 and EPA's proprietary oxidant to scrubber liquid

Projected to be Commercially Available on:

Path to Commercial Availability:
Multiple oxidative chemical suppliers.

Cost Summary:

Cap	Staffing	Maint.	Aux. Power	Disposal	By Product	Reagent	Fuel	Total O&M Cost

Total Installed Cost: **Total Annual O&M:**

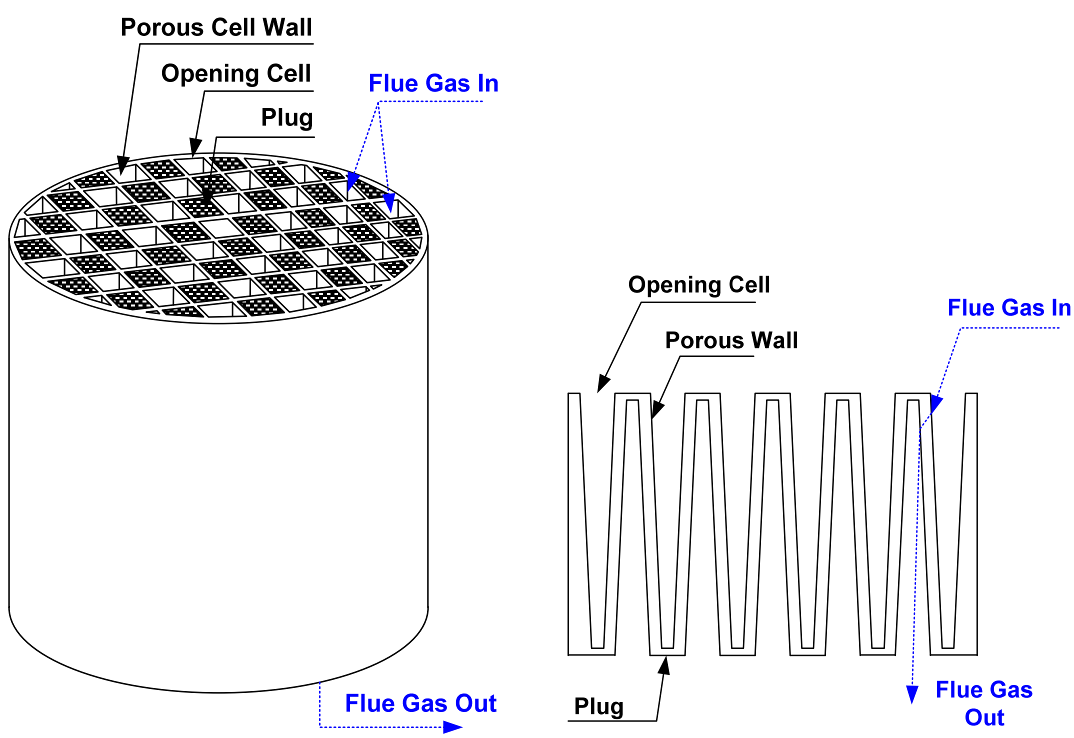
Technology Survey: Oxidative Chemical Addition
Source(s) of Cost Data:
Comments on Costs: Least expensive option.
Integration Potential: Integrates easily, except for impacts to iron and scrubber waste water/solid reuse.
Imposed Operational Limitations/Plant Impact: • Impact on Scrubber Solid Recycle: Yes, chemical additives increase the mercury concentration in the scrubber solids. To minimize the impact, the scrubber solids should be recycled to the grinding mill, instead of the green ball feed. • Impact on Iron Chemistry During the Induration Process: Possible for the additives added directly to the kiln. • Others: There is a potential for corrosion and erosion, especially when the halogenated (Br and Cl) additives are used due to a generation of halogen gases (Br_2 and Cl_2). If the tests for halide addition yielded positive results for mercury control, corrosion studies and cost analysis would be required prior to considering a viable technology.
Other Technologies:
Materials of Construction (erosion, corrosion, etc.): Corrosion resistant materials may be needed if the halogenated (Br and Cl) additives are used.
Safety Comments: Most oxidants are very safe. H_2O_2, if considered, is hazardous. Oxygen stored for ozone production hazardous (compressed gas).
General Comments: It is a commercially emerging technology with relatively simple process integration to the taconite processing plant. It is the least expensive option among other technologies. Further testing is recommended to understand the effect of oxidative chemicals on the chemistry of iron product, mercury reemission, scrubber liquids/solids and corrosion.
Benefits and Drawbacks: <u>Benefits</u> • For in-scrubber oxidation, the equipment required is inexpensive and simple since it involves only a tank to contain the oxidant and a small pump to feed the material in the scrubber system. <u>Drawbacks</u> • The EPA oxidant can react extensively with NO_x and SO_x. This implies both a higher consumption rate for the oxidant and a potential for high NO_3^- in the scrubber effluent, which may lead to a water treatment problem. • It can impact scrubber solids recycling and/or chemistry.

Technology Survey: Oxidative Chemical Addition
• It is likely to impact iron chemistry, especially when the additive is added during the induration process.
References: 1. Laudal, D.L., Dunham, G.E. Mercury Control Technologies for the Taconite Industry (2007). 2. Berndt, M.E., Engesser, J. Mercury Transport in Taconite Processing Facilities: (III) Control Method Test Results (2007).

Stantec

Technology Survey: Monolithic Honeycomb Adsorption
Date of Technology Assessment: May 08, 2012
Equipment Summary: • Adsorption vessels • Honeycomb monoliths

Detailed Description:
A series of activated carbon honeycomb catalyst monoliths is used to remove mercury from the flue gas. The honeycomb monolith is usually made of an activated carbon powder and catalyst (e.g. elemental sulfur). It comprises multiple opening cells and plugs, which are interconnected by porous walls extending from the inlet to the outlet. Each cell is preferably plugged only at one end. This plugging configuration in Fig. 1(a) will improve intimate contace between the flue gas and the porous wall of the monolith. Fig. 1(b) shows that the flue gas enters the monolith through the opening cells at the inlet end, then through the porous cell walls and out of the monolith through the open cells at the outlet end.

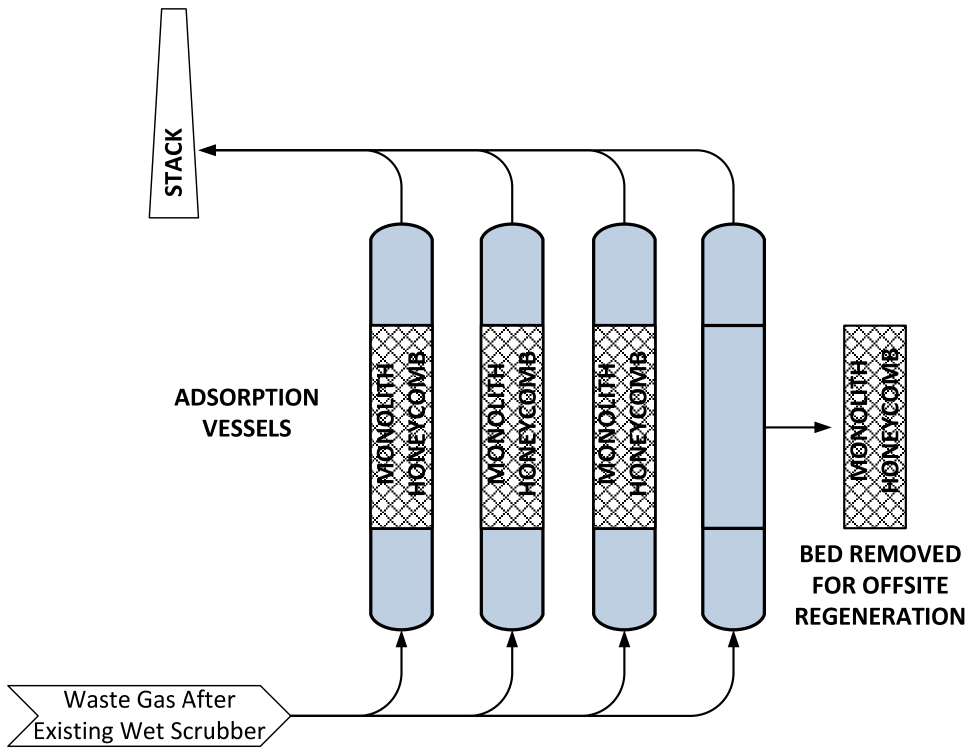


(a) (b)

Figure 1 (a) Plugged wall flow honeycomb monolith, (b) Cross-sectional view of plugged wall flow honeycomb monolith

Potential for Use with Generic Taconite Plant:
This technology is no longer being commercially developed, thus further evaluation has been halted.

Technology Survey: Monolithic Honeycomb Adsorption
Flow Sheet:



- Scrubber Compatible:
- Pressure Drop:
- Footprint:
- Size:
- Power Usage:
- Suitability for IndurationType:
- Suitability for Fuel Type:
- Susceptibility to Flue Gas Compositions:
- Regeneration Capability:
- Chemistry Between Mercury and Chemical Additive or Sorbents:
- Possibility of Mercury Re-emission/Desorption:

Maturity/Risk Comments:
No longer commercially developed.

State of Development:
☐ Conceptual ☐ Bench Scale ☐ Pilot Scale ☐ Full Scale ☐ Commercially Available & Performance Guaranteed

List of Users/Pilot Sites (include size of plant and type of fuel):

Projected to be Commercially Available on:

Stantec

Technology Survey: Monolithic Honeycomb Adsorption

Path to Commercial Availability:
The honeycomb technology is no loger considered a commercially viable technology for mercury control. The technology developers were MeadWestvaco amd Corning Incorporated.

Cost Summary:

Cap	Staffing	Maint.	Aux. Power	Disposal	By Product	Reagent	Fuel	Total O&M Cost

Total Installed Cost: **Total Annual O&M:**

Source(s) of Cost Data:

Comments on Costs:

Integration Potential:

Imposed Operational Limitations/Plant Impact:

- Impact on Scrubber Solid Recycle:
- Impact on Iron Chemistry During the Induration Process:
- Others:

Other Technologies:

Materials of Construction (erosion, corrosion, etc.):

Safety Comments:

General Comments:

Technology Survey: Monolithic Honeycomb Adsorption
Benefits and Drawbacks: Benefit • > 90% of Hg^0 removal efficiency without adding active materials such as activated carbon powder or ammonia to the system [1]. • No a particulate matter such as FF and ESP required to remove the active material added [1]. • Compared to ACI, Lower amount of contaminated activated carbon material being regenerated with low hazardous waste disposal cost [1].
References: 1. Gadkaree, K.P.; He, L.; Shi, Y. Activated Carbon Honeycomb Catalyst Beds and Methods for the Use Thereof. U.S. Patent No. 7,722,705 B2 (2010).

APPENDIX B

Evaluation Backup Information

PARAMETER		UNIT	KEEWATIN TACONITE (KEETAC)	HIBBING TACONITE (HIBTAC)			ARCELOR MITTAL	USS MINNTAC (MINNTAC)					UNITED TACONITE (U-TAC)		GENERIC TACONITE PLANT 1 - STRAIGHT GRATE	GENERIC TACONITE PLANT 2 - GRATE KILN
LOCATION			Keewatin	Hibbing			Virginia	Mountain Iron					Eveleth			
STACK RELATIVE HUMIDITY		(%)	Not given	70[a]	Not given	Not given	94[a]	Not given					Not given	67[1]	70	70
STACK TEMPERATURE		(°F)	Not given	124[a]	Not given	Not given	125[a]	125[e]					Not given	140[1]	125	125
LINE NO.		(-)	2[e]	1	2	3	1	3	4	5	6	7	1	2	1	1
INDURATION TYPE		(-)	Grate Kiln	Straight Grate	Straight Grate	Straight Grate	Straight Grate	Grate Kiln	Grate Kiln	Grate Kiln	Grate Kiln	Grate Kiln	Grate Kiln	Grate Kiln	Straight Grate	Grate Kiln
PELLET TYPE		(-)	Standard	Standard	Standard	Standard	Flux	Standard/Flux[e]	Standard/Flux[e]	Standard/Flux[e]	Standard/Flux[e]	Standard/Flux[e]	Standard	Standard	Standard	Standard
EXISTING PM CONTROL DEVICE	• Wet Venturi Type Scrubber	(-)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	• Multiclone	(-)	Yes	Yes	Yes	Yes	Yes	Yes[e]	Yes[e]	Yes[e]	Yes[e]	Yes[e]	No	No	No	No
	• Lime Neutralization	(-)	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	No
SCRUBBER TYPE		(-)	Recirculating	Once through	Once through	Once through	Recirculating	Recirculating	Once Through	Once Through	Once Through	Once Through	Recirculating	Recirculating	Recirculating	Recirculating
SCRUBBER LIQUID		(gpm)	7250[b]	3500[b]	3500[b]	3500[b]	4000[b]	2500[e]	3000[b]	3000[b]	3000[b]	3000[b]	Not given	5800[b]	7250	7250
WASTE GAS TO SCRUBBER		(scfm)	570000[b]	500000[b]	500000[b]	500000[b]	350000[b]	225000[e]	410000[b]	410000[b]	400000[b]	400000[b]	Not given	580000[b]	580000	580000
WASTE GAS AFTER SCRUBBER		(scfm)	570000[e]	756000[f]	756000[f]	756000[f]	854000[3]	225000[e]	410000[e]	410000[e]	410000[e]	410000[e]	292000[e]	636000[e]	854000	854000
GASEOUS COMPOSITION AFTER SCRUBBER	• Moisture	(%)	15[e]	9.96[f]	9.96[f]	9.96[f]	13.98[c]	15[e]	15[e]	15[e]	15[e]	15[e]	Not given	15.27[g]	15.27	15.27
	• Mercury	($\mu g/m^3$)	Not given	10[f]	10[f]	10[f]	10[c]	Not given	Not given	Not given	Not given	Not given	Not given	10[g]	10	10
SCRUBBER BLOWDOWN		(gpm)	375[b]	Not given	Not given	Not given	350[b]	100[e]	Not given	Not given	Not given	Not given	Not given	800[b]	800	800
% SOLIDS IN SCRUBBER BLOWDOWN		(%)	Not given	Not given	Not given	Not given	Not given	Not given	0.07[b]	0.07[b]	0.07[b]	0.07[b]	Not given	2[b]	2	2
SOLID RECYCLE TO THE PROCESS		(-)	No	Yes	Yes	Yes	Yes	No	Yes[e]	Yes[e]	Yes[e]	Yes[e]	Not given	Yes	Yes	Yes
RECYCLE LOCATION		(-)	N/A	Grinding Mills	Grinding Mills	Grinding Mills	Thickener[e]	N/A	Thickener[e]	Thickener[e]	Thickener[e]	Thickener[e]	Not given	Green Ball Feed	Green Ball Feed	Green Ball Feed
SOLID DISPOSAL		(-)	Landfill	N/A	N/A	N/A	N/A	Settling Pond	N/A	N/A	N/A	N/A	Not given	N/A	N/A	N/A
PRODUCTION RATE		(Lt/hr)	700[d]	300-350[d]	300-350[d]	300-350[d]	350[d]	200-250[d]	400-450[d]	400-450[d]	400-450[d]	400-450[d]	200-250[d]	400-450[d]	700	700
FUEL TYPE	• Coal	(-)	Yes (Power River Basin Coal)								Yes (Power River Basin Coal)	Yes (Power River Basin Coal)	Yes (Eastern bit.)	Yes (Eastern bit.)	Yes (PRB Subbit. Coal)	Yes (PRB Subbit. Coal)
	• Natural Gas	(-)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes[e]	Yes[e]	Yes	Yes
	• Wood	(-)							Yes	Yes	Yes[e]	Yes[e]			No	No
	• Petroleum Coke	(-)											Yes	Yes	No	No
AIR FLOW RATE		(kscfm)	550-650[d]	350-400[d]	350-400[d]	350-400[d]	350[d]	180-250[d]	370-450[d]	370-450[d]	370-450[d]	370-450[d]	180-250[d]	450-600[d]	650	650
PM EMISSION RATE	• Dry Catch Only (Filterable)	(lb/hr)		17[a]	Not given	Not given	29.7[a, Note 1]	Not given	Not given	54[e]	Not given	25[e]	12	19.7	54	54
	• Dry Catch Only (Filterable) + Organic Condensibles	(lb/hr)		21[a]	Not given	Not given	36.1[a, Note 1]	Not given	Not given	56[e]	Not given	25[e]	13	20.3	56	56
	• Dry Catch Only (Filterable) + Organic Cond. + Inorganic Cond.	(lb/hr)		Not given	Not given	Not given	Not given	Not given	Not given	62[e]	Not given	29[e]	Not given	26.1	62	62
	• Dry Catch Only (Filterable) + Organic Cond. + Aq. Phase Cond.	(lb/hr)	N/A[e]	28[a]	Not given	Not given	Not given	N/A[e]	N/A[e]	N/A[e]	N/A[e]	N/A[e]	Not given	Not given	28	28
SO_2 EMISSION RATE		(lb/hr)	272[e]	55[a]	Not given	Not given	Not given	Not given	Not given	Not given	Not given	Not given	Not given	Not given	272	272
NO_x EMISSION RATE		(lb/hr)	Not given	311[a]	Not given	Not given	Not given	Not given	Not given	Not given	Not given	Not given	Not given	Not given	311	311

[a] Stack data received from Task Force via email on April 20, 2012

Note [1] It is a sum of Stack A - D. Since no unit is given in the stack data table, "lb/hr" is assumed.

[b] Data from "Taconite Processes.docx" on February 17, 2012

[c] ADAES, Draft final report "Developing Cost-Effective solutions to Reduce Mercury Emissions from Minnesota Taconite Plants - ArcelorMittal Minorna Mine Inc.Plant", February 28, 2012

[d] Berndt, M., Technical report "Mercury Control Technologies for the Taconite Industry", June, 2007

[e] Data from Task Force's comments on May 30, 2012

[f] ADAES, Draft final report "Developing Cost-Effective solutions to Reduce Mercury Emissions from Minnesota Taconite Plants - Hibbing Taconite Plant", February 28, 2012

[g] ADAES, Draft final report "Developing Cost-Effective solutions to Reduce Mercury Emissions from Minnesota Taconite Plants - United Taconite Plant", February 28, 2012

Technology Survey (Generic Taconite Plant 1 - Straight Grate)

Stantec Project #: 111100111
Prepared by: MER
Date: 14-Aug-12

		Desirable Criteria	Weight	Activated Carbon Injection (ACI) - Scrubber Capture			ACI - Fabric Filter			Fixed Bed Adsorption			Fixed Bed Adsorption - Fabric Filter			Oxidative Chemical Addition		
				Sc	Wt Sc	Notes	Sc	Wt Sc	Notes	Sc	Wt Sc	Notes	Sc	Wt Sc	Notes	Sc	Wt Sc	Notes
1.0		Economic - 20%																
	1.1	Capital Cost	10	10	100		6	60		2	20		1	10		10	100	
	1.2	Operating Cost	10	4	40		3	30		2	20		1	10		10	100	
		SUB-TOTAL	**20**		**140**			**90**			**40**			**20**			**200**	
2.0		Risk - 30%																
	2.1	Turndown	1	8	8	Limited by existing scrubber	10	10	Not limited by existing scrubber. Fabric filter replaces scrubber.	10	10	Multiple vessels give flexibility	10	10	Multiple vessels give flexibility	8	8	Limited to turndown of entire system
	2.2	Availability / Reliability	1	10	10	Minimal moving parts	8	8	Minimal moving parts / Bag changes	6	6	Carbon bed replacement	5	5	Carbon bed replacement / Bag changes	10	10	Minimal moving part
	2.3	Erosion / Corrosion / Plugging / Scaling	3	8	24	Existing scrubber should be able to handle particle	9	27	Proper design necessary to avoid bag blinding	5	15	Susceptible to plugging from residual particulate	6	18	Fabric filter protects fixed bed.	3	9	Corrosion risk due to halide gas generation
	2.4	Simplicity	3	10	30	Just lances	8	24	Lances / fabric filter	3	9	Multiple vessels	1	3	Multiple vessels / fabric filter	10	30	Just lances
	2.5	Modularization	2	10	20		8	16		9	18		8	16	Fabric filter typically field erected.	10	20	
	2.6	Technology Maturity	3	8	24	Well tested in utilities	8	24	Well tested in utilites	7	21	Tested in other industries (e.g., solvent recovery / VOC emission control)	7	21	Tested in other industries (e.g., solvent recovery / VOC emission control)	5	15	Emerging technology, but tested with the taconite flue gas
	2.7	Commercial Scale	1	10	10		10	10		6	6	The number of parallel trains indicative of scale issues	6	6	The number of parallel trains indicative of scale issues	8	8	
	2.8	Construction Schedule	0.5	10	5	Just lances	7	3.5	Fabric filter / ductwork	2	1	Many pieces of equipment	1	0.5	Many pieces of equipment	10	5	Just lances
	2.9	Retrofit Integration	2.5	8	20	Impacts scrubber	7	17.5	Ductwork required	6	15	Significant ductwork required	6	15	Significant ductwork required	8	20	Impacts scrubber
	2.10	Safety	10	9	90	Entry into AC silo required, but rare	9	90	Entry into AC silo required, but rare	8	80	Vessel entry likely required.	8	80	Vessel entry likely required.	9	90	Some chemical storage required
	2.11	Materials of Construction	1	10	10	Just lances	8	8		4	4	Many pieces of stainless steel equipment	3	3		10	10	Just lances
	2.12	Maintenance	2	10	20	Just lances	7	14	Bag changes	5	10	Carbon bed replacement	3	6	Carbon bed replacement / Bag changes	10	20	Just lances
		SUB-TOTAL	**30**		**271**			**252**			**195**			**183.5**			**245**	
3.0		Performance - 40%																
	3.1	Scrubber Compatible	8	4	32	Particulate loading increase	6	48	Replace scrubber	8	64	No scrubber impact	6	48	Replace scrubber	2	16	Oxidant may upset scrubber operation
	3.2	ΔP (Energy use)	7	10	70	Just lances	5	35	Fabric filter	3	21	Multiple vessels	1	7	Multiple vessel / Farbric filter	10	70	Just lances
	3.3	Footprint	6	10	60	Just lances	5	30	Fabric filter	3	18	Multiple vessels	1	6	Multiple vessels	10	60	Just lances
	3.4	Suitability for Induration Type	2	10	20		10	20		10	20		10	20		5	10	Score 10 for the other induration type
	3.5	Sensitivity to Flue Gas Compositions (e.g., SO_x, NO_x and Moisture)	2	6	12	Water vapor / SO_x	6	12	Water vapor / SO_x	5	10	Water vapor / SO_x	5	10	Water vapor / SO_x	8	16	Potential reaction with waste gas
	3.6	Regeneration Capability	2	1	2	Throwaway sorbent	1	2	Throwaway sorbent	10	20	Yes	10	20	Yes	1	2	Not possible to regenerate
	3.7	Impact on Scrubber Solid Recycle	6	2	12	Contaminate scrubber solid	2	12	Contaminate scrubber solid	10	60	After scrubber	2	12	Contaminate scrubber solid	2	12	Increase mercury concentration in the scrubber solid
	3.8	Impact on Iron chemistry During the Induration Process	5	10	50	No impact	10	50	No impact	10	50	No impact	10	50	No impact	3	15	Some impact to process
	3.9	Possibility of Mercury Reemission/Desorption	2	7	14	Possible mercury desorption if a very high level of SO_2, NO_x, and HCl control is not obtained.	7	14	Possible mercury desorption if a very high level of SO_2, NO_x, and HCl control is not obtained.	7	14	Possible mercury desorption if a very high level of SO_2, NO_x, and HCl control is obtained or bed is not replaced.	7	14	Possible mercury desorption if a very high level of SO_2, NO_x, and HCl control is obtained or bed is not replaced.	5	10	Further testing required.
		SUB-TOTAL	**40**		**272**			**223**			**277**			**187**			**211**	
4.0		Enviromental - 5%																
	4.1	Particulate Co-Benefits / Fugitive Emissions	5	1	5	May overload poor scrubbers	10	50	Fabric filter should capture PM	8	40	Should capture PM, may emit attrited AC	8	40	Should capture PM, may emit attrited AC	3	15	Possible oxidant emission
	4.2	Waste Quantity	5	5	25	Spent AC	5	25	Spent AC	9	45	Spent AC is sent to off-site regeneration.	9	45	Spent AC is sent to off-site regeneration.	7	35	Contaminates scrubber waste water.
		SUB-TOTAL	**10**		**30**			**75**			**85**			**85**			**50**	
		GRAND-TOTAL	**100**		**713**			**640**			**597**			**475.5**			**706**	

Notes: Score assigned by project team (0 = least, 10 = best).
Weighted score is the product of the 'weight' and the 'score'.

Technology Survey (Generic Taconite Plant 2 - Grate Kiln)

Stantec Project # 111100111
Prepared by: MER
Date: 14-Aug-12

	Desirable Criteria	Weight	Activated Carbon Injection (ACI) - Scrubber Capture			ACI - Fabric Filter			Fixed Bed Adsorption			Fixed Bed Adsorption - Fabric Filter			Oxidative Chemical Addition		
			Sc	Wt Sc	Notes	Sc	Wt Sc	Notes	Sc	Wt Sc	Notes	Sc	Wt Sc	Notes	Sc	Wt Sc	Notes
1.0	Economic - 20%																
1.1	Capital Cost	10	10	100		6	60		2	20		1	10		10	100	
1.2	Operating Cost	10	4	40		3	30		2	20		1	10		10	100	
	SUB-TOTAL	**20**		**140**			**90**			**40**			**20**			**200**	
2.0	Risk - 30%																
2.1	Turndown	1	8	8	Limited by existing scrubber	10	10	Not limited by existing scrubber. Fabric filter replaces scrubber.	10	10	Multiple vessels give flexibility	10	10	Multiple vessels give flexibility	8	8	Limited to turndown of entire system
2.2	Availability / Reliability	1	10	10	Minimal moving parts	8	8	Minimal moving parts / Bag changes	6	6	Carbon bed replacement	5	5	Carbon bed replacement / Bag changes	10	10	Minimal moving part
2.3	Erosion / Corrosion / Plugging / Scaling	3	8	24	Existing scrubber should be able to handle particle	9	27	Proper design necessary to avoid bag blinding	5	15	Susceptible to plugging from residual particulate	6	18	Fabric filter protects fixed bed.	3	9	Corrosion risk due to halide gas generation
2.4	Simplicity	3	10	30	Just lances	8	24	Lances / fabric filter	3	9	Multiple vessels	1	3	Multiple vessels / fabric filter	10	30	Just lances
2.5	Modularization	2	10	20		8	16		9	18		8	16	Fabric filter typically field erected.	10	20	
2.6	Technology Maturity	3	8	24	Well tested in utilities	8	24	Well tested in utilites	7	21	Tested in other industries (e.g., solvent recovery / VOC emission control)	7	21	Tested in other industries (e.g., solvent recovery / VOC emission control)	5	15	Emerging technology, but tested with the taconite flue gas
2.7	Commercial Scale	1	10	10		10	10		6	6	The number of parallel trains indicative of scale issues	6	6	The number of parallel trains indicative of scale issues	8	8	
2.8	Construction Schedule	0.5	10	5	Just lances	7	3.5	Fabric filter / ductwork	2	1	Many pieces of equipment	1	0.5	Many pieces of equipment	10	5	Just lances
2.9	Retrofit Integration	2.5	8	20	Impacts scrubber	7	17.5	Impacts scrubber	6	15	Significant ductwork required	6	15	Significant ductwork required	8	20	Impacts scrubber
2.10	Safety	10	9	90	Entry into AC silo required, but rare	9	90	Entry into AC silo required, but rare	8	80	Vessel entry likely required.	8	80	Vessel entry likely required.	9	90	Some chemical storage required
2.11	Materials of Construction	1	10	10	Just lances	8	8		4	4	Many pieces of stainless steel equipment	3	3		10	10	Just lances
2.12	Maintenance	2	10	20	Just lances	7	14	Bag changes	5	10	Carbon bed replacement	3	6	Carbon bed replacement / Bag changes	10	20	Just lances
	SUB-TOTAL	**30**		**271**			**252**			**195**			**183.5**			**245**	
3.0	Performance - 40%																
3.1	Scrubber Compatible	8	4	32	Particulate loading increase	6	48	Replace scrubber	8	64	No scrubber impact	6	48	Replace scrubber	2	16	Oxidant may upset scrubber operation
3.2	ΔP (Energy use)	7	10	70	Just lances	5	35	Fabric filter	3	21	Multiple vessels	1	7	Multiple vessel / Farbric filter	10	70	Just lances
3.3	Footprint	6	10	60	Just lances	5	30	Fabric filter	3	18	Multiple vessels	1	6	Multiple vessels	10	60	Just lances
3.4	Suitability for Induration Type	2	10	20		10	20		10	20		10	20		10	20	
3.5	Sensitivity to Flue Gas Compositions (e.g., SO_x, NO_x and Moisture)	2	6	12	Water vapor / SO_x	6	12	Water vapor / SO_x	5	10	Water vapor / SO_x	5	10	Water vapor / SO_x	8	16	Potential reaction with waste gas
3.6	Regeneration Capability	2	1	2	Throwaway sorbent	1	2	Throwaway sorbent	10	20	Yes	10	20	Yes	1	2	Not possible to regenerate
3.7	Impact on Scrubber Solid Recycle	6	2	12	Contaminate scrubber solid	2	12	Contaminate scrubber solid	10	60	After scrubber	2	12	Contaminate scrubber solid	2	12	Increase mercury concentration in the scrubber solid
3.8	Impact on Iron chemistry During the Induration Process	5	10	50	No impact	10	50	No impact	10	50	No impact	10	50	No impact	3	15	Some impact to process
3.9	Possibility of Mercury Reemission/Desorption	2	7	14	Possible mercury desorption if a very high level of SO_2, NO_x, and HCl control is not obtained.	7	14	Possible mercury desorption if a very high level of SO_2, NO_x, and HCl control is not obtained.	7	14	Possible mercury desorption if a very high level of SO_2, NO_x, and HCl control is obtained or bed is not replaced.	7	14	Possible mercury desorption if a very high level of SO_2, NO_x, and HCl control is obtained or bed is not replaced.	5	10	Further testing required.
	SUB-TOTAL	**40**		**272**			**223**			**277**			**187**			**221**	
4.0	Enviromental - 5%																
4.1	Particulate Co-Benefits / Fugitive Emissions	5	1	5	May overload poor scrubbers	10	50	Fabric filter should capture PM	8	40	Should capture PM, may emit attrited AC	8	40	Should capture PM, may emit attrited AC	3	15	Possible oxidant emission
4.2	Waste Quantity	5	5	25	Spent AC	5	25	Spent AC	9	45	Spent AC is sent to off-site regeneration.	9	45	Spent AC is sent to off-site regeneration.	7	35	Contaminates scrubber waste water.
	SUB-TOTAL	**10**		**30**			**75**			**85**			**85**			**50**	
	GRAND-TOTAL	**100**		**713**			**640**			**597**			**475.5**			**716**	

Notes: Score assigned by project team (0 = least, 10 = best).
Weighted score is the product of the 'weight' and the 'score'.

Appendix D: Slides from April 2, 2012 Industry Meeting

Developing Cost-Effective Solutions to Reduce Mercury Emissions from Minnesota Taconite Plants

Industry Update Meeting

April 2, 2012

Sharon M. Sjostrom, P.E. – Chief Technology Officer, ADA-ES
Kyle S. Bowell – Project Engineer, ADA-ES
H. Ray Johnson, PH.D. – Activated Carbon Technologies

Topics for Discussion

- Program overview
- Technical Approach
- Results from Screening Tests
- Review of Technology Options
  - Description of Fixed-Bed Design
  - Description of Fixed-Bed Pilot
- Recommended Path Forward
- Discussion

Program Overview

Program Goal: Develop cost-effective solutions to reduce mercury emissions from Minnesota taconite plants

Options: Hg oxidation and capture in WFGD

Sorbent injection and capture in WFGD

Sorbent injection and capture in FF

Activated carbon bed

ADA Feasibility Project

Question: Is activated carbon a viable mercury control approach for the industry?

Sorbent Screening

- ☑ Slipstream Testing
- ☑ Develop an Integrated Process Concept
- ☑ Pilot Plant Design
- ☐ Techno-Economic Analysis

Pilot Scale Testing

Full Scale Testing

General Approach

- Determine if process gas negatively impacts performance of activated carbon
  - Lab results and other commercial applications indicate activated carbon (fixed bed and powdered injection) can be effective at controlling mercury
- Determine most cost effective option to achieve mercury control goals
- Pilot test appropriate control options

Sorbent Screening: Technical Approach

Compare mercury capture characteristics of four activated carbon sorbents in actual process gas from three plants

Key Questions:

- Do some sorbents perform better than others?
- Is sorbent performance negatively impacted by process gas?
- What is the effect of relative humidity on performance?

Plants Included in Screening

	United Taconite	Hibbing Taconite	ArcelorMittal Mineorca
Grate	Grate/Kiln	Straight Grate	Straight Grate
APC Equipment	Recirculating scrubber with no lime neutralization	Multiclone + once through scrubbers	Multiclone + recirc scrubber with no lime neutralization
Pellet Type	Std pellets with an organic binder	Standard pellets	Fluxed pellets

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Potential Differences in Key Process Gas Characteristics

Pellets	Description	SO_2 Emissions Factors (Gas-Fired) (lb/ton)	
Standard	Ore + binder	Grate/kiln[a]	0.29
		Grate/kiln, with wet scrubber[a]	0.053
		Straight grate	ND
		Straight grate, with wet scrubber[b]	0.1
Flux	1 to 10% limestone	Grate/kiln, with wet scrubber[a]	0.14
		Straight grate	ND

Emissions of NOx and SO_2 generally are higher with flux pellets due to additional heating requirements

[a]*Air Pollution Emissions Test, Eveleth Taconite, Eveleth, MN*, EMB 76-IOB-3, U. S. Environmental Protection Agency, Research Triangle Park, NC, November 1975

[b]*Results Of The May 5-7, 1987, Atmospheric Emission Tests On The Induration Furnaces At The Hibbing Taconite Company In Hibbing, MN*, Interpoll, Inc., Circle Pines, MN, May 14, 1987.

Screening Test Method

Specially prepared sorbent beds

- Grind AC samples to <325 mesh (powder)
- Mix with sand to manage pressure and channeling

Meter flow through beds

Measure collected mercury in beds

Bed Preparation

Sorbent ground until 95% by weight passed through a 325 mesh (45µm) screen.

Ground sorbents mixed with sand

- Ratio of 20 milligrams of sorbent to 50 grams of sand
  - Found to be highest carbon content without clogging

Sample traps contained 4 grams of the sand/sorbent mixture in the test beds

- 1.6 milligrams of sorbent present in the traps

Screening Test Method

Test four samples simultaneously

Draw process gas through the beds using EPA M30B sampling consoles

Conduct tests at 3 sample durations for improved characterization

Repeat each test

Sorbents

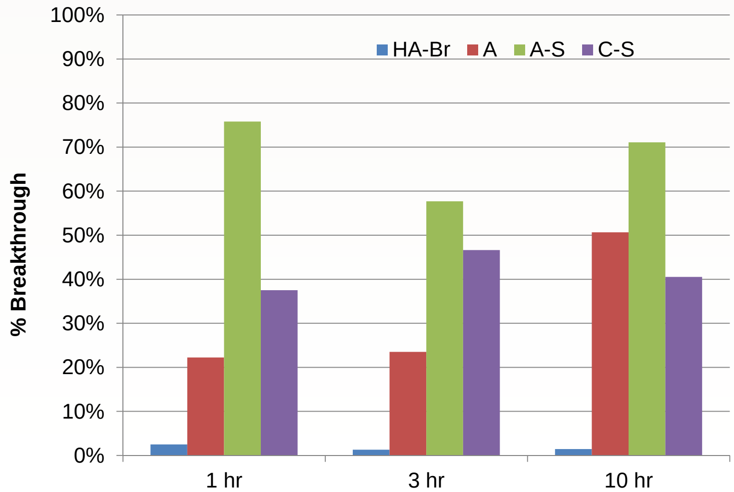
Bromine-Treated, high activity, low ash, coal-based (**HA-Br**)
Note that bromine-treated AC is not a practical choice for fixed bed systems

Anthracite-based (**A**)
Carbon Resources CR4AN

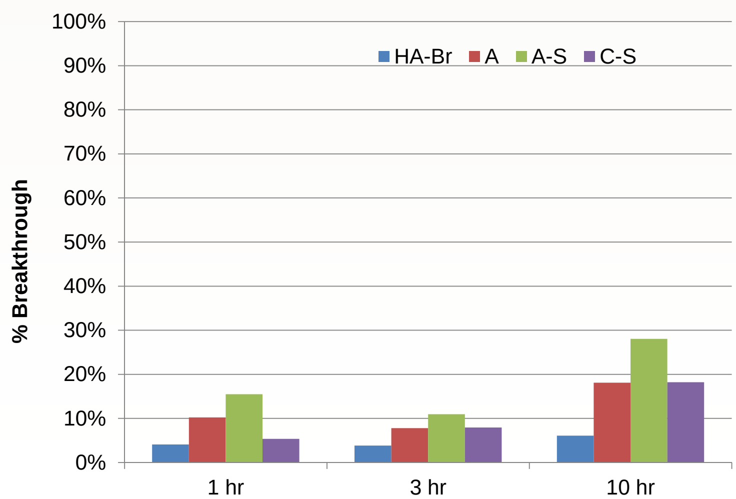
Sulfur-treated, anthracite-based (**A-S**)
Carbon Resources CR4AN-Hg

Sulfur-treated, coconut-shell based (**C-S**)
Carbon Resources CT612C-Hg

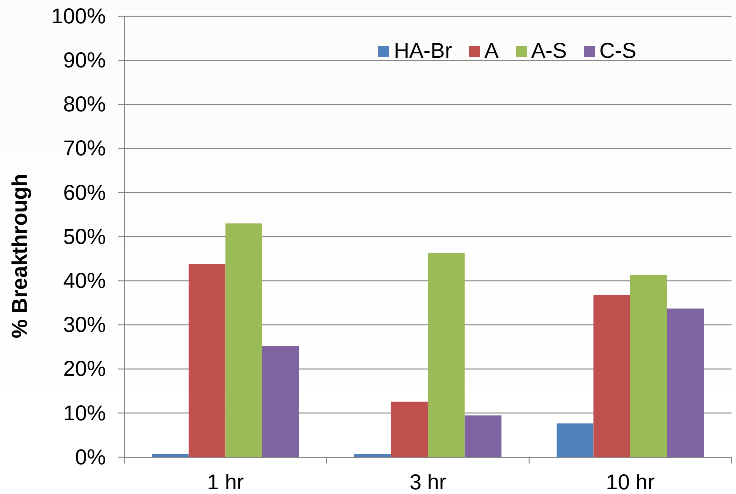
United Taconite Results



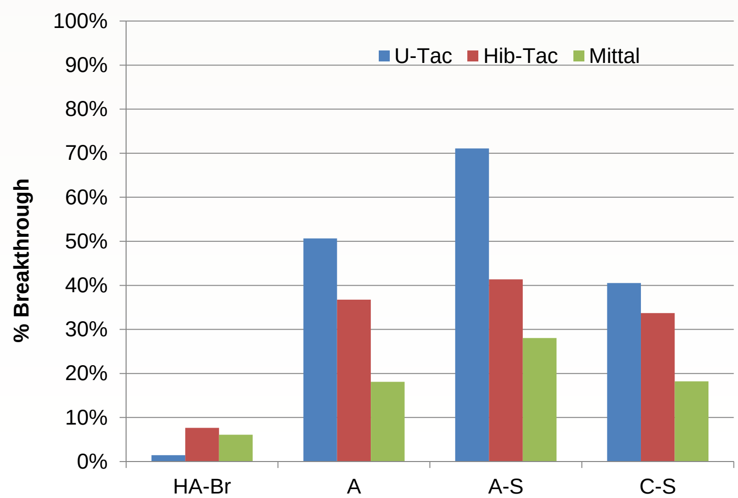
ArcelorMittal Results



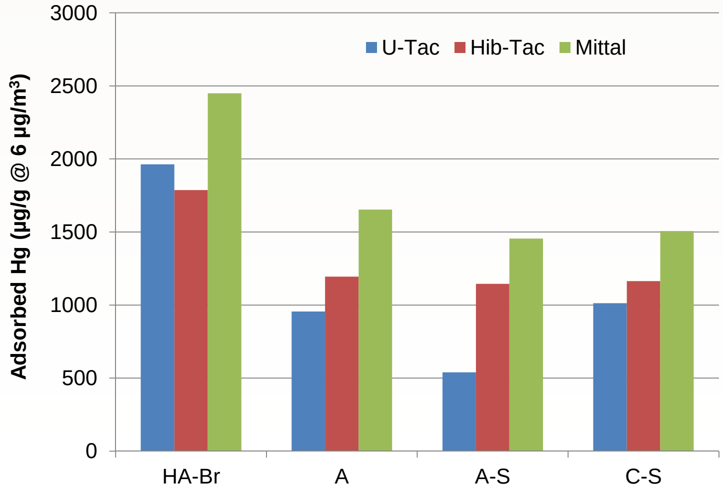
Hibbing Taconite Results



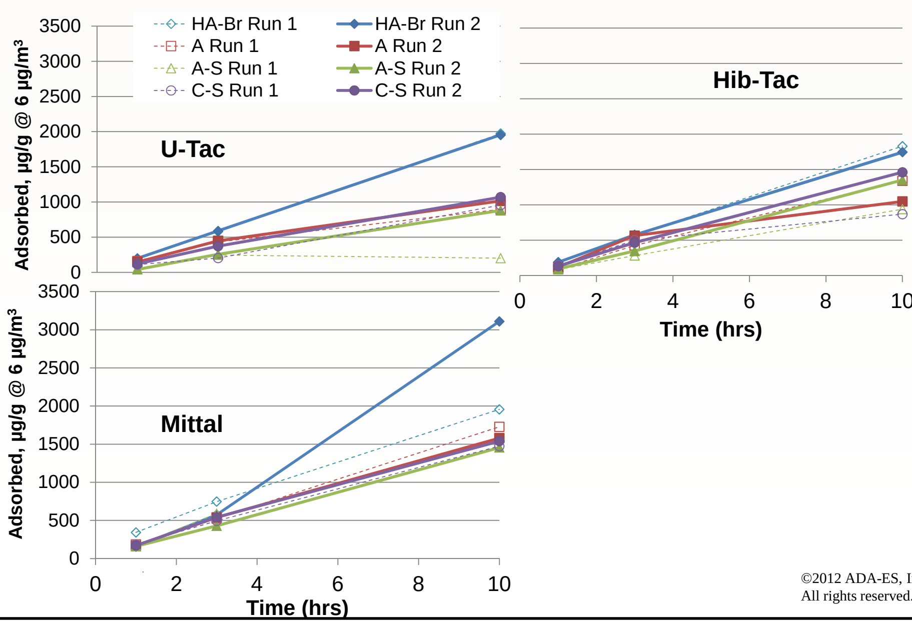
10-hr Comparison - Breakthrough



10-hr Comparison - Adsorption



Adsorption Comparison



Comparison of AC

Relative differences in sorbent performance were consistent across all sites

- All test samples showed initial breakthrough at 1 hr.
- 1 hr breakthrough on sulfur-treated carbons typically higher than at 3 hr. This could indicate a “conditioning” effect.
- Sulfur-treated anthracite showed highest breakthrough for all sites.
- Sulfur-treated coconut-shell presented least sensitivity to differences in process gas.
- In general, sulfur-treated coconut-shell performed best of all fixed-bed candidates.

Site-specific performance differences

United Tac beds showed highest breakthrough

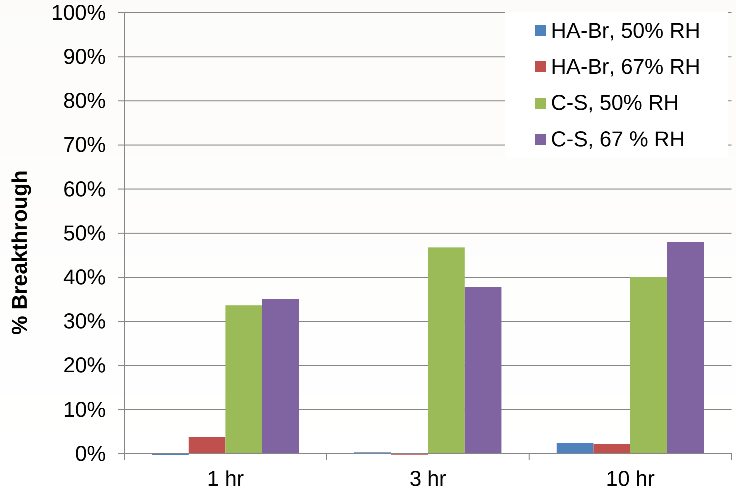
- Grate/kiln, standard pellets, no multiclone, recirculating scrubber with no lime neutralization

ArcelorMittal showed lowest breakthrough

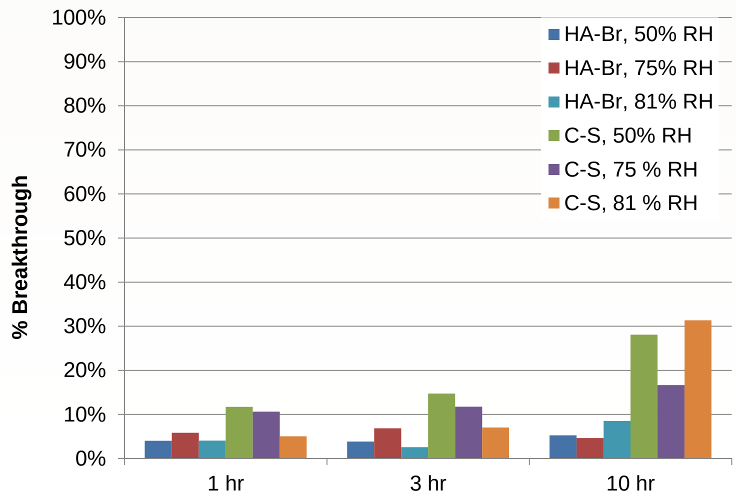
- Straight grate, flux pellets, multiclone, recirculating scrubber with no lime neutralization

SO_2 concentration at United Taconite expected to be lower than ArcelorMittal
Are there other differences in process gas?

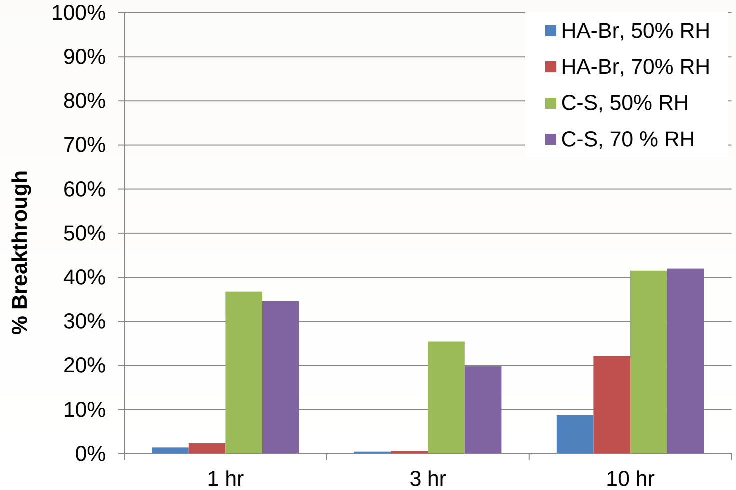
United Taconite RH Results



ArcelorMittal RH Results



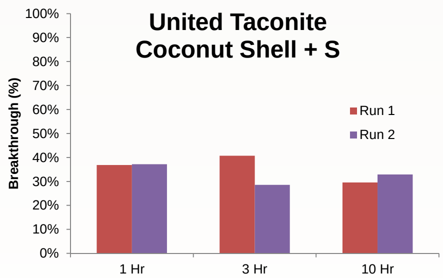
Hibbing Taconite RH Results

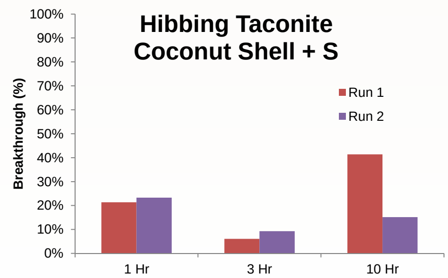


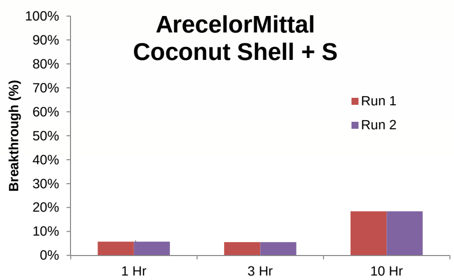
Screening Summary – RH Tests

- No impact on sorbent performance resulting from increased relative humidity (50 to 81%)

Repeatability - Example







Good repeatability for most tests

Comparison to Other Testing

- 2009 Fixed Bed Lab Study by EERC
- Test Details

  Bromine-treated, lignite carbon and
  Sulfur-treated bituminous carbon evaluated

  1000 hour test

  2 ppm HCl and 20 ppm NO_2 in simulated gas

  Temp ~ 180ºF
- 100% removal achieved throughout test for both sorbents

Dunham 2009, Demonstration of Mercury Capture in a Fixed Bed

Comparison to Other Testing

- 2002 Test by ADA Technologies
  - Temperature ~ 100ºF
  - Sulfur-treated carbon
  - N_2, Hg and 25% moisture
- Good capture noted
- Increasing RH from 25% to 50% improved Hg removal

Broderic, 2002, Spallation Neutron Source Carbon Adsorption Tests

Techno-Economic Analysis

- Define industry economic goals
- Compare the technical and economic aspects of potential AC technology options, determine applicability to each plant and impact on plant operations
- Compare the technical and economic aspects of all available technology options to AC-based solutions, including oxidizing chemicals and scrubber additives

*This Task is < 5% complete and **Currently on Hold***

Review of Technology Options

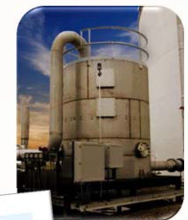
Hg oxidation and capture in WFGD

Sorbent injection and capture in WFGD

Sorbent injection and capture in FF

Activated carbon bed

Others?



Sorbent Injection

- Commercially available
- Removal expected to be limited without baghouse
- May increase PM emissions unless baghouse added
- Addition of baghouse may increase costs above fixed-bed system

Sorbent Monolith Approach

- Activated carbon based and polymer-based
- Not applied commercially for mercury at required scale
  - Costs uncertain
  - Polymer developer (Gore) estimates polymer-based system cost-competetive with ACI for in-scrubber application
- Lower pressure drop expected

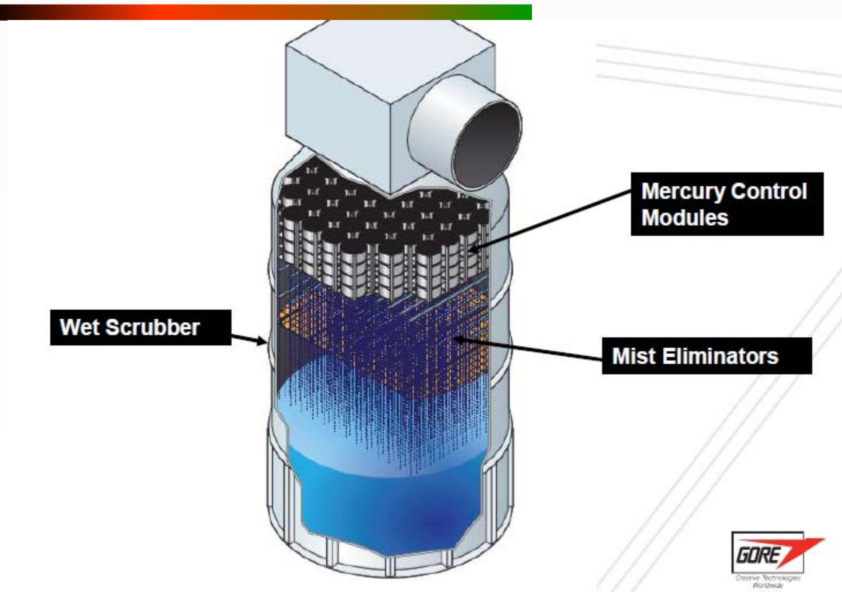
Carbon Honeycomb

MeadWestvaco

- 30-40,000 SCFM systems in commercial operation (5 + years) *No commercial mercury systems in service*
- Fast removal kinetics, low pressure drop, high velocity ~ 500 ft. /min. (5 x typical fixed bed)
- Example: Flint Hills Resources Pine Bend Refinery in Rosemount, Minnesota

Corning, Inc. System in Development

Polymer Design (Gore)

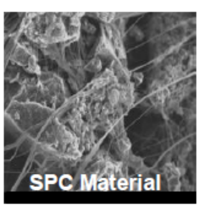


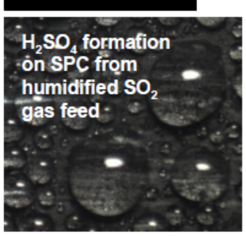
Sorbent Polymer Composite (SPC) material developed by Gore efficiently captures Hg for long periods of time even in the presence of high acid gas concentrations

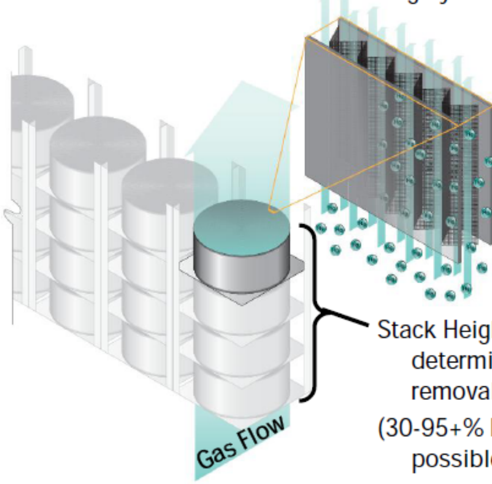
SPC tape is incorporated in discrete modules (2' wide x 1' high)

Open channel design:

- Low Pressure Drop
- Resists Fouling by dust







Stack Height determines mercury removal efficiency

(30-95+% Hg removal possible)

W. L. Gore & Associates

Sorbent Bed Approach

- Commercially available at required scale
  - Fixed bed systems
  - Moving bed systems
- Higher cost than sorbent injection alone
- Higher pressure drop across system expected

Fixed-Bed AC Systems

- Commercial use for 80+ years
- Large systems/vessels used in solvent recovery applications for many years
  - Example: AMCEC (inst. 1982, still operating)
  - Vessels are 12 feet diam x 47 feet long
  - 43,000 lbs AC pellets/vessel

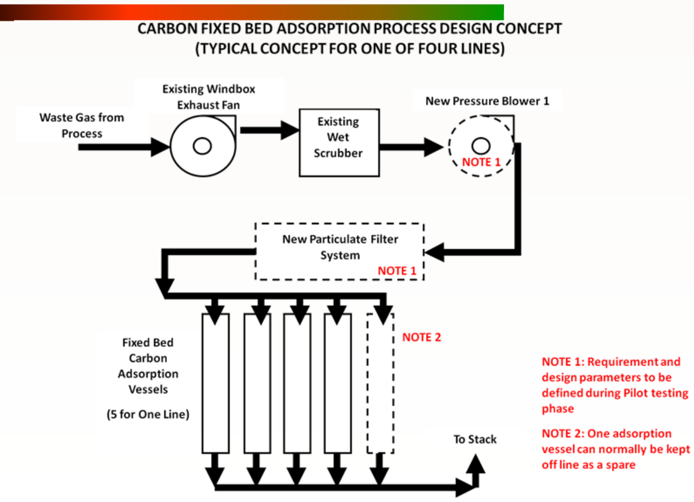
Fixed Bed Design Parameters

	ArcelorMittal	Hibbing Taconite	United Taconite
Total Flow (ACFM)	854,000	756,000	493,000
Temperature (F°)	125	123	140
Hg Concentration (µg/m^3)	10	10	10
Total Hg (lb/yr)	180.8	222.32	140.87
Gas flow per vessel (acfm)	43,000	43,000	43,000
# Vessels	22	20	13
Bed Depth (ft)	3	3	3
Pressure drop (in H_2O, est)	6 to 12	6 to 12	6 to 12
Total Carbon (lbs)	1,368,553	1,225,874	842,970
AC Life	TBD*	TBD*	TBD*

* *Based on lab results, estimated carbon ~ 35,000 to 100,000 lbs/yr, Life est > 10 yrs*

H. Ray Johnson, PH.D., Activated Carbon Technologies

Full-Scale Fixed Bed Design



H. Ray Johnson, PH.D., Activated Carbon Technologies

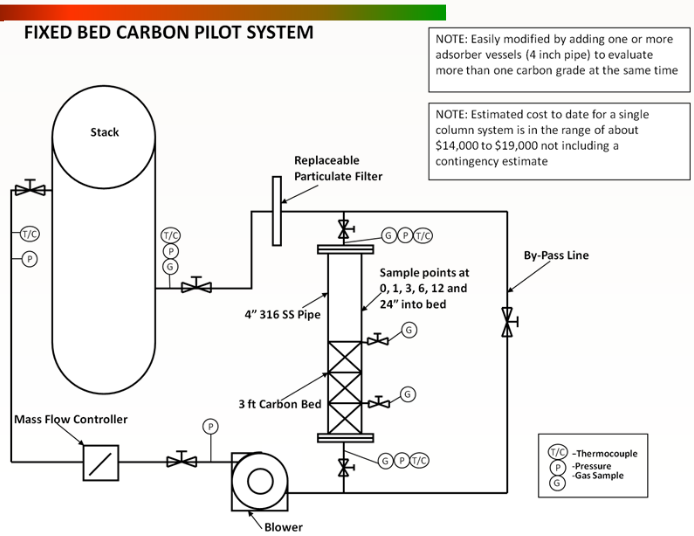
Key Considerations for Fixed-Bed

- Mercury capacity from pilot testing
- System capital costs

  If particulate filter is required, costs will likely be higher than ACI + FF

  Sorbent characteristics will determine bed pressure drop. Fan power must be included

Pilot Scale Design



H. Ray Johnson, PH.D., Activated Carbon Technologies

Pilot Testing Recommendations

- Conduct extended slipstream test (1000 hrs+) on actual process gas
- Use most promising AC based on economics (expected Hg capacity, cost/lb, pressure characteristics, etc)
- Sample Hg at multiple locations (example 0, 1, 3, 6, 12, and 24 inches) to monitor the mercury adsorption wave front
- Monitor temperatures and pressures

Recommended Next Steps

Techno-economic assessment is required prior to determining path forward

- Oxidation technologies may be lowest cost option. Confirm sufficient and reliable mercury removal with minimal balance-of-plant issues
- Confirm removal effectiveness, particulate emissions, and impacts to scrubber solution for sorbent injection alone (ACI)
- Fixed beds should be pursued if costs are competitive. Pilot-scale testing is required for design engineering
- Moving beds systems and polymer-based monolith costs should be considered for comparison

Tasks and Budget Status

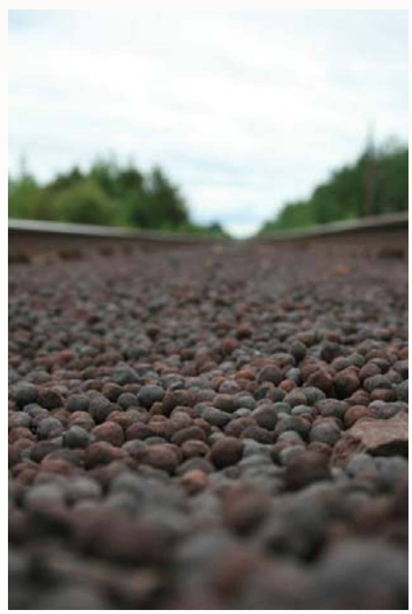
Project Tasks	Estimated % Complete
Gather Site-Specific Information and Conduct Screening Tests	100%
Develop Integrated Process Concept	100%
Techno-Economic Analysis	5%
Pilot Plant Design and Test Plan	100%
Reporting	50%

Contract Amount: $350,000
Invoiced Through February 2012: $210,000

Questions and Discussion

ADA Environmental Solutions
- Sharon M. Sjostrom
- Kyle S. Bowell

Activated Carbon Technologies
- H. Ray Johnson



12. Appendix E: Sorbent Trap Method Testing

This project employed the EPA Method 30B titled "Determination of Total Vapor Phase Mercury Emissions from Coal-Fired Combustion Sources Using Carbon Sorbent Traps". When using this mercury measurement method, the operator extracted a known volume of process gas from a duct through a dry sorbent trap (containing a specially treated form of activated carbon) as a single-point sample, with a nominal flow rate which was varied based on process gas mercury concentrations. The sample rate typically varies between 250 cm^3/min to 1000 cm^3/min of dry gas. The sampling flow rate was held constant (+/- 25%) during testing. The dry sorbent trap, which was in the process gas stream during testing, represents the entire mercury sample. Each trap was analyzed in an offsite laboratory for total mercury using an Ohio Lumex 915+ RP-M. Samples can be collected over time periods ranging from less than an hour to weeks in duration. The test result provides a total vapor-phase mercury measurement of the process gas stream for the time period of the test.

STM testing requires that paired samples be collected in the field. The analysis results of the paired sample trains are compared and are typically in agreement within 5-20% relative percent difference (RPD). Another built-in quality assurance measure is achieved through the analysis of two trap sections in series. Each trap has two separate mercury sorbent sections, as shown in Figure 9 the "B" section is analyzed to evaluate whether any mercury breakthrough occurred. Low B section mercury, in conjunction with a field blank trap, is used to confirm overall sample handling quality.

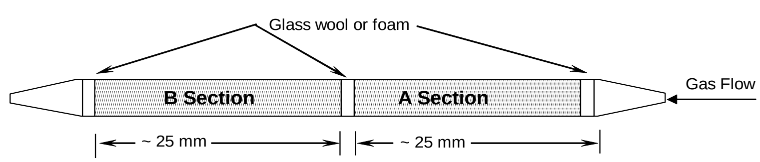


Figure 1: Sorbent Trap Side View

The STM sample train is fairly simple. Major components are a sorbent trap mounted directly on the end of a probe, a moisture knockout is located in series with each channel of sampling train outside the duct, and a console that controls the sampling rate and meters the gas, as well as recording data in a data logger. Key temperatures, sampling volume, and barometric pressure are recorded on field sampling data sheets and/or by a data logger for each sample run. A picture of the STM sampling console is shown in Figure 10 and a figure of the sampling train arrangement is shown in Figure 11.

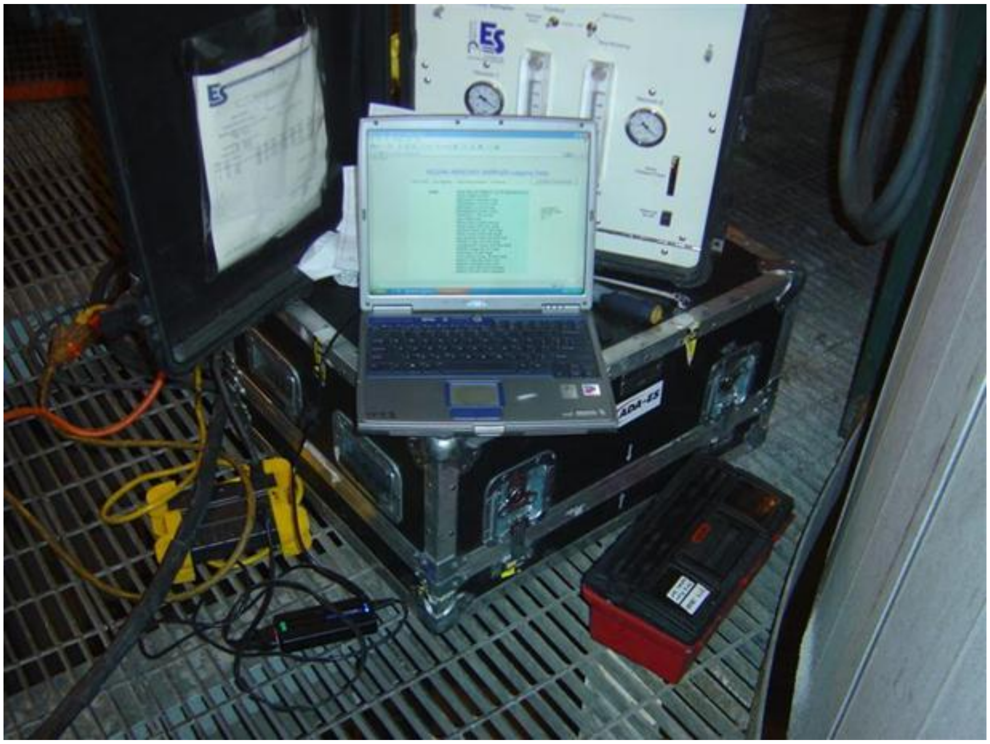


Figure 2: STM Sampling Console Setup at a Stack Sampling Location

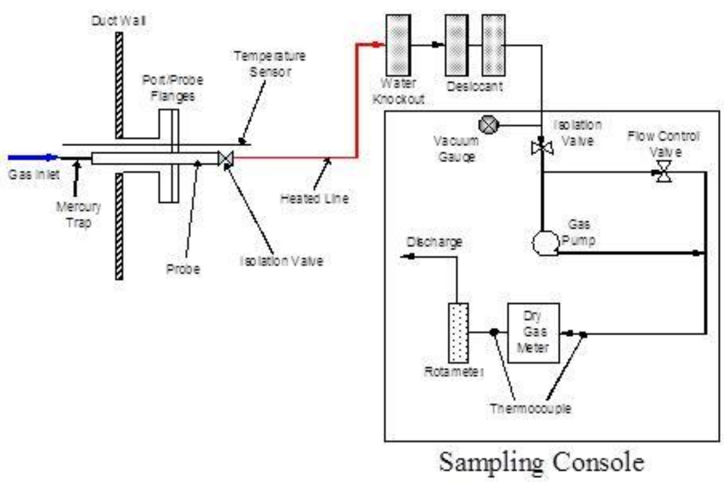


Figure 3: **Sorbent Trap Method Sampling Train STM**

STM testing collects a mass of mercury on the trap media. Using stack gas flow rate, gaseous data from the plant's CEMS, and coal ultimate analysis (or EPA Method 19 F-Factors if ultimate analysis is unavailable), mercury concentration are calculated and typically reported in lb/TBtu.

Method 30B versus STM QA Criteria

QA/QC Test or Spec	Acceptance Criteria	Method 30B Frequency	STM Frequency	Consequences
Gas flow meter calibration (3 settings)	Calibration factor (Yi) at each flow rate must be within ±2% of the average value (Y)	Prior to initial use and when post-test check is not within ±5% of Y	Prior to initial use and when post-test check is not within ±5% of Y	Recalibrate at 3 points until the acceptance criteria are met
Gas flow meter post-test calibration check	Calibration factor (Yi) must be within ±5% of the Y value from the most recent 3 point calibration	After each field test. For mass flow meters, must be done onsite, using stack gas	After each field test, mass flow meter volume is verified using a totalizer	Recalibrate gas flow meter at 3 points to determine a new value of Y. For mass flow meters, must be done on-site, using stack gas. Apply the new Y value to the field test data
Temperature sensor calibration	Absolute temperature measured by sensor within ± 1.5% of a reference sensor	Prior to initial use and before each test thereafter	Prior to initial use. Before each test thereafter or quarterly, sensor is checked against calibration standard	Recalibrate; sensor may not be used until specification is met
Barometer calibration	Absolute pressure measured by instrument within ± 10 mm Hg of reading with a mercury barometer	Prior to initial use and before each test thereafter	Prior to initial use, then quarterly	Recalibrate; instrument may not be used until specification is met
Pre-test leak check	≤ 4% of target sampling rate	Prior to sampling	Prior to sampling	Sampling shall not commence until the leak check is passed
Post-test leak check	≤ 4% of target sampling rate	After sampling	After sampling	Sample invalidated
Analytical bias test	Average recovery between 90% and 110% for Hg0 and HgCl2 at each of the 2 spike concentration levels	Prior to analyzing field samples and prior to use of new sorbent media	Annual test with both Hg0 and HgCl2. Prior to analyzing field samples and prior to use of new sorbent media analyzer is tested with HgCl2.	Field samples shall not be analyzed until the percent recovery criteria has been met
Multipoint analyzer calibration	Each analyzer reading within ± 10% of true value and r2 ≥ 0.99	On the day of analysis, Before analyzing any samples	On the day of analysis, Before analyzing any samples	Recalibrate until successful
Analysis of independent calibration standard	Within ± 10% of true value	Following daily calibration, prior to analyzing field samples	Following daily calibration, prior to analyzing field samples	Recalibrate and repeat independent standard analysis until successful
Analysis of continuing calibration verification standard (CCVS)	Within ± 10% of true value	Following daily calibration, After analyzing ≤ 10 field samples, and at end of each set of analyses	Following daily calibration, After analyzing ≤ 10 field samples, and at end of each set of analyses	Recalibrate and repeat independent standard analysis, reanalyze samples until successful, if possible; for destructive techniques, samples invalidated
Test run total sample volume	Within ± 20% of total volume sampled during field recovery test	Each individual sample	Spike recovery test (i.e. field recovery) not conducted	Sample invalidated
Sorbent trap section 2 breakthrough	< 10% of section 1 Hg mass for Hg concentrations > 1 µg/dscm; ≤ 20% of section 1 Hg mass for Hg concentrations ≤ 1 µg/dscm	Every sample	Every sample	Sample invalidated
Paired sorbent trap agreement	≤ 10% Relative Deviation (RD) mass for Hg concentrations > 1 µg/dscm; ≤ 20% RD or < 0.2 µg/dscm absolute difference for Hg concentrations ≤ 1 µg/dscm	Every run	Every run	Run invalidated
Sample analysis	Within valid calibration range (within calibration curve)	All Section 1 samples where stack Hg concentration is ≥ 0.5 µg/dscm	All Section 1 samples where stack Hg concentration is ≥ 0.5 µg/dscm Is ≥ 0.5 µg/dscm	Reanalyze at more concentrated level if possible, samples invalidated if not within calibrated range
Sample analysis	Within bounds of Hg0 and HgCl2 Analytical Bias Test	All Section 1 samples where stack Hg concentration is ≥ 0.5 µg/dscm	All Section 1 samples where stack Hg concentration is ≥ 0.5 µg/dscm	Expand bounds of Hg0 and HgCl2 Analytical Bias Test; if not successful, samples invalidated
Field recovery test	Average recovery between 85% and 115% for Hg0	Once per field test	Spike recovery test (i.e. field recovery) not conducted	Field sample runs not validated without successful field recovery test

Appendix F: Quality Assurance Program

F.1 Data Quality Assessment Worksheet

F.2 Quality Assurance Discussion Slides

F.3 STM Equipment Calibrations

- Thermocouple Calibrations
- DGM Calibrations
- Mercury Analyzer Calibrations

F.4 Raw Data

DATA QUALITY ASSESSMENT WORKSHEET FOR PROJECT 3

Data Quality Assessment Worksheet

Title of Project: Developing Cost-Effective Solutions to Reduce Mercury Emissions from Minnesota Taconite Plants: United Taconite
Project Leader: Richard Schlager
Date Submitted : July 9, 2012

(1) Method Description/Key Parameters:

a. Screening tests were conducted at ArcelorMittal, Hibbing Taconite, and United Taconite Unit 2. Results are specific to these plants, but can be applied to similarly-configured plants.

b. The Mercury Index Method (MIM) screening tool used for testing was based on EPA Method 30B. In particular, equation 30B-2 in section 12.3 Calculation of Breakthrough, equation 30B-3 in section 12.4 Calculation of Hg Concentration, and equation 30B-5 in section 12.6 Calculation of Paired Trap Agreement will be utilized. These are shown below. Mercury removal efficiency for the screening tests is determined based on breakthrough.

12.1 Nomenclature. The terms used in the equations are defined as follows:

B = Breakthrough (%).

C_a = Concentration of Hg for the sample collection period, for sorbent trap "a" (µg/dscm).

C_b = Concentration of Hg for the sample collection period, for sorbent trap "b" (µg/dscm).

m_1 = Mass of Hg measured on sorbent trap section 1 (µg).

m_2 = Mass of Hg measured on sorbent trap section 2 (µg).

RD = Relative deviation between the Hg concentrations from traps "a" and "b" (%).

V_t = Total volume of dry gas metered during the collection period (dscm); for the purposes of this method, standard temperature and pressure are defined as 20° C and 760 mm Hg, respectively.

DATA QUALITY ASSESSMENT WORKSHEET FOR PROJECT 3

12.3 Calculation of Breakthrough. Use Equation 30B-2 to calculate the percent breakthrough to the second section of the sorbent trap.

$$B = \frac{m_2}{m_1} \times 100 \qquad \text{Eq. 30B-2}$$

12.4 Calculation of Hg Concentration. Calculate the Hg concentration measured with sorbent trap "a", using Equation 30B-3.

$$C_a = \frac{(m_1 + m_2)}{V_t} \qquad \text{Eq. 30B-3}$$

For sorbent trap "b", replace "C_a " with "C_b " in Equation 30B-3. Report the average concentration, i.e., ½ (C_a + C_b).

12.6 Calculation of Paired Trap Agreement. Calculate the relative deviation (RD) between the Hg concentrations measured with the paired sorbent traps using Equation 30B-5.

$$RD = \frac{|C_a - C_b|}{C_a + C_b} \times 100 \qquad \text{Eq. 30B-5}$$

c. The phase of the project funded to-date is limited to Slipstream Testing at a very small scale. Mercury removal efficiency for full scale can be projected using the slipstream screening results, within the limitations of the technique. For the tests conducted during the Slipstream Testing, the mercury measured in the second trap section (m_2 in equation 30B-2), which is packed with standard 30B carbon trap, was never zero. This is a result of mercury present on the "blank" traps prior to exposure to process gas. Because the amount of mercury captured during testing was very low, m_1 in equation 30B-2, the resultant calculated breakthrough was always less than 100%. EPA Method 30B allows the breakthrough calculated using equation 30B-2 to be up to 10% before the test is considered failing. Thus, within the limitations of the method, 100% actual mercury capture in the first section trap of the MIM that contained the test carbon would be reported as up to 10% breakthrough, or ≥ 90% mercury removal.

Results from Slipstream Testing were extrapolated to full-scale operation by calculating the capacity of the carbon for mercury using the equation below:

DATA QUALITY ASSESSMENT WORKSHEET FOR PROJECT 3

Capacity = m_1/M1, where

m_1 is the mass of Hg measured in the first section trap and

M1 = mass of carbon in first section trap

As carbon in the first section becomes saturated with mercury and begins to break through to the second section, m_1 will begin to approach a constant mass and the capacity will approach the equilibrium capacity for the material. For the estimated carbon required for the full-scale application, the capacity calculated during the 10 hour MIM sample run was utilized because it was the best representation of the equilibrium capacity for the data collected. Full scale design details, including the amount of carbon that will be required per year to assure the full-scale fixed bed does not reach breakthrough, must be determined using pilot-testing.

(2) <u>Data Quality Assessment for key variables:</u>

a. EPA Method 30B is an EPA reference method for vapor-phase mercury emissions. Due to the design of the testing in this program, all Method 30B results and all MIM results provided are collected in the uncontrolled gas stream. To determine the mercury concentration in the uncontrolled gas stream, EPA Method 30B measurements were conducted. Relative difference between the duplicate, simultaneous, Method 30B samples were calculated and all results met the goal of < 10% relative difference. All MIM samples were collected in a quad, simultaneous manner (4 tests conducted simultaneously). The relative difference for these tests was calculated by determined the average of all four simultaneous (Ca in equation 30B-5) and comparing each separate test to the quad average using equation 30B-5. These results are included in the Quality Assurance Program appendix of the final report. Calibration records for the dry gas meters used during testing (V_t in equation 30B-3) and analytical records of m_1 and m_2 on equations 30B-2 and 30B-3 are included in the Quality Assurance Program appendix of the final report.

b. Contributions to the scale-up uncertainty using the approach in 1(c) include: 1) the measurement uncertainty of carbon in the trap (M1) and 2) the measurement of the mercury collected (m_1). The precision of the carbon mass measurement is 0.25% based on the accuracy of the balance. However, because the sample preparation technique requires mixing the carbon with sand and utilizing a portion of the mixture for the test, the primary uncertainty is related to how homogenous the sample mixture is. This cannot be measured directly. To quantify the accuracy of the results and include any variability resulting from sample mixing, all tests conducted in the field were repeated and the standard deviation of the sample pairs was calculated. The average SD for the United Taconite pairs was -2%, and the maximum SD for a single pair was -19%. This demonstrates good repeatability and suggests low uncertainty for the sample preparation. Quality control standards were used during mercury analysis. Standards were analyzed nominally every tenth sample. On average, the QC standards analyzed during the United Taconite MIM trap analyses were within 1% of the standard value. The maximum difference for a single sample was 11%.

c. Relevant raw data records are included in the Quality Assurance Program appendix of the final report.

(3) Mercury Removal Estimates:

a. A fixed-bed device for this industry would be designed to capture all incoming mercury within the bed. Therefore, the mercury emissions from a unit currently emitting 100 units of mercury per unit time would be 0 lbs of mercury. For the tests conducted during the Slipstream Testing, the mercury measured in the second trap section was never zero, in part due to mercury present on the "blank" traps prior to exposure to process gas. Due to the design of the test, this introduced some uncertainty into the breakthrough analysis because, according to equation 30B-2, some breakthrough was always calculated. EPA Method 30B allows up to 10% breakthrough before the test is considered failing. Thus, within the limitations of this screening test, the mercury emissions from a taconite plant currently emitting 100 units of mercury per unit time would be 0 +10 units of mercury per unit time.

b. Process gas components such as sulfuric acid were not measured during the program but may affect the mercury removal effectiveness of activated carbon. Results from field MIM tests were compared to tests conducted in the laboratory. There was an insignificant difference between the laboratory and the field results. This data is included in the QA presentation included in the Quality Assurance Program appendix of the final report.

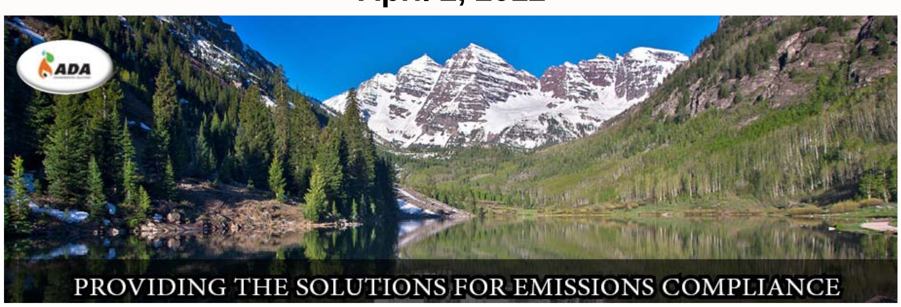
c. The mercury measured on the Sabre carbon and section 2 trap was consistently lower than the mercury measured from any test carbon + section 2 trap. An analytical bias is suspected that is related to the thermal decomposition technique used to analyze the traps. No problems were noted with any of the test carbons or the standard Method 30B carbon traps, thus this problem did not affect the overall conclusions of the study.

Quality Assurance Assessment

Developing Cost-Effective Solutions to Reduce Mercury Emissions from Minnesota Taconite Plants

Industry Update Meeting

April 2, 2012



Sharon M. Sjostrom, P.E. – Chief Technology Officer, ADA-ES
Kyle S. Bowell – Project Engineer, ADA-ES
H. Ray Johnson, PH.D. – Activated Carbon Technologies

QA Objectives

- Determine mercury concentration in the untreated flue gas with sufficient accuracy and precision to validate results;
- Run a sufficient number of tests to verify data are representative of long-term operation at a taconite plant with no mercury control;
- Use the Sorbent Trap Method to evaluate comparability of data;
- Collect data on mercury present downstream of a sorbent bed for each sorbent tested;
- Perform a comparison of sorbents tested at each plant to determine the best sorbents for later pilot and full scale testing in subsequent Phases of this program if funded.

QA Results

✓ Determine mercury concentration in the untreated flue gas with sufficient accuracy and precision to validate results

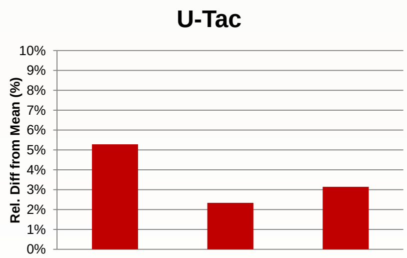
Used calibrated DGM, flowmeters, and thermocouples (NIST traceable)

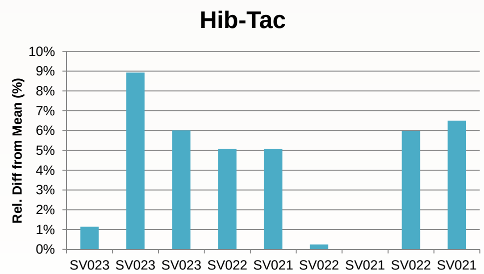
✓ Use the Sorbent Trap Method to evaluate comparability of data

Relative Difference for EPA 30B sorbent traps within QA Criteria of < 10% RD

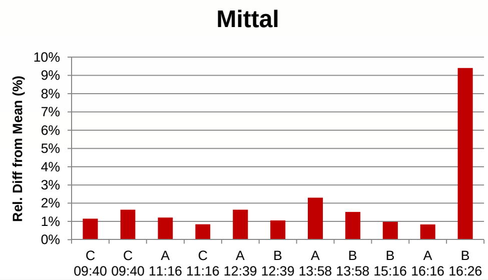
Total mercury measured by EPA 30B representative of total mercury measured using test beds

30B Rel. Diff: Paired Traps

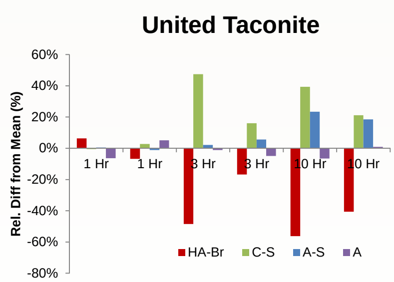


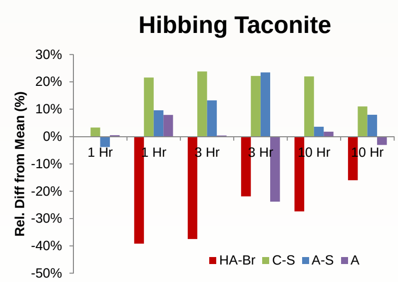


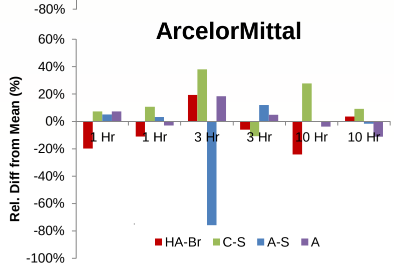
☑ Goal: <10% RD



Comparison of Quad Samples: Total Hg (Concentration)







Consistently low relative recovery for HA-Br
Analytical bias suspected (thermal decomposition)

Note: Breakthrough analysis conducted by correcting data to quad average

QA Results

✓ Run a sufficient number of tests to verify data are representative of long-term operation at a taconite plant with no mercury control

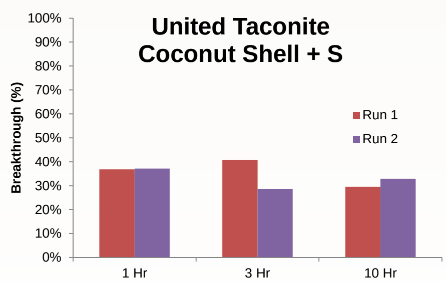
Tests were designed to compare relative sorbent performance, indicate impacts of process gas on sorbent performance, and indicate effect of relative humidity on performance.

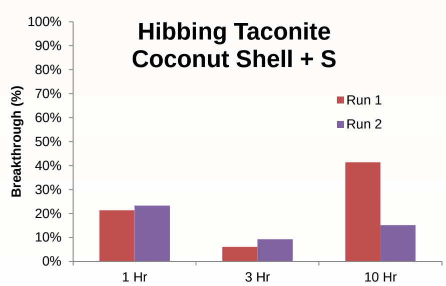
4 sorbents x 3 time conditions x 2 tests = 24 tests
(Each timed test repeated for each condition)

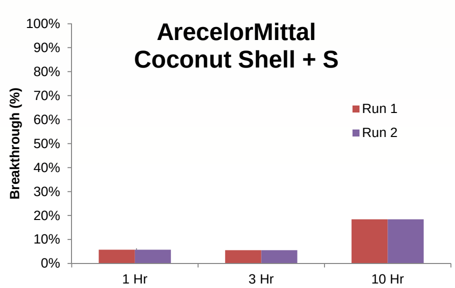
2 sorbents x 2 RH/sorbent x 3 times = 12 relative humidity tests

→ **At least 36 tests conducted per site**

QA Results: Repeatability

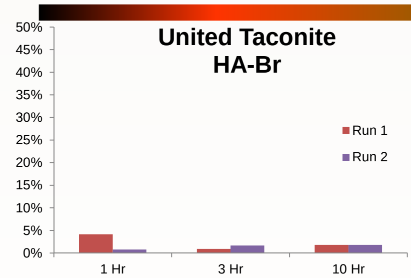


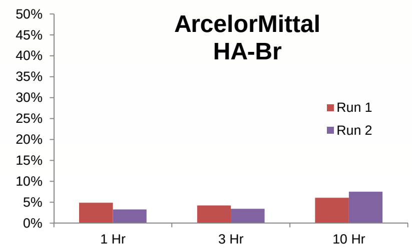


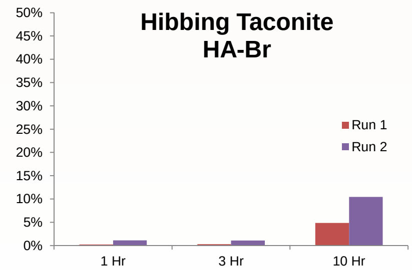


Good repeatability for most tests

QA Results: Repeatability



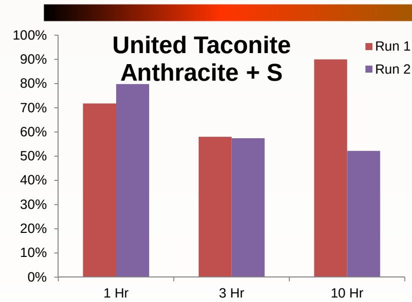


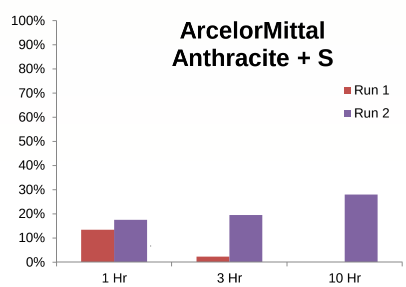


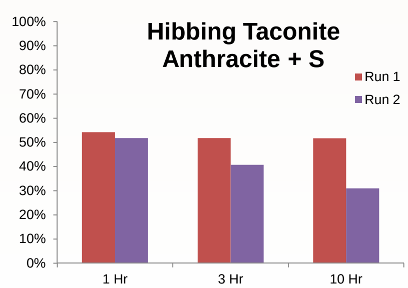
% Breakthrough
Good repeatability for most tests

Note: HA-Br = Sabre

QA Results: Repeatability

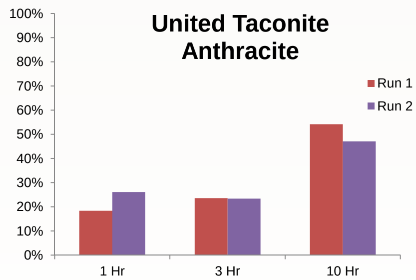


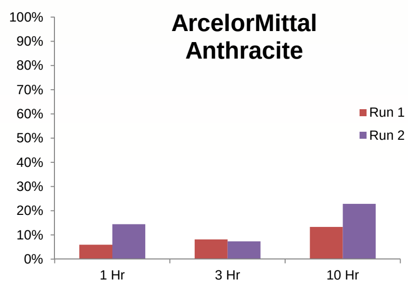


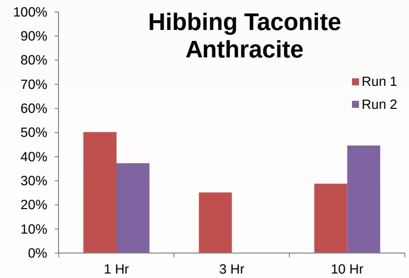


% Breakthrough
Good repeatability for most tests

QA Results: Repeatability







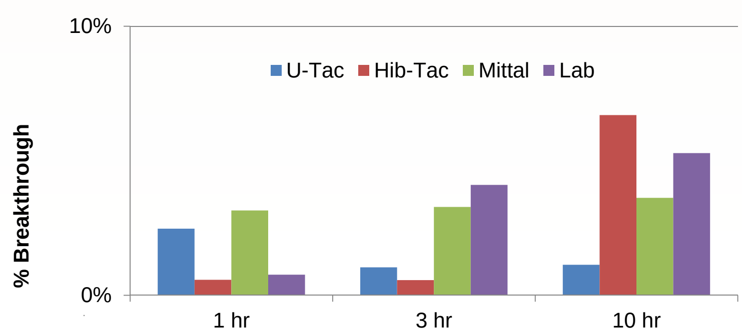
% Breakthrough

Good repeatability for most tests

Comparison with Lab Results

HA-Br characterized in lab (mercury in dry nitrogen) for up to 10 hours

Insignificant difference in lab and field results

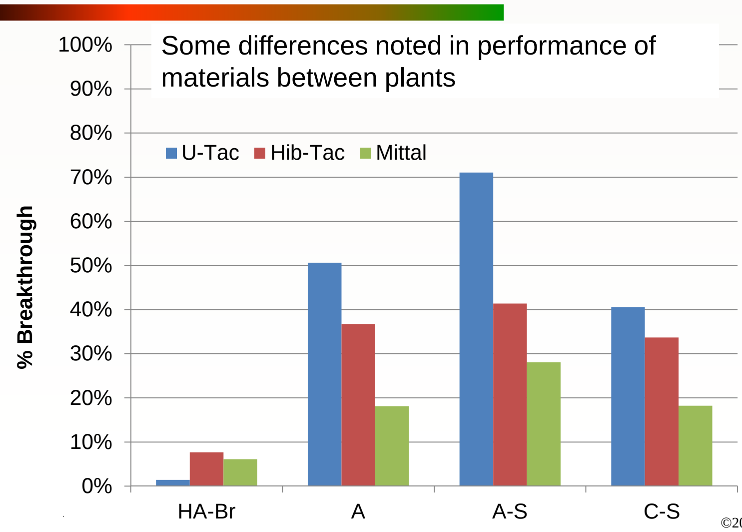


QA Results

✓ Collect data on mercury present downstream of a sorbent bed for each sorbent tested

Mercury breakthrough was measured for all tests by collecting and analyzing all mercury exiting the test traps in a standard EPA M30B sorbent trap

10-hr Hg Breakthrough Comparison



QA Objectives

- ✓ Perform a comparison of sorbents tested at each plant to determine the best sorbents for later pilot and full scale testing

  Four sorbents were tested and performance was compared. Final determination of material for scale-up should factor in cost and physical characteristics that may impact equipment design.

F.3 STM Equipment Calibrations

ADA used two separate sets of STM equipment to conduct testing. These boxes are identified as HG-324K-1026 and HG-324K-1064. Before either box was utilized in the field they were sent to the manufacturer, Environmental Supply Company, for calibration. The calibration of the two Dry Gas Meters, the thermocouple, barometer, and flowmeter for both boxes is presented in the following pages in the report format received from Environmental Supply.

NOTE: While both calibrations took place several months before testing, their Initial Use (as specified in the QA Program) was not until August 1st, 2011.

Environmental Supply Company, Inc.

Quality Source Sampling Systems & Accessories

DGM Reference Calibration

Date: May 4, 2011

Reference Meter: Shinagawa Wet Test Meter

Model: W-NK-1A

S/N: 538787

Pbar: 29.70 in. Hg

Dry Gas Meter: Actaris ACD G1.6

S/N: 3750037

AVG γ: 1.005

Counts Per Liter (CPL): 500

Counter Scale Factor: 2.0000 at dP 1.000

RUN #	Flow (lpm)	DGM (liters)	DGM (°F)	WTM initial	WTM final	WTM (liters)	WTM (°F)	DGM Gamma (γ)	Diff (%)
1	0.400	12.084	71.9	716.588	728.644	12.056	70.4	1.000	-0.41
2	0.600	12.056	72.4	728.644	740.692	12.048	70.5	1.003	-0.17
3	0.800	15.876	72.7	740.692	756.667	15.975	70.6	1.010	0.58

Assigned To: HG-324K-1026 Ch-1

Signature

05/04/11

Date

2142 E. Geer Street, Durham, North Carolina 27704 www.environsupply.com 919-956-9688 FAX: 919-682-0333

Environmental Supply Company, Inc.

Quality Source Sampling Systems & Accessories

DGM Reference Calibration

Date: May 4, 2011

Reference Meter: Shinagawa Wet Test Meter

Pbar: 29.70 in. Hg

Model: W-NK-1A

S/N: 538789

Dry Gas Meter: Actaris ACD G1.6

AVG γ: 1.003

S/N: 3750038

Counts Per Liter (CPL): 520

Counter Scale Factor: 1.9231 at dP 1.000

RUN #	Flow (lpm)	DGM (liters)	DGM (°F)	WTM initial	WTM final	WTM (liters)	WTM (°F)	DGM Gamma (γ)	Diff (%)
1	0.400	12.029	72.8	145.290	157.282	11.992	70.4	1.001	-0.13
2	0.600	11.996	73.2	157.282	169.249	11.967	70.5	1.003	0.01
3	0.800	15.919	73.5	169.249	185.141	15.892	70.5	1.004	0.13

Assigned To: HG-324K-1026 Ch-2

Signature

05/04/11

Date

2142 E. Geer Street, Durham, North Carolina 27704 www.environsupply.com 919-956-9688 FAX: 919-682-0333

Environmental Supply Company, Inc.

Quality Source Sampling Systems & Accessories

HG-324K THERMOCOUPLE CALIBRATION

Date: May 3, 2011

Console S/N: HG-324K- 1026

Reference Thermocouple: PIE Thermocouple
Serial Number: 104547 (NIST Traceable)
Model: 520

TC Simulator Output (°F)	Stack T/C Reading (°F)	Sorbent T/C Reading (°F)	Probe T/C Reading (°F)	Condenser T/C Reading (°F)	Max % Diff	Min % Diff
30	30.49	30.49	30.49	30.60	2.00	1.62
60	60.51	60.49	60.50	60.62	1.03	0.81
120	120.45	120.45	120.45	120.61	0.51	0.37
250	250.45	250.43	250.43	250.58	0.23	0.17
500	500.58	500.56	500.57	500.72	0.14	0.11

HG-324K BAROMETER CALIBRATION

Reference Barometer: Compact Digital Barometer from Control Company
Serial Number: 72402089 (NIST Traceable)
Model: 61161-396
ES Elevation: 379' above sea level

Date	Time	Reference (in Hg)	HG-324K (in Hg)	Difference (in Hg)	% Diff.
3-May-11	13:25	29.71	29.694	0.016	0.05

HG-324K FLOWMETER CALIBRATION

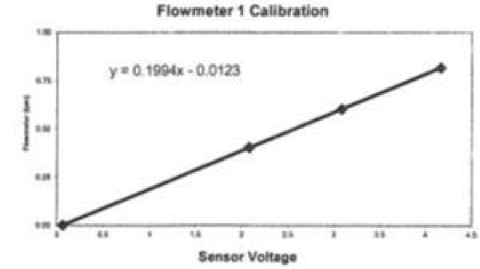
Reference Flowmeter DryCal Technologies
Serial Number: 112234 (NIST Traceable)
Model: Definer 220

Flowmeter 1	
Sensor Voltage	Reference Meter Flow (lpm)
0.064	0.000
2.0819	0.404
3.0866	0.603
4.1601	0.817

SLOPE 0.1994

INTERCEPT -0.0123

Flowmeter 1 Calibration

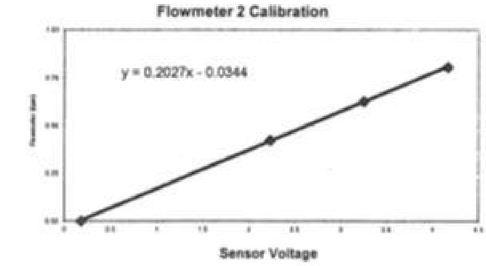


Flowmeter 2	
Sensor Voltage	Reference Meter Flow (lpm)
0.1819	0.000
2.2327	0.423
3.2501	0.626
4.1633	0.806

SLOPE 0.2027

INTERCEPT -0.0344

Flowmeter 2 Calibration



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Environmental Supply Company, Inc.

Quality Source Sampling Systems & Accessories

DGM Reference Calibration

Date: February 4, 2011

Reference Meter: Shinagawa Wet Test Meter **Pbar:** 29.90 in. Hg

Model: W-NK-1A

S/N: 538787

Dry Gas Meter: Actaris ACD G1.6 **AVG γ:** **1.003**

S/N: 3600875

Counts Per Liter (CPL): 545 **Counter Scale Factor:** 1.8349 at dP 1.000

RUN #	Flow (lpm)	DGM (liters)	DGM (°F)	WTM initial	WTM final	WTM (liters)	WTM (°F)	DGM Gamma (γ)	Diff (%)
1	0.400	11.903	69.4	904.119	916.014	11.895	67.6	1.003	0.01
2	0.600	11.855	69.8	916.014	927.863	11.849	67.8	1.003	0.07
3	0.800	15.882	70.0	927.863	943.710	15.847	67.7	1.002	-0.07

Assigned To: HG-324K-1064 Ch-1

Signature

02/04/11

Date

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Environmental Supply Company, Inc.

Quality Source Sampling Systems & Accessories

DGM Reference Calibration

Date: February 4, 2011

Reference Meter: Shinagawa Wet Test Meter **Pbar:** 29.90 in. Hg

Model: W-NK-1A

S/N: 538789

Dry Gas Meter: Actaris ACD G1.6 **AVG γ:** 1.004

S/N: 3600876

Counts Per Liter (CPL): 535 **Counter Scale Factor:** 1.8692 at dP 1.000

RUN #	Flow (lpm)	DGM (liters)	DGM (°F)	WTM initial	WTM final	WTM (liters)	WTM (°F)	DGM Gamma (γ)	Diff (%)
1	0.400	12.029	69.7	546.621	558.641	12.020	67.6	1.003	-0.04
2	0.600	11.924	70.1	558.641	570.567	11.926	67.8	1.005	0.09
3	0.800	15.962	70.1	570.567	586.509	15.942	67.8	1.003	-0.05

Assigned To: HG-324K-1064 Ch-2

Tony Baker
Signature

02/04/11
Date

Environmental Supply Company, Inc.

Quality Source Sampling Systems & Accessories

HG-324K THERMOCOUPLE CALIBRATION

Date: February 3, 2011

Console S/N: HG-324K- 1064

Reference Thermocouple: PIE Thermocouple
Serial Number: 104547 (NIST Traceable)
Model: 520

TC Simulator Output (°F)	Stack T/C Reading (°F)	Sorbent T/C Reading (°F)	Probe T/C Reading (°F)	Condenser T/C Reading (°F)	Max % Diff	Min % Diff
30	30.60	30.63	30.69	30.68	2.29	2.00
60	60.57	60.58	60.61	60.62	1.03	0.95
120	120.55	120.58	120.55	120.61	0.51	0.46
250	250.50	250.51	250.50	250.56	0.22	0.20
500	500.48	500.50	500.55	500.59	0.12	0.10

HG-324K BAROMETER CALIBRATION

Reference Barometer: Compact Digital Barometer from Control Company
Serial Number: 72402089 (NIST Traceable)
Model: 61161-396
ES Elevation: 379' above sea level

Date	Time	Reference (in Hg)	HG-324K (in Hg)	Difference (in Hg)	% Diff.
3-Feb-11	14:55	29.91	29.972	0.062	0.21

HG-324K FLOWMETER CALIBRATION

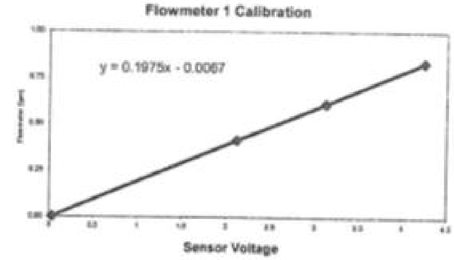
Reference Flowmeter DryCal Technologies
Serial Number: 112234 (NIST Traceable)
Model: Definer 220

Flowmeter 1	
Sensor Voltage	Reference Meter Flow (lpm)
0.0344	0.000
2.1183	0.412
3.1246	0.610
4.2477	0.833

SLOPE 0.1975

INTERCEPT -0.0067

Flowmeter 1 Calibration

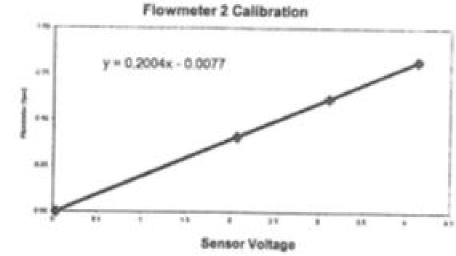


Flowmeter 2	
Sensor Voltage	Reference Meter Flow (lpm)
0.0368	0.000
2.0754	0.407
3.1166	0.617
4.133	0.821

SLOPE 0.2004

INTERCEPT -0.0077

Flowmeter 2 Calibration



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F.3.1 Flowmeter checks

ADA performed a flowmeter check, confirming the validity of all data gathered. A handheld reference flowmeter (Aalborg) was placed in line with the fully assembled STM equipment, and a 5 minute test was run using stack gas to confirm the accuracy of the instrument's flowmeter, the results of the tests for both channels of both sets of equipment is presented in Table F-1.

Table F-1: STM Equipment Flowmeter Quality Check

			Visual Check		Totalizer vs GFM							Results	
			Aalborg	Instrument	Inst	Inst	Aalborg	GFM Temp	B.P.	Time	Inst Calc	Visual	Volume
Date	STM Box ID#	Channel	(L/min)	(L/min)	(L STP)	(L nom)	(L)	(F)	("Hg)	(min)	(L STP)	% diff	% diff
8/23/2011	1064	A1	0.75	0.790	3.650	3.976	3.61	78.111	27.903	5	3.652	5.33	1.17
		A2	0.75	0.790	3.610	3.865	3.64	69.667	27.887	5	3.605	5.33	0.97
	1026	E1	0.76	0.790	3.640	3.952	3.62	76.839	27.865	5	3.634	3.95	0.38
		E2	0.73	0.806	3.499	3.819	3.53	78.464	27.871	5	3.502	10.41	0.81

The QA Program allows for up to a 10% difference between the reference flowmeter (Aalborg) total volume reading and the instrument's flowmeter total volume reading, but as seen in Table F-1, 1.17% was the highest observed.

F.3.2 Leak checks

Pre and Post-Test Leak-Checks were performed before and after each test. If the Pre-Test Leak-Check failed, the leak was found and repaired until the Leak-Check passed and the test was begun. If the Post-Test Leak-Check failed then the data for that individual test was discarded and the test was repeated. The results of the Leak-Checks are presented in Table F-2.

Table F-2: Pre and Post-Test Leak-Checks

Date	Start Time	End Time	Flow Rate [cc/min]	Trap ID	Leak Test$_i$ (Pass/Fail)	Leak Test$_f$ (Pass/Fail)	DGM [L (STP)]
08/02/11	12:20	13:20	800	04113	PASS	PASS	0.051
				01105	PASS	PASS	0.869
08/02/11	12:20	13:20	800	02106	PASS	PASS	43.720
				03115	PASS	PASS	39.652
08/02/11	14:30	17:30	800	04112	PASS	PASS	132.696
				01102	PASS	PASS	128.019
08/02/11	14:30	17:30	800	02107	PASS	PASS	132.111
				03113	PASS	PASS	114.327
08/02/11	18:30	04:30	800	04110	PASS	PASS	450.454
				01106	PASS	PASS	441.534
08/02/11	18:30	04:30	800	02103	PASS	PASS	452.104
				03112	PASS	PASS	367.748
08/03/11	08:37	09:37	800	27461	PASS	PASS	45.013
				01103	PASS	PASS	44.692
08/03/11	08:37	09:37	800	02109	PASS	PASS	45.988
				03102	PASS	PASS	44.381
08/03/11	09:57	12:57	800	90146	PASS	PASS	135.079
				01104	PASS	PASS	132.165
08/03/11	09:57	12:57	800	02105	PASS	PASS	136.486
				03109	PASS	PASS	125.951
08/03/11	14:37	00:37	800	91412	PASS	PASS	449.449
				01108	PASS	PASS	449.449
08/03/11	14:37	00:37	800	02113	PASS	PASS	415.275
				03111	PASS	PASS	401.749
08/04/11	09:37	10:37	800	98905	PASS	PASS	45.380
				98914	PASS	PASS	42.925
08/04/11	11:02	12:02	800	98912	PASS	PASS	45.099
				98956	PASS	PASS	41.950
08/04/11	12:18	13:18	800	98920	PASS	PASS	44.520
				98938	PASS	PASS	41.290
08/06/11	09:30	10:30	800	91369	PASS	PASS	44.081
				03114	PASS	PASS	44.068
08/06/11	09:30	10:30	800	03104	PASS	PASS	43.528
				89045	PASS	PASS	45.399
08/06/11	10:51	13:51	800	90183	PASS	PASS	134.321
				03107	PASS	PASS	132.307
08/06/11	10:51	13:51	800	91301	PASS	PASS	134.247
				03110	PASS	PASS	133.588
08/06/11	14:05	00:05	800	81788	PASS	PASS	450.440
				03101	PASS	PASS	442.055
08/06/11	14:05	00:05	800	91321	PASS	PASS	451.560
				03105	PASS	PASS	419.200
08/07/11	08:46	09:46	800	04109	PASS	PASS	45.035
				01110	PASS	PASS	44.316
08/07/11	11:20	12:20	800	98776	PASS	PASS	44.879
				98895	PASS	PASS	42.453
08/07/11	12:37	13:37	800	98878	PASS	PASS	45.152
				98910	PASS	PASS	42.536
08/07/11	13:49	14:49	800	98906	PASS	PASS	45.293
				98967	PASS	PASS	42.711

F.3.3 Mercury Analyzer Calibrations

Mercury analyzer analytical bias test 3/24/2011

Spike recovery study certificate 3/24/2011

Mercury Analyzer Calibration Certificate and gas bottle certificate of analysis 3/27/2011

Mercury Analyzer Calibration Certificate and gas bottle certificate of analysis 6/15/2012

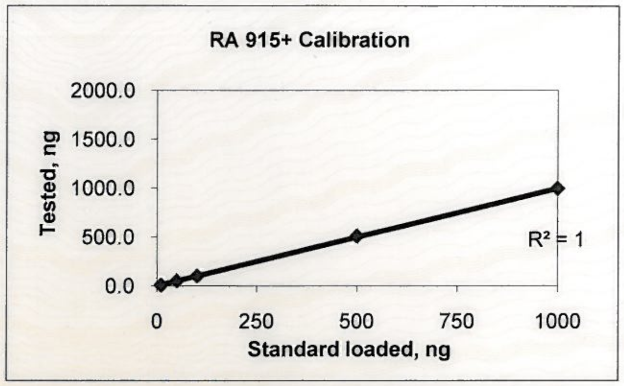
Ohio Lumex Co.
9263 Ravenna Rd, Unit A-3
Twinsburg Ohio 44087
Tel. 1-888-876-2611
Email: Mail@Ohiolumex.com

Analyzer # 1364 Certificate

Testing is based on EPA Method 30B QA/QC requirements

No.	Standard (ng)	Tested (ng)
1	10	10.0
2	50	52
3	100	104
4	500	511
5	1000	1000
6	2000	1990

Flow= 2.0 L/min
% RSD= 2.2



Initial Calibration Response Factor = 182.8 (Area/ng)

Method Detection Limit Test

No.	Standard (ng)	Tested (ng)
1	3.0	3.1
2	3.0	3.2
3	3.0	3.1
4	3.0	2.9
5	3.0	3.3
6	3.0	3.0
7	3.0	3.1
8	3.0	3.0

Std Dev = 0.125ng
MDL= 0.374 ng

Bias Test

Hg	Trap No.	Spiked (ng)	Tested (ng)	Recovery (%)	Rec. Ave (%)
Hg(0)	81779	10	9.9	99	
	80468	10	10	100	100
	80469	10	10	100	
	21165	1900	1930	102	
	21506	1900	1950	103	101
	21437	1900	1860	98	
Hg(2+)	0000-1	10	11	110	
	0000-2	10	10	100	101
	0000-3	10	9.2	92	
	0001-1	1900	1890	99	
	0001-2	1900	1910	101	100
	0001-3	1900	1920	101	

QA/QC manager: [signature]

Date: 3/24/2011

Analyst: [signature]

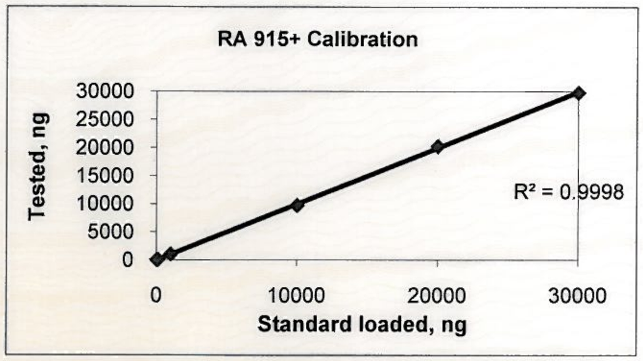
All standards used are NIST traceable, certificates attached.
Method Detection Limit (MDL) is defined by "40 CFR, part 136, Appendix B"
This certification will expire on March 24, 2012

Ohio Lumex Co.
9263 Ravenna Rd, Unit A-3
Twinsburg Ohio 44087
Tel. 1-888-876-2611
Email: Mail@Ohiolumex.com

Spike Recovery Study Certificate
for Analyzer # 1364

Testing is based on EPA Method Appendix K QA/QC requirements

No.	Standard (ng)	Tested (ng)
1	10	10
2	100	92
3	1000	1050
4	10000	9760
5	20000	20300
6	30000	29800



Flow= 4.0 L/min

% RSD= 4.8

Initial Calibration Response Factor = 108.6 (Area/ng)

Spiked Traps Recovery Tests

Hg0	Trap No.	Spiked (ng)	Received (ng)	Recovery (%)	Rec. Ave (%)
Level 1	67838	50	46	92	94
	67846	50	47	94	
	67850	50	48	96	
Level 2	57186	3000	2780	93	95
	57074	3000	2910	97	
	57090	3000	2840	95	
Level 3	51861	30000	28500	95	94
	51889	30000	28400	95	
	51869	30000	28100	94	

QA/QC manager: [signature]

Date: 3/24/2011

Analyst: [signature]

All standards used are NIST traceable, certificates attached.
Spiking procesure followed EPA CFR 40 Part 75 requirements
This certification will expire on March 24, 2012

CERTIFICATE OF ANALYSIS

SALES#:	107702332		
PRODUCTION#:	1157050	**CYLINDER # :**	CC-266087
CERTIFICATION DATE:	11/04/2010	**CYLINDER PRES:**	2000 psig
P.O.# :	101110JS	**CYLINDER VALVE:**	CGA 660
BLEND TYPE:	CERTIFIED	**PRODUCT EXPIRATION DATE:**	05/03/2011

ANALYTICAL ACCURACY: + / - 10%

COMPONENT	REQUESTED GAS CONC	ANALYSIS
Mercury	6.5 ug/m3	6.7 ug/m3
Air	Balance	Balance

1 ATM/20 *C

ANALYST: [signature] Cody Hamlin

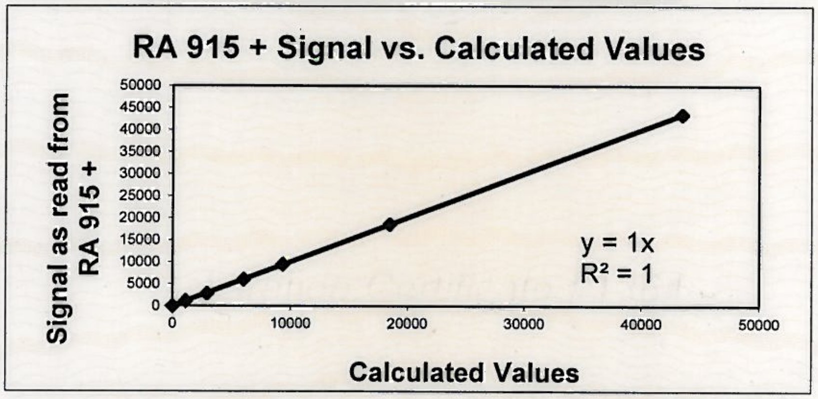
DATE: 11/04/2010

Ohio Lumex Co.
9263 Ravenna Rd, Unit A-3
Twinsburg Ohio 44087
Tel. 1-888-876-2611
Email: Mail@Ohiolumex.com

Calibration Certificate #1364

RA 915 +

Standard #	Temp C	Calculated value	Signal (10m cell)
1	20.5	0	0
2	20.5	1122	1145
3	20.5	2907	2827
4	20.5	6016	5966
5	20.5	9341	9445
6	20.5	18453	18537
7	20.5	43470	43423



Spectra Gas certified value: 6.7ug/m3
Calibration Parameter A : 656

Reading observed: 6.7ug/m3.
Calibration Parameter B : 38400

CALIBRATION DATE: 03/27/11 NEXT CALIBRATION DUE: 03/27/12

ON THE DATE CALIBRATED, THIS UNIT OPERATED WITHIN SPECIFIED TOLERANCES

Digital Barometer: Cert. # 4245-3250914, Cal. Due: 10/26/2012
Digital Thermometer: Cert. # 4245-3250914, Cal. Due: 10/26/2012
Set of Calibrated Saturated Mercury Vapor Cells, Due: 12/15/2011
Gas NIST traceable Standard: SpectraGas Calibration cylinder #: CC-266087
Concentration: 6.7ug/m3, Analytical Accuracy: +/- 10%.Expiration date:05/03/2011

SERVICE TECHNICIAN: ___J.S.. d. Sipcrotov

RECOMMENDATION NOTE: INSTRUMENT SHOULD BE RECALIBRATED EVERY 12 MONTHS OR SOONER, IF EXPOSED TO EXTREME CONDITIONS OR DAMAGE IS SUSPECTED

THE LINDE GROUP Linde

SHIPPED TO: Ohio Lumex Company
9263 Ravenna Rd Unit A-3
Twinsburg, OH 44087

CERTIFICATE OF ANALYSIS

Sales#:	108894131	**Cylinder Size:**	2A (8" X 47.5")
Production#:	1215054	**Cylinder # :**	CC-270699
Certification Date:	May-18-2012	**Cylinder Pressure:**	2000 psig
P.O.# :	VERBAL JOSEPH	**Cylinder Valve:**	CGA 660 / Steel
Blend Type:	CERTIFIED	**Cylinder Volume:**	29.5 Liter
Material#:	24086892	**Cylinder Material:**	Aluminum
		Gas Volume:	4000 Liter
Expiration Date:	Nov-13-2012	**Blend Tolerance:**	20% Relative
Do NOT use under:	150 psig	**Analytical Accuracy:**	10% Relative

COMPONENT	REQUESTED CONC	CERTIFIED CONC
Mercury	7.0 ug/m3	6.7 ug/m3
Air	Balance	Balance

1 ATM/20*C

ANALYST: Justin Kutz

DATE: May-18-2012

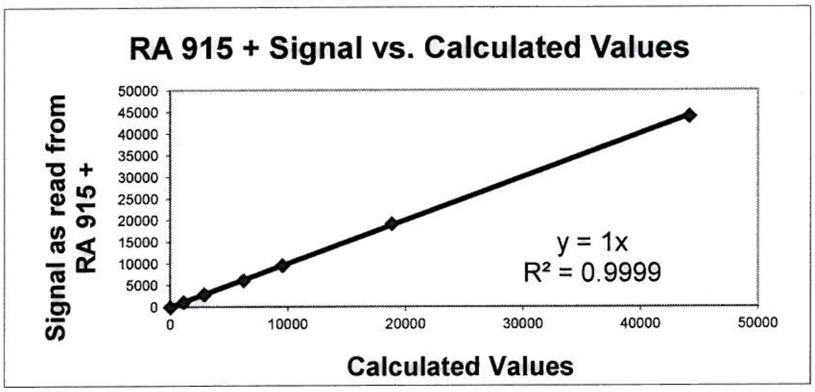
Linde Gas North America LLC (908) 329-9700 Main (908) 329-9740 Fax
www.Lindeus.com

Ohio Lumex Co.
9263 Ravenna Rd, Unit A-3
Twinsburg Ohio 44087
Tel. 1-888-876-2611
Email: Mail@Ohiolumex.com

Calibration Certificate #1364

RA 915 +

Standard #	Temp C	Calculated value	Signal (10m cell)
1	24	0	0
2	24	1131	1125
3	24	2896	2881
4	24	6214	6149
5	24	9531	9573
6	24	18814	19176
7	24	44150	43996



Spectra Gas certified value: 6.7 ug/m3 Reading observed: 6.7 ug/m3.
Calibration Parameter A : 851 Calibration Parameter B : 48888

CALIBRATION DATE: 06/15/12 NEXT CALIBRATION DUE: 06/15/13

ON THE DATE CALIBRATED, THIS UNIT OPERATED WITHIN SPECIFIED TOLERANCES

Digital Barometer: Cert. # 4245-3250914, Cal. Due: 10/26/2012
Digital Thermometer: Cert. # 4245-3250914, Cal. Due: 10/26/2012
Gas NIST traceable Standard: SpectraGas Calibration cylinder #: CC-270699
Concentration: 6.7 ug/m3, Analytical Accuracy: +/- 10%.Expiration date: 11/13/2012

SERVICE TECHNICIAN: ___J.S._ L. Sipcrsten
QC Check: YB

RECOMMENDATION NOTE: INSTRUMENT SHOULD BE RECALIBRATED EVERY 12 MONTHS OR SOONER, IF EXPOSED TO EXTREME CONDITIONS OR DAMAGE IS SUSPECTED

F.4 Raw Data

Tables F-3 and F-4 which follow present all data collected and used by ADA to generate this report. Table F-3 is organized chronologically by the times in which the samples were run.

NOTE: The carbon sorbents in Table F-4 are denoted as:

1. Sabre 8% Br (STD)
2. CR4AN
3. CR4AN-Hg
4. CR612C-Hg

Table F-4 is the raw data from the Ohio Lumex analyzer.

Table F-3: Data Validation and Verification

Taconite

Project #: 8088-11
Plant: United Taconite
Boiler ID: Line 2
Sampling Location: Stack 2A, unless otherwise noted
Ohio Lumex ID:

i = Initial
f = Final
AMD = Difference
RA = Relative Accuracy
RD = Relative
No O_2 Correction

	Sampling						Analysis										
Run	Date	Start Time	End Time	Flow Rate [cc/min]	Trap ID	DGM [L (STP)]	Stack Wet Bulb Temp (F)	Stack Dry Bulb Temp (F)	Stack RH (%)	STM Box Set Temp (F)	Trap RH (%)	Carbon	Test Length (hrs)	Description	M_{Sect1} [ng]	M_{Sect2} [ng]	Comments
1	08/02/11	12:20	13:20	800	04113	0.051	126.0	140.0	67.0	150.0	50.0	1	1	Sabre 8% Br Sand Bed: STO 1HR A1	0.7	1.0	ADA STM Box 1064, clog insuf volume pull. Data not used
					01105	0.869	126.0	140.0	67.0	150.0	50.0	2	1	CR4AN Sand Bed: 2 1HR A2	4.3	0.5	
2	08/02/11	12:20	13:20	800	02106	43.720	126.0	140.0	67.0	150.0	50.0	3	1	CR4AN -Hg Sand Bed: 3 1HR E1	81	202.0	
					03115	39.652	126.0	140.0	67.0	150.0	50.0	4	1	CR612 - Hg Sand bed: 4 1HR E2	160	94.0	
3	08/02/11	14:30	17:30	800	04112	132.696	126.0	140.0	67.0	150.0	50.0	1	3	Sabre 8% Br Sand Bed: STO 3 HR A1	320	6.0	
					01102	128.019	126.0	140.0	67.0	150.0	50.0	2	3	CR4AN Sand Bed: 2 3HR A2	459	144.0	
4	08/02/11	14:30	17:30	800	02107	132.111	126.0	140.0	67.0	150.0	50.0	3	3	CR4AN -Hg Sand Bed: 3 3 HR E1	278	365.0	
					03113	114.327	126.0	140.0	67.0	150.0	50.0	4	3	CR612 - Hg Sand Bed: 4 3HR E2	476	327.0	
5	08/02/11	18:30	04:30	800	04110	450.454	126.0	140.0	67.0	150.0	50.0	1	10	Sabre 8% Br Sand bed: STO 10HR A1	884	22.0	
					01106	441.534	126.0	140.0	67.0	150.0	50.0	2	10	CR4AN Sand bed: 2 10HR A2	798	1100.0	
6	08/02/11	18:30	04:30	800	02103	452.104	126.0	140.0	67.0	150.0	50.0	3	10	CR4AN -Hg Sand Bed: 3 10HR E1	695	1870.0	
					03112	367.748	126.0	140.0	67.0	150.0	50.0	4	10	CR612 - Hg Sand Bed: 4 10hr E2	1660	697.0	
7	08/03/11	08:37	09:37	800	27461	45.013	126.0	140.0	67.0	150.0	50.0	1	1	Sabre 8% Br Sand Bed: STO 1HR A1	299.2	2.6	
					01103	44.692	126.0	140.0	67.0	150.0	50.0	2	1	CR4AN Sand Bed: 2 1HR A2	254	84.0	
8	08/03/11	08:37	09:37	800	02109	45.988	126.0	140.0	67.0	150.0	50.0	3	1	CR4AN -Hg Sand Bed: 3 1HR E1	63	264.0	
					03102	44.381	126.0	140.0	67.0	150.0	50.0	4	1	CR612 - Hg Sand bed: 4 1HR E2	206	122.0	
9	08/03/11	09:57	12:57	800	90146	135.079	126.0	140.0	67.0	150.0	50.0	1	3	Sabre 8% Br Sand Bed: STO 3 HR A1	588	12.0	
					01104	132.165	126.0	140.0	67.0	150.0	50.0	2	3	CR4AN Sand Bed: 2 3HR A2	506	165.0	
10	08/03/11	09:57	12:57	800	02105	136.486	126.0	140.0	67.0	150.0	50.0	3	3	CR4AN -Hg Sand Bed: 3 3 HR E1	351	418.0	
					03109	125.951	126.0	140.0	67.0	150.0	50.0	4	3	CR612 - Hg Sand Bed: 4 3HR E2	557	223.0	
11	08/03/11	14:37	00:37	800	91412	449.449	126.0	140.0	67.0	150.0	50.0	1	10	Sabre 8% Br Sand bed: STO 10HR A1	1266	40.0	
					01108	449.449	126.0	140.0	67.0	150.0	50.0	2	10	CR4AN Sand bed: 2 10HR A2	1142	1000.0	
12	08/03/11	14:37	00:37	800	02113	415.275	126.0	140.0	67.0	150.0	50.0	3	10	CR4AN -Hg Sand Bed: 3 10HR E1	1348	1060.0	
					03111	401.749	126.0	140.0	67.0	150.0	50.0	4	10	CR612 - Hg Sand Bed: 4 10hr E2	1598	783.0	
13	08/04/11	09:37	10:37	800	98905	45.380						na	1	STM trap on Stack 2B	329	0.0	1026, Stack 2B, STM
					98914	42.925						na	1		280	0.2	
14	08/04/11	11:02	12:02	800	98912	45.099						na	1	STM trap on Stack 2B	328	1.0	1026, Stack 2B, STM
					98956	41.950						na	1		292	0.0	
15	08/04/11	12:18	13:18	800	98920	44.520						na	1	STM trap on Stack 2B	302	0.1	1026, Stack 2B, STM
					98938	41.290						na	1		296	0.2	
16	08/06/11	09:30	10:30	800	91369	44.081	126.0	140.0	67.0	140.0	67.0	1	1	Sabre 8% Br: STD 1HR A1	224	10.0	
					03114	44.068	126.0	140.0	67.0	140.0	67.0	4	1	CR612 - Hg: 4 1hr A2	237	93.2	
17	08/06/11	09:30	10:30	800	03104	43.528	126.0	140.0	67.0	150.0	50.0	4	1	CR612 - Hg: 4 1hr E1	223	92.0	
					89045	45.399	126.0	140.0	67.0	150.0	50.0	1	1	Sabre 8% Br: STD 1HR E2	192.2	-2.7	
18	08/06/11	10:51	13:51	800	90183	134.321	126.0	140.0	67.0	140.0	67.0	1	3	Sabre 8% Br: STD 3HR A1	315	-1.5	
					03107	132.307	126.0	140.0	67.0	140.0	67.0	4	3	CR612 - Hg: 4 3hr A2	668	245.0	
19	08/06/11	10:51	13:51	800	91301	134.247	126.0	140.0	67.0	150.0	50.0	1	3	Sabre 8% Br: STD 3HR E1	406	1.8	
					03110	133.588	126.0	140.0	67.0	150.0	50.0	4	3	CR612 - Hg: 4 3hr E2	654	295.0	
20	08/06/11	14:05	00:05	800	81788	450.440	126.0	140.0	67.0	140.0	67.0	1	10	Sabre 8% Br: STD 10HR A1	1540	46.0	
					03101	442.055	126.0	140.0	67.0	140.0	67.0	4	10	CR612 - Hg: 4 10hr A2	1821	983.0	
21	08/06/11	14:05	00:05	800	91321	451.560	126.0	140.0	67.0	150.0	50.0	1	10	Sabre 8% Br: STD 10HR E1	1124	51.0	
					03105	419.200	126.0	140.0	67.0	150.0	50.0	4	10	CR612 - Hg: 4 10hr E2	1758	778.0	
22	08/07/11	08:46	09:46	800	04109	45.035	126.0	140.0	67.0	150.0	50.0	1	1	Sabre 8% Br Sand Bed: STO 1HR A1	368	15.0	Retest
					01110	44.316	126.0	140.0	67.0	150.0	50.0	2	1	CR4AN Sand Bed: 2 1HR A2	267	65.0	
23	08/07/11	11:20	12:20	800	98776	44.879						na	1	STM trap on Stack 2B	415	0.2	1026, Stack 2B, STM
					98895	42.453						na	1		381	0.3	
24	08/07/11	12:37	13:37	800	98878	45.152						na	1	STM trap on Stack 2B	421	0.6	1026, Stack 2B, STM
					98910	42.536						na	1		416	-0.3	
25	08/07/11	13:49	14:49	800	98906	45.293						na	1	STM trap on Stack 2B	50	-0.1	1026, Stack 2B, STM
					98967	42.711						na	1		332	2.2	

Table F-4: Ohio Lumex Hg Analyzer Produced Raw Data

Description	M, mg	C, ng/g	Area
Std__10	1	10	903
Std__100	1	108	9040
Std__500	1	502	41900
Std__1000	1	1040	86900
QC__250	1	264	22800
QC__500	1	511	42600
27461 STD 1HR A1 sand pt1	1	294	21500
27461 sand pt 2	1	5.2	379
27461 carbon bed	1	2.6	191
01103 02 1HR A2 sand pt1	1	208	15200
01103 sand pt2	1	46	3360
01103 carbon bed	1	84	6200
02109 3 1 HR E1 sand pt 1	1	35	2600
02109 3 sand pt2	1	28	2100
02109 carbon bed	1	264	19300
03102 4 1HR E2 sand pt1	1	154	11300
03102 sand pt2	1	52	3850
03102 carbon bed	1	122	8940
QC__250	1	269	19700
QC__250	1	238	17400
QC__250	1	256	18700
90146 STD 3HR A1 Sand pt1	1	564	41200
90146 sand pt2	1	24	1820
90146 carbon bed	1	12	881
01104 2 3HR A2 sand pt1	1	421	30800
01104 sand pt 2	1	85	6250
01104 carbon bed	1	165	12100
QC__250	1	268	19600
02105 3 3HR E1 sand pt 1	1	316	26400
02105 part 2	1	35	2940
02105 Carbon Bed	1	418	34900
03109 4 3HR E2 Sand pt 1	1	436	36400
03109 part 2	1	121	10100
03109 carbon bed	1	223	18600
QC__250	1	253	21100
91412 1 STD 10HR A1sand pt 1	1	1200	100000
91412 pt 2	1	66	5540
91412 carbon bed	1	40	3410
01108 2 10HR A2 sand pt1	1	898	74900
01108 pt 2	1	244	20400
01108 carbon bed	1	1000	83800
02113 3 10HR E1	1	1220	102000
02113 pt 2	1	128	10700
02113 carbon bed	1	1060	88900
03111 4 10HR E2 SAND PT 1	1	1200	100000
03111 PT 2	1	398	33200
03111 CARBON BED	1	783	65300
QC__250	1	242	20200
BLANK	1		-4
BLANK	1		71
Std__10	1	9.2	815
Std__10	1	9.4	831
Std__100	1	98	8010
Std__100	1	96	7910
Std__1000	1	905	73300
Std__1000	1	955	77300
Std__5000	1	5150	417000
Std__5000	1	4870	394000
QC_500	1	488	39600
UTac_8711_T1_1hr_04109_1_A1_SandA	1	279	22700
UTac_8711_T1_1hr_04109_1_A1_SandB	1	89	7290
UTac_8711_T1_1hr_04109_1_A1_Carbon	1	15	1350
UTac_8711_T1_1hr_01110_2_A2_SandA	1	177	14400
UTac_8711_T1_1hr_01110_2_A2_SandB	1	90	7370
UTac_8711_T1_1hr_01110_2_A2_Carbon	1	65	5330
UTac_8611_T2_1hr_91369_2_A1_SandA	1	205	16700
UTac_8611_T2_1hr_91369_2_A1_SandB	1	19	1670
UTac_8611_T2_1hr_91369_2_A1_Carbon	1	10	956

Description	M, mg	C, ng/g	Area
BLANK	1	0.0	302
Std__10	1	9.4	1150
Std__100	1	100	9380
Std__1000	1	980	88600
Std__5000	1	5000	451000
QC_300	1	299	27300
UTac_8611_T2_1hr_4_03114_A2_SandA	1	119	11100
UTac_8611_T2_1hr_4_03114_A2_SandB	1	118	11000
UTac_8611_T2_1hr_4_03114_A2_CarbonA	1	95	8900
UTac_8611_T2_1hr_4_03114_A2_CarbonB	1	-1.8	143
UTac_8611_T2_1hr_4_03104_E1_SandA	1	144	13300
UTac_8611_T2_1hr_4_03104_E1_SandB	1	79	7480
UTac_8611_T2_1hr_4_03104_E1_Carbon	1	92	8610
UTac_8611_T2_1hr_1_89045_E2_SandA	1	186	17100
UTac_8611_T2_1hr_1_89045_E2_SandB	1	6.2	861
UTac_8611_T2_1hr_1_89045_E2_Carbon	1	-2.7	63
UTac_8611_T2_3hr_1_90183_A1_SandA	1	309	28200
UTac_8611_T2_3hr_1_90183_A1_SandB	1	6.0	840
UTac_8611_T2_3hr_1_90183_A1_Carbon	1	-1.5	167
QC_300	1	299	24600
QC__100	1	100	7600
QC__100	1	89	6770
QC__100	1	97	7370
QC__100	1	103	7810
91301 Std 3hr E1 Sand	1	402	29600
Std 3 hr E1 sand pt 2	1	4.0	540
Std 3 hr E1 carbon bed	1	1.8	376
03110 3hr E2 Sand pt 1	1	578	42500
03110 3hr E2 Sand pt 2	1	76	5800
03110 3 hr E2 Carbon Bed	1	295	21800
03107 4 3 hr A2 sand pt 1	1	514	37800
03107 4 3 hr A2 sand pt 2	1	154	11500
03107 4 3hr A2 carbon bed	1	245	18200
QC__100	1	99	7530
UTac_8611_T2_10hr_1_81788_A1_SandA	1	1400	103000
UTac_8611_T2_10hr_1_81788_A1_SandB	1	140	10500
UTac_8611_T2_10hr_1_81788_A1_Carbon	1	46	3610
UTac_8611_T2_10hr_4_03101_A2_SandA	1	691	50700
UTac_8611_T2_10hr_4_03101_A2_SandB	1	1130	83000
UTac_8611_T2_10hr_4_03101_A2_Carbon	1	983	72000
UTac_8611_T2_10hr_1_91321_E1_SandA	1	955	70000
UTac_8611_T2_10hr_1_91321_E1_SandB	1	169	12600
UTac_8611_T2_10hr_1_91321_E1_Carbon	1	51	4040
UTac_8611_T2_10hr_4_03105_E2_SandA	1	688	50500
UTac_8611_T2_10hr_4_03105_E2_SandB	1	1070	78900
UTac_8611_T2_10hr_4_03105_E2_Carbon	1	778	57100
QC_1000	1	968	63500
QC_1000	1	1030	67600
QC_1000	1	997	65400
QC_1000	1	995	65300
QC_1000	1	997	65400
QC_1000	1	995	65300
98905 carbon bed A	1	329	30600
98905 Carbon bed B	1	0.0	0
98914 Carbon bed A	1	280	26000
98914 Carbon Bed B	1	0.2	18
98912 Carbon A	1	328	28600
98912 Carbon B	1	1.0	83
98956 Carbon Bed A	1	292	24400
98956 Carbon Bed B	1	0.0	2
98895 Carbon Bed A	1	381	31800
98895 Carbon Bed B	1	0.3	26
98776 Carbon Bed A	1	415	34600
98776 Carbon Bed B	1	0.2	13
98920 Carbon Bed A	1	302	25200
98920 Carbon Bed B	1	0.1	8
98938 Carbon Bed 1	1	296	23000
98938 Carbon Bed 2	1	0.2	57
98878 Carbon Bed 1	1	421	32700
98878 Carbon bed 2	1	0.6	89
98910 Carbon Bed 1	1	416	32300
98910 Carbon Bed 2	1	-0.3	18
98906 Carbon Bed 1	1	50	3970
98906 Carbon Bed 2	1	-0.1	34
98967 Carbon Bed 1	1	332	25800
98967 Carbon Bed 2	1	2.2	212

F.4.1 Sample Trap Preparation

The sample traps were prepared by ADA with the following parameters:

- Each sorbent was ground until 95% by weight passed through a 325 mesh (45µm) screen.
- The ground sorbents were mixed with sand with a ratio of 20 milligrams of sorbent to 50 grams of sand
- The sample traps each contained 4 grams of the sand/sorbent mixture in the test beds, meaning 1.6 milligrams of sorbent was present in the traps.

F.4.2 Sorbent Trap Method Raw Data

On 8/4/11 and 8/7/11, ADA performed a modified Method 30B test on Stack 2B. Three pairs of standard Ohio Lumex made STM traps were collected during 1-hour runs twice on Stack 2B and the results are presented in Table F-5. The total mass of mercury captured in each pair is used to calculate the mercury concentration of the process gas (column Hg-STM) and then averaged together. The relative difference (RD) between the paired traps is required to be less than 10%. One test failed this criteria do to an error during the lab analysis, but was not included in any data analysis.

Table F-5: STM Results

Date	Start Time	End Time	Stack	DGM [L (STP)]	M_{Sect1} [ng]	M_{Sect2} [ng]	%Break Through	Hg-STM $[ng/L]_{dry}$	$Hg\text{-}STM_{AVG}$ $[ng/L]_{dry}$	RD [%]	RD Pass/Fail	Comments
08/04/11	09:37	10:37	2B	45.380	329	0.0	0.0	7.25	6.89	5.24	PASS	
				42.925	280	0.2	0.1	6.53				
08/04/11	11:02	12:02	2B	45.099	328	1.0	0.3	7.30	7.13	2.35	PASS	
				41.950	292	0.0	0.0	6.96				
08/04/11	12:18	13:18	2B	44.520	302	0.1	0.0	6.79	6.98	2.78	PASS	
				41.290	296	0.2	0.1	7.17				
08/07/11	11:20	12:20	2B	44.879	415	0.2	0.0	9.25	9.12	1.48	PASS	
				42.453	381	0.3	0.1	8.98				
08/07/11	12:37	13:37	2B	45.152	421	0.6	0.1	9.34	9.56	2.28	PASS	
				42.536	416	-0.3	-0.1	9.77				
08/07/11	13:49	14:49	2B	45.293	50	-0.1	-0.2	1.10	4.46	75.32	FAIL	Error in Lab Anaysis
				42.711	332	2.2	0.7	7.82				