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January 25, 2012

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Dear Dr. Berndt:

Subject: Revised Final Report Entitled "Project 4: Evaluation for a Slipstream Baghouse for the Taconite Industry"; EERC Fund 15726

Please find enclosed the revised subject final report.

If you have any questions or require clarification of any point, please contact me by phone at (701) 777-5138 or by e-mail at dlaudal@undeerc.org.

Sincerely,

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Enclosures

c/enc: Ryan Siats, U.S. Steel

PROJECT 4: EVALUATION OF A SLIPSTREAM BAGHOUSE FOR THE TACONITE INDUSTRY

Revised Final Report

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PROJECT 4: EVALUATION OF A SLIPSTREAM BAGHOUSE FOR THE TACONITE INDUSTRY

ABSTRACT

Over the past 20 years, there has been a concerted effort by national and state agencies to reduce mercury emissions from all sources. In November of 2011, the U.S. Environmental Protection Agency (EPA) is required to issue an air toxic rule that will include mercury based on maximum achievable control technology (MACT) requirements for the coal-fired power industry. Although utilities are the largest source of anthropogenic mercury emissions, they are not the only source. In Minnesota, one of these sources is the taconite industry. As a result, the Energy & Environmental Research Center tested a mercury control technology utilizing a slipstream baghouse with activated carbon injection at the United States Steel Corporation, Minnesota Ore Operations – Keetac Plant. Results showed that by using as little as 2.2 lb/Macf of standard activated carbon or 1.1 lb/Macf of a treated carbon >75% mercury removal can be achieved.

ACKNOWLEDGMENTS

The authors of this report would like to thank Mike Berndt of the Minnesota Department of Natural Resources for all of his support and input. We would also like to thank Region 5 EPA for providing funding for the project. In addition, we thank Keith Hanson of Barr Engineering. Lastly, we gratefully acknowledge and thank Ryan Siats and Keetac for supporting this project and allowing the installation of the slipstream baghouse at their site.

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NOMENCLATURE

AC	activated carbon
ACI	activated carbon injection
BH	baghouse
C_a and C_b	mercury concentrations measured by the paired sorbent traps
C_m	meter constant
CMM	continuous mercury monitor
CVAA	cold vapor atomic adsorption
CVAF	cold-vapor atomic fluorescence
EERC	Energy & Environmental Research Center
EPA	U.S. Environmental Protection Agency
FOB	freight on board
ISP	inertial separation probe
Keetac	United States Steel Corporation, Minnesota Ore Operations – Keetac
Lt	long ton
Macf	million actual cubic feet
MACT	maximum achievable control technology
MNDNR	Minnesota Department of Natural Resources
NIST	National Institute of Standards and Technology
PAC	powdered activated carbon
PPS	polyphenylene sulfide
PRB	Powder River Basin
QA/QC	quality assurance/quality control
RSD	relative standard difference
scfm	standard cubic feet per min
TPE	total purchased equipment

PROJECT 4: EVALUATION OF A SLIPSTREAM BAGHOUSE FOR THE TACONITE INDUSTRY

EXECUTIVE SUMMARY

Introduction

Over the past 20 years, there has been a concerted effort by national and state agencies to reduce mercury emissions from all sources. In December of 2011, the U.S. Environmental Protection Agency (EPA) issued an air toxic rule for the coal-fired power industry. This rule will include mercury and is based on maximum achievable control technology requirements.

Although utilities are the largest source of anthropogenic mercury, they are not the only source. In Minnesota, one of these sources is the taconite industry. Taconite processing has two potential sources of mercury: mercury released from processing the ore and mercury released from the fuels used during processing. The greatest percentage of mercury emissions results from mercury inherent in the ore, which is related to the ore's geographical location in the Biwabik Iron Formation.

The taconite industry formed a working group to evaluate and help fund research to reduce mercury emissions. This group, the Minnesota Taconite Mercury Control Advisory Committee, along with the Minnesota Department of Natural Resources and EPA, funded five projects. One of those projects was an Energy & Environmental Research Center (EERC) project to evaluate the use of a slipstream baghouse (BH) with activated carbon injection (ACI) to reduce mercury emissions.

Although the technology would be expected to provide effective mercury control for any of the taconite plants (straight grate or grate kilns), in reality, the technology would only be economical for those plants where, in addition to mercury, particulate control is a potential concern. The plant chosen for this project was the United States Steel Corporation, Minnesota Ore Operations – Keetac (Keetac) Plant. The primary goal of the project was to provide a minimum of 75% reduction in mercury emissions, where mercury reduction is defined by:

$$(\text{BH Inlet Hg Conc.} - \text{BH Outlet Hg Conc.}) \div \text{BH Inlet Hg Conc.} \times 100\% \quad [\text{Eq. 1}]$$

The EERC slipstream baghouse is a trailer-mounted baghouse that was transported to the test site and connected in slipstream fashion to allow for testing “real” flue gases under actual operating conditions. Because the slipstream baghouse was located after a wet scrubber, the flue gas at the inlet was saturated at about 132°F. To avoid wetting the bags and fan, an additional drip leg and heating elements were installed to raise the inlet flue gas temperature to about 165°F. For a full-scale unit, it would be expected that a portion of the flow (prior to the wet scrubber) would be routed to the baghouse to maintain a temperature above the water dew point.

For the Keetac test, the baghouse was operated at a nominal air-to-cloth ratio of 6 ft/min (actual ft³/min of gas per ft² of cloth). The bags that were used for this test were Ryton® PPS

(polyphenylene sulfide). Because the gas flow rate was about 600 scfm (720 acfm at 190°F), a total of seven bags were needed to maintain an actual air-to-cloth ratio of 5.45. A picture of the portable baghouse is shown in Figure ES-1. Ports were installed so that the mercury concentrations at both the baghouse inlet and outlet could be measured using continuous mercury monitors (CMMs) and sorbent traps.

Approach

The original test plan is shown in Table ES-1. However, several problems were encountered during this testing that altered the overall test plan as originally proposed. It was planned that most, if not all, of the testing would occur when coal was fired, but the plant had difficulty operating its coal feed unit. As a result, more testing was conducted when natural gas was fired than was planned. In a taconite plant, the mercury emitted by the fuel is only a fraction of the total mercury, so the mercury control technology could still be evaluated. The second problem that occurred was a result of the shutdown of the Minnesota state government on July 1, 2011. Therefore, the project ended somewhat earlier than intended. Finally, the mercury removal was such that the tests using the higher add rates were not necessary. The actual tests that were completed are shown in Table ES-2.



Figure ES-1. Baghouse, trailer, and control room.

Table ES-1. Project Test Plan

Test	Carbon	Carbon Feed Rate, lb/Macf	Test Duration, days
1	Standard ACI	4	2
2	Standard ACI	2	2
3	Standard ACI	1	2
4	Treated ACI	4	2
5	Treated ACI	2	2
6	Treated ACI	1	2
7	Contingency tests		3

Table ES-2. Actual Tests Conducted at Keetac

Test	Date/Time Start	Date/Time End	Fuel	Sorbent	Add Rate, g/hr	Add ¹ Rate, lb/Macf	Run Time, hrs
1	6/17/11 17:30	6/19/11 12:05	Natural gas	Baseline	0	0	42.5
2	6/19/11 12:41	6/23/11 08:57	Natural gas	Standard	21.27	1.1	92.3
3	6/23/11 08:57	6/24/11 12:36	Natural gas	Standard	39.40	2	27.6
4	6/24/11 12:36	6/24/11 16:10	Natural gas	Standard	42.50	2.2	3.6
5	6/24/11 16:10	6/26/11 08:28	Natural gas	Baseline	0	0	40.7
6	6/26/11 09:05	6/27/11 10:59	Natural gas	Bromine-treated	12.11	0.6	25.9
7	6/27/11 10:59	6/27/11 18:31	PRB ²	Bromine-treated	12.11	0.6	7.5
8	6/27/11 18:31	6/28/11 16:00	Natural gas	Bromine-treated	12.11	0.6	21.3 ³
9	6/28/11 08:26	6/28/11 08:39	PRB	Bromine-treated	12.11	0.6	0.2
10	6/28/11 16:00	6/29/11 10:07	Natural gas	Bromine-treated	21.36	1.1	18.1
11	6/29/11 14:37	6/29/11 23:33	PRB	Bromine-treated	21.36	1.1	9.1
12	6/29/11 23:33	6/30/11 06:28	Natural gas	Bromine-treated	21.36	1.1	6.5
13	6/30/11 06:28	7/1/11 07:57	PRB	Bromine-treated	21.36	1.1	25.4

¹Based on an actual gas flow rate of 720 acf.

²Powder River Basin coal

³Does not include the short time the coal was on (Test 9).

Results and Discussion

The slipstream baghouse operated very well, and particulate emissions were very low during the entire test period. There were no unplanned down periods. However, additional external heaters and insulation were needed to prevent wetting of the bags. In a full-scale installation of a baghouse to control mercury, a wet scrubber bypass of about 18%–20% of the flow would be needed to prevent condensation.

The primary goal of this project was to provide a minimum of 75% reduction in mercury emissions utilizing a slipstream baghouse with two different types of activated carbon. The first was a standard activated carbon and the second a bromine-treated activated carbon (DARCO Hg-LH). The mercury reductions achieved were determined by measuring the mercury at the inlet and the outlet of the slipstream baghouse utilizing CMMs and sorbent traps. The mercury

removals achieved are shown in Table ES-3, where it can be seen that the goal of 75% removal can be achieved consistently using 2.0 lb/Macf of standard activated carbon or 1.1 lb/Macf of treated activated carbon.

A preliminary cost estimate was also made. The results showed that the capital costs for purchasing and installing a pulse-jet baghouse and activated carbon systems at Keetac would be between \$10 million and \$12 million for the baghouse and \$1.5 million – \$2 million for an ACI system. The yearly operating cost for the baghouse would be about \$2.0 million. The operating cost for the ACI system is greatly impacted by the cost of the sorbent and selected injection rates. Based on the results above and current costs, the annual operating cost would be about \$725,000/yr using the treated carbon at an injection rate of 1.1 lb/Macf or about \$870,000/yr with standard activated carbon (2 lb/Macf).

Conclusions and Recommendations

Based on the results of the testing, the following conclusions can be made:

- 75% mercury removal can be achieved at the Keetac Plant with either standard or bromine-treated activated carbon at feed rates of 2 lb/Macf and 1.1 lb/Macf, respectively.
- Very low particulate emissions are achieved.
- Because of the relatively high cost of installing a fabric filter, the most economic installation would be for those taconite facilities that require fuel flexibility and/or have concerns about particulate emissions.
- If a baghouse is to be installed at the Keetac taconite plant, about 18%–20% of the flue gas would need to bypass the wet particulate scrubber to prevent wetting of the bags.

Table ES-3. Mercury Removal Using a Slipstream BH at Keetac

Type of Activated Carbon	Fuel	Feed Rate, lb/Macf	Inlet Hg Conc., $\mu\text{g}/\text{Nm}^3$	Outlet Hg Conc., $\mu\text{g}/\text{Nm}^3$	Mercury Removal, %	Std. Dev., %
Standard	Natural gas	1.1	6.00	1.42	76.3	6.3
Standard	Natural gas	2.0	5.99	0.93	84.5	7.7
Standard	Natural gas	2.2	5.18	0.47	91.0	1.6
Treated	Natural gas*	0.60	5.18	0.89	82.9	4.9
Treated	PRB coal	0.60	5.25	0.60	88.6	2.3
Treated	Natural gas	1.1	4.55	0.55	88.1	4.8
Treated	PRB coal	1.1	4.38	0.19	95.6	2.0

* Only the last 28 hours of the test was considered.

If this is to be a viable technology, the following recommendations are made for future testing:

- Longer-term testing is needed to determine the resultant steady-state pressure drop across the baghouse as a function of air-to-cloth ratio.
- Longer-term tests are also needed to ensure that required mercury control will be maintained over time.
- The economic evaluation presented in this report is based on a model developed for utilities and may or may not be totally valid for a taconite plant. Therefore, more specific economic data are needed.

PROJECT 4: EVALUATION OF A SLIPSTREAM BAGHOUSE FOR THE TACONITE INDUSTRY

1.0 INTRODUCTION AND BACKGROUND

Mercury is a naturally occurring element that is ubiquitous in the Earth's crust. Both anthropogenic activities such as combustion and mining processes and natural sources such as volcanoes release mercury into the atmosphere. Through transport and deposition, some mercury enters the aquatic systems, resulting in an increase in mercury loading in fish. Over the past 20 years, there has been a concerted effort by national and state agencies to reduce anthropogenic mercury emissions from all sources. For example, in December of 2011, the U.S. Environmental Protection Agency (EPA) issued an air toxic rule for the coal-fired power industry that will include mercury. This rule was based on maximum achievable control technology (MACT) requirements.

Although utilities are the largest source of anthropogenic mercury, they are not the only source. In Minnesota, one of these sources is the taconite industry. It has been estimated that these plants emit 250–350 kg of mercury a year into the atmosphere (1). Taconite processing has two potential sources of mercury: mercury released from processing the ore and mercury released from the fuels used when the ore is processed. Unlike coal-fired utilities, the major source of mercury is not the combustion fuel but the processing of the ore into taconite pellets. Even for those facilities that fire coal, it only takes 20–30 lb of coal to process 1 long ton (Lt) of green balls. The concentration of mercury in the unprocessed ore is related to the ore's geographical location in the Biwabik Iron Formation.

Because of EPA's intent to issue a small boiler MACT and continued pressure on the Minnesota Pollution Control Agency to regulate mercury emissions from taconite plants. The taconite industry formed a working group to evaluate and help fund research to reduce mercury emissions. This group, the Minnesota Taconite Mercury Control Advisory Committee, along with the Minnesota Department of Natural Resources (MNDNR) and EPA, funded five projects. One of those was an Energy & Environmental Research Center (EERC) project to evaluate the potential of using a slipstream baghouse (BH) with activated carbon injection (ACI) to reduce mercury emissions.

Although the technology would be expected to provide effective mercury control for any of the taconite plants (straight grate or grate kilns), in reality, the technology would only be economical for those plants where, in addition to mercury, particulate control is a potential concern. All Minnesota taconite plants have rod-type venturi scrubbers for particulate control. For plants with a straight grate configuration, the only fuel that can be utilized is natural gas, and therefore, these scrubbers provide enough control so that particulate emissions are not usually a concern. However, for plants using grate kilns and burn coal, there is the potential for increased particulate emissions. Because the United States Steel Corporation, Minnesota Ore Operations – Keetac (Keetac) Plant has a grate kiln and burns coal, it volunteered to host the EERC project. The Keetac Plant has the following configuration:

- Line type: grate kiln
- Number of lines: one
- Production: 700 Lt/hr
- Pellets: acid
- Fuel: natural gas and Powder River Basin (PRB) coal
- Gas flow rate: 550–650 kscfm
- Particulate control: rod-type venturi scrubber (may also add lime to control SO₂ emissions)

This report provides the results of the EERC project.

2.0 PROJECT OBJECTIVES

The primary goal of this project was to provide a minimum of 75% reduction in mercury emissions, where mercury reduction is defined by:

$$(\text{BH Inlet Hg Conc.} - \text{BH Outlet Hg Conc.}) \div \text{BH Inlet Hg Conc.} \times 100\% \quad [\text{Eq. 1}]$$

Specific objectives of the project are as follows:

- Determine the effectiveness of a slipstream baghouse to reduce mercury utilizing both a standard activated carbon (DARCO[®] Hg) and a bromine-treated activated carbon (DARCO[®] Hg-LH).
- Determine the required feed rate for the two types of carbon to meet the goal of 75% mercury removal.
- Determine the mercury speciation (elemental and oxidized mercury) at both the inlet and outlet of the baghouse.
- Determine the particulate removal across the slipstream baghouse.

3.0 EXPERIMENTAL APPROACH

As stated previously, the overall approach was to install a slipstream baghouse at the outlet of the wet scrubber at the Keetac taconite plant. Activated carbon would then be fed into the inlet piping of the slipstream baghouse. Mercury would be continuously measured at the inlet and outlet of the baghouse, thereby determining the mercury removal. Because this is a true

slipstream of the plant gas flow, the mercury removal obtained during the testing should be directly comparable to that obtained if the plant installed a full-scale baghouse.

3.1 Description of Equipment

All of the equipment used for testing at Keetac was owned by the EERC. However, help was provided by the plant and its contractors to install the slipstream baghouse at Keetac.

3.1.1 EERC Portable Slipstream Baghouse

The EERC slipstream baghouse is a trailer-mounted baghouse that was transported to the test site and connected in slipstream fashion to the existing duct at the outlet of the wet scrubber to allow for testing “real” flue gases under actual operating conditions. The slipstream baghouse chamber was designed to accommodate up to twelve 6-inch bags, with lengths of 12 feet. This equates to 226 ft² of filtration area. To connect the slipstream baghouse to the plant ducting, two separate 10-inch flanges were installed, one at the immediate exit of the wet scrubber and the other directly into the stack.

A variable-speed blower capable of drawing between 450 and 2700 acfm of flue gas (~300°F) through the baghouse was provided as part of the mobile unit. In this way, the filter face velocity could be varied between 2 and 12 ft/min. An 8-inch baghouse bypass line and an orifice meter were utilized to control and to maintain isokinetic flow at the inlet nozzle for all test conditions. In addition, pipe velocities were maintained near 75 ft/sec, preventing dropout of fly ash particles. The baghouse chamber and inlet piping runs were insulated and heat-traced.

Because the slipstream baghouse was located after a wet scrubber, the flue gas at the inlet was saturated at about 132°F. To avoid condensation and the resulting wetting of the bags and fan, an additional drip leg and heating elements were installed. This allowed the inlet flue gas temperature to be maintained at approximately 165°F. The baghouse chambers were heated to maintain a temperature of about 215°F at the baghouse outlet. For a full-scale unit, it would be expected that a portion of the flow (prior to the scrubber) would be routed to the baghouse to maintain a temperature above the water dew point.

Most of the parameters of the slipstream baghouse were controlled using an automated data acquisition system; however, the temperature of the inlet ducting and baghouse were maintained through manual inputs. The unit was designed so that the temperature of the bottom, middle, and top of the baghouse could be independently set. Cleaning of the bags was achieved by the use of medium-pressure pulse-jets that could be computer-controlled or operated manually. All baghouse operational parameters were recorded by the computer and later downloaded to a flash drive. Emptying of the baghouse hopper was achieved through a manual gate valve. Hopper ash was collected in barrels placed under the hopper. For this project, the baghouse hoppers were emptied at the end of each test. Ports were installed at both the inlet and outlet of the baghouse, so mercury measurements could be taken using continuous mercury monitors (CMMs) and carbon traps. A picture of the portable baghouse is shown in Figure 1.



Figure 1. Photograph of the EERC baghouse, trailer, and control room.

For the Keetac project, the baghouse was operated at a nominal air-to-cloth ratio of 6 ft/min (ft³/min of gas at actual temperatures and pressures per ft² of cloth). The bags that were used for this test were Ryton[®] PPS (polyphenylene sulfide). These are relatively standard bags used in pulse-jet baghouse installations because of their chemical resistance. The gas flow rate averaged 584 scfm. The actual gas flow was based on the average temperature at the inlet to the baghouse (165°F) and at the outlet (215°F), or 190°F, resulting in an actual gas flow rate of 719 acfm. This would require between six and seven bags to provide an air-to-cloth ratio of 6 ft/min. For these tests, the more conservative approach was taken, and seven bags were installed, resulting in an actual air-to-cloth ratio of 5.45 ft/min. The bag layout is shown in Figure 2. Cleaning of the bags was computer-controlled and based on a set differential pressure. The calculations for air-to-cloth ratio are shown in Appendix A.

3.1.2 Activated Carbon Injection System

Activated carbon was injected into the slipstream baghouse using a K-Tron feed system. The K-Tron is a dual-screw feeder that has been used in a number of projects to continuously inject sorbents into flue gas entering the slipstream baghouse. From the feeder, the sorbent was introduced into baghouse inlet piping via an Air-Vac eductor driven by compressed air. The feeder was filled with activated carbon as needed; however, none of the tests required the feeder to be filled more than once a day. The feed rate was set using a controller and was also bucket-calibrated.

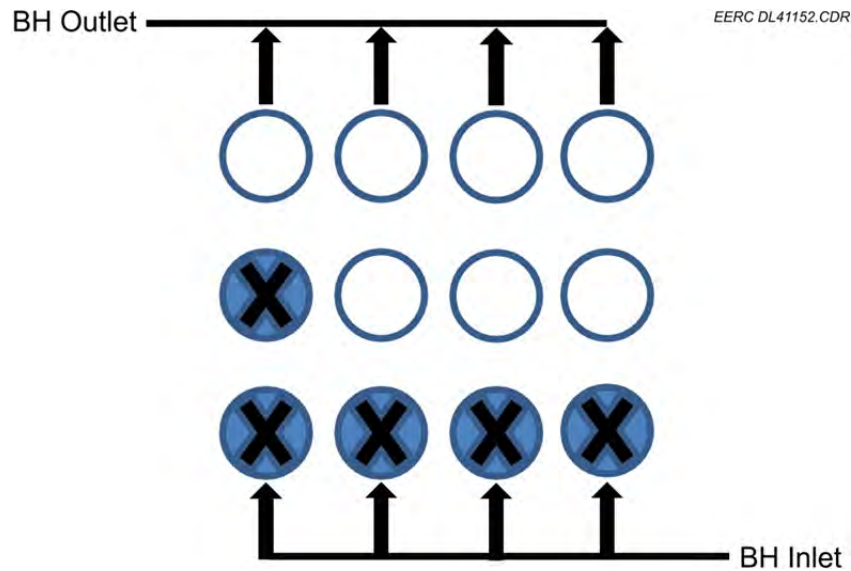


Figure 2. Bag layout of the EERC slipstream baghouse resulting in an air-to-cloth ratio of 5.45 ft/min (open circles are the bags).

3.1.3 Mercury Measurement Equipment

The CMMs used for these tests were Tekran instruments. A Tekran analyzes mercury using cold-vapor atomic fluorescence (CVAF) techniques and has gold traps that are used to capture and concentrate the mercury. The system consists of three parts. The first is the inertial separation probe (ISP), which is designed to remove particles with minimal contact with the flue gas. The second section is the pretreatment and conversion system. These instruments only measure elemental mercury, and the gold trap can be poisoned by some of the gases that are typically found in both utility and industrial processes. These include HCl, NO₂, and SO₂. Therefore, the pretreatment and conversion system must take out or greatly reduce these gases as well as convert all the mercury to elemental mercury. The Tekran uses dilution and thermal conversion to accomplish these tasks. The final section of the instrument is the CVAF mercury analyzer.

Mercury was also measured utilizing sorbent traps by pulling flue gas through the trap using a pump and then measuring the gas flow with a dry gas meter. The sorbent traps were then analyzed for mercury using an OhioLumex analyzer, which is a cold-vapor atomic adsorption analyzer that uses a thermal attachment to release the mercury captured on the sorbent trap. The mercury is then carried by a gas stream into the analyzer. All of the equipment for conducting sorbent trap mercury measurements was used in compliance with the protocols outlined in EPA Method 30B.

3.2 Project Test Plan

Once the slipstream baghouse and CMMs were installed and the temperatures set so that wetting of the bags/fan did not occur, actual testing began (June 17, 2011). The original test plan

is shown in Table 1. However, several problems were encountered that altered the overall test plan as originally proposed. It was planned that most, if not all, of the testing would occur when coal was fired, but the plant had difficulty operating its coal feed unit. As a result, more testing was conducted when natural gas was fired than was planned. In a taconite plant, the mercury emitted by the fuel is only a fraction of the total mercury, so the mercury control technology could still be evaluated. The second problem that occurred was a shutdown of the Minnesota state government on July 1, 2011. As a result, the project ended earlier than intended. Finally, the mercury removal was such that the tests using the higher rates of sorbents, 4 lb/Macf for the standard activated carbon and 2 and 4 lb/Macf for the bromine-treated activated carbon, were not necessary. As will be discussed later, much higher mercury removals than 75% were achieved at these lower ACI rates. The actual tests that were completed are shown in Table 2. Test 4 was intended to be overnight to reestablish the baseline conditions prior to beginning the tests using the treated activated carbon. However, as will be discussed in Section 4, this took substantially longer than was planned.

4.0 RESULTS AND DISCUSSION

4.1 Operation of the Slipstream Baghouse

The slipstream baghouse operated very well during the entire test period. There were no unplanned down periods. As discussed earlier, a major concern was the potential for wetting of the bags as a result of the saturated gas exiting the wet scrubber. However, by adding additional external heaters and extra insulation to prevent cold spots, the inlet temperature of the flue gas was increased such that no wetting took place. Figure 3 shows the baghouse inlet and outlet temperatures were relatively constant over the entire project.

In a full-scale installation of a baghouse to control mercury emissions, external heaters would not be possible. Therefore, a wet scrubber bypass would be required to provide additional heat to prevent water condensation on the bags. If the following assumptions are made:

- Total flue gas flow rate is 600,000 scfm.
- The temperature of the gas entering the wet scrubber is 300°F.

Table 1. Project Test Plan

Test	Carbon	Carbon Feed Rate, lb/Macf	Test Duration, days
1	Standard ACI	4	2
2	Standard ACI	2	2
3	Standard ACI	1	2
4	Treated ACI	4	2
5	Treated ACI	2	2
6	Treated ACI	1	2
7	Contingency tests		3

Table 2. Actual Tests Conducted at Keetac

Test	Date/Time Start	Date/Time End	Fuel	Sorbent	Add Rate, g/hr	Add ¹ Rate, lb/Macf	Run Time, hr
1	6/17/11 17:30	6/19/11 12:05	Natural gas	Baseline	0	0	42.5
2	6/19/11 12:41	6/23/11 08:57	Natural gas	Standard	21.27	1.1	92.3
3	6/23/11 08:57	6/24/11 12:36	Natural gas	Standard	39.40	2	27.6
4	6/24/11 12:36	6/24/11 16:10	Natural gas	Standard	42.50	2.2	3.6
5	6/24/11 16:10	6/26/11 08:28	Natural gas	Baseline	0	0	40.7
6	6/26/11 09:05	6/27/11 10:59	Natural gas	Bromine-treated	12.11	0.6	25.9
7	6/27/11 10:59	6/27/11 18:31	PRB ²	Bromine-treated	12.11	0.6	7.5
8	6/27/11 18:31	6/28/11 16:00	Natural gas	Bromine-treated	12.11	0.6	21.3 ³
9	6/28/11 08:26	6/28/11 08:39	PRB	Bromine-treated	12.11	0.6	0.2
10	6/28/11 16:00	6/29/11 10:07	Natural gas	Bromine-treated	21.36	1.1	18.1
11	6/29/11 14:37	6/29/11 23:33	PRB	Bromine-treated	21.36	1.1	9.1
12	6/29/11 23:33	6/30/11 06:28	Natural gas	Bromine-treated	21.36	1.1	6.5
13	6/30/11 06:28	7/1/11 07:57	PRB	Bromine-treated	21.36	1.1	25.4

¹Based on an actual gas flow rate of 720 acf.

²Powder River Basin coal.

³Does not include the short time the coal was on (Test 9).

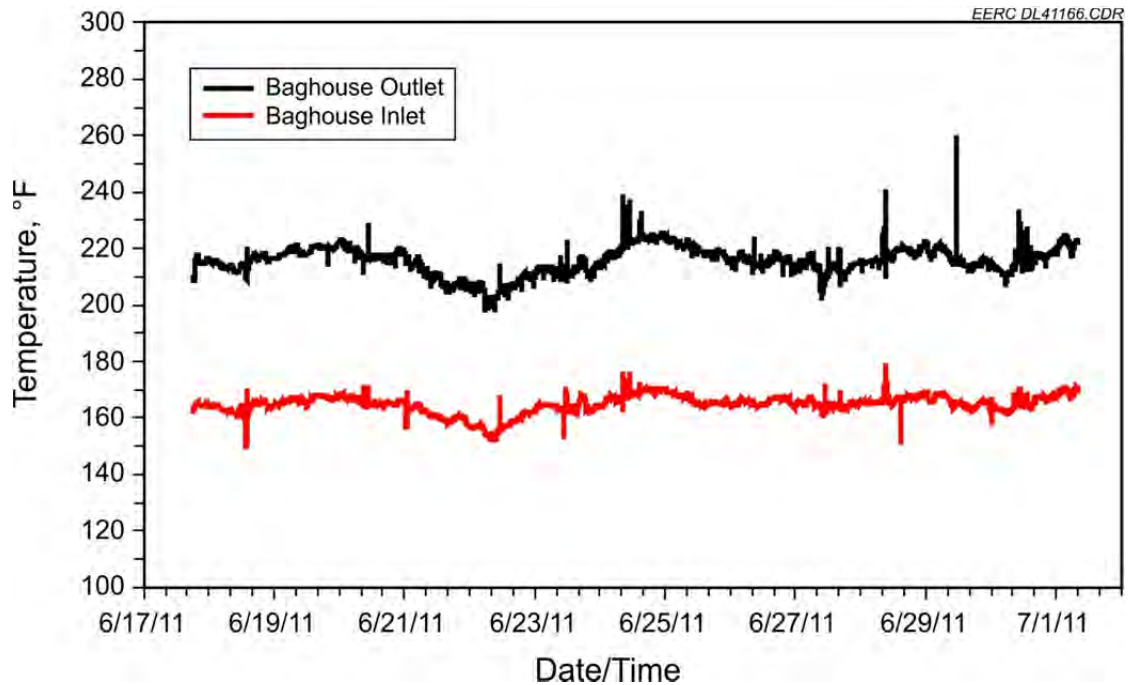


Figure 3. Slipstream baghouse operating temperatures.

- The temperature of the gas exiting the wet scrubber is saturated at 135°F.
- All water droplets are small, with little impact on the thermodynamics.
- The temperature of the gas entering the baghouse must be $\geq 155^{\circ}\text{F}$ to ensure no wetting of the bags.

The amount of reheat that would be needed would require that 18.2% of the flow bypass the wet scrubber (calculations are shown in Appendix A). If relatively large water droplets exist, the percentage of bypass needed may be greater. Therefore, to minimize the amount of flue gas bypass, it will be important to minimize and reduce the size of any water droplets exiting the wet scrubber. This may necessitate using enhanced mist eliminators and/or adding a drip leg at the outlet of the scrubber.

Another important operational variable for any baghouse is the pressure drop across the bags. This impacts the needed fan capacity, the footprint (air-to-cloth ratio) of the baghouse, the particulate collection efficiency, bag life, and overall economics. This project was not designed to determine the final pressure drop that would be experienced under “normal” operation, as the tests were too short to reach any steady-state condition. Often this can take several months before a reasonable steady state is reached. These tests were designed simply to facilitate the mercury measurement, and therefore, the pulsing of the bags was done on a regular basis and at a reasonably low pressure drop set point. Between each test, the baghouse was pulsed off-line to facilitate cleaning. Figure 4 shows the baghouse pressure drop and gas flow rate over the length of the project. When Keetac was firing natural gas, the bags were pulsed when the pressure drop reached 3 in. W.C. However, a higher set point was used, first 4 and then 6 in. W.C. when a PRB coal was the fuel. It is clear that longer-term testing is needed to determine the ultimate pressure drop that will be experienced. This will obviously determine what air-to-cloth ratio is needed to maintain a reasonable pressure drop.

4.2 Particulate Control

Because the baghouse was installed following a particulate scrubber, it was expected that the inlet dust loading was going to be very low, and this was the case. Also, as expected, the baghouse inlet dust loading was higher when coal was fired. In either case, the dust loading at the outlet of the baghouse was exceedingly low and, therefore, would allow for flexibility in the use of fuel as well as flexibility in overall plant operations without greatly impacting particulate emissions. The results of EPA Method 5 particulate sampling is shown in Table 3. The calculations are shown in Appendix A, and the dust-loading data sheets are provided in Appendix B. As Table 3 shows, the actual particulate removal was somewhat higher when coal was fired. This may be the result of a dust cake forming on the bags. Because the baghouse inlet dust loadings are so low, especially for tests firing natural gas, the particulate removal efficiency is somewhat misleading. Very small changes in the outlet particulate concentration have a major effect on the particulate removal efficiency.

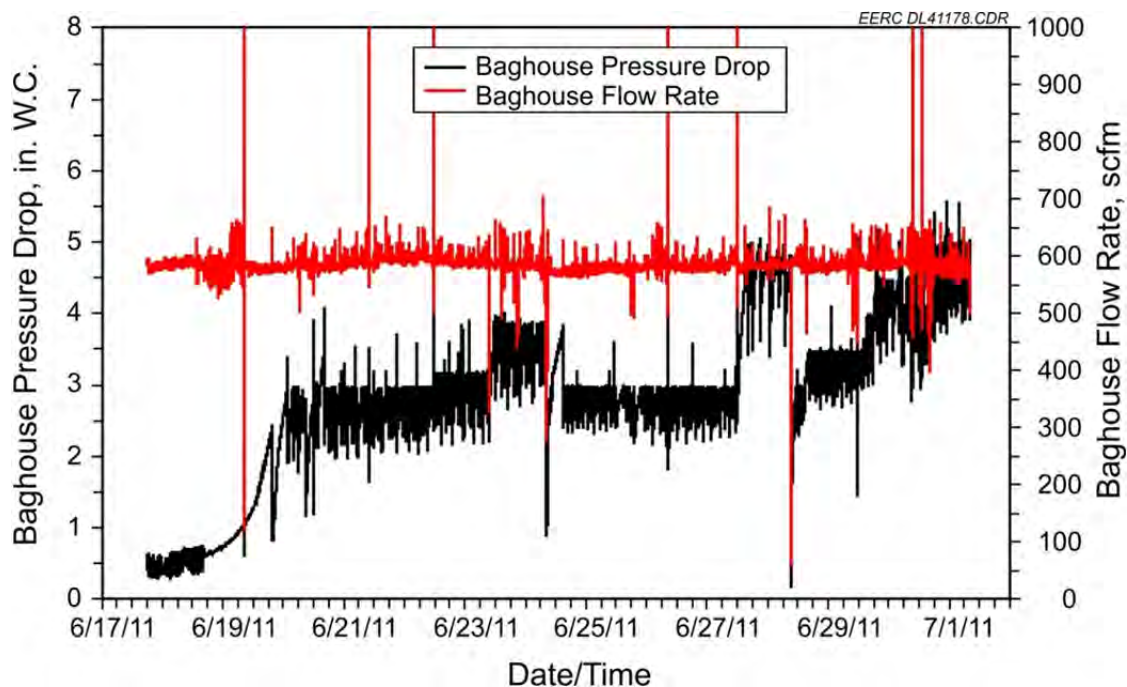


Figure 4. Slipstream baghouse pressure drop and gas flow rate.

Table 3. Particulate Sampling Across the Slipstream BH at Keetac

Date	Fuel	Time	Sample Pt.	Sample		H ₂ O, %	Isokinetic, %	Dust Loading, grains/scf	Removal, %
				Time, min					
06/16/11	Natural gas	14:10	BH in	40		15.6	105.6	0.0026	–
06/18/11	Natural gas	14:51	BH in	120		16.3	104.1	0.0027	
06/18/11	Natural gas	14:47	BH out	120		16.2	104.2	0.0006	80.8
06/20/11	Natural gas	13:50	BH in	120		16.1	99.3	0.0022	
06/20/11	Natural gas	13:41	BH out	120		16.0	100.5	0.0009	59.1
06/30/11	PRB coal	09:43	BH in	180		16.0	98.3	0.0040	
06/30/11	PRB coal	09:35	BH out	180		16.1	103.3	0.0004	90.0
06/30/11	PRB coal	16:17	BH in	180		17.2	101.1	0.0045	
06/30/11	PRB coal	16:08	BH out	180		17.2	103.9	0.0003	93.3

4.3 Mercury Control

The primary goal of this project was to provide a minimum of 75% reduction in mercury emissions utilizing a slipstream baghouse with both a standard and bromine-treated activated carbon. The mercury reductions achieved (see Equation 1 in Section 2.0) were evaluated by measuring the mercury at the inlet and the outlet of the slipstream baghouse utilizing CMMs and sorbent traps. The CMMs also provided the mercury speciation at each location. An example of the mercury calculations is provided in Appendix A.

4.3.1 Baseline Results

The baseline results are shown in Figure 5, which shows there was no mercury removal across the baghouse without activated carbon addition. In fact, the outlet mercury concentration was somewhat higher than at the inlet. Although new bags were used for this project, most likely there was some carbon attached to the walls of the baghouse from previous tests which resulted in a small amount of offgassing of mercury. Initially the inlet and outlet mercury concentrations were about the same, but then for a period of time, the outlet concentration was greater than the inlet. Near the end of the baseline test, the two concentrations again appeared to be about the same. This again supports the occurrence of mercury offgassing. The phenomenon of mercury offgassing was more prominent, as shown in Figure 6, when later in the project the carbon feed system was turned off prior to changing the type of carbon. The goal was to return to the baseline condition. Offgassing of mercury occurs when activated carbon becomes mercury-saturated and then other components in the flue gas, such as HCl, SO₂ and NO₂, replace the already-collected mercury (2). The sorbent trap samples that were taken during the initial baseline test support the CMM data indicating a higher mercury concentration at the outlet than at the inlet.

As would be expected following a wet scrubber, the mercury at the baghouse inlet was >80% elemental mercury. Under baseline conditions, at the outlet of the baghouse, the mercury speciation did not change.

The CMM mercury measurement results using the standard activated carbon are shown in Figure 7. Two ACI rates, 1.1 and 2.0 lb/Macf, were tested. Unfortunately, because the coal feeder was not operating properly at the plant and because of the state shutdown, we were unable

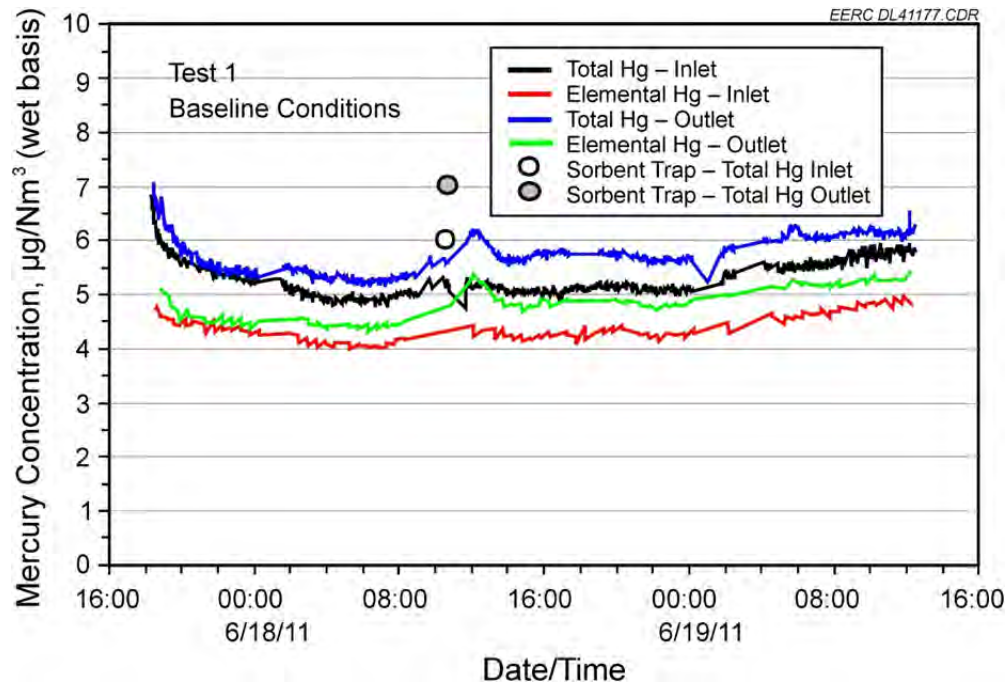


Figure 5. Initial baseline mercury results.

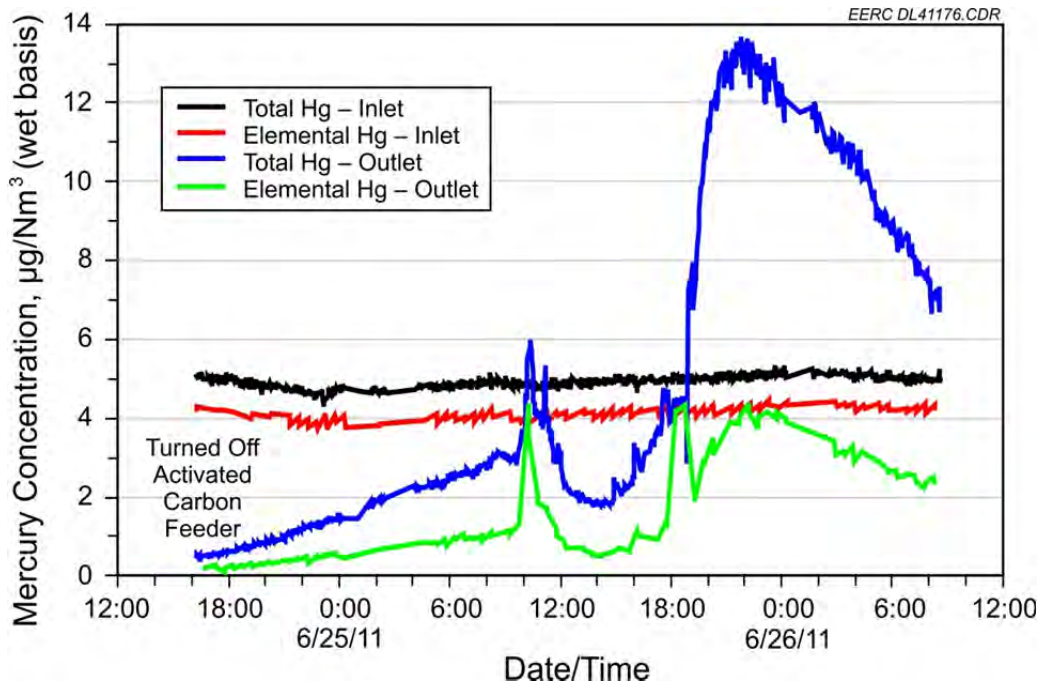


Figure 6. Results showing mercury reemission after shutting off the ACI.

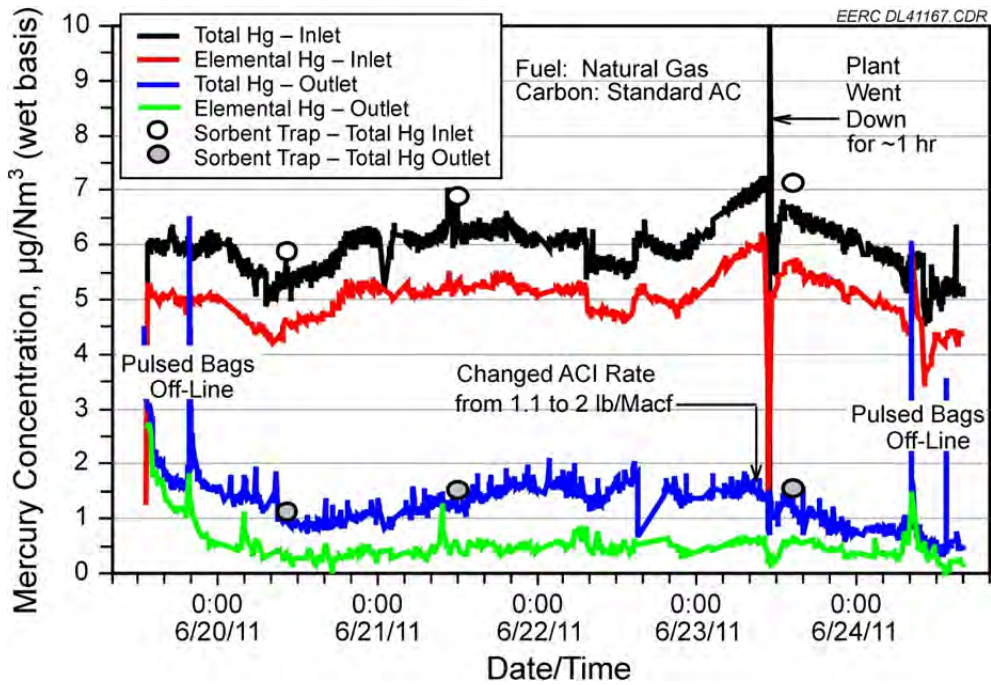


Figure 7. Mercury results utilizing standard activated carbon.

to test the standard activated carbon when coal was fired. Therefore, all of the tests were done firing natural gas.

4.3.2 Mercury Removal Using Standard Activated Carbon (DARCO Hg)

The CMM mercury measurement results using the standard activated carbon are shown in Figure 7. Two ACI rates, 1.1 and 2.0 lb/Macf, were tested. Unfortunately, because the coal feeder was not operating properly at the plant and because of the state shutdown, we were unable to test the standard activated carbon when coal was fired. Therefore, all of the tests were done with natural gas.

At an ACI rate of 1.1 lb/Macf, the mercury removal averaged 76.1% with a standard deviation of 6.3%. Therefore, the results were somewhat borderline as to whether the goal of 75% mercury removal was met. At an ACI rate of 2.0 lb/Macf, the mercury removal averaged 84.5% with a standard deviation of 8.5%. At this feed rate when natural gas was fired, the mercury removal goal was met. When the ACI rate was increased to 2.2 lb/Macf, mercury removal averaged 91.0%. A summary of the results is shown in Table 4.

Based on the mercury speciation measured by the CMM at the outlet of the baghouse, it appears that the activated carbon not only captured mercury but converted a percentage of the mercury not captured to oxidized mercury. At the outlet of the baghouse, the mercury being emitted was only about 35% elemental mercury. It is interesting to note that when the ACI rate was increased from 1.1 to 2.0 lb/Macf, the concentration of elemental mercury remained approximately the same. Therefore, the decrease in total mercury emissions is due to additional removal of the oxidized mercury.

4.3.3 Mercury Removal Using Bromine-Treated Activated Carbon (DARCO LH-Hg)

The CMM mercury measurement results using the bromine-treated activated carbon are shown in Figures 8 and 9. Figures 8 and 9 show the results when the ACI rate was 0.6 lb/Macf and 1.1 lb/Macf, respectively. During the time these tests were being conducted, both natural gas and PRB coal were fired. The results for these tests are summarized in Table 5.

As shown in Figure 8, once the bromine-treated ACI was started and natural gas was fired, there was a slow decrease in the mercury removal. This slow decrease may be related to the previous test when no activated carbon was injected and there was substantial offgassing of mercury (Figure 6). Because of this slow decrease in mercury, the mercury removal averaged only 74.2% with a very high standard deviation of 16.8%. It took almost 12 hours before the

Table 4. Mercury Removal Using a Slipstream BH and Standard Activated Carbon

Fuel	Feed Rate, lb/Macf	Inlet Hg Conc., $\mu\text{g}/\text{Nm}^3$	Outlet Hg Conc., $\mu\text{g}/\text{Nm}^3$	Mercury Removal, %	Std. Dev., %
Natural Gas	1.1	6.00	1.42	76.3	6.3
Natural Gas	2	5.99	0.93	84.5	7.7
Natural Gas	2.2	5.18	0.47	91.0	1.6

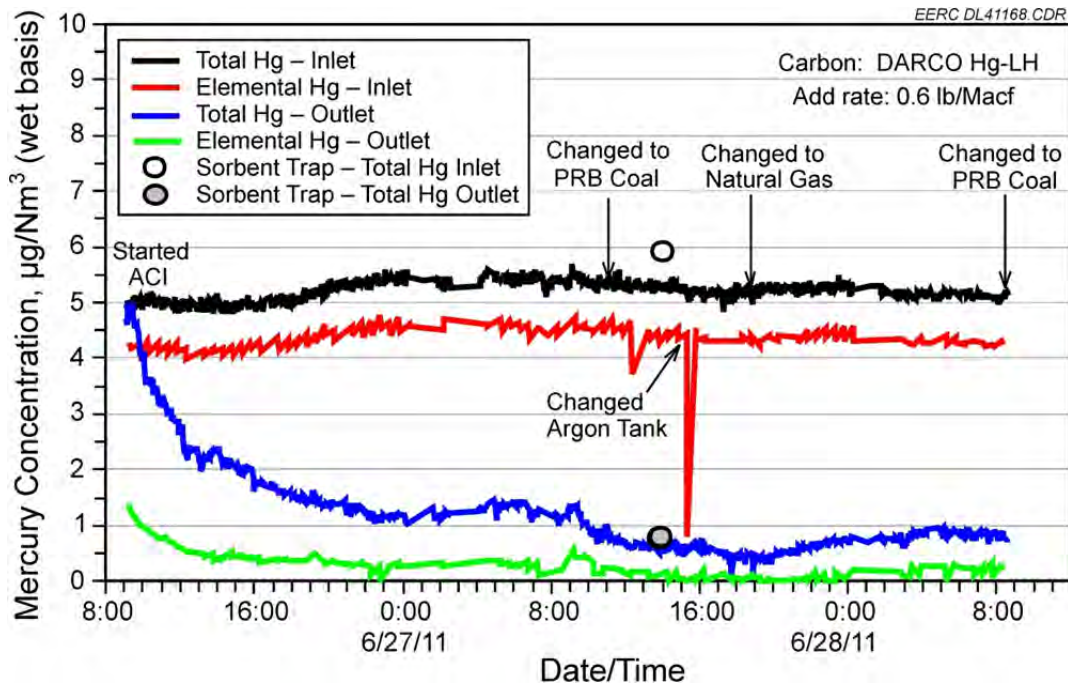


Figure 8. Mercury results utilizing bromine-treated activated carbon at a feed rate of 0.6 lb/Macf.

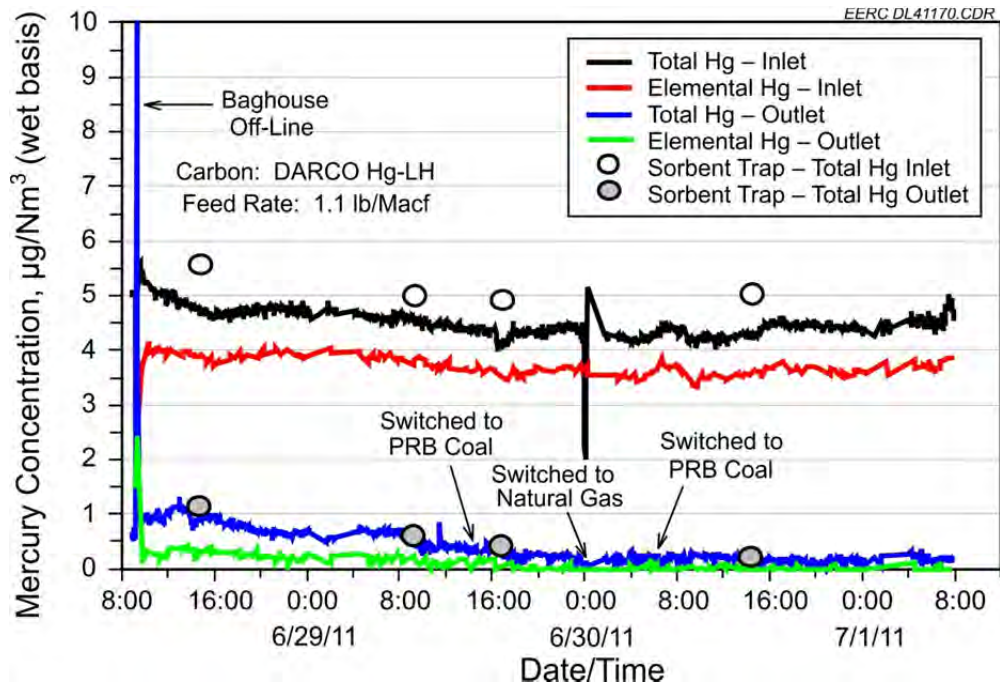


Figure 9. Mercury results utilizing bromine-treated activated carbon at a feed rate of 1.1 lb/Macf.

Table 5. Mercury Removal Using a Slipstream Baghouse and Bromine-Treated Activated Carbon

Fuel	Feed Rate, lb/Macf	Inlet Hg Conc., $\mu\text{g}/\text{Nm}^3$	Outlet Hg Conc., $\mu\text{g}/\text{Nm}^3$	Mercury Removal, %	Std. Dev., %
Natural Gas*	0.60	5.25	0.89	82.9	4.9
PRB Coal	0.60	5.25	0.60	88.6	2.3
Natural Gas	1.1	4.55	0.55	88.1	4.8
PRB Coal	1.1	4.38	0.19	95.6	2.0

* Only the last 28 hours of the test was considered.

mercury removal was >75%. For the remaining 28 hours of testing, the mercury removal was 82.9% with a standard deviation of only 4.9%. During this period, the goal of 75% mercury removal was met at a bromine-treated ACI rate of only 0.6 lb/Macf.

The mercury removal was higher when the PRB coal was fired compared to natural gas. Even at 0.6 lb/Macf of bromine-treated carbon, the mercury removal averaged 88.6% with a standard deviation of only 2.3%. Figure 9 shows the mercury results when the bromine-treated ACI rate was increased to 1.1 lb/Macf. With coal, a very high mercury removal of >95% was achieved. For the entire testing with bromine-treated activated carbon, the concentration of elemental mercury at the baghouse was very low at <0.5 $\mu\text{g}/\text{Nm}^3$.

4.3.4 Comparison of the Mercury Removal Between the CMMs and Sorbent Traps

The results of the sorbent trap sampling, along with the CMM results, were provided in Figures 5–9. Table 6 shows a comparison of the mercury removal measured by the two different mercury measurement methods. As shown, there was very good agreement between the two, but the measured removal was somewhat greater when using the CMMs. This may be a result of how each of the methods measures mercury, as will be discussed in Section 6.0.

Table 6. Comparison of Sorbent Trap and CMM Results

Fuel	Type Activated Carbon	Injection Rate, lb/Macf	Sorbent Trap Averages			CMM Averages		
			BH Inlet Hg Conc., $\mu\text{g}/\text{Nm}^3$	BH Outlet Hg Conc., $\mu\text{g}/\text{Nm}^3$	Hg Removal, %	BH Inlet Hg Conc., $\mu\text{g}/\text{Nm}^3$	BH Outlet Hg Conc., $\mu\text{g}/\text{Nm}^3$	Hg Removal, %
Natural Gas	None	Baseline	6.042	7.038	-16.5	5.18	5.669	-10.5
Natural Gas	Standard	1.1	5.900	1.140	80.7	5.34	0.908	83.0
Natural Gas	Standard	1.1	6.896	1.536	77.7	6.31	1.185	81.2
Natural Gas	Standard	2.0	7.151	1.577	77.9	6.55	1.179	82.0
PRB Coal	Treated	0.6	5.936	0.808	86.4	5.30	0.629	88.3
Natural Gas	Treated	0.6	5.590	1.163	79.2	4.70	0.929	80.2
Natural Gas	Treated	1.1	5.020	0.621	87.6	4.52	0.451	90.0
PRB Coal	Treated	1.1	4.930	0.441	91.1	4.21	0.290	93.1
PRB Coal	Treated	1.1	5.051	0.232	95.4	4.30	0.093	97.8

4.4 Preliminary Economic Evaluation

A very preliminary economic evaluation was done. The evaluation included the capital cost of purchasing and installing both a pulse-jet baghouse operating at an air-to-cloth ratio of 6 ft/min and an ACI system. All costs are based on 2011 dollars. Please note, the costs presented in this report were determined based on a model developed for the utility industry, and therefore, the economic information provided should be used for discussion purposes only. Site-specific cost information would need to be developed if a full-scale baghouse were to be installed.

4.4.1 Installation and Operating Costs for a Pulse-Jet Baghouse

The capital costs for purchasing and installing a baghouse at Keetac are shown in Table 7. The total capital cost would be between \$10,000,000 and \$12,000,000. The first-year operating cost for the baghouse is shown in Table 8. The estimated operating cost for the first year is \$2,044,920.

Table 7. Capital Cost for a Pulse-Jet Baghouse at Keetac

Capital Cost Items	Cost
Purchased Equipment	
Basic Fabric Filter	\$3,750,500
Insulation	\$244,930
Cages	\$105,670
Initial Bags (including spares)	\$466,000
Auxiliary Equipment (fan, ductwork, motor, starter, dampers, compressor, screw conveyor)	\$1,170,400
Instrument and Controls, %	\$345,000
Taxes, %	\$103,500
Freight, %	\$172,500
Total Purchased Equipment (TPE)	\$6,358,500
Installation Direct Costs (calculated as a % of TPE)	
Foundations and Supports	\$162,840
Erection and Handling	\$2,035,500
Electrical, %	\$325,680
Piping, %	\$84,900
Insulation for Ductwork	\$81,420
Painting	\$40,710
Total Installation Direct Costs	\$2,731,050
Total Direct Costs for Purchased Equipment and Installation	\$9,089,550
Indirect Costs (calculated as a % of TPE)	
Engineering and Supervision	\$844,750
Contingencies (project and process)	\$544,164
General Facilities	\$422,370
Total Indirect Costs	\$1,811,290
Total Capital Requirements	\$10,900,840

Table 8. Baghouse Annual Operating and Maintenance Costs for Keetac

Operating Item	Cost
Direct Annual Costs	
Operating and Supervision Labor	\$125,200
Replace Bags (labor and materials)	\$97,210
Utilities (fan and cleaning bags)	\$498,020
Total Annual Direct Cost	\$720,430
Indirect Annual Costs	
Taxes, Insurance and Administration	\$382,530
Capital Recovery	\$908,960
Total Annual Indirect Cost	\$1,291,490
Total Annual Cost	\$2,011,920

4.4.2 Installation and Operating Costs for an ACI System

A price quote was obtained from Norit Americas Inc. to provide a complete powdered activated carbon (PAC) injection system. The total capital cost (FOB) is \$1,220,410. Included in this price are the following items:

- PAC storage silo and all associated equipment
- Volumetric feeder, hopper, and associated equipment for two delivery lines
- Eductors and blowers
- All structural steel and piping
- Control panel and associated software and hardware
- Injection distribution system (injection lances) and flow/distribution modeling field support services. Norit would provide the services of a technician to support installation and start-up of the equipment.

In addition to capital equipment provided by a vendor, certain site preparation and infrastructure would be required by plant personnel. Based on information provided by Norit, an estimate of \$125,000 would be required to provide the following:

- Concrete foundations for the silo, feeders, and blowers
- Unloading and assembly of vendor-supplied equipment with support from the Norit Americas on-site technician
- Piping to provide dry compressed air (100 psi) to the feeder and silo

- Drainage and containment as required by the site to collect and dispose of wash-down and any other wastes generated by the PAC system
- Electrical service including single-phase 120-volt and three-phase 480-volt power
- Communication wiring to the plant process and data control system
- General lighting
- Applicable permits

The total capital cost for the PAC system, including both the vendor-supplied process equipment and site preparation work is \$1,345,410. The primary operating cost for the ACI system is the cost of the sorbent and the sorbent feed rate. Based on the results for this test, to ensure meeting the mercury reduction goal of 75%, the feed rate for standard activated carbon would be 2 lb/Macf and 1.1 lb/Macf if bromine-treated activated carbon were assumed. Table 9 presents the estimated sorbent costs at Keetac. These results also assume that the total gas flow rate for the plant is 600,000 scfm, the baghouse temperature at the ACI location is 155°F, and the plant has an operating factor of 0.90 (7884 hr/yr). Including maintenance costs and utilities for the ACI system, the total yearly operating cost would be \$861,700 if standard activated carbon is used and \$723,750 if the bromine-treated carbon is used. Again, operating cost of the ACI system are going to be very sensitive to sorbent costs.

5.0 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

Prior to beginning the project, a quality assurance plan was submitted and approved by MNDNR and EPA. This document was used as a guideline for the project. All project data from the baghouse operation, CMMs, and other sampling was either downloaded from the computers to a flash drive or recorded onto data sheets. The data sheets were properly labeled, and chain-of-custody procedures were followed for all samples and data sheets.

5.1 K-Tron Activated Carbon Feeder

Prior to beginning the project, the EERC K-Tron feeder was calibrated. The results are shown in Figure 10. As can be seen, the calibration curve is highly linear and correlates directly with the rpm set point. In addition to the development of the initial calibration curve, several

Table 9. Estimated Sorbent Costs at Keetac with a Pulse-Jet Baghouse

Item	Standard Activated Carbon	Treated Activated Carbon
ACI Rate	2.0 lb/Macf	1.1 lb/Macf
Yearly Consumption	788,400 lb	394,200 lb
Cost per lb Delivered	\$0.85	\$1.35
Yearly Sorbent Costs	\$670,140	\$532,170

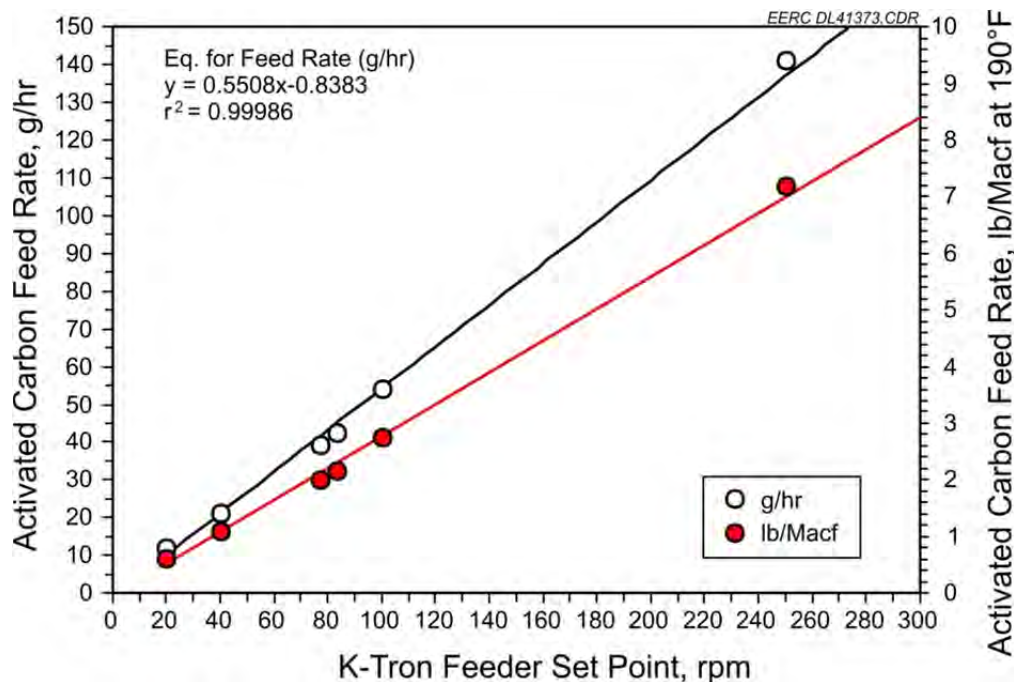


Figure 10. Calibration of the K-Tron activated carbon feed system.

times during the project, the feeder was bucket-calibrated to ensure the feed rate had remained constant, which it had.

5.2 Particulate Samples (EPA Method 5)

All particulate sampling followed the procedures outlined in EPA Method 5. The only exception was that the piping was not traversed as it was a slipstream and the piping was only 10 in. in diameter so stratification was not a concern. All sampling boxes were calibrated prior to arriving on-site, and a meter constant (C_m) was calculated. The primary sampling QC criteria are that the sampling be conducted in an isokinetic manner so particles captured on the filter are representative of those in the gas stream. The requirement is that all samples be isokinetic within 10%. As can be seen in Table 10, all samples met this criteria.

The filters were preweighed to a constant temperature and stored in labeled petri dishes. Once the dust loading was completed as prescribed in EPA Method 5, the filters were carefully removed from the filter holders, and any remaining dust was brushed onto the filters. The filters and any dust brushed from the filter holder were once again placed in labeled petri dishes and desiccated prior to weighing. The filters were weighed on-site using a calibrated five-place balance.

Table 10. Particulate Sampling Isokinetic Determination

Sample No.	Date	Fuel	Isokinetic, %
1	06/16/11	Natural gas	105.6
2	06/18/11	Natural gas	104.1
3	06/18/11	Natural gas	104.2
4	06/20/11	Natural gas	99.3
5	06/20/11	Natural gas	100.5
6	06/30/11	PRB coal	98.3
7	06/30/11	PRB coal	103.3
8	06/30/11	PRB coal	101.1
9	06/30/11	PRB coal	103.9

5.3 Mercury Measurements

Two different mercury measurements were made during the project. The primary measurements were provided by CMMs installed at the inlet and outlet of the baghouse. The second method used sorbent traps. These were taken for QA/QC purposes and to compare to the CMM results.

5.3.1 Calibration of the CMMs

The requirements for calibration, spanning, and zeroing of the CMMs are listed in Table 11. The leak check was <1% following installation of the two CMMs. The multipoint linearity checks are shown in Table 12. With the exception of the second check for the CMM located at the baghouse outlet, which was a bit high, they all were within 10% of the expected value. The daily zero and span results are shown in Tables 13 and 14.

In all cases, the span was within the required 90%–100% range, and the zero values were at or near zero. The internal calibration results are shown in Tables 15 and 16. The instrument was calibrated both at the probe tip and directly into the analyzer. Again, as was the case with the span data, all recoveries were within the 10% range.

5.3.2 QA/QC Requirements for the Sorbent Traps

An additional QA/QC for the CMMs was to compare the results to those obtained using sorbent traps. Sorbent traps are considered to be a reference method (EPA Method 30B). At least one paired sorbent trap sample was taken at the baghouse inlet and outlet for each test. The results were then compared to the CMM data taken over the same time period.

Table 11. CMM Calibration Requirements

Test	Criteria	How Often
Leak Check	>2% of total sample flow	Immediately after installation
Internal Zero and Span	Automatically adjusted by the instrument	Daily
Local and Probe Tip Calibration	90%–110% of anticipated value	Every other day or more as needed
Multipoint Span	Automatically adjusted by the instrument	Once a week

Table 12. Multipoint Linearity Checks

Baghouse Inlet CMM		Calibration Gas Recovery, %		
Date/Time	Side	Low 6.00 $\mu\text{g}/\text{Nm}^3$	Mid 8.00 $\mu\text{g}/\text{Nm}^3$	High 10.0 $\mu\text{g}/\text{Nm}^3$
6/17/11 3:27	A	102.88	104.45	103.71
	B	104.63	106.75	105.79
6/17/11 17:20	A	129.15	116.53	112.74
	B	120.31	114.71	109.93
6/23/11 13:42	A	95.85	97.68	98.49
	B	98.04	100.94	102.36
Baghouse Outlet CMM		Calibration Gas Recovery, %		
Date/Time	Side	Low 1.32 $\mu\text{g}/\text{Nm}^3$	Mid 3.32 $\mu\text{g}/\text{Nm}^3$	High 6.60 $\mu\text{g}/\text{Nm}^3$
6/17/11 3:27	A	106.53	100.76	100.44
	B	106.05	102.19	100.15
6/17/11 17:20	A	101.85	100.94	98.94
	B	96.95	102.65	101.43
6/23/11 13:42	A	94.64	94.54	95.66
	B	99.18	100.10	99.09

To measure the mercury adsorbed by the sorbent traps, an OhioLumex instrument was used. This instrument uses cold-vapor atomic absorption to measure the mercury that is desorbed from the traps using thermal techniques. This instrument is currently considered to be the standard for these types of measurements. Before beginning analysis of the samples, a five-point linear calibration curve is generated. This curve must have an R^2 of >99% before it is acceptable. Because the samples were taken back to the EERC for analysis, the samples were analyzed over two separate time periods. Therefore, two calibration curves were generated. Once a calibration curve has been generated, separate National Institute of Standards and Technology (NIST) traceable QC samples are used to check the calibration curve. The requirement is that the recovery of the QC standards be $\pm 10\%$, or a new curve must be generated.

The two calibration curves for this project are shown in Table 17. As shown, both calibration curves were acceptable.

In addition to the development of the calibration curve, for every ten samples and at least once a day, check standards must be analyzed. These also have to have recoveries within 10% of the known value or a new calibration curve must be developed. Table 18 presents the check standards that were completed for this project. All QA/QC check standards were within the acceptable range.

5.3.3 Comparison of CMMs to Sorbent Trap Mercury Measurements

For each test, at least one paired set of sorbent trap samples was taken at the baghouse inlet and outlet. These results were then compared to the results obtained using the CMMs. The

Table 13. Baghouse Inlet CMM Zero and Span Data

Date/Time	Side	Probe Zero, μg/Nm ³	Probe Tip, μg/Nm ³	Date/Time	Side	Probe Zero, μg/Nm ³	Probe Tip, μg/Nm ³
6/17/11 3:27	A	0.000		6/23/11 1:12	A	0.000	
	B	0.065			B	0.000	
6/17/11 7:27	A	0.000		6/23/11 1:32	A		100.17
	B	0.000			B		98.42
6/17/11 18:07	A		98.06	6/24/11 1:12	A	0.000	
	B		98.11		B	0.075	
6/18/11 1:10	A	0.571		6/24/11 1:32	A		99.87
	B	0.563			B		99.19
6/18/11 1:17	A		102.39	6/25/11 1:15	B	0.177	
	B		100.81		A	0.000	
6/18/11 9:10	A	0.234		6/25/11 1:35	B		97.96
	B	0.097			A		102.30
6/18/11 9:30	A		97.40	6/26/11 1:12	A	0.000	
	B		98.63		B	0.000	
6/18/11 9:55	A	0.000		6/26/11 1:32	A		100.63
	B	0.000			B		99.88
6/18/11 10:15	A		98.87	6/27/11 1:15	B	0.000	
	B		99.67		A	0.000	
6/19/11 1:12	A	0.000		6/27/11 1:35	B		96.93
	B	0.082			A		101.70
6/19/11 1:32	A		96.34	6/28/11 1:15	B	0.000	
	B		100.14		A	0.000	
6/19/11 3:57	A		101.94	6/28/11 1:35	B		99.83
	B		99.11		A		103.86
6/20/11 1:32	A		101.94	6/29/11 1:12	A	0.132	
	B		99.11		B	0.000	
6/21/11 1:12	B	0.061		6/29/11 1:32	A		98.02
	A	0.052			B		99.73
6/21/11 1:32	A		99.17	6/30/11 1:12	A	0.000	
	B		98.36		B	0.000	
6/22/11 1:12	A	0.000		6/30/11 1:32	A		98.72
	B	0.000			B		100.73
6/22/11 1:32	A		102.60	7/1/11 1:12	A	0.000	
	B		102.48		B	0.000	
				7/1/11 1:32	A		97.56
					B		99.66

comparison was shown previously in Section 4.3, Figures 5–9. This section discusses the QA/QC associated with those comparisons.

Table 14. Baghouse Outlet CMM Zero and Span Data

Date/Time	Side	Probe Zero, $\mu\text{g}/\text{Nm}^3$	Probe Tip, $\mu\text{g}/\text{Nm}^3$	Date/Time	Side	Probe Zero, $\mu\text{g}/\text{Nm}^3$	Probe Tip, $\mu\text{g}/\text{Nm}^3$
6/17/2011 11:00	B	0.149		6/22/2011	A	0.000	
	A	0.000			B	0.000	
6/17/2011 11:15	B		108.05	6/22/2011	A		102.76
	A		110.32		B		102.37
6/17/2011 12:40	B	0.193		6/23/2011	B	0.000	
	A	0.000			A	0.000	
6/17/2011 12:55	B		103.00	6/23/2011	B		100.38
	A		104.25		A		99.39
6/17/2011 13:15	B	0.027		6/24/2011	B	0.000	
	A	0.066			A	0.000	
6/17/2011 13:30	B		101.06	6/24/2011	B		96.37
	A		102.46		A		96.14
6/17/2011 18:00	A	0.199		6/25/2011	B	0.000	
	B	0.201			A	0.000	
6/17/2011 18:15	A		100.21	6/25/2011	B		98.07
	B		102.58		A		98.34
6/18/2011 1:07	A	0.047		6/26/2011	B	0.000	
	B	0.000			A	0.000	
6/18/2011 1:22	A		96.71	6/26/2011	B		104.16
	B		98.16		A		101.33
6/18/2011 9:07	A	0.000		6/27/2011	B	0.000	
	B	0.000			A	0.000	
6/18/2011 9:27	A		94.54	6/27/2011	B		96.69
	B		95.07		A		99.30
6/18/2011 9:55	B	0.000		6/28/2011	B	0.000	
	A	0.000			A	0.000	
6/18/11 10:15	B		99.90	6/28/2011	B		106.80
	A		101.79		A		106.46
6/18/2011 18:52	A	0.000		6/29/2011	A	0.000	
	B	0.000			B	0.000	
6/19/2011 1:10	A	0.045		6/29/2011	A		96.02
	B	0.000			B		99.67
6/19/2011 1:30	A		98.97	6/30/2011	B	0.000	
	B		101.36		A	0.000	
6/20/2011 1:10	B	0.000		6/30/2011	B		98.25
	A	0.000			A		101.29
6/20/2011 1:30	B		98.87	7/1/2011 1:07	A	0.000	
	A		102.40		B	0.000	
6/21/2011 1:10	A	0.000		7/1/2011 1:27	A		96.57
	B	0.000			B		98.41
6/21/2011 1:30	A		100.03				
	B		103.33				

Table 15. Baghouse Inlet CMM Calibration Data

Directly into Analyzer		At the Probe Tip		Directly into Analyzer		At the Probe Tip	
Date/Time	Recovery, %	Date/Time	Recovery, %	Date/Time	Recovery, %	Date/Time	Recovery, %
6/19/11 3:00	100.64	6/19/11 3:30	101.84	6/27/11 3:02	101.23	6/27/11 3:32	100.88
6/19/11 3:02	99.20	6/19/11 3:32	99.97	6/27/11 3:05	102.06	6/27/11 3:35	102.49
6/19/11 3:05	100.72	6/19/11 3:35	102.03	6/27/11 3:07	101.18	6/27/11 3:37	101.02
6/19/11 3:07	99.72	6/19/11 3:37	98.93	6/27/11 3:10	102.24	6/27/11 3:40	102.52
6/19/11 3:10	101.46	6/19/11 3:40	101.22	6/27/11 3:12	101.34	6/27/11 3:42	101.45
6/19/11 3:12	100.01	6/19/11 3:42	98.14	6/27/11 3:15	102.30	6/27/11 3:45	101.81
6/23/11 3:00	102.40	6/23/11 3:30	102.20	6/29/11 3:00	101.73	6/29/11 3:30	102.90
6/23/11 3:02	101.41	6/23/11 3:32	101.59	6/29/11 3:02	101.42	6/29/11 3:32	102.12
6/23/11 3:05	102.53	6/23/11 3:35	101.47	6/29/11 3:05	101.84	6/29/11 3:35	101.67
6/23/11 3:07	101.39	6/23/11 3:37	99.98	6/29/11 3:07	101.26	6/29/11 3:37	101.45
6/23/11 3:10	102.47	6/23/11 3:40	101.83	6/29/11 3:10	102.14	6/29/11 3:40	101.57
6/23/11 3:12	101.58	6/23/11 3:42	100.97	6/29/11 3:12	101.68	6/29/11 3:42	100.42
6/25/11 3:02	99.34	6/25/11 3:32	101.51	7/1/11 3:00	102.30	7/1/11 3:30	104.17
6/25/11 3:05	100.34	6/25/11 3:35	102.52	7/1/11 3:02	101.78	7/1/11 3:32	102.41
6/25/11 3:07	99.99	6/25/11 3:37	99.75	7/1/11 3:05	102.26	7/1/11 3:35	103.43
6/25/11 3:10	100.97	6/25/11 3:40	101.90	7/1/11 3:07	101.86	7/1/11 3:37	102.21
6/25/11 3:12	100.74	6/25/11 3:42	99.47	7/1/11 3:10	102.39	7/1/11 3:40	102.94
6/25/11 3:15	101.66	6/25/11 3:45	99.81	7/1/11 3:12	101.75	7/1/11 3:42	101.92

To be a valid paired sample, the paired sorbent traps must have a relative standard difference (RSD) of $\leq 20\%$, where the RSD is defined by:

$$RSD = \frac{|C_a - C_b|}{C_b + C_b} \times 100\% \quad [\text{Eq. 2}]$$

where C_a and C_b are the mercury concentration measured by the paired sorbent traps.

As shown in Table 19, all the sorbent trap paired sample RSD values were substantially less than the requirements of $<20\%$ outlined in EPA Method 30B. In addition, to be a valid sample, the amount of mercury captured in the back half (breakthrough) cannot be $>5\%$ of the total mercury captured by the sorbent trap. With the exception of one sample that was 3.6% in the second half, all samples had a breakthrough that was $<1\%$.

The comparison between the sorbent trap samples and the CMMs is also provided in Table 19. With the exception of the last three baghouse outlet samples, a comparison between the mercury concentrations measured using the sorbent traps and those measured using the CMMs had an RSD of $<15\%$. The last three mercury concentrations measured at the baghouse outlet were very low, and very small differences in concentrations result in higher RSDs, but in terms of mercury removal across the baghouse, these differences have little meaning.

Table 16. Baghouse Outlet CMM Calibration Data

Directly into Analyzer		At the Probe Tip		Directly into Analyzer		At the Probe Tip	
Date/Time	Recovery, %	Date/Time	Recovery, %	Date/Time	Recovery, %	Date/Time	Recovery, %
6/17/11 9:52	100.31	6/17/11 10:17	100.53	6/23/11 3:07	101.03	6/23/11 3:37	102.43
6/17/11 9:55	99.40	6/17/11 10:20	99.03	6/23/11 3:10	100.61	6/23/11 3:40	101.42
6/17/11 9:57	100.21	6/17/11 10:22	99.44	6/25/11 2:57	102.25	6/25/11 3:27	100.72
6/17/11 10:00	99.42	6/17/11 10:25	97.99	6/25/11 3:00	100.89	6/25/11 3:30	100.44
6/17/11 10:02	99.85	6/17/11 10:27	99.62	6/25/11 3:02	101.93	6/25/11 3:32	101.84
6/18/11 17:55	98.99	6/18/11 18:25	100.38	6/25/11 3:05	100.89	6/25/11 3:35	100.17
6/18/11 17:57	99.86	6/18/11 18:27	99.27	6/25/11 3:07	101.34	6/25/11 3:37	100.97
6/18/11 18:00	99.14	6/18/11 18:30	99.46	6/25/11 3:10	101.31	6/25/11 3:40	98.76
6/18/11 18:02	99.88	6/18/11 18:32	99.12	6/27/11 2:57	102.29	6/27/11 3:27	102.23
6/18/11 18:05	99.16	6/18/11 18:35	99.44	6/27/11 3:00	101.09	6/27/11 3:30	99.80
6/18/11 18:07	99.52	6/18/11 18:37	98.88	6/27/11 3:02	102.05	6/27/11 3:32	101.46
6/19/11 2:57	100.93	6/19/11 3:27	102.32	6/27/11 3:05	101.24	6/27/11 3:35	100.66
6/19/11 3:00	99.51	6/19/11 3:30	101.17	6/27/11 3:07	101.47	6/27/11 3:37	101.46
6/19/11 3:02	100.72	6/19/11 3:32	101.96	6/27/11 3:10	101.02	6/27/11 3:40	100.72
6/19/11 3:05	100.13	6/19/11 3:35	99.71	6/29/11 2:57	101.99	6/29/11 3:27	100.98
6/19/11 3:07	101.22	6/19/11 3:37	100.97	6/29/11 3:00	101.38	6/29/11 3:30	100.84
6/19/11 3:10	100.24	6/19/11 3:40	98.23	6/29/11 3:02	102.05	6/29/11 3:32	100.67
6/21/11 2:57	101.77	6/21/11 3:27	102.50	6/29/11 3:05	100.75	6/29/11 3:35	100.81
6/21/11 3:00	101.16	6/21/11 3:30	102.03	6/29/11 3:07	101.71	6/29/11 3:37	100.44
6/21/11 3:02	101.98	6/21/11 3:32	102.51	6/29/11 3:10	101.40	6/29/11 3:40	99.10
6/21/11 3:05	100.81	6/21/11 3:35	102.69	7/1/11 2:57	101.52	7/1/11 3:27	102.50
6/21/11 3:07	101.71	6/21/11 3:37	102.89	7/1/11 3:00	100.72	7/1/11 3:30	101.46
6/21/11 3:10	100.72	6/21/11 3:40	101.41	7/1/11 3:02	101.78	7/1/11 3:32	101.86
6/23/11 2:57	101.30	6/23/11 3:27	102.11	7/1/11 3:05	101.21	7/1/11 3:35	100.65
6/23/11 3:00	100.51	6/23/11 3:30	101.65	7/1/11 3:07	101.57	7/1/11 3:37	101.79
6/23/11 3:02	101.37	6/23/11 3:32	102.04	7/1/11 3:10	100.78	7/1/11 3:40	99.86
6/23/11 3:05	101.05	6/23/11 3:35	100.58				

Table 17. OhioLumex Calibration Results

Calibration Curve 1		Calibration Curve 2	
Known Mass, ng	Calculated Mass, ng	Known Mass, ng	Calculated Mass, ng
Blank	0.0	Blank	0
10	9.7	10	10
10	10.0	10	9.3
100	103	100	100
100	92		
250	231	250	247
250	241		
500	508	500	500
500	496	500	500
R ²	0.9993	R ²	1.00

Table 18. QC Check Standard Results for the OhioLumex

Known Mass, ng	Measured Mass, ng	Recovery, %	Known Mass, ng	Measured Mass, ng	Recovery, %
40	38	95	20	20	100
400	390	98	400	394	99
250	250	100			
20	18	90	100	108	108
400	406	102	450	475	95
550	556	101	200	198	99
100	106	106	40	42	105
500	492	98	100	104	104
			400	399	100
10	11	110	10	10	100
100	98	98	200	203	102
200	190	95	500	526	105
500	533	107			
10	10	100	20	21	105
100	105	105	200	198	99
200	190	95	400	419	105
500	493	99			
20	20	100			
500	510	102			
100	106	106			
400	386	97			

Table 19. QA/QC Comparison of CMMs to Sorbent Traps

Date	Sample Location	C _a , µg/Nm ³	C _b , µg/Nm ³	Paired Trap	Sorbent Trap	CMM	
				RSD, %	Average, µg/Nm ³	Average, µg/Nm ³	RSD, %
6/18/11	BH inlet	6.033	6.050	0.14	6.042	5.184	7.64
6/18/11	BH outlet	7.041	7.036	0.04	7.038	5.669	10.77
6/20/11	BH inlet	5.784	6.017	1.98	5.900	5.341	4.98
6/20/11	BH outlet	1.166	1.115	2.20	1.140	0.908	11.36
6/21/11	BH inlet	6.946	6.846	0.73	6.896	6.306	4.47
6/21/11	BH outlet	1.544	1.529	0.51	1.536	1.185	12.90
6/23/11	BH inlet	7.311	6.991	2.24	7.151	6.554	4.35
6/23/11	BH outlet	1.568	1.587	0.58	1.577	1.179	14.45
6/27/11	BH inlet	5.850	6.023	1.45	5.936	5.300	5.66
6/27/11	BH outlet	0.814	0.802	0.75	0.808	0.629	12.46
6/28/11	BH inlet	5.598	5.582	0.15	5.590	4.701	8.64
6/28/11	BH outlet	1.156	1.171	0.67	1.163	0.929	11.20
6/29/11	BH inlet	4.966	5.074	1.07	5.020	4.521	5.23
6/29/11	BH outlet	0.619	0.623	0.25	0.621	0.451	15.85
6/29/11	BH inlet	4.979	4.880	1.00	4.930	4.212	7.85
6/29/11	BH outlet	0.448	0.434	1.64	0.441	0.290	20.59
6/30/11	BH inlet	5.098	5.004	0.93	5.051	4.299	8.05
6/30/11	BH outlet	0.234	0.231	0.51	0.232	0.093	43.04

Although small, there appears to be a bias in the measurements. The sorbent trap mercury measurements were in all cases greater than the CMM results. This almost certainly is a result of differences in how the two measurement methods deal with particulate matter. The sorbent trap samples have a quartz wool plug prior to the mercury sorbent. When the analysis is done, the quartz wool is analyzed with the first sorbent section. Therefore, any mercury captured by the particulate matter on the quartz plug is considered to be part of the overall measured concentration. However, with a CMM, the ISP helps ensure only gas-phase mercury is measured. The fact that the bias is greater at the baghouse inlet where the particulate concentration is the greatest supports this. Based on previous testing done at taconite plants, it has been found that the high iron content of the dust results in mercury capture (3).

The complete sorbent trap data along with the CMM comparison information is presented in Appendix C.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the testing conducted using a slipstream baghouse at Keetac, the following conclusions can be made:

- Mercury removal of >75% can be achieved at Keetac with either standard or bromine-treated activated carbon.
- To ensure >75% removal when natural gas is fired, 2.0 lb/Macf is needed when using standard activated carbon.
- To ensure >75% removal when natural gas is fired, 1.1 lb/Macf is needed when using bromine-treated activated carbon.
- To ensure >75% removal when a PRB coal is fired, only 0.6 lb/Macf of bromine-treated activated carbon is needed.
- Very low particulate emissions can be achieved.
- Because of the relatively high cost of installing a fabric filter, the most economical installation would be for those taconite facilities that require fuel flexibility and/or where particulate emissions are a concern.
- If a baghouse is to be installed at Keetac, 18%–20% flue would need to bypass the wet particulate scrubber to prevent wetting of the bags.
- As expected, the mercury at the outlet of the scrubber is ~80% elemental mercury.
- It appears that if the ACI is turned off, there is the potential of high mercury emissions as a result of reemission.

- Overall, the slipstream baghouse and CMMs operated well during the test period.

If this is to be a viable technology, the following recommendations are made for future testing.

- Longer-term testing is needed to determine the resultant steady-state pressure drop across the baghouse as a function of air-to-cloth ratio.
- Longer-term tests are also needed to ensure that required mercury control will be maintained.
- It appeared that the bromine-treated activated carbon worked better when firing coal compared to natural gas. The same may be true using standard activated carbon. Therefore, additional coal tests are needed.
- The economic evaluation presented in this report is based on the utility requirements and may or may not be the same for a taconite plant. Therefore, more specific economic data are needed.
- There may be a need to evaluate or update the existing wet scrubber mist eliminators.

7.0 REFERENCES

1. Berndt, M.; Engesser, J.; Johnson, A. *On Distribution of Mercury in Taconite Plant Scrubber Systems*; Submitted to the Minnesota Pollution Control Agency, Oct 2003.
2. Pavlish, J.H.; Sondreal, E.A.; Mann, M.D.; Olson, E.S.; Galbreath, K.C.; Laudal, D.L.; Benson, S.A. Status Review of Mercury Control Options for Coal-Fired Power Plants. *Fuel* **2003**, 82, 89–165.
3. Laudal, D.L. *Methods Testing for Measurement of Mercury Speciation for High Reactive Dust*; Report to the Minnesota Pollution Control Agency; Energy & Environmental Research Center: Grand Forks, ND, March 2007.

APPENDIX A
SAMPLE CALCULATIONS

SAMPLE CALCULATIONS

1.0 AIR-TO-CLOTH RATIO

Gas flow rate = 584 scfm

Pressure = 1 atm.

Temperature at baghouse inlet = 165°F

Temperature at baghouse outlet = 215°F

Average temperature = $(165+215)/2 = 190^\circ\text{F}$

Standard temperature = 68°F

Actual gas flow rate = $(584)*(190+460)/(68+460) = 719$ acfm

Bag diameter = 6 in

Bag length = 12 ft

No. of bags = 7

Total bag surface area = $\pi*(6/12)*12*7 = 131.95$ ft²

Air-to-cloth ratio = $719/131.95 = \underline{5.45}$ ft/min

2.0 ACTIVATED CARBON FEED RATE IN lb/Macf

Activated carbon feed rate = 42.5 g/hr

Actual gas flow rate = 719 acfm

Activated carbon feed rate = $42.5/(454*719*60)*10^6 = \underline{2.17}$ lb/Macf

3.0 FLUE GAS BYPASS CALCULATION FOR REHEAT

Saturated gas temperature = 135°F = 57.22°C

Gas flow rate = 600,000 scfm (68°F) = 15,830.4 scm/min (0°C) = 19,148.4 m³/min (actual)

Desired gas temperature to prevent bag wetting = 155°F = 68.33°C

Temperature of flue gas prior to wet scrubber = 300°F = 148.89°C

Flue gas molecular weight = 30.4 kg-moles/m³

Molecular weight of water = 18.01 kg-moles/m³

Ideal gas law = 1kg-mole/22.4 m³ at standard pressure (1 atm.) and temp. (0°C)

Pressure = 1 atm. = $1*101.325 = 101.325$ kPa

From steam table the moisture vapor pressure at 135°F = 17.49 kPa

Gas vapor pressure = $101.325-17.49 = 83.83$ kPa

Gas flow rate (mass basis) = $15,830.4*(30.4/22.4)*(83.83/100) = 18,010.1$ kg/min

Moisture flow rate (mass basis) = $15,830.4*(18.01/22.4)*(17.50/100) = 2227.4$ kg/min

Flue gas heat capacity = 1.01 kJ/kg/°K

Moisture heat capacity = 1.87 kJ/kg/°K

Energy needed to heat gas to desired temp. = $18,010.1*1.01*(68.33-57.22) = 202,093.1$ kJ/min

Energy needed to heat moisture = $2227.4*1.87*(68.33-57.22) = 46,275.8$ kJ/min

High temperature dilution gas needed = $(202,093.1+46,275.8)/1.01/(148.89-68.33) = 3052.5$ kg/min

Dilution gas volume flow rate = $3052.5 \times (22.4/30.4) \times (148.89+273)/273 = 3475.9 \text{ m}^3/\text{min}$ (actual)
 % bypass needed of high-temperature gas = $3475.9/19148.4 \times 100 = \underline{18.2\%}$

4.0 PARTICULATE-SAMPLING CALCULATIONS

4.1 Volume of Gas Sample

$V_m(\text{std})$ = Volume of gas sample measured by the dry gas meter, connected to standard conditions, dscf

$$V_m(\text{std})(\text{dscf}) = \frac{K_1 \times V_m \times C_m \times P_m}{T_m + 460}$$

$$V_m(\text{std}) = \frac{17.64 \times 81.588 \times 1.010 \times 28.15}{70 + 460} = 77.207 \text{ dscf}$$

Where:

K_1 = 17.64 R/in. Hg

V_m = Volume of gas sample as measured by dry gas meter corrected for C_m = meter calibration coefficient) (dcf)

P_m = Meter pressure (in. Hg)

T_m = Meter temperature ($^{\circ}\text{F}$)

4.2 Volume of Water Vapor

$V_w(\text{std})$ = Volume of water vapor in the gas sample, corrected to standard conditions, scf

$$V_w(\text{std})(\text{scf}) = K_2 \times H_2O(g)$$

$$V_w(\text{std}) = 0.04715 \times 314.7 = 14.813 \text{ scf}$$

Where:

K_2 = 0.04715 ft^3/g

$H_2O(g)$ = Mass of liquid collected in impingers and silica gel (g)

4.3 Water Vapor in the Gas Stream

B_{ws} = Water vapor in the gas stream, proportion by volume

$$B_{ws} = \frac{V_w(\text{std})}{V_m(\text{std}) + V_w(\text{std})}$$

$$B_{ws} = \frac{14.813}{77.207 + 14.813} = 0.1613$$

4.4 Molecular Weight

$$M_w = 30 \times (1 - B_{ws}) + 18 \times B_{ws} = 30 \times (1 - 0.1613) + 18 \times 0.1613 = 28.06$$

4.5 Average Stack Gas Velocity

V_s = Average stack gas velocity, ft/sec

$$V_s \text{ (ft/sec)} = K_3 \times C_p \times (\Delta p)^{1/2} (\text{avg}) \times \left[\frac{T_s + 460}{P_s \times M_s} \right]^{1/2}$$

$$V_s = 85.49 \times 0.84 \times 0.40 \times \left[\frac{165 + 460}{28.09 \times 28.06} \right]^{1/2} = 25.58 \text{ ft/sec}$$

Where:

$$K_3 = 85.49 \text{ ft/sec} \times \left[\frac{\frac{lb}{lb-mole} \times in. Hg}{R \times in. H_2O} \right]^{1/2}$$

C_p = Pitot tube coefficient, dimensionless

Δp = Velocity head of stack gas (in. Hg)

$(\Delta p)^{1/2} (\text{avg})$ = Average of the square root of Δp values

T_s = Stack gas temperature ($^{\circ}F$)

P_s = Stack pressure (in. Hg)

4.6 Isokinetic Sampling Rate

I = Percent of isokinetic sampling, %

$$I (\%) = \frac{K_4 \times (T_s + 460) \times V_m(\text{std}) \times 144}{P_s \times V_s \times A_n \times \theta \times (1 - Bws)}$$

$$I = \frac{0.09450 \times (165 + 460) \times 77.207 \times 144}{28.07 \times 25.58 \times 0.06158 \times 180 \times (1 - 0.1613)} = 98.3\%$$

Where:

$$K_4 = \frac{0.09450\% (\text{in. Hg})(\text{min})}{R \times \text{sec}}$$

A_n = Cross-sectional area of nozzle (in.^2)

θ = Total sampling time (min)

4.7 Dust Loading

Filter tare weight = 0.23651 g

Final filter weight = 0.25662 g

Net weight on filter = 0.25662 - 0.23651 = 0.02011 g

Petri dish tare weight = 0.74168 g
 Petri dish and probe dust = 0.74182 g
 Net weight on petri dish = 0.74182 - 0.74168 = 0.00014 g
 Total dust collected = 0.02011 + 0.00014 = 0.02025 g = 0.02025 * 15.43 = 0.31246 grains
 Gas volume sampled = 77.207 dscf
 Dust loading = 0.31246 / 77.027 = 0.0041 grains/dscf

5.0 MERCURY SAMPLING

5.1 Mercury Concentration in Flue Gas Based on Sorbent Traps (Sample 7A)

Volume of gas sampled = 50.277 L (dry)
 Moisture in flue gas = 16.2% (from dust loading sample)
 Volume of moisture sampled = 50.277 * (1 - 0.162) = 9.719 L
 Total gas sampled = 50.277 + 9.719 = 59.996 L (wet)
 Tm = 65°F
 Pb (barometric) = 28.35 in Hg
 Elevation = 20 ft
 Cm = 1.015
 N (normal conditions) = 68°F and 29.92 in Hg
 Vt (corrected) = 59.996 * 1.015 * (29.92 / [28.35 - 20/1000]) * 528 / (65 + 460) =
 57.990 NL(wet)
 Section 1 Hg = 288 ng
 Section 2 Hg = 0 ng
 Back plug = 0 ng
 Total Hg collected = 288 ng
 Breakthrough = 0 / 288 * 100 = 0%
 Total Hg conc. in gas stream = 288 / 57.990 = 4.966 ng/NL = 4.966 µg/Nm³

5.2 Paired Sorbent Trap Calculations (7A and 7B)

Hg concentration from Trap 7A = 4.966 µg/Nm³
 Hg concentration from Trap 7B = 5.074 µg/Nm³
 Relative standard difference = ABS[(5.074 - 4.966)] / (5.074 + 4.966) * 100 = 1.07%

5.3 Mercury Removal Across Slipstream Baghouse (Sample 7 sorbent trap and CMM average over the time the sorbent trap sample was taken)

Sorbent trap avg. Hg at the BH inlet = (4.966 + 5.074) / 2 = 5.020 µg/Nm³
 Sorbent trap avg. Hg at the BH outlet = (0.619 + 0.623) / 2 = 0.621 µg/Nm³
 CMM avg. Hg at the BH inlet = 4.52 µg/Nm³
 CMM avg. Hg at the BH outlet = 0.451 µg/Nm³
 Hg removal based on sorbent traps = (5.020 - 0.621) / 5.020 * 100 = 87.6%
 Hg removal based on CMMs = (4.52 - 0.451) / 4.52 * 100 = 90.0%

APPENDIX B
DUST-LOADING DATA SHEETS

Sample Pt.	DWN LEG BH IN		Date	6/15/2011
			Run #	0
Train Type			Fund #	15726
			Cost Center #	
STOPPER TYPE	TYPE OF SOLUTION	INITIAL WT. (g)	FINAL WT. (g)	NET WT. (g)
Straight	DI	645.3	655.3	10.0
Straight	DI	614.3	616.0	1.7
Impinger	DRY	637.7	638.7	1.0
Straight	SIL GEL	958.7	960.7	2.0
Straight		616.2	616.3	0.1
Straight				0.0
Impinger				0.0
Straight				0.0
			TOTAL H2O (g)	14.8
FILTER		wet	wet	#VALUE!
				0.00000
Additional Dust				0.00000
			TOTAL DUST (g)	#VALUE!
Vwstd	0.697	SCF		
Vmstd	6.297	SCF		
Vtstd	6.994	SCF		
% H2O	10.0	%		
% Isokinetic	38.3	%		
DCL	#VALUE!	grains/SCF		
DCL - Metric	#VALUE!	grams/SCM = grains/SCF*2.288		
DUST LOADING CALCULATIONS (Concentration Basis)				
Inlet DCL				grains/SCF
% Efficiency = (Inlet DCL - Outlet DCL) * 100			#VALUE!	%
	Inlet DCL			
Pipe Area				ft2
ACFM = VS * Pipe Area (ft2)			0.0000	ACFM
SCFM = ACFM * PS/TS * 17.64			0.0	SCFM
lbs/hour = grains/scf * 0.000143 * SCFM * 60			#VALUE!	lbs/hour

Equations		
Page 1		
PS (Stack Pressure)	=PB + (PS in H2O / 13.6) - elevation/1000	in. Hg Abs.
TS (Stack Temperature)	=average TS oF + 460	oR
VS (Stack Velocity)ft/min	=60*85.49 * Cp * sqrt(P * TS oR / PS in Hg Abs / MS)	ft/min
MS	=30 * (1-%H2O/100) + 18 * %H2O/100	g/mol
QN (Nozzle Flow Rate)	=VS * pi * DN2 / 576	ACFM
QM (Meter Flow Rate)	=QN * TM * PS in Hg Abs/(Cm * TS oR * (HM /13.6)) - (1-%H2O/100)	ACFM
H (orifice)	=QM2 * H@ * (PB + HM /13.6)/(0.03175 * (TM + 460))	in H2O
Seconds/Rev	=1/(QM / 0.1 / 60)	
Page 2		
VWstd	=0.04707 * (H2O g)	SCF
VMstd	=17.64 * VWstd * Cm * (PB+ HM /13.6 - Elevation/1000)	SCF
VTstd	=VWstd + VMstd	SCF
% H2O	=(VWstd / VTstd) * 100	%
% Isokinetic	= 0.0945 * TS oR * VMstd * 60 sec/min * 144 in2/ft2 (PS in Hg Abs * VS * (DN2/4*pi) * time min * (1-%H2O/100)	%
DCL	=15.43 * (dust g) / VMstd	grains/SCF
% Efficiency	=(Inlet DCL - Outlet DCL) / Inlet DCL * 100	%
ACFM	=VS * Pipe Area (ft2)	ACFM
SCFM	=ACFM * PS / TS * 17.64	SCFM
lbs/hour	=grains/SCF * 0.000143 * SCFM * 60 min/hr	lbs/hour
PPM Calculation		
PPM	=Conc mg/L * Vol mL * L/1000 mL * 2.205e-6 lb/mg * 387 ft3/mol / VTstd * e6	
Stack Vel ft./sec.	Vs=85.49*Cp*SQRT Dp*SQRT(Ts/Ps/Mw)	
Mol Wt. Wet	Mw=30*(1-Bws)+18*Bws	

ID			
Run #			
Start Time			
Fund #			
Vt Std			ft ³
Volume of Sample			mL
Concentration			mg/L or ppm
Molecular Weight			g/mole
Molecular Weights (g/mole)			
SO3	80.06		
SO2	64.06		
NH3	17.04		
Cl2	70.90		
HCl	36.46		
F2	38.00		
HF	20.02		
Hg	200.59		
#DIV/0!	ppm in flue gas		
<i>387 ft³/mol at 68oF</i>			

DATE	6/15/2011	KEETAC-BHIN-MS-1	DWN	LEG	BH	IN	RS	SAMPLER		START TIME	15:24	TEST TIME	30	BARO PRESS (in Hg)	28.97	STACK PRESS (in H2O)	-1.1	STACK TEMP (F)	140	O2%	0.0	ΔP	0.21	NOZ DIA	0.280	GAS METER VOL (cf)	6.240	TOTAL H2O	14.8	TOTAL DUST #VALUE!	6.297	VMSTD (SCF)	6.994	% H2O	10.0	METER TEMP	52	ΔH	0.70	% ISO	36.3	DLC GRAINS/ SCF	#VALUE!
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OPERATORS		RS									
ID		KEETAC-BHOUT-M5-6-2			Vwstd	15.971	SCF				
RUN #		2			Vmstd	76.845	SCF				
DATE		6/30/2011			Vtstd	92.816	SCF				
TIME		16:08			% H2O	17.2	%				
FUND #		15726			% Isokin	#VALUE!	%				
DUST LOADING DATA SHEET					DCL	0.0003	grains/SCF				
Sample Pt.		BH OUT DWN LG									
Traverse Pt.		3' BIN			Ps =	27.52	in. Hg Abs.				
Pb (Barometric Press.)		28.05	in Hg		Ts =	676	°R				
Elevation correction		5 ft (1 in Hg / 1000 ft)									
Ps (Stack Pressure)		-7.2	in H2O		VS (Stack Velocity)		1613	ft/min			
Dn (Nozzle Diam.)		0.280	in		QN (Nozzle Flow Rate)		0.6896	ACFM			
Est. ΔP (Pitot)		0.16	in H2O		QM (Meter Flow Rate)		0.4390	ACFM			
Cm		1.040			ΔH (orifice)		0.49	in H2O			
Cp		0.84 (Type S=.84, Std=.99)			Seconds/Rev		13.7				
Est. Ts (Stack Temp)		216	°F								
Est. % H2O		16			O2 %		16.9				
ΔH@		1.57			CO ppm		3				
Tm (Est)		85	°F		NO ppm		83				
ΔH (Est)		0.50	in Hg		NO2 ppm		2				
					SO2 ppm		12				
					CO2 %						
					coal CO2=18.6*(21-02%)/21						
<i>Note: Standard Temperature and Pressure are 68 oF and 29.92 in. Hg</i>											
Time (min.)	Temp stack	Gas Meter (ft3)	Tm Inlet	Tm Outlet	ΔH	ΔP Pitot	Pump Vac in Hg	MUFF	Temp Box	Temp Impinger	
0	216	308.770	80	79	0.53	0.16	2.0	254		OK	
15	216	315.410	83	78	0.55	0.16	2.0	249		OK	
30	216	322.130	83	78	0.55	0.16	2.0	250		OK	
45	216	328.950	83	76	0.55	0.16	2.0	249		OK	
60	216	335.600	81	78	0.52	0.16	2.0	249		OK	
75	216	342.160	82	76	0.52	0.16	2.0	252		OK	
90	216	348.990	83	82	0.52	0.16	2.1	247		OK	
105	216	355.720	81	76	0.52	0.16	2.1	252		OK	
120	216	362.440	81	77	0.52	0.16	2.1	250		OK	
135	216	369.140	80	76	0.52	0.16	2.1	247		OK	
150	216	375.840	81	75	0.52	0.16	2.2	255		OK	
165	216	382.530	81	76	0.52	0.16	2.2	255		OK	
180	216	389.197	80	74	0.52	0.16	2.2	254		OK	
Averages:	216	80.427	79		0.53	0.16	2.1	251	#DIV/0!	#DIV/0!	
Comments	Leak ck OK										

Sample Pt.	BH OUT DWN LG		Date	6/30/2011
			Run #	2
Train Type			Fund #	15726
			Cost Center #	
STOPPER TYPE	TYPE OF SOLUTION	INITIAL WT. (g)	FINAL WT. (g)	NET WT. (g)
Straight	DI	799.7	999.6	199.9
Straight	DI	641.6	756.8	115.2
Impinger	DRY	668.3	673.8	5.5
Straight	SIL GEL	1015.6	1034.3	18.7
Straight				0.0
Straight				0.0
Impinger				0.0
Straight				0.0
			TOTAL H2O (g)	339.3
FILTER		0.24056	0.24147	0.00091
		0.79902	0.79951	0.00049
Additional Dust				0.00000
			TOTAL DUST (g)	0.00140
Vwstd	15.971	SCF		
Vmstd	76.845	SCF		
Vtstd	92.816	SCF		
% H2O	17.2	%		
% Isokinetic	#VALUE!	%		
DCL	0.0003	grains/SCF		
DCL - Metric	0.0006	grams/SCM = grains/SCF*2.288		
DUST LOADING CALCULATIONS (Concentration Basis)				
Inlet DCL			0.0045	grains/SCF
% Efficiency = (Inlet DCL - Outlet DCL) * 100			93.7531	%
Inlet DCL				
Pipe Area				ft2
ACFM = VS * Pipe Area (ft2)			0.0000	ACFM
SCFM = ACFM * PS/TS * 17.64			0.0	SCFM
lbs/hour = grains/scf * 0.000143 * SCFM * 60			0.0000	lbs/hour

Equations		
Page 1		
PS (Stack Pressure)	=PB + (PS in H2O / 13.6) - elevation/1000	in. Hg Abs.
TS (Stack Temperature)	=average TS oF + 460	oR
VS (Stack Velocity)ft/min	=60*85.49 * Cp * sqrt(P * TS oR / PS in Hg Abs / MS)	ft/min
MS	=30 * (1-%H2O/100) + 18 * %H2O/100	g/mol
QN (Nozzle Flow Rate)	=VS * pi * DN2 / 576	ACFM
QM (Meter Flow Rate)	=QN * TM * PS in Hg Abs/(Cm * TS oR * (HM /13.6)) - (1-%H2O/100)	ACFM
H (orifice)	=QM2 * H@ * (PB + HM /13.6)/(0.03175 * (TM + 460))	in H2O
Seconds/Rev	=1/(QM / 0.1 / 60)	
Page 2		
VWstd	=0.04707 * (H2O g)	SCF
VMstd	=17.64 * VWstd * Cm * (PB+ HM /13.6 - Elevation/1000)	SCF
VTstd	=VWstd + VMstd	SCF
% H2O	=(VWstd / VTstd) * 100	%
% Isokinetic	= 0.0945 * TS oR * VMstd * 60 sec/min * 144 in2/ft2 (PS in Hg Abs * VS * (DN2/4*pi) * time min * (1-%H2O/100)	%
DCL	=15.43 * (dust g) / VMstd	grains/SCF
% Efficiency	=(Inlet DCL - Outlet DCL) / Inlet DCL * 100	%
ACFM	=VS * Pipe Area (ft2)	ACFM
SCFM	=ACFM * PS / TS * 17.64	SCFM
lbs/hour	=grains/SCF * 0.000143 * SCFM * 60 min/hr	lbs/hour
PPM Calculation		
PPM	=Conc mg/L * Vol mL * L/1000 mL * 2.205e-6 lb/mg * 387 ft3/mol / VTstd * e6	
Stack Vel ft./sec.	Vs=85.49*Cp*SQRT Dp*SQRT(Ts/Ps/Mw)	
Mol Wt. Wet	Mw=30*(1-Bws)+18*Bws	

ID			
Run #			
Start Time			
Fund #			
Vt Std			ft ³
Volume of Sample			mL
Concentration			mg/L or ppm
Molecular Weight			g/mole
Molecular Weights (g/mole)			
SO3	80.06		
SO2	64.06		
NH3	17.04		
Cl2	70.90		
HCl	36.46		
F2	38.00		
HF	20.02		
Hg	200.59		
#DIV/0!	ppm in flue gas		
387 ft ³ /mol at 68oF			

DATE	ID	SAMPLE PORT	SAMPLER	START TIME	TEST TIME	BARO PRESS (in Hg)	STACK PRESS (in H2O)	TEMP (F)	O2%	ΔP	NOZ DIA	GAS METER VOL (cf)	TOTAL H2O	TOTAL DUST	VMSTD (SCF)	VTSTD	% H2O	METER TEMP	ΔH	% ISO	DLC GRAINS/SCF
6/30/2011	KEETAC-BHOUT-MSBH	OUT DYN LG	RS	16:08	180	28.05	-7.2	216	15.9	0.16	0.280	80.427	339.3	0.0014	76.845	92.816	17.2	79	0.53	#VALUE!	0.0003

OPERATORS		RS									
ID		KEETAC-BHOUT-M5-5			Vwstd	14.629	SCF				
RUN #					Vmstd	76.326	SCF				
DATE		6/30/2011			Vtstd	90.955	SCF				
TIME		9:35			% H2O	16.1	%				
FUND #		15726			% Isokin	103.3	%				
DUST LOADING DATA SHEET					DCL	0.0004	grains/SCF				
Sample Pt.		BH OUT DWN LG									
Traverse Pt.		3' BIN			Ps =	27.59	in. Hg Abs.				
Pb (Barometric Press.)		28.11	in Hg		Ts =	676	*R				
Elevation correction		5 ft (1 in Hg / 1000 ft)									
Ps (Stack Pressure)		-7.0		in H2O	VS (Stack Velocity)		1611	ft/min			
Dn (Nozzle Diam.)		0.280		in	QN (Nozzle Flow Rate)		0.6887	ACFM			
Est. ΔP (Pitot)		0.16		in H2O	QM (Meter Flow Rate)		0.4264	ACFM			
Cm		1.040			ΔH (orifice)		0.48	in H2O			
Cp		0.84 (Type S=.84, Std=.99)			Seconds/Rev		14.1				
Est. Ts (Stack Temp)		216		*F							
Est. % H2O		16				O2 %	17.2				
ΔH@		1.57				CO ppm	3				
Tm (Est)		70		*F		NO ppm	101				
ΔH (Est)		0.60		in Hg		NO2 ppm	0				
						SO2 ppm	7				
						CO2 %					
						coal CO2=18.6*(21-02%)/21					
<i>Note: Standard Temperature and Pressure are 68 oF and 29.92 in. Hg</i>											
Time (min.)	Temp stack	Gas Meter (ft3)	Tm Inlet	Tm Outlet	ΔH	ΔP Pitot	Pump Vac in Hg	MUFF	Temp Box	Temp Impinger	
0	216	230.378	70	69	0.48	0.16	2.0	251		OK	
15	216	236.620	71	67	0.48	0.16	2.0	247		OK	
30	216	243.140	71	65	0.51	0.16	2.0	249		OK	
45	216	249.670	72	65	0.51	0.16	2.0	247		OK	
60	216	256.220	72	67	0.51	0.16	2.0	254		OK	
75	216	262.720	72	66	0.51	0.16	2.0	256		OK	
90	216	268.920	71	67	0.51	0.16	2.0	248		OK	
105	216	275.750	73	67	0.51	0.16	2.0	247		OK	
120	216	282.390	73	68	0.51	0.16	2.1	253		OK	
135	216	288.900	75	69	0.51	0.16	2.1	248		OK	
150	216	295.440	73	69	0.51	0.16	2.2	250		OK	
165	216	302.000	76	70	0.51	0.16	2.2	254		OK	
180	216	308.754	75	71	0.51	0.16	2.2	255		OK	
Averages:	216	78.376	70		0.51	0.16	2.1	251	#DIV/0!	#DIV/0!	
Comments	Leak ck OK										

Sample Pt.	BH OUT DWN LG		Date	6/30/2011
			Run #	0
Train Type			Fund #	15726
			Cost Center #	
STOPPER TYPE	TYPE OF SOLUTION	INITIAL WT. (g)	FINAL WT. (g)	NET WT. (g)
Straight	DI	788.5	996.4	207.9
Straight	DI	641.5	721.3	79.8
Impinger	DRY	668.3	673.8	5.5
Straight	SIL GEL	981.8	999.4	17.6
Straight				0.0
Straight				0.0
Impinger				0.0
Straight				0.0
			TOTAL H2O (g)	310.8
FILTER		0.23657	0.23741	0.00084
		0.79765	0.79902	0.00137
Additional Dust				0.00000
			TOTAL DUST (g)	0.00221
Vwstd	14.629	SCF		
Vmstd	76.326	SCF		
Vtstd	90.955	SCF		
% H2O	16.1	%		
% Isokinetic	103.3	%		
DCL	0.0004	grains/SCF		
DCL - Metric	0.0010	grams/SCM = grains/SCF*2.288		
DUST LOADING CALCULATIONS (Concentration Basis)				
Inlet DCL			0.0040	grains/SCF
% Efficiency = (Inlet DCL - Outlet DCL) * 100			88.8307	%
Inlet DCL				
Pipe Area				ft2
ACFM = VS * Pipe Area (ft2)			0.0000	ACFM
SCFM = ACFM * PS/TS * 17.64			0.0	SCFM
lbs/hour = grains/scf * 0.000143 * SCFM * 60			0.0000	lbs/hour

Equations		
Page 1		
PS (Stack Pressure)	=PB + (PS in H2O / 13.6) - elevation/1000	in. Hg Abs.
TS (Stack Temperature)	=average TS oF + 460	oR
VS (Stack Velocity)ft/min	=60*85.49 * Cp * sqrt(P * TS oR / PS in Hg Abs / MS)	ft/min
MS	=30 * (1-%H2O/100) + 18 * %H2O/100	g/mol
QN (Nozzle Flow Rate)	=VS * pi * DN2 / 576	ACFM
QM (Meter Flow Rate)	=QN * TM * PS in Hg Abs/(Cm * TS oR * (HM /13.6)) - (1-%H2O/100)	ACFM
H (orifice)	=QM2 * H@ * (PB + HM /13.6)/(0.03175 * (TM + 460))	in H2O
Seconds/Rev	=1/(QM / 0.1 / 60)	
Page 2		
VWstd	=0.04707 * (H2O g)	SCF
VMstd	=17.64 * VWstd * Cm * (PB+ HM /13.6 - Elevation/1000)	SCF
VTstd	=VWstd + VMstd	SCF
% H2O	=(VWstd / VTstd) * 100	%
% Isokinetic	= 0.0945 * TS oR * VMstd * 60 sec/min * 144 in2/ft2 (PS in Hg Abs * VS * (DN2/4*pi) * time min * (1-%H2O/100))	%
DCL	=15.43 * (dust g) / VMstd	grains/SCF
% Efficiency	=(Inlet DCL - Outlet DCL) / Inlet DCL * 100	%
ACFM	=VS * Pipe Area (ft2)	ACFM
SCFM	=ACFM * PS / TS * 17.64	SCFM
lbs/hour	=grains/SCF * 0.000143 * SCFM * 60 min/hr	lbs/hour
PPM Calculation		
PPM	=Conc mg/L * Vol mL * L/1000 mL * 2.205e-6 lb/mg * 387 ft3/mol / VTstd * e6	
Stack Vel ft./sec.	Vs=85.49*Cp*SQRT Dp*SQRT(Ts/Ps/Mw)	
Mol Wt. Wet	Mw=30*(1-Bws)+18*Bws	

ID			
Run #			
Start Time			
Fund #			
Vt Std			ft^3
Volume of Sample			mL
Concentration			mg/L or ppm
Molecular Weight			g/mole
Molecular Weights (g/mole)			
SO3	80.06		
SO2	64.06		
NH3	17.04		
Cl2	70.90		
HCl	36.46		
F2	38.00		
HF	20.02		
Hg	200.59		
#DIV/0!	ppm in flue gas		
387 ft3/mol at 68oF			

DATE	ID	SAMPLE PORT	SAMPLER	START TIME	TEST TIME	BARO PRESS (in Hg)	STACK PRESS (in H2O)	TEMP (F)	O2%	ΔP	NOZ DIA	GAS METER VOL (cf)	TOTAL H2O	TOTAL DUST	VMSTD (SCF)	% H2O	METER TEMP	ΔH	% ISO	DLC GRAINS/SCF	
6/30/2011	KEETAC-BHOUT-MS9H	OUT DWN LG	RS	9:35	180	28.11	-7	216	17.2	0.16	0.280	78.376	310.8	0.00221	76.326	90.955	15.1	70	0.51	103.3	0.0004

Sample Pt.	BH OUT DWN LG		Date	6/20/2011
			Run #	0
Train Type			Fund #	15726
			Cost Center #	
STOPPER TYPE	TYPE OF SOLUTION	INITIAL WT. (g)	FINAL WT. (g)	NET WT. (g)
Straight	DI	801.1	965.8	164.7
Straight	DI	641.3	665.1	23.8
Impinger	DRY	668.0	671.5	3.5
Straight	SIL GEL	970.7	981.9	11.2
Straight				0.0
Straight				0.0
Impinger				0.0
Straight				0.0
			TOTAL H2O (g)	203.2
FILTER		0.23764	0.23956	0.00192
		0.79651	0.79767	0.00116
Additional Dust				0.00000
			TOTAL DUST (g)	0.00308
Vwstd	9.565	SCF		
Vmstd	50.122	SCF		
Vtstd	59.687	SCF		
% H2O	16.0	%		
% Isokinetic	100.5	%		
DCL	0.0009	grains/SCF		
DCL - Metric	0.0022	grams/SCM = grains/SCF*2.288		
DUST LOADING CALCULATIONS (Concentration Basis)				
Inlet DCL			0.0022	grains/SCF
% Efficiency = (Inlet DCL - Outlet DCL) * 100 Inlet DCL			56.9011	%
Pipe Area				ft2
ACFM = VS * Pipe Area (ft2)			0.0000	ACFM
SCFM = ACFM * PS/TS * 17.64			0.0	SCFM
lbs/hour = grains/scf * 0.000143 * SCFM * 60			0.0000	lbs/hour

Equations		
Page 1		
PS (Stack Pressure)	=PB + (PS in H2O / 13.6) - elevation/1000	in. Hg Abs.
TS (Stack Temperature)	=average TS oF + 460	oR
VS (Stack Velocity)ft/min	=60*85.49 * Cp * sqrt(P * TS oR / PS in Hg Abs / MS)	ft/min
MS	=30 * (1-%H2O/100) + 18 * %H2O/100	g/mol
QN (Nozzle Flow Rate)	=VS * pi * DN2 / 576	ACFM
QM (Meter Flow Rate)	=QN * TM * PS in Hg Abs/(Cm * TS oR * (HM /13.6)) - (1-%H2O/100)	ACFM
H (orifice)	=QM2 * H@ * (PB + HM /13.6)/(0.03175 * (TM + 460))	in H2O
Seconds/Rev	=1/(QM / 0.1 / 60)	
Page 2		
VWstd	=0.04707 * (H2O g)	SCF
VMstd	=17.64 * VWstd * Cm * (PB+ HM /13.6 - Elevation/1000)	SCF
VTstd	=VWstd + VMstd	SCF
% H2O	=(VWstd / VTstd) * 100	%
% Isokinetic	= 0.0945 * TS oR * VMstd * 60 sec/min * 144 in2/ft2 (PS in Hg Abs * VS * (DN2/4*pi) * time min * (1-%H2O/100)	%
DCL	=15.43 * (dust g) / VMstd	grains/SCF
% Efficiency	=(Inlet DCL - Outlet DCL) / Inlet DCL * 100	%
ACFM	=VS * Pipe Area (ft2)	ACFM
SCFM	=ACFM * PS / TS * 17.64	SCFM
lbs/hour	=grains/SCF * 0.000143 * SCFM * 60 min/hr	lbs/hour
PPM Calculation		
PPM	=Conc mg/L * Vol mL * L/1000 mL * 2.205e-6 lb/mg * 387 ft3/mol / VTstd * e6	
Stack Vel ft./sec.	Vs=85.49*Cp*SQRT Dp*SQRT(Ts/Ps/Mw)	
Mol Wt. Wet	Mw=30*(1-Bws)+18*Bws	

ID			
Run #			
Start Time			
Fund #			
Vt Std			ft ³
Volume of Sample			mL
Concentration			mg/L or ppm
Molecular Weight			g/mole
Molecular Weights (g/mole)			
SO3	80.06		
SO2	64.06		
NH3	17.04		
Cl2	70.90		
HCl	36.46		
F2	38.00		
HF	20.02		
Hg	200.59		
#DIV/0!	ppm in flue gas		
387 ft ³ /mol at 68oF			

DATE	ID	SAMPLE PORT	SAMPLER	START TIME	TEST TIME	BARO PRESS (in Hg)	STACK PRESS (in H2O)	TEMP (F)	O2%	ΔP	NOZ DIA	METER VOL (cf)	GAS METER VOL (cf)	TOTAL H2O	TOTAL DUST	VMSTD (SCF)	VTSTD (SCF)	% H2O	METER TEMP	ΔH	% ISO	DLC GRAINS/SCF
6/20/2011	KEETAC-BHOUT-M5BH	OUT DWN LG	RS	13:41	120	28.17	-4.6	224	17.9	0.16	0.280	50.824	50.824	203.2	0.00308	50.122	59.667	16.0	65	0.49	100.5	0.0009

Sample Pt.	BH OUT DWN LG		Date	6/17/2011
			Run #	0
Train Type			Fund #	15726
			Cost Center #	
STOPPER TYPE	TYPE OF SOLUTION	INITIAL WT. (g)	FINAL WT. (g)	NET WT. (g)
Straight	KCl	838.8	1009.9	171.1
Straight	KCl	637.6	662.4	24.8
Impinger	KCl	616.1	623.8	7.7
Straight	H2O2	986.0	996.7	10.7
Straight	KMnO4			0.0
Straight	KMnO4			0.0
Impinger	KMnO4			0.0
Straight	Silica Gel			0.0
			TOTAL H2O (g)	214.3
FILTER		0.24222	0.24357	0.00135
				0.00000
Additional Dust		0.79573	0.79643	0.00070
			TOTAL DUST (g)	0.00205
Vwstd	10.087	SCF		
Vmstd	51.992	SCF		
Vtstd	62.079	SCF		
% H2O	16.2	%		
% Isokinetic	104.2	%		
DCL	0.0006	grains/SCF		
DCL - Metric	0.0014	grams/SCM = grains/SCF*2.288		
DUST LOADING CALCULATIONS (Concentration Basis)				
Inlet DCL			0.0027	grains/SCF
% Efficiency = (Inlet DCL - Outlet DCL) * 100 / Inlet DCL			77.4670	%
Pipe Area				ft2
ACFM = VS * Pipe Area (ft2)			0.0000	ACFM
SCFM = ACFM * PS/TS * 17.64			0.0	SCFM
lbs/hour = grains/scf * 0.000143 * SCFM * 60			0.0000	lbs/hour

Equations		
Page 1		
PS (Stack Pressure)	=PB + (PS in H2O / 13.6) - elevation/1000	in. Hg Abs.
TS (Stack Temperature)	=average TS oF + 460	oR
VS (Stack Velocity)ft/min	=60*85.49 * Cp * sqrt(P * TS oR / PS in Hg Abs / MS)	ft/min
MS	=30 * (1-%H2O/100) + 18 * %H2O/100	g/mol
QN (Nozzle Flow Rate)	=VS * pi * DN2 / 576	ACFM
QM (Meter Flow Rate)	=QN * TM * PS in Hg Abs/(Cm * TS oR * (HM /13.6)) - (1-%H2O/100)	ACFM
H (orifice)	=QM2 * H@ * (PB + HM /13.6)/(0.03175 * (TM + 460))	in H2O
Seconds/Rev	=1/(QM / 0.1 / 60)	
Page 2		
VWstd	=0.04707 * (H2O g)	SCF
VMstd	=17.64 * VWstd * Cm * (PB+ HM /13.6 - Elevation/1000)	SCF
VTstd	=VWstd + VMstd	SCF
% H2O	=(VWstd / VTstd) * 100	%
% Isokinetic	= 0.0945 * TS oR * VMstd * 60 sec/min * 144 in2/ft2 (PS in Hg Abs * VS * (DN2/4*pi) * time min * (1-%H2O/100)	%
DCL	=15.43 * (dust g) / VMstd	grains/SCF
% Efficiency	=(Inlet DCL - Outlet DCL) / Inlet DCL * 100	%
ACFM	=VS * Pipe Area (ft2)	ACFM
SCFM	=ACFM * PS / TS * 17.64	SCFM
lbs/hour	=grains/SCF * 0.000143 * SCFM * 60 min/hr	lbs/hour
PPM Calculation		
PPM	=Conc mg/L * Vol mL * L/1000 mL * 2.205e-6 lb/mg * 387 ft3/mol / VTstd * e6	
Stack Vel ft./sec.	Vs=85.49*Cp*SQRT Dp*SQRT(Ts/Ps/Mw)	
Mol Wt. Wet	Mw=30*(1-Bws)+18*Bws	

ID			
Run #			
Start Time			
Fund #			
Vt Std			ft ³
Volume of Sample			mL
Concentration			mg/L or ppm
Molecular Weight			g/mole
Molecular Weights (g/mole)			
SO3	80.06		
SO2	64.06		
NH3	17.04		
Cl2	70.90		
HCl	36.46		
F2	38.00		
HF	20.02		
Hg	200.59		
#DIV/0!	ppm in flue gas		
387 ft ³ /mol at 68oF			

DATE	ID	SAMPLE PORT	SAMPLER	START TIME	TEST TIME	BARO PRESS (in Hg)	STACK PRESS (in H2O)	TEMP (F)	O2%	ΔP	NOZ DIA	GAS METER VOL (cf)	TOTAL H2O	TOTAL DUST	VTSTD (SCF)	% H2O	METER TEMP	ΔH	% ISO	DLC GRAINS/SCF	
6/7/2011	KEETAC-BHOUT-MESH	OUT DWN LG	RS	0:00	1:20	28.20	-3	224	17.9	0.16	0.280	53.300	214.3	0.00205	51.992	62.079	16.2	71	0.53	104.2	0.0008

OPERATORS		RS									
ID	KEETAC-BHIN-M5-6-2					Vwstd	16.296	SCF			
RUN #	2					Vmstd	78.373	SCF			
DATE	6/30/2011					Vtstd	94.669	SCF			
TIME	16:17					% H2O	17.2	%			
FUND #	15726					% Isokin	101.1	%			
DUST LOADING DATA SHEET						DCL	0.0045	grains/SCF			
Sample Pt.	BHIN DWN LG										
Traverse Pt.	3' IN					Ps =	28.02	in. Hg Abs.			
Pb (Barometric Press.)	28.05 in Hg					Ts =	626	°R			
Elevation correction	20 ft (1 in Hg / 1000 ft)										
Ps (Stack Pressure)	-0.2 in H2O					VS (Stack Velocity)		1538	ft/min		
Dn (Nozzle Diam.)	0.280 in					QN (Nozzle Flow Rate)		0.6577	ACFM		
Est. ΔP (Pitot)	0.16 in H2O					QM (Meter Flow Rate)		0.4654	ACFM		
Cm	1.010					ΔH (orifice)		0.52	in H2O		
Cp	0.84 (Type S=.84, Std=.99)					Seconds/Rev		12.9			
Est. Ts (Stack Temp)	166 °F										
Est. % H2O	16					O2 %		16.8			
ΔH@	1.46					CO ppm		3			
Tm (Est)	75 °F					NO ppm		85			
ΔH (Est)	0.60 in Hg					NO2 ppm		3			
						SO2 ppm		10			
						CO2 %					
						coal CO2=18.6*(21-02%)/21					
<i>Note: Standard Temperature and Pressure are 68 oF and 29.92 in. Hg</i>											
Time (min.)	Temp stack	Gas Meter (ft3)	Tm Inlet	Tm Outlet	ΔH	ΔP Pitot	Pump Vac in Hg	Temp Probe	Temp Box	Temp Impinger	
0	166	288.248	75	75	0.52	0.16	3.0	248		OK	
15	166	295.740	78	75	0.53	0.16	3.0	251		OK	
30	166	302.650	80	76	0.54	0.16	3.0	250		OK	
45	166	309.760	81	77	0.54	0.16	3.0	249		OK	
60	166	316.720	82	78	0.54	0.16	3.5	249		OK	
75	166	323.730	83	78	0.54	0.16	4.0	252		OK	
90	166	330.750	82	79	0.54	0.16	4.5	260		OK	
105	166	337.790	82	78	0.54	0.16	5.0	260		OK	
120	166	344.830	83	79	0.54	0.16	5.5	258		OK	
135	166	351.750	83	79	0.54	0.16	5.5	254		OK	
150	166	358.740	81	78	0.54	0.16	5.5	249		OK	
165	166	365.760	81	78	0.54	0.16	6.0	250		OK	
180	166	372.742	80	77	0.54	0.16	6.0	250		OK	
Averages:	166	84.494	79		0.54	0.16	4.4	252	#DIV/0!	#DIV/0!	
Comments	Leak ck OK										

Sample Pt.	BHIN DWN LG		Date	6/30/2011
			Run #	2
Train Type			Fund #	15726
			Cost Center #	
STOPPER TYPE	TYPE OF SOLUTION	INITIAL WT. (g)	FINAL WT. (g)	NET WT. (g)
Straight	DI	802.2	1014.3	212.1
Straight	DI	641.7	739.7	98.0
Impinger	DRY	618.4	627.4	9.0
Straight	SIL GEL	993.5	1020.6	27.1
Straight				0.0
Straight				0.0
Impinger				0.0
Straight	Silica Gel			0.0
			TOTAL H2O (g)	346.2
FILTER		0.24493	0.26753	0.02260
		0.74182	0.74194	0.00012
Additional Dust				0.00000
			TOTAL DUST (g)	0.02272
Vwstd	16.296	SCF		
Vmstd	78.373	SCF		
Vtstd	94.669	SCF		
% H2O	17.2	%		
% Isokinetic	101.1	%		
DCL	0.0045	grains/SCF		
DCL - Metric	0.0102	grams/SCM = grains/SCF*2.288		
DUST LOADING CALCULATIONS (Concentration Basis)				
Inlet DCL				grains/SCF
% Efficiency = (Inlet DCL - Outlet DCL) * 100			#DIV/0!	%
Inlet DCL				
Pipe Area				ft2
ACFM = VS * Pipe Area (ft2)			0.0000	ACFM
SCFM = ACFM * PS/TS * 17.64			0.0	SCFM
lbs/hour = grains/scf * 0.000143 * SCFM * 60			0.0000	lbs/hour

Equations		
Page 1		
PS (Stack Pressure)	=PB + (PS in H2O / 13.6) - elevation/1000	in. Hg Abs.
TS (Stack Temperature)	=average TS oF + 460	oR
VS (Stack Velocity)ft/min	=60*85.49 * Cp * sqrt(P * TS oR / PS in Hg Abs / MS)	ft/min
MS	=30 * (1-%H2O/100) + 18 * %H2O/100	g/mol
QN (Nozzle Flow Rate)	=VS * pi * DN2 / 576	ACFM
QM (Meter Flow Rate)	=QN * TM * PS in Hg Abs/(Cm * TS oR * (HM /13.6)) - (1-%H2O/100)	ACFM
H (orifice)	=QM2 * H@ * (PB + HM /13.6)/(0.03175 * (TM + 460))	in H2O
Seconds/Rev	=1/(QM / 0.1 / 60)	
Page 2		
VWstd	=0.04707 * (H2O g)	SCF
VMstd	=17.64 * VWstd * Cm * (PB+ HM /13.6 - Elevation/1000)	SCF
VTstd	=VWstd + VMstd	SCF
% H2O	=(VWstd / VTstd) * 100	%
% Isokinetic	= 0.0945 * TS oR * VMstd * 60 sec/min * 144 in2/ft2 (PS in Hg Abs * VS * (DN2/4*pi) * time min * (1-%H2O/100)	%
DCL	=15.43 * (dust g) / VMstd	grains/SCF
% Efficiency	=(Inlet DCL - Outlet DCL) / Inlet DCL * 100	%
ACFM	=VS * Pipe Area (ft2)	ACFM
SCFM	=ACFM * PS / TS * 17.64	SCFM
lbs/hour	=grains/SCF * 0.000143 * SCFM * 60 min/hr	lbs/hour
PPM Calculation		
PPM	=Conc mg/L * Vol mL * L/1000 mL * 2.205e-6 lb/mg * 387 ft3/mol / VTstd * e6	
Stack Vel ft./sec.	Vs=85.49*Cp*SQRT Dp*SQRT(Ts/Ps/Mw)	
Mol Wt. Wet	Mw=30*(1-Bws)+18*Bws	

ID			
Run #			
Start Time			
Fund #			
Vt Std			ft ³
Volume of Sample			mL
Concentration			mg/L or ppm
Molecular Weight			g/mole
Molecular Weights (g/mole)			
SO3	80.06		
SO2	64.06		
NH3	17.04		
Cl2	70.90		
HCl	36.46		
F2	38.00		
HF	20.02		
Hg	200.59		
#DIV/0!	ppm in flue gas		
387 ft ³ /mol at 68oF			

DATE	ID	SAMPLE PORT	SAMPLER	START TIME	TEST TIME	BARO PRESS (in Hg)	STACK PRESS (in H2O)	TEMP (F)	O2%	ΔP	NOZ DIA	GAS METER VOL (cf)	TOTAL H2O	TOTAL DUST	VMSTD (SCF)	VTSTD (SCF)	% H2O	METER TEMP	ΔH	ISO	DLC GRAINS/SCF
6/30/2011	KEETAC-BHIN-M5-6	BHIN DWN LG	RS	16:17	180	28.05	-0.2	166	16.8	0.16	0.280	84.494	346.2	0.02272	78.373	94.669	17.2	79	0.54	101.1	0.0045

OPERATORS		RS									
ID		KEETAC-BHIN-M5-5			Vwstd	14.813	SCF				
RUN #					Vmstd	77.207	SCF				
DATE		6/30/2011			Vtstd	92.020	SCF				
TIME		9:43			% H2O	16.1	%				
FUND #		15726			% Isokin	98.3	%				
DUST LOADING DATA SHEET					DCL	0.0040	grains/SCF				
Sample Pt.		BHIN DWN LG									
Traverse Pt.		3' IN			Ps =	28.07	in. Hg Abs.				
Pb (Barometric Press.)		28.11	in Hg		Ts =	625	°R				
Elevation correction		20 ft (1 in Hg / 1000 ft)									
Ps (Stack Pressure)		-0.3 in H2O			VS (Stack Velocity)		1535	ft/min			
Dn (Nozzle Diam.)		0.280 in			QN (Nozzle Flow Rate)		0.6566	ACFM			
Est. ΔP (Pitot)		0.16 in H2O			QM (Meter Flow Rate)		0.4565	ACFM			
Cm		1.010			ΔH (orifice)		0.51	in H2O			
Cp		0.84 (Type S=.84, Std=.99)			Seconds/Rev		13.1				
Est. Ts (Stack Temp)		165 °F									
Est. % H2O		16			O2 %		17.1				
ΔH@		1.46			CO ppm		3				
Tm (Est)		65 °F			NO ppm		102				
ΔH (Est)		0.60 in Hg			NO2 ppm		0				
					SO2 ppm		8				
					CO2 %						
					coal CO2=18.6*(21-02%)/21						
<i>Note: Standard Temperature and Pressure are 68 oF and 29.92 in. Hg</i>											
Time (min.)	Temp stack	Gas Meter (ft3)	Tm Inlet	Tm Outlet	ΔH	ΔP Pitot	Pump Vac in Hg	Temp Probe	Temp Box	Temp Impinger	
0	165	206.629	64	65	0.51	0.16	2.0	251		OK	
15	165	213.240	67	64	0.52	0.16	2.0	251		OK	
30	165	219.980	69	65	0.52	0.16	2.0	250		OK	
45	165	226.770	71	66	0.52	0.16	2.0	250		OK	
60	165	233.560	72	67	0.52	0.16	2.5	250		OK	
75	165	240.330	71	67	0.52	0.16	3.0	253		OK	
90	165	247.130	72	68	0.52	0.16	3.0	249		OK	
105	165	253.890	73	69	0.52	0.16	3.5	251		OK	
120	165	260.850	73	69	0.52	0.16	3.5	249		OK	
135	165	267.670	73	69	0.52	0.16	4.0	251		OK	
150	165	274.480	74	69	0.52	0.16	4.5	249		OK	
165	165	281.42	75	70	0.52	0.16	5	252		OK	
180	165	288.217	76	71	0.52	0.16	5.5	251		OK	
Averages:	165	81.588	70		0.52	0.16	3.3	251	#DIV/0!	#DIV/0!	
Comments	Leak check OK										

Sample Pt.	BHIN DWN LG		Date	6/30/2011
			Run #	0
Train Type			Fund #	15726
			Cost Center #	
STOPPER TYPE	TYPE OF SOLUTION	INITIAL WT. (g)	FINAL WT. (g)	NET WT. (g)
Straight	DI	821.7	1025.0	203.3
Straight	DI	640.5	724.2	83.7
Impinger	DRY	618.5	626.0	7.5
Straight	SIL GEL	980.5	1000.7	20.2
Straight				0.0
Straight				0.0
Impinger				0.0
Straight	Silica Gel			0.0
			TOTAL H2O (g)	314.7
FILTER		0.23651	0.25662	0.02011
		0.74168	0.74182	0.00014
Additional Dust				0.00000
			TOTAL DUST (g)	0.02025
Vwstd	14.813	SCF		
Vmstd	77.207	SCF		
Vtstd	92.020	SCF		
% H2O	16.1	%		
% Isokinetic	98.3	%		
DCL	0.0040	grains/SCF		
DCL - Metric	0.0093	grams/SCM = grains/SCF*2.288		
DUST LOADING CALCULATIONS (Concentration Basis)				
Inlet DCL				grains/SCF
% Efficiency = (Inlet DCL - Outlet DCL) * 100 Inlet DCL			#DIV/0!	%
Pipe Area				ft2
ACFM = VS * Pipe Area (ft2)			0.0000	ACFM
SCFM = ACFM * PS/TS * 17.64			0.0	SCFM
lbs/hour = grains/scf * 0.000143 * SCFM * 60			0.0000	lbs/hour

Equations		
Page 1		
PS (Stack Pressure)	=PB + (PS in H2O / 13.6) - elevation/1000	in. Hg Abs.
TS (Stack Temperature)	=average TS oF + 460	oR
VS (Stack Velocity)ft/min	=60*85.49 * Cp * sqrt(P * TS oR / PS in Hg Abs / MS)	ft/min
MS	=30 * (1-%H2O/100) + 18 * %H2O/100	g/mol
QN (Nozzle Flow Rate)	=VS * pi * DN2 / 576	ACFM
QM (Meter Flow Rate)	=QN * TM * PS in Hg Abs/(Cm * TS oR * (HM /13.6)) - (1-%H2O/100)	ACFM
H (orifice)	=QM2 * H@ * (PB + HM /13.6)/(0.03175 * (TM + 460))	in H2O
Seconds/Rev	=1/(QM / 0.1 / 60)	
Page 2		
VWstd	=0.04707 * (H2O g)	SCF
VMstd	=17.64 * VWstd * Cm * (PB+ HM /13.6 - Elevation/1000)	SCF
VTstd	=VWstd + VMstd	SCF
% H2O	=(VWstd / VTstd) * 100	%
% Isokinetic	= 0.0945 * TS oR * VMstd * 60 sec/min * 144 in2/ft2 (PS in Hg Abs * VS * (DN2/4*pi) * time min * (1-%H2O/100)	%
DCL	=15.43 * (dust g) / VMstd	grains/SCF
% Efficiency	=(Inlet DCL - Outlet DCL) / Inlet DCL * 100	%
ACFM	=VS * Pipe Area (ft2)	ACFM
SCFM	=ACFM * PS / TS * 17.64	SCFM
lbs/hour	=grains/SCF * 0.000143 * SCFM * 60 min/hr	lbs/hour
PPM Calculation		
PPM	=Conc mg/L * Vol mL * L/1000 mL * 2.205e-6 lb/mg * 387 ft3/mol / VTstd * e6	
Stack Vel ft./sec.	Vs=85.49*Cp*SQRT Dp*SQRT(Ts/Ps/Mw)	
Mol Wt. Wet	Mw=30*(1-Bws)+18*Bws	

ID			
Run #			
Start Time			
Fund #			
Vt Std			ft ³
Volume of Sample			mL
Concentration			mg/L or ppm
Molecular Weight			g/mole
Molecular Weights (g/mole)			
SO3	80.06		
SO2	64.06		
NH3	17.04		
Cl2	70.90		
HCl	36.46		
F2	38.00		
HF	20.02		
Hg	200.59		
#DIV/0!	ppm in flue gas		
387 ft ³ /mol at 68oF			

DATE	ID	SAMPLE PORT	SAMPLER	START TIME	TEST TIME	BARO		STACK		NOZ DIA	GAS		VTSTD	% H2O	METER TEMP	DLC					
						PRESS (In Hg)	PRESS (In H2O)	TEMP (F)	TEMP (F)		METER VOL (cf)	TOTAL H2O					TOTAL DUST	VMSTD (SCF)	% ISO	GRAINS/SCF	
6/30/2011	KEETAC-BHIN-M5-5	BHIN DWN LG	RS	9:43	180	28.11	-0.3	165	17.1	0.16	0.280	81.588	314.7	0.02025	77.207	92.020	16.1	70	0.52	98.3	0.0040

Sample Pt.	DWN LG BHIN		Date	6/20/2011
			Run #	0
Train Type			Fund #	15726
			Cost Center #	
STOPPER TYPE	TYPE OF SOLUTION	INITIAL WT. (g)	FINAL WT. (g)	NET WT. (g)
Straight	DI	811.1	980.1	169.0
Straight	DI	640.4	666.2	25.8
Impinger	DRY	618.2	623.8	5.6
Straight	SIL GEL	969.3	980.7	11.4
Straight				0.0
Straight				0.0
Impinger				0.0
Straight	Silica Gel			0.0
			TOTAL H2O (g)	211.8
FILTER		0.23076	0.23762	0.00686
		0.74072	0.74139	0.00067
Additional Dust				0.00000
			TOTAL DUST (g)	0.00753
Vwstd	9.969	SCF		
Vmstd	52.138	SCF		
Vtstd	62.107	SCF		
% H2O	16.1	%		
% Isokinetic	99.3	%		
DCL	0.0022	grains/SCF		
DCL - Metric	0.0051	grams/SCM = grains/SCF*2.288		
DUST LOADING CALCULATIONS (Concentration Basis)				
Inlet DCL				grains/SCF
% Efficiency = (Inlet DCL - Outlet DCL) * 100			#DIV/0!	%
Inlet DCL				
Pipe Area				ft2
ACFM = VS * Pipe Area (ft2)			0.0000	ACFM
SCFM = ACFM * PS/TS * 17.64			0.0	SCFM
lbs/hour = grains/scf * 0.000143 * SCFM * 60			0.0000	lbs/hour

Equations		
Page 1		
PS (Stack Pressure)	=PB + (PS in H2O / 13.6) - elevation/1000	in. Hg Abs.
TS (Stack Temperature)	=average TS oF + 460	oR
VS (Stack Velocity)ft/min	=60*85.49 * Cp * sqrt(P * TS oR / PS in Hg Abs / MS)	ft/min
MS	=30 * (1-%H2O/100) + 18 * %H2O/100	g/mol
QN (Nozzle Flow Rate)	=VS * pi * DN2 / 576	ACFM
QM (Meter Flow Rate)	=QN * TM * PS in Hg Abs/(Cm * TS oR * (HM /13.6)) - (1-%H2O/100)	ACFM
H (orifice)	=QM2 * H@ * (PB + HM /13.6)/(0.03175 * (TM + 460))	in H2O
Seconds/Rev	=1/(QM / 0.1 / 60)	
Page 2		
VWstd	=0.04707 * (H2O g)	SCF
VMstd	=17.64 * VWstd * Cm * (PB+ HM /13.6 - Elevation/1000)	SCF
VTstd	=VWstd + VMstd	SCF
% H2O	=(VWstd / VTstd) * 100	%
% Isokinetic	= 0.0945 * TS oR * VMstd * 60 sec/min * 144 in2/ft2 (PS in Hg Abs * VS * (DN2/4*pi) * time min * (1-%H2O/100)	%
DCL	=15.43 * (dust g) / VMstd	grains/SCF
% Efficiency	=(Inlet DCL - Outlet DCL) / Inlet DCL * 100	%
ACFM	=VS * Pipe Area (ft2)	ACFM
SCFM	=ACFM * PS / TS * 17.64	SCFM
lbs/hour	=grains/SCF * 0.000143 * SCFM * 60 min/hr	lbs/hour
PPM Calculation		
PPM	=Conc mg/L * Vol mL * L/1000 mL * 2.205e-6 lb/mg * 387 ft3/mol / VTstd * e6	
Stack Vel ft./sec.	Vs=85.49*Cp*SQRT Dp*SQRT(Ts/Ps/Mw)	
Mol Wt. Wet	Mw=30*(1-Bws)+18*Bws	

ID			
Run #			
Start Time			
Fund #			
Vt Std			ft ³
Volume of Sample			mL
Concentration			mg/L or ppm
Molecular Weight			g/mole
Molecular Weights (g/mole)			
SO3	80.06		
SO2	64.06		
NH3	17.04		
Cl2	70.90		
HCl	36.46		
F2	38.00		
HF	20.02		
Hg	200.59		
#DIV/0!	ppm in flue gas		
387 ft ³ /mol at 68oF			

DATE	ID	SAMPLE PORT	SAMPLER	START TIME	TEST TIME	BARO PRESS (in Hg)	STACK PRESS (in H2O)	TEMP (F)	O2%	ΔP	NOZ DIA	GAS METER VOL (cf)	TOTAL H2O	TOTAL DUST	VMSTD (SCF)	VTSTD	% H2O	METER TEMP	ΔH	% ISO	DLC GRAINS/SCF
8/20/2011	KEETAC-BHIN-MS-4	DWN LG BHIN	RS	13:50	120	28.17	-0.15	162	17.9	0.16	0.280	54.304	211.8	0.00753	52.138	62.107	16.1	63	0.50	99.3	0.0022

Sample Pt.	BH IN DWN LG		Date	6/18/2011
			Run #	0
Train Type			Fund #	15726
			Cost Center #	
STOPPER TYPE	TYPE OF SOLUTION	INITIAL WT. (g)	FINAL WT. (g)	NET WT. (g)
Straight	KCl	854.5	1016.3	161.8
Straight	KCl	636.1	681.8	45.7
Impinger	KCl	641.3	647.9	6.6
Straight	H2O2	948.7	963.4	14.7
Straight	KMnO4			0.0
Straight	KMnO4			0.0
Impinger	KMnO4			0.0
Straight	Silica Gel			0.0
			TOTAL H2O (g)	228.8
FILTER		0.23647	0.24528	0.00881
		0.74021	0.74072	0.00051
Additional Dust		0.74021	0.74072	0.00051
			TOTAL DUST (g)	0.00983
Vwstd	10.770	SCF		
Vmstd	55.416	SCF		
Vtstd	66.186	SCF		
% H2O	16.3	%		
% Isokinetic	104.1	%		
DCL	0.0027	grains/SCF		
DCL - Metric	0.0063	grams/SCM = grains/SCF*2.288		
DUST LOADING CALCULATIONS (Concentration Basis)				
Inlet DCL			0.0060	grains/SCF
% Efficiency = (Inlet DCL - Outlet DCL) * 100			54.3678	%
Inlet DCL			76.60%	
Pipe Area				ft2
ACFM = VS * Pipe Area (ft2)			0.0000	ACFM
SCFM = ACFM * PS/TS * 17.64			0.0	SCFM
lbs/hour = grains/scf * 0.000143 * SCFM * 60			0.0000	lbs/hour

Equations		
Page 1		
PS (Stack Pressure)	=PB + (PS in H2O / 13.6) - elevation/1000	in. Hg Abs.
TS (Stack Temperature)	=average TS oF + 460	oR
VS (Stack Velocity)ft/min	=60*85.49 * Cp * sqrt(P * TS oR / PS in Hg Abs / MS)	ft/min
MS	=30 * (1-%H2O/100) + 18 * %H2O/100	g/mol
QN (Nozzle Flow Rate)	=VS * pi * DN2 / 576	ACFM
QM (Meter Flow Rate)	=QN * TM * PS in Hg Abs/(Cm * TS oR * (HM /13.6)) - (1-%H2O/100)	ACFM
H (orifice)	=QM2 * H@ * (PB + HM /13.6)/(0.03175 * (TM + 460))	in H2O
Seconds/Rev	=1/(QM / 0.1 / 60)	
Page 2		
VWstd	=0.04707 * (H2O g)	SCF
VMstd	=17.64 * VWstd * Cm * (PB+ HM /13.6 - Elevation/1000)	SCF
VTstd	=VWstd + VMstd	SCF
% H2O	=(VWstd / VTstd) * 100	%
% Isokinetic	= 0.0945 * TS oR * VMstd * 60 sec/min * 144 in2/ft2 (PS in Hg Abs * VS * (DN2/4*pi) * time min * (1-%H2O/100)	%
DCL	=15.43 * (dust g) / VMstd	grains/SCF
% Efficiency	=(Inlet DCL - Outlet DCL) / Inlet DCL * 100	%
ACFM	=VS * Pipe Area (ft2)	ACFM
SCFM	=ACFM * PS / TS * 17.64	SCFM
lbs/hour	=grains/SCF * 0.000143 * SCFM * 60 min/hr	lbs/hour
PPM Calculation		
PPM	=Conc mg/L * Vol mL * L/1000 mL * 2.205e-6 lb/mg * 387 ft3/mol / VTstd * e6	
Stack Vel ft./sec.	Vs=85.49*Cp*SQRT Dp*SQRT(Ts/Ps/Mw)	
Mol Wt. Wet	Mw=30*(1-Bws)+18*Bws	

ID			
Run #			
Start Time			
Fund #			
Vt Std			ft^3
Volume of Sample			mL
Concentration			mg/L or ppm
Molecular Weight			g/mole
Molecular Weights (g/mole)			
SO3	80.06		
SO2	64.06		
NH3	17.04		
Cl2	70.90		
HCl	36.46		
F2	38.00		
HF	20.02		
Hg	200.59		
#DIV/0!	ppm in flue gas		
387 ft3/mol at 68oF			

DATE	ID	SAMPLE PORT	SAMPLER	START TIME	TEST TIME	BARO PRESS (in Hg)	STACK PRESS (in H2O)	TEMP (F)	O2%	ΔP	NOZ DIA	GAS METER VOL (cf)	TOTAL H2O	TOTAL DUST (SCF)	VMSTD (SCF)	VTSTD (SCF)	% H2O	METER TEMP	ΔH	ISO	DLC GRAINS/SCF
6/18/2011	KEETAC-BHIN-M5-3	BH IN DWN LG	RS	14:51	120	28.20	-0.15	145	17.8	0.16	0.280	58.838	228.8	0.00883	55.416	66.186	15.3	74	0.60	104.1	0.0027

Sample Pt.	DWN LEG BH IN		Date	6/16/2011
			Run #	0
Train Type			Fund #	15726
			Cost Center #	
STOPPER TYPE	TYPE OF SOLUTION	INITIAL WT. (g)	FINAL WT. (g)	NET WT. (g)
Straight	DI	654.8	702.5	47.7
Straight	DI	615.8	636.3	20.5
Impinger	DRY	639.0	645.2	6.2
Straight	SIL GEL	960.5	971.6	11.1
Straight				0.0
Straight				0.0
Impinger				0.0
Straight				0.0
			TOTAL H2O (g)	85.5
FILTER		0.21974	0.22343	0.00369
				0.00000
Additional Dust				0.00000
			TOTAL DUST (g)	0.00369
Vwstd	4.024	SCF		
Vmstd	21.826	SCF		
Vtstd	25.851	SCF		
% H2O	15.6	%		
% Isokinetic	105.6	%		
DCL	0.0026	grains/SCF		
DCL - Metric	0.0060	grams/SCM = grains/SCF*2.288		
DUST LOADING CALCULATIONS (Concentration Basis)				
Inlet DCL				grains/SCF
% Efficiency = (Inlet DCL - Outlet DCL) * 100			#DIV/0!	%
Inlet DCL				
Pipe Area				ft2
ACFM = VS * Pipe Area (ft2)			0.0000	ACFM
SCFM = ACFM * PS/TS * 17.64			0.0	SCFM
lbs/hour = grains/scf * 0.000143 * SCFM * 60			0.0000	lbs/hour

Equations		
Page 1		
PS (Stack Pressure)	=PB + (PS in H2O / 13.6) - elevation/1000	in. Hg Abs.
TS (Stack Temperature)	=average TS of + 460	oR
VS (Stack Velocity)ft/min	=60*85.49 * Cp * sqrt(P * TS oR / PS in Hg Abs / MS)	ft/min
MS	=30 * (1-%H2O/100) + 18 * %H2O/100	g/mol
QN (Nozzle Flow Rate)	=VS * pi * DN2 / 576	ACFM
QM (Meter Flow Rate)	=QN * TM * PS in Hg Abs/(Cm * TS oR * (HM /13.6)) - (1-%H2O/100)	ACFM
H (orifice)	=QM2 * H@ * (PB + HM /13.6)/(0.03175 * (TM + 460))	in H2O
Seconds/Rev	=1/(QM / 0.1 / 60)	
Page 2		
VWstd	=0.04707 * (H2O g)	SCF
VMstd	=17.64 * VWstd * Cm * (PB+ HM /13.6 - Elevation/1000)	SCF
VTstd	=VWstd + VMstd	SCF
% H2O	=(VWstd / VTstd) * 100	%
% Isokinetic	= 0.0945 * TS oR * VMstd * 60 sec/min * 144 in2/ft2 (PS in Hg Abs * VS * (DN2/4*pi) * time min * (1-%H2O/100)	%
DCL	=15.43 * (dust g) / VMstd	grains/SCF
% Efficiency	=(Inlet DCL - Outlet DCL) / Inlet DCL * 100	%
ACFM	=VS * Pipe Area (ft2)	ACFM
SCFM	=ACFM * PS / TS * 17.64	SCFM
lbs/hour	=grains/SCF * 0.000143 * SCFM * 60 min/hr	lbs/hour
PPM Calculation		
PPM	=Conc mg/L * Vol mL * L/1000 mL * 2.205e-6 lb/mg * 387 ft3/mol / VTstd * e6	
Stack Vel ft./sec.	Vs=85.49*Cp*SQRT Dp*SQRT(Ts/Ps/Mw)	
Mol Wt. Wet	Mw=30*(1-Bws)+18*Bws	

ID			
Run #			
Start Time			
Fund #			
Vt Std			ft ³
Volume of Sample			mL
Concentration			mg/L or ppm
Molecular Weight			g/mole
Molecular Weights (g/mole)			
SO3	80.06		
SO2	64.06		
NH3	17.04		
Cl2	70.90		
HCl	36.46		
F2	38.00		
HF	20.02		
Hg	200.59		
#DIV/0!	ppm in flue gas		
387 ft ³ /mol at 68oF			

DATE	ID	SAMPLE PORT	SAMPLER	START TIME	TEST TIME	BARO PRESS (in Hg)	STACK PRESS (in H2O)	STACK TEMP (F)	O2%	ΔP	NOZ DIA	GAS METER VOL (cf)	TOTAL H2O	TOTAL DUST	VMSTD (SCF)	% H2O	METER TEMP	ΔH	% ISO	DLC GRAINS/SCF	
6/16/2011	KEETAC-BHIN-M5-2	DWN LEG BH IN	RS	14:10	40	29.00	-1.1	148	0.0	0.21	0.280	22.065	85.5	0.00369	21.826	25.851	15.6	63	0.65	105.6	0.0026

APPENDIX C

COMPLETE SORBENT TRAP AND CMM COMPARISON DATA

(Copies of the original sorbent trap data sheets and the CMM data are available upon request.)

Table C-1. Complete Sorbent Trap and CMM Comparison Data

Sample No.	Units	1A	1B	1A	1B	2A	2B	2A	2B	3A	3B	3A	3B
Trap ID		88413	88410	88425	88419	88443	88406	88423	88376	88402	88417	88420	88385
Date		6/18/11	6/18/11	6/18/11	6/18/11	6/20/11	6/20/11	6/20/11	6/20/11	6/21/11	6/21/11	6/21/11	6/21/11
Time		10:29	10:29	10:36	10:38	10:20	10:22	10:13	10:15	12:02	12:04	11:55	11:57
Location		BH-in	BH-in	BH-out	BH-out	BH-in	BH-in	BH-out	BH-out	BH-in	BH-in	BH-out	BH-out
Duration	min	60	60	60	60	60	60	60	60	60	60	60	60
Vm	dL	61.705	65.522	60.949	65.515	61.673	62.727	118.32	115.60	60.816	67.876	119.099	117.688
Pb	in Hg	28.14	28.14	28.14	28.14	28.17	28.17	28.17	28.17	28.02	28.02	28.02	28.02
Elev Corr.	ft	20	20	20	20	20	20	20	20	20	20	20	20
Tm	°F	65	67	63	64	61	63	59	61	64	66	63	65
Cm	–	1.0150	1.0050	1.0000	1.0000	1.0150	1.0050	1.0000	1.0000	1.0150	1.0050	1.0000	1.0000
Moisture	%	16.3	16.3	16.2	16.2	16.1	16.1	16.0	16.0	16.2	16.2	16.1	16.1
Vw	L	12.017	12.760	11.825	12.711	11.792	11.994	22.581	22.061	11.757	13.122	22.855	22.584
Front Wool+Plug	ng	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sect 1	ng	426	448	486	521	411	429	157	146	482	523	200	201
Sect 2 w/Plug	ng	0.7	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.5	0.5	7.1	0.8
Back Plug	ng	0	0	0	0	0	0	0	0	0.2	0	0	0
Breakthrough	%	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.1	0.1	3.6	0.4
Vt (corrected)*	NL(wet)	70.728	74.081	69.050	74.081	71.098	71.327	134.87	131.25	69.461	76.469	134.114	132.020
Hg(wet)	µg/Nm ³	6.033	6.050	7.041	7.036	5.784	6.017	1.166	1.115	6.946	6.846	1.544	1.529
Hg Avg (wet)	µg/Nm ³		6.042		7.038		5.900		1.140		6.896		1.536
RSD (paired traps)	%		0.14		0.04		1.98		2.20		0.73		0.51
Removal (sorbent trap)	%	-16.5				80.7				77.7			
No. CMM Data Points		8		6		21		20		18		18	
Average	µg/Nm ³	5.18		5.669		5.34		0.908		6.31		1.185	
Std. Dev.	µg/Nm ³	0.081		0.136		0.153		0.029		0.210		0.078	
RSD (sorbent trap to CMM)	%	7.640		10.268		4.981		11.358		4.469		12.903	
Removal (CMM)	%	-9.5				83.0				81.2			

Continued . . .

C-1

Table C-1. Complete Sorbent Trap and CMM Comparison Data (continued)

Sample No.	Units	4A	4B	4A	4B	5A	5B	5A	5B	6A	6B	6A	6B
Trap ID		88405	88421	88440	88438	88442	88414	88404	88417	88422	88399	88412	88396
Date		6/23/11	6/23/11	6/23/11	6/23/11	6/27/11	6/27/11	6/27/11	6/27/11	6/28/11	6/28/11	6/28/11	6/28/11
Time		14:30	14:32	14:20	14:20	13:55	13:57	13:48	13:50	14:42	14:44	14:35	14:37
Location		BH-in	BH-in	BH-out	BH-out	BH-in	BH-in	BH-out	BH-out	BH-in	BH-in	BH-out	BH-out
Duration	min	60	60	60	60	60	60	60	60	60	60	60	60
Vm	dL	58.741	65.936	120.16	117.45	61.361	66.886	123.23	124.12	63.876	65.065	129.29	125.69
Pb	in Hg	28.08	28.08	28.08	28.08	28.02	28.02	28.02	28.02	28.35	28.35	28.35	28.35
Elev Corr.	ft	20	20	20	20	20	20	20	20	20	20	20	20
Tm	°F	60	63	59	60	65	68	62	63	76	79	70	71
Cm	–	1.0150	1.0050	1.0000	1.0000	1.0150	1.0050	1.0000	1.0000	1.0150	1.0050	1.0000	1.0000
Moisture	%	16.2	16.2	16.1	16.1	16.2	16.2	16.1	16.1	16.2	16.2	16.1	16.1
Vw	L	11.356	12.747	23.059	22.539	11.862	12.930	23.648	23.819	12.348	12.578	24.811	24.120
Front Wool+Plug	ng	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sect 1	ng	495	523	214	210	409	452	113	112	404	404	168	165
Sect 2 w/Plug	ng	0.3	0.4	0.3	1.5	0.2	0.1	0.2	0.1	0.0	0.0	0.0	0.2
Back Plug	ng	0	0	0	0	0	0	0	0	0	0	0	0
Breakthrough	%	0.1	0.1	0.1	0.7	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.1
Vt (corrected)*	NL(wet)	67.752	74.869	136.64	133.31	69.950	75.068	139.03	139.77	72.163	72.377	145.36	141.04
Hg(wet)	µg/Nm ³	7.311	6.991	1.568	1.587	5.850	6.023	0.814	0.802	5.598	5.582	1.156	1.171
Hg Avg (wet)	µg/Nm ³		7.151		1.577		5.936		0.808		5.590		1.163
RSD (paired)	%		2.24		0.58		1.45		0.75		0.15		0.67
Removal (sorbent trap)	%	77.9				86.4				79.2			
No. CMM Data Points		21		21		21		21		21		21	
Average	µg/Nm ³	6.55		1.179		5.30		0.629		4.70		0.929	
Std. Dev.	µg/Nm ³	0.092		0.128		0.082		0.058		0.053		0.036	
RSD (sorbent trap to CMM)	%	4.35		14.454		5.663		12.457		8.644		11.196	
Removal (CMM)	%	82.0				88.1				80.2			

Continued . . .

Table C-1. Complete Sorbent Trap and CMM Comparison Data (continued)

Sample No.	Units	7A	7B	7A	7B	8A	8B	8A	8B	9A	9B	9A	9B
Trap ID		88326	88415	88407	88413	88389	88398	88408	88377	88397	88386	88403	88388
Date		6/29/11	6/29/11	6/29/11	6/29/11	6/29/11	6/29/11	6/29/11	6/29/11	6/30/11	6/30/11	6/30/11	6/30/11
Time		9:15	9:17	9:04	9:05	16:52	16:54	16:45	16:47	14:22	14:23	14:17	14:19
Location		BH-in	BH-in	BH-out	BH-out	BH-in	BH-in	BH-out	BH-out	BH-in	BH-in	BH-out	BH-out
Duration	min	46	45	60	60	60	60	60	60	60	60	60	60
Vm	dL	50.277	53.715	121.181	119.469	62.370	65.610	123.327	120.354	61.901	62.808	143.270	143.830
Pb	in Hg	28.35	28.35	28.35	28.35	28.32	28.32	28.32	28.32	28.05	28.05	28.05	28.05
Elev Corr.	ft	20	20	20	20	20	20	20	20	20	20	20	20
Tm	°F	65	67	65	67	78	81	79	81	77	80	76	77
Cm	–	1.0150	1.0050	1.0000	1.0000	1.0150	1.0050	1.0000	1.0000	1.0150	1.0150	1.0000	1.0000
Moisture	%	16.2	16.2	16.1	16.1	16.0	16.0	16.1	16.1	17.2	17.2	17.2	17.2
Vw	L	9.719	10.384	23.254	22.926	11.873	12.490	23.637	23.068	12.871	13.060	29.790	29.906
Front	ng	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wool+Plug													
Sect 1	ng	288	310	85	84	348	353	61	57	356	351	37	37
Sect 2 w/Plug	ng	0.0	0.1	0.2	0.1	0.3	0.6	0.0	0.4	0.4	2.0	0.3	0.0
Back Plug	ng	0	0	0	0	0	0	0	0	0	0	0	0
Breakthrough	%	0.0	0.0	0.2	0.1	0.1	0.2	0.0	0.7	0.1	0.6	0.8	0.0
Vt (corrected)*	NL(wet)	57.990	61.112	137.541	135.083	69.952	72.457	136.170	132.396	69.908	70.538	159.708	160.034
Hg(wet)	µg/Nm ³	4.966	5.074	0.619	0.623	4.979	4.880	0.448	0.434	5.098	5.004	0.234	0.231
Hg Avg (wet)	µg/Nm ³		5.020		0.621		4.930		0.441		5.051		0.232
RSD (paired traps)	%		1.07		0.25		1.00		1.64		0.93		0.51
Removal (sorbent trap)	%	87.6				91.1				95.4			
No. CMM Data Points		20		20		21		22		21		20	
Average	µg/Nm ³	4.52		0.451		4.21		0.290		4.30		0.093	
Std. Dev.	µg/Nm ³	0.076		0.078		0.123268		0.055		0.066525		0.056	
RSD (sorbent trap to CMM)	%	5.231		15.846		7.847127		20.594		8.049454		43.042	
Removal (CMM)	%	90.0				93.1				97.8			