

Investigation and Demonstration of Dry Carbon-Based Sorbent Injection for Mercury Control

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Abstract

The U.S. Department of Energy (DOE) has issued Public Service Company of Colorado (PSCo) a cost sharing contract to evaluate carbon-based sorbents for mercury control on a 600 acfm laboratory scale particulate control module (PCM). The PCM can simulate an electrostatic precipitator, a pulse-jet fabric filter, and a reverse air fabric filter and uses actual flue gas from an operating coal-fired power plant. Up to 3 different dry carbon-based sorbents will be tested to determine the mercury removal capability in the different configurations.

The project is currently in the fifth quarter of an eight quarter Phase I project. The PCM has been fabricated and mercury removal testing with the ESP configuration has been completed. Original plans included the use on an on-line mercury analyzer to collect test data. However, due to very low baseline mercury concentration, on-line measurement did not provide accurate data. The project has continued using a modified MESA method grab sample technique to determine inlet and outlet mercury concentrations. A major concern during sorbent evaluations has been the natural ability of the flyash at the test site to remove mercury. This has made determination of sorbent only mercury removal difficult. Overall vapor-phase mercury removals of 15 to 70% have been obtained but this includes mercury removals in the range of 30% by the flyash. It is believed that a maximum of approximately 40% removal due to the sorbent only has been obtained. A number of test and sampling modifications are in progress to increase the data confidence and many questions remain.

Startup of the pulse jet configuration began in early November but results of this testing are not available at this time. Testing of the pulse jet configuration with flyash will be completed in January. The project team has decided to proceed with pulse jet testing using flue gas that does not contain significant flyash quantities to further investigate the sorbent only mercury removal. This testing will also include mercury doping to increase the baseline elemental mercury concentration in an attempt to gather better data. Modified sampling that may lessen the sampling impact of flyash mercury removal is also being investigated.

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Executive Summary

The overall objective of this two phase program is to investigate the use of dry carbon-based sorbents for mercury control at coal-fired utilities. This information is important to the utility industry in anticipation of pending regulations. During Phase I, a 600 cfm laboratory-scale particulate control module (PCM) that can be configured as an electrostatic precipitator (ESP), a pulse-jet baghouse, or a reverse-gas baghouse has been designed, built and integrated with an existing pilot-scale facility at PSCo's Comanche Station. The PCM may be configured to treat the actual fluegas from before the full scale fabric filter to simulate a full scale collector. It may also be configured to treat the clean fluegas from the outlet of the fabric filter to allow testing without flyash in the fluegas. Up to three candidate sorbents will be injected into the flue gas stream upstream of the test device and mercury concentration measurements will be made to determine the mercury removal efficiency for each sorbent. If the project is selected to continue into Phase II, the most promising dry sorbent technology will be scaled up to the 5000 acfm and further testing will be completed.

In previous quarters the PCM module has been constructed, installed and testing was begun on the ESP configuration. An on-line mercury analyzer was installed and significant effort has been expended to obtain real-time accurate data. Due to the very low mercury concentrations at Comanche (approximately $5 \mu\text{g}/\text{Nm}^3$), reliable accurate data has not been obtained. A number of modifications improved the monitor's accuracy.

In the current quarter work has continued with carbon injection of various sorbents of the ESP configurations. Due to the inability of the on-line mercury analyzer to provide accurate data, it was decided to complete testing using a modified MESA method. The modified MESA method uses a quartz probe with a quartz wool insert to collect a non-isokinetic sample of particulate. The sampled flue gas is passed through two iodated carbon sorbent traps to determine the elemental mercury emissions. Full MESA testing has shown that the majority of the mercury at Comanche is elemental.

Testing of the ESP configuration was completed October 21 with the completion of 23 valid test points using two different sorbents at various operating conditions. The data indicate that an overall vapor phase mercury removal of 15 to 70% was possible. A substantial amount of mercury removal is occurring without any carbon injection with an average baseline mercury vapor removal of approximately 30%. The baseline mercury removal is not fully understood but

it is believed that a combination of Comanche's ash and the low flue gas temperature are related to this removal. Due to the high baseline removal it has been difficult to determine the mercury removal achieved with only sorbent injection. A modified sampling method that uses two cyclones to remove a large portion of the flyash before filtering with a method 29 filter has been assembled. The technique should remove the majority of the ash and prevent additional mercury removal or adsorption across the filter cake. Testing of the revised method will be completed next quarter. While an exact determination of the sorbent related mercury removal has not been possible, it is believed that a maximum of roughly 40% vapor phase mercury has been achieved.

Testing of the pulse-jet configuration began operation on November 12 at an air-to-cloth ratio of 4 ft/min. A number of tests were completed this month but data is not yet available for analysis. Due to the concerns and difficulties measuring sorbent-only mercury removal, the project team decided to begin testing of the pulse-jet configuration using "clean" fluegas obtained from Comanche's fabric filter outlet. It is anticipated that this testing will allow data collection of mercury removal due only to sorbent injection without the problems associated with flyash mercury adsorption. It is believed that baseline mercury levels after Comanche's fabric filter will be very low due to the ability of the ash to remove mercury and the high ash collection efficiency of Comanche's fabric filter. In order to test at meaningful mercury concentrations, a mercury doping system is being designed that will increase the baseline mercury by 10 to 20 $\mu\text{g}/\text{Nm}^3$. The pulse-jet configuration testing with flyash will be completed in January 1997 and testing will continue in early February with no-ash and mercury doping. Testing will then continue with the reverse air configuration.

The project remains slightly behind the original schedule and is slightly over the original budget for the work scope completed to date. The project will be returned to schedule and budget by minor changes to the remaining schedule. A revised test plan and budget schedule will be completed next quarter.

Introduction

This report describes ongoing work in a two phase program is to investigate the use of dry carbon-based sorbents for mercury control. A laboratory-scale field particulate control module (PCM) that can be configured as an electrostatic precipitator, a pulse-jet baghouse, or a reverse-gas baghouse has been designed, built and integrated with an existing pilot-scale facility at Public Service Company of Colorado (PSCo)'s Comanche Station in Pueblo, Colorado. Carbon-based sorbents are injected upstream of the PCM and mercury concentration measurements are made to determine the mercury removal efficiency for each sorbent. This report includes work performed this quarter and is not intended to be a summary of work performed to-date. Earlier project work referred to in this report is described in previous quarterly reports.

Equipment Description

Electrostatic Precipitator

The ESP pilot fabricated for these tests is wire-tube type unit designed to treat 620 acfm. The pilot is operated with a velocity of 5 ft/sec through the 20 foot long collection section. The specific collection area (SCA), a standard measure of collection area to total gas flow, at these operating conditions is 327 ft²/Kacfm. This SCA is representative of many ESPs installed at utilities in the United States.

Four 10-inch diameter collection tubes, the gas passages for the ESP, are hung from a tubesheet at the top of the 28-inch diameter collection vessel housing. Four electrodes, one on the centerline of each gas passage, are attached to a rigid frame and powered from a single transformer-rectifier (T/R) set. The lower frame is weighted to keep the wires straight and a pneumatic vibrator is attached for cleaning ash from the electrodes. The top frame is attached to the high voltage bus at the feedthrough insulators. The T/R set is located at ground level and power is brought to the electrodes through a shielded bus. The T/R set is controlled by an automatic voltage controller (AVC) and is set to simulate conditions in a full-scale wire-plate ESP. For these tests, the T/R set is operated in the 40 KV, 15 ma range. Comanche Station burns a Powder River Basin coal, which often causes problems with back corona on full-scale ESPs because of the high resistivity flyash. The ESP T/R controls were set for intermittent energization which successfully quenched the back corona in the pilot.

Pulse-Jet Baghouse

When the control module is configured as a pulse-jet baghouse, the four 10-inch diameter ESP tubes and the associated tubesheet are removed and replaced with a tubesheet that contains six 5-inch diameter holes. The pulse-jet was designed to filter 628 acfm flue gas at an air-to-cloth ratio of 4 ft/min. To achieve this ratio, six 20-foot long bags (full-scale utility) are hung from the pulse-jet tubesheet. Full-scale bags are used to better simulate the filtering and cleaning characteristics experienced in a full-scale unit. A rigid steel cage is inserted into each bag. Flue gas enters the bag compartment at the bottom and passes through the bags from outside to inside, depositing the particulate matter on the outside of the bags. The flue gas then flows out of the compartment through the outlet plenum on the clean side of the tubesheet. The bags are cleaned with a pulse of compressed air from a pulse pipe located above each row of three bags.

Activities Performed This Quarter

Task 2. Design, Fabrication, and Installation of Laboratory-Scale Test Facility

Some small sub-assemblies specific to the pulse-jet and reverse-gas configurations of the test facility were fabricated this quarter. These sub-assemblies included the pulse pipes and pressure reservoir for the pulse-jet and the reverse-gas valving sub-assembly. In addition, a mercury doping system was designed and some equipment was ordered for fabrication. The doping system was designed to increase the elemental mercury concentration in the PCM flue gas sample stream to 10 - 20 $\mu\text{g}/\text{Nm}^3$. Measurements of current total vapor phase mercury levels indicate concentrations below 2 $\mu\text{g}/\text{Nm}^3$ at times. It is difficult to evaluate sorbents at these low concentrations due to limitations in sampling techniques.

Sampling System - Developments

Results from ESP testing with the modified Mercury Speciation Adsorption (MESA) method showed high mercury levels on the quartz wool particulate filter. Although the MESA is sampled non-isokinetically, a large fraction of mercury on the particulate under some conditions indicates significant mercury adsorption onto the flyash. The flyash entering the MESA train and collecting on the glass wool particulate filter may not be representative of the flue gas flyash concentration as it is not sampled isokinetically and is dependent on parameters such as flyash size distribution and gas velocities.

In addition to the mercury measurement concerns using the MESA related to isokinetic sampling, other changes within in the system (such as changes in bulk flue gas temperature) further complicated data analysis. During testing at Comanche, the flue gas is often cooled or heated to a target temperature for a particular test condition. If the temperature of the flyash is modified, it is likely that the ash is adsorbing or desorbing mercury; thus the vapor mercury downstream of heating/cooling will be different than what was upstream of heating/cooling. The inlet sampling location is downstream of heating/cooling and it is possible that ash is not in equilibrium with the flue gas with respect to mercury in the gas or adsorbed on the flyash when it reaches this sampling location. Carbon sorbents are injected just downstream of the inlet sampling port. If mercury continues to adsorb onto the flyash beyond the inlet sampling location, vapor mercury removal is occurring that should not be attributed to the sorbent. Since the temperature of the flue gas in Comanche's duct changes with Comanche operation, different amounts of heating or cooling are required to maintain the PCM at a given temperature. It is likely the fraction of mercury vapor adsorbed/desorbed will be affected by the variations in heating/cooling. Thus, although baseline flyash mercury removal measurements were made, significant uncertainty remains when assessing contribution of the flyash to overall mercury removal during sorbent injection for this dynamic system. If a representative total mercury measurement can be obtained, erroneous conclusions concerning the affinity of a sorbent for mercury drawn from non-isokinetic flue gas sampling could be minimized.

Comanche flyash adsorbs mercury and it is likely that forcing the flue gas through a fixed bed of flyash (i.e. EPA method 29 or similar sampling filter) would increase the amount of mercury collected on the ash and bias the vapor measurements low. Sorbents, such as activated carbon, are evaluated for their ability to remove mercury from the vapor phase and unrepresentative low inlet vapor measurements could introduce difficulties in assessing the effectiveness of the sorbent. Rigorous sample system development and testing is outside the scope of this project; therefore, the selected device must be similar to existing devices that have proven effective for mercury measurement. For initial tests, the front-end of a Method 29 sampling train will be used with the addition of glass cyclones upstream of the particulate filter. The cyclones should remove a large fraction of the flyash, thus minimizing the contact of the flue gas and flyash. A sketch of the arrangement is shown in Figure 2.

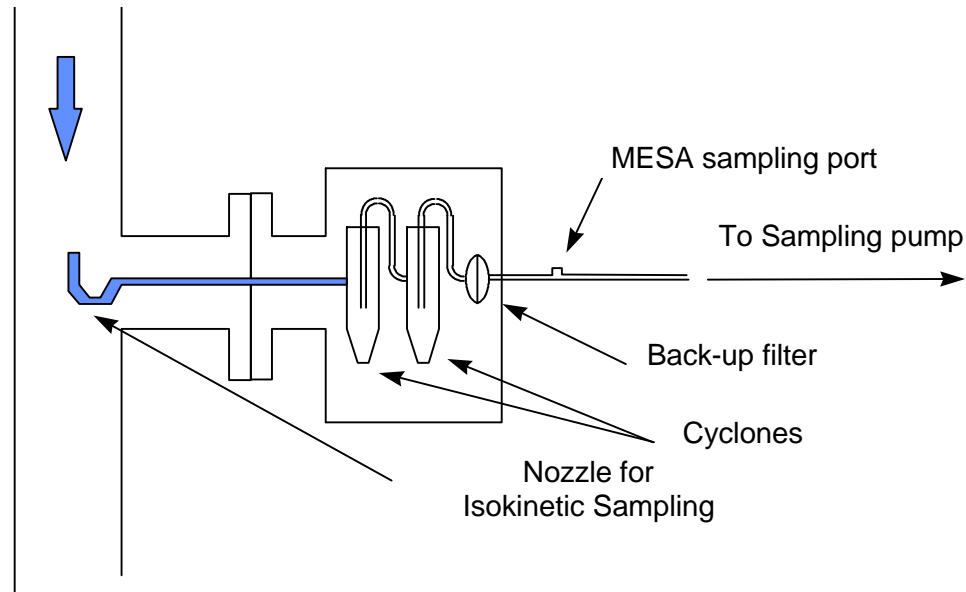


Figure 2. Isokinetic sampling system.

Hg Doping System Design

The mercury doping system was designed during this quarter to introduce a known concentration of elemental mercury vapor into the 18" duct feeding flue gas to the pilot plant. The fundamental design of this doping system is based on previous system designed on other DOE programs. The doping system consists of a nitrogen tank, a mass flow controller, a diffusion vessel, and a vessel containment box. Nitrogen is delivered from the tank through the mass flow controller to the diffusion vessel. The diffusion vessel, located in a temperature controlled container, contains Pyrex trays holding pools of liquid mercury. Nitrogen passes over the trays of mercury thus picking up mercury vapor. The mercury concentration exiting the diffusion vessel is determined by the temperature of the vessel and the nitrogen flowrate. The nitrogen-elemental mercury mixture then leaves the Pyrex vessel and is injected into the 18" duct through heat traced electropolished stainless steel tubing. The mercury vapor will be injected upstream of the sampling ports on the pilot plant to allow a 1 second in-duct residence time to promote uniform dispersion prior to inlet mercury sampling or carbon injection.

Task 3. Field Evaluations of Sorbents for Mercury Control

The particulate control module (PCM) was brought on-line configured as an ESP on July 7, 1996. Initial carbon injection was begun July 26. Carbon injection in the ESP was completed

October 21, 1996. Particulate samples were collected with EPA Method 17 to determine the particulate loading to the PCM and the efficiency of the ESP. The PCM was configured as a pulse-jet baghouse and brought on-line November 12. Total vapor-phase mercury concentration data was collected with a modified MESA method. The modified MESA method consists of a quartz probe with a glass wool insert to collect particulate followed by two iodated carbon traps to collect vapor phase mercury. Further modifications were made to the sampling system during this quarter due to high fractions of mercury apparently adsorbed onto the flyash. The modified method is described in the Sampling System Developments section of this report.

ESP Evaluation

A summary of the completed ESP tests is shown in Table 1. Evaluations were conducted in three temperature regimes: 200-210 °F, 230 - 260 °F, and 275 - 290 °F. The sorbent injection rates are shown as pounds per million actual cubic feet (Macf) for better comparison with tests conducted at other facilities and to facilitate scale-up. The injection rates shown correspond to injection ratios (wt carbon per wt mercury) of 800 - 8000:1. Sampling time for the initial 10 tests was 2 hours. Sample analysis indicated that an adequate sample could be collected in 20 - 30 minutes, thus, the sample time for subsequent 17 tests was 30 - 45 minutes. For most tests, duplicate samples were collected at each test condition.

Table 1. ESP Test Summary

| Sorbent | ESP Inlet Temperature (°F) | Injection Rate (lb/Macf) |
|----------|-------------------------------|-----------------------------|
| Baseline | 200-210 | N/A |
| | 230-260 | N/A |
| Norit | 200-220 | 1 |
| | 230-260 | 0.2-0.4, 1-1.2, 1.7-1.9 |
| | 275-290 | 1-1.2, 1.7-1.9 |
| AC-1 | 230-260 | 1-1.2, 1.7-1.9 |
| | 275-290 | 1-1.2, 1.7-1.9 |

Sorbents were injected through an inlet test port to allow 1 second of in-duct residence before entering the ESP for all but two tests. AC-1 (a proprietary activated carbon made from

bituminous coal) and Norit (a commercially available activated carbon made from lignite coal by American Norit) were evaluated at a residence time of 1.5-2 seconds residence time. Results of the testing is presented in the Preliminary Results and Discussion section of this report.

Pulse-Jet Evaluation

The pulse-jet baghouse was brought on-line November 12, 1996 at an air-to-cloth ratio of 4 ft/min. Ryton bags are installed in the unit to facilitate testing at higher temperatures. Acrylic bags will be used during some of the lower temperature tests.

DOE, PSCo and ADA met on December 6 to review the status of the program, and a decision was made to change the original test schedule due to the difficulty encountered thus far interpreting mercury removal data from the facility. The test plan was revised to better evaluate the performance of the sorbents by testing with flyash (first pulse-jet test series), and in the absence of most of the ash (second and third test series). This change required fabricating an isokinetic ash sampling system, designing a mercury doping system and preparing for testing in the absence of flyash. This no ash testing was originally planned at the end of the test program.

Initially, a series of tests with ash was conducted by collecting total mercury samples (particulate and vapor phase). The test matrix in Table 2 shows collection of baseline measurements in three temperature ranges: 190 - 210 °F, 225 - 260 °F, and 275 - 325 °F. Two of these ranges will likely require heating or cooling the pilot with the in-duct heater. Due to the uncertainties introduced by mercury adsorption and desorption on the flyash when temperatures are altered, heating or cooling will only take place during baseline conditions. During sorbent injection tests, the temperature of the flue gas will not be altered.

During these tests, care was taken to collect a representative ash sample using the previously discussed sampling method and to test on a strict injection schedule. When evaluating sorbent effectiveness in a baghouse, the amount of sorbent on the fabric can have a significant impact on results. Two hours before obtaining MESA samples (one at the inlet to the unit, the other at the outlet), the automatic pulse cleaning system is placed in manual operation. At this time the bags are pulsed manually, and the sorbent feeder is activated. After an hour and a half with sorbent injection, the filter bags are again cleaned manually. At this time the isokinetic flyash sampling begins at the inlet to the pilot, allowing this system to equilibrate before the MESA set is run. Exactly one half hour later sampling for one MESA measurement on the inlet and one on the outlet is begun. This provides an hour and a half of seasoning the bags with sorbent, and half an

hour of accumulation of the ash sample before a data point is taken. Sorbent feed rates are measured before and after the MESA tests to ensure consistency. When the first set of MESA tests is complete, the unit is again manually pulsed. Exactly one half hour later a duplicate MESA measurement on the inlet and outlet is started. Thus, four MESA samples are obtained for each test condition, as shown on Tables 2, 3 and 4. The ash sample is not retrieved between MESA tests so that adequate ash can be collected for analysis. Running each set of MESA tests one half hour after a pulse clean creates bag surface conditions that are very similar from test to test, enhancing the reproducibility of the data.

Table 2. Pulse-jet configuration - full ash loading

| Sorbent | Temp °F | Inj Rates (lb/Macf) | MESA Samples Obtained |
|---------|------------|------------------------|--------------------------|
| None | 190-210 | N/A | 4 |
| | 225-260 | N/A | 4 |
| | 275-325 | N/A | 4 |
| Norit | 225-260* | 0.4, 2.1 | 8 |
| AC-1 | 225-260* | 0.4, 2.1 | 8 |

* No heating or cooling

The second series of tests planned for the following quarter will be conducted with little flyash in the flue gas entering the PCM. This requires pilot operation on a slipstream of gas from downstream of Comanche's full-scale baghouse. During testing completed to date, the slipstream was drawn from upstream of Comanche's baghouse. It is believed that mercury adsorbs on flyash collected in Comanche's baghouse, thus the inlet mercury levels are expected to be lower.

Only a limited test is scheduled because when the mercury concentration at the inlet to the pilot is low, it is difficult to evaluate the performance of the sorbents. Therefore, only a baseline and one injection rate with Norit are shown on the test matrix in Table 3. The bags will be replaced before beginning this test to minimize the effect of residual ash on the bags. The Ryton bags will be replaced with acrylic bags.

Table 3. Pulse-jet - no ash (inlet downstream of R-G baghouse)

| Sorbent | Temp °F | Inj Rates (lb/Macf) | MESA Samples Obtained |
|---------|------------|------------------------|--------------------------|
| None | 225-260 | | 4 |
| Norit | 225-260* | 0.4 | 4 |

* No heating or cooling

The final series of planned pulse-jet tests are shown in Table 4. During these tests, a mercury vapor doping system will be used to increase the natural mercury levels in the flue gas. Only elemental mercury vapor will be injected into the pilot's inlet gas stream. The mercury concentration will be increased to 10 - 20 µg/Nm³. These tests will be completed next quarter.

Table 4. Pulse-jet - no ash (inlet downstream of R-G baghouse)
Mercury Doping

| Sorbent | Temp °F | Inj Rates (lb/Macf) | MESA Samples Obtained |
|---------|------------|------------------------|--------------------------|
| None | 190-210 | | 4 |
| | 225-260 | | 4 |
| | 275-325 | | 4 |
| Norit | 225-260* | 0.3, 2.1 | 8 |
| AC-1 | 225-260* | 0.3, 2.1 | 8 |

* No heating or cooling

Task 6. Management and Reporting

The project is behind the original schedule due to delays encountered in an attempt to employ a continuous, real-time mercury analyzer and the change in schedule due to difficulties interpreting data. A decision was made this quarter to discontinue analyzer use and to proceed with the program using the modified MESA method. The project will be returned to schedule by reorganization of the remaining work and adjustments to the test schedule.

Preliminary Results and Discussion

ESP operation

Particulate samples were collected with EPA method 17. The average of three samples indicated the ESP was collecting 97.3% of the particulate and the average outlet emission was 0.026 gr/acf. The secondary current during the mass emission tests was 5-6 mA, and the secondary voltage was 30-32 KV. The secondary current during mercury testing was 5 - 13 mA and the secondary voltage was 28 - 33 KV. The power levels did not change significantly as a result of carbon injection.

Mercury Removal - ESP Configuration

Preliminary mercury removal results using the Norit and AC-1 sorbents are summarized on Figure 3, which presents mercury removal as a function of sorbent feedrate. Overall the data presented does indicate a general increase in mercury removal with increased sorbent injection rate. Note that the mercury removal plotted is for the overall vapor phase and not just the mercury removal that occurs due to sorbent injection. Overall mercury removal is not shown as it is believed that the modified MESA method used for this sampling does not accurately report the total particulate and vapor phase mercury.

As was discussed in detail in previous sections of this report, it is believed that the ash at Comanche adsorbs a large portion of the mercury. Baseline (no sorbent injection) removals of 11 to 36%, which average approximately 30%, are shown. The mercury fractions on the MESA particulate filter which is collected non-isokinetically and thus may not be representative of the average particulate show 2 to 37% of the total mercury collected in the sample. The mercury in the particulate sample may be representative of the duct ash or it may be biased due to the sampling method. However, in either case the data strongly suggests that mercury is adsorbing onto the flyash. Thus, while the mercury removal shown provide data for analysis, they do not relate to an accurate measurement of the sorbents ability to remove mercury. In order to obtain a rough estimate of the sorbent's mercury removal capability, it could be assumed that the flyash removes 30% of the vapor phase mercury. The inlet data can be corrected to show the estimated flyash removal and a "sorbent" removal can be calculated. For example, the 1.2 lb/Macf test 15 data point reports about 58% vapor Hg removal. Correcting the data to an assumed 30% flyash Hg removal reduces the Hg removal to 40%.

As discussed in the previous section, total (vapor + mercury adsorbed on the flyash) isokinetic measurements were not made during the ESP tests. Information regarding mercury desorption or adsorption onto the flyash is inconclusive and it is believed that mercury adsorbing onto the flyash has made identifying trends of changes in removal effectiveness with temperature very difficult. Because high flyash mercury adsorption is not typical and was not expected, the flue gas temperature was purposefully altered for many of the tests, complicating data interpretation. In tests 1-10, the inlet sample was collected upstream of cooling or heating. In tests 11-29, inlet samples were collected just downstream of the heating/cooling section. It is believed that mercury measurements made at the two inlet sampling locations may be different due to flyash adsorption/desorption. The data is still being analyzed.

All data shown except the inlet measurements on Test ID 1, 3 and 5 were conducted with the modified MESA method (glass wool plug for particulate followed by two iodated carbon traps). Tests 1, 3 and 5 were conducted with full MESA trains. The full MESA train contains a KCl/soda lime trap designed to capture Hg(II) upstream of the iodated carbon trap. The results from these tests are summarized in Table 5, which suggests that Hg(II) is 11 to 34% of the vapor fraction. The data also indicates that the mercury collected on the glass wool plug is 8 to 19% of the total mercury collected in the train. Some researchers contend that the KCl/soda lime trap can overestimate the fraction of speciated mercury (Hg(II)) under some conditions including NO_x in the presence of ≥ 1500 ppm SO₂. (Laudel, 1996). Comanche's flue gas has low SO₂ (250 ppm), however, recent mercury samples have not been collected at Comanche with other methods to verify the ability of the MESA to adequately speciate at this site.

Table 5. MESA Train Speciation Results

| Test ID | Hg(0) ($\mu\text{g}/\text{Nm}^3$) | Hg(II) ($\mu\text{g}/\text{Nm}^3$) | Hg on Particulate ($\mu\text{g}/\text{Nm}^3$) |
|---------|----------------------------------------|-----------------------------------------|----------------------------------------------------|
| 2 | 5.62 | 0.713 | 0.537 |
| 3 | 2.98 | 1.51 | 0.882 |
| 5 | 3.99 | 0.796 | 1.1 |

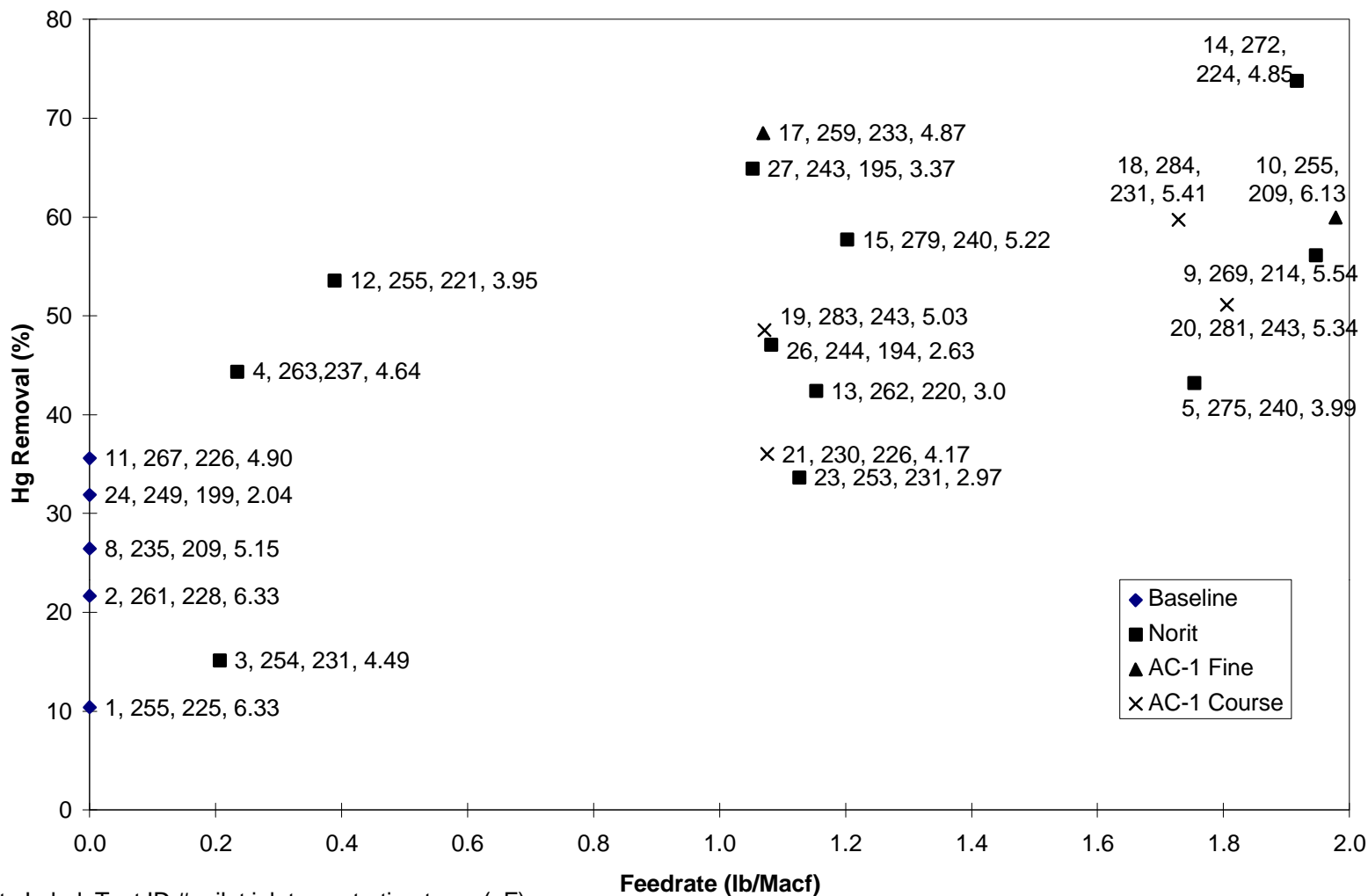
A summary of test conditions for each MESA sample is shown in Table 6. PCM operating conditions including temperatures throughout the unit, flue gas flowrate through the unit, and secondary voltage and current are included. Comanche's boiler load and duct temperature upstream of the PCM penetration. Some test points are not included on the table due to sampling errors, changes in PCM operation during a test, changes in feedrate during a test, or other similar conditions which are believed to have interfered with meaningful data analysis. Tests

28 and 29 are not included because these were conducted with the ESP filtering gas from downstream of Comanche's reverse-gas baghouse. Mercury measurements were conducted less than an hour after the inlet damper upstream of Comanche's baghouse was closed and the damper downstream was opened. It is believed that very low inlet measurements ($< 0.5 \mu\text{g}/\text{Nm}^3$) measured during these two tests are a result of mercury adsorbed on the flyash collected in Comanche's baghouse and mercury capture on the steel duct walls not in equilibrium with the flue gas mercury.

A condition occurred during a few tests which likely affected mercury removal. These tests: 15, 19 and 20, are included in Figure 3 and Table 6. During these tests, there was significant temperature loss (36 - 48 °F) from the inlet of the ESP to the outlet. The quantitative effect of the temperature loss is difficult to determine and is complicated by particulate collection along the length of the ESP. Ash and sorbent collected at a higher temperature in the first stages of the ESP may adsorb different mercury concentrations than material collected in the last stage at a much lower temperature. However, it is likely an increase in mercury removal across the ESP occurred as a result of the temperature loss and possible higher mercury adsorption on the flyash during these tests. Modifications will be made to the skin heaters and/or the insulation on the collection vessel to lessen temperature loss across the vessel next quarter to reduce this concern.

In addition to measuring the mercury in the flue gas, two coal samples and two PCM hopper ash samples were collected and analyzed. The two coal samples were collected on the same day (10/15/96) and show a slight variation in mercury concentration (57.4 and 62.06 ng/g). However, a recent study of the variability in the analysis of mercury in coal (Lengyel, 1996) suggests that, of the eleven laboratories studied, the intralaboratory repeatability for a coal sample mercury analysis averaged 20 ng/g. Thus, the variation in the reported coal mercury levels is not considered significant. The two ash samples collected showed much higher mercury concentrations (3073.74 ng/g and 1818.49 ng/g). These were collected in the ESP hopper at temperatures below 210 °F. Based on mass tests conducted in October, the inlet particulate loading to the pilot ESP was 3.3 lb/MMBtu. If the mercury in the coal is 60 ng/g and all the mercury were collected with the flyash, the mercury concentration in the ash would be roughly 2000 ng/g. Thus, the mercury collected with the flyash is a significant fraction of the mercury in the flue gas at these lower temperatures.

Comanche



Data Label: Test ID #, pilot inlet penetration temp (oF),
ESP outlet temp (oF), Inlet Hg (ug/Nm3)

Figure 3. ESP mercury removal results.

Table 6. Preliminary MESA results: Comanche Station

Comanche Station
Sorbent Injection Testing
ESP Configuration

| Test Sorbent | Res Time (sec) | Host Duct | Temperatures (oF) | | | | load (MW) | av flow (acfm) | Inj Rate lb/Macf | Inj Ratio mass C/ mass Hg | Inlet Tot vapor ug/Nm3 | Inlet* Part ug/Nm3 | Total Hg ug/Nm3 Inlet | Outlet Tot vapor ug/Nm3 | Outlet* Part ug/Nm3 | Total Hg ug/Nm3 Outlet | Corrected to inlet flow **** | | |
|--------------|----------------|-----------|-------------------|---------------|-----------|---------|-----------|----------------|------------------|---------------------------|------------------------|--------------------|-----------------------|-------------------------|---------------------|------------------------|------------------------------|------------------------|------|
| | | | Pilot Inlet | Inject middle | ESP Inlet | ESP Out | | | | | | | | | | | Outlet vapor ug/Nm3 | Vapor Hg % removal *** | |
| 1 Baseline | | 291 | 255 | 248 | 243 | 225 | 310 | 563 | 0.00 | 0 | | | | 5.44 | | 5.44 | ** | 5.67 | 10.4 |
| 2 Baseline | | 310 | 261 | 249 | 243 | 228 | 365 | 586 | 0.00 | 0 | 6.33 | 0.537 | 6.87 | 4.76 | | 4.76 | | 4.96 | 21.7 |
| 3 Norit | 1 | 294 | 254 | 255 | 245 | 231 | 318 | 587 | 0.21 | 822 | 4.49 | 0.882 | 5.37 | 3.49 | | 3.49 | | 3.81 | 15.1 |
| 4 Norit | 1 | 305 | 263 | 259 | 248 | 237 | 318 | 583 | 0.23 | 856 | | | | 2.37 | | 2.37 | ** | 2.58 | 44.4 |
| 5 Norit | 1 | 325 | 275 | 263 | 253 | 240 | 320 | 591 | 1.75 | 6446 | 4.79 | 1.1 | 5.89 | 2.48 | | 2.48 | | 2.72 | 43.2 |
| 6 Norit | 1 | 278 | 246 | 251 | 243 | 232 | 318 | 590 | 1.91 | | | | | 1.29 | | 1.29 | | 1.37 | |
| 8 Baseline | | 263 | 235 | 269 | 209 | 209 | 251 | 557 | 0.00 | 0 | 5.15 | 0.36 | 5.51 | 3.61 | 0.01 | 3.61 | | 3.79 | 26.4 |
| 9 Norit | 1 | 319 | 269 | 267 | 235 | 214 | 363 | 566 | 1.95 | 6966 | 5.54 | 0.35 | 5.89 | 2.40 | 0.00 | 2.4 | | 2.43 | 56.1 |
| 10 AC-1F | 1 | 295 | 255 | 257 | 224 | 209 | 317 | 557 | 1.98 | 6247 | 6.13 | 0.44 | 6.57 | 2.34 | 0.00 | 2.34 | | 2.46 | 59.9 |
| 11 Baseline | | 314 | 267 | 256 | 247 | 226 | | 504 | 0.00 | 0 | 4.90 | 0.50 | 5.41 | 3.00 | 0.00 | 3 | | 3.16 | 35.6 |
| 12 Norit | 1 | 306 | 255 | 254 | 241 | 221 | | 567 | 0.39 | 1857 | 3.95 | 0.50 | 4.46 | 1.92 | 0.01 | 1.92 | | 1.84 | 53.5 |
| 13 Norit | 1 | 314 | 262 | 254 | 243 | 220 | | 574 | 1.15 | 7619 | 3.00 | 0.23 | 3.23 | 1.83 | 0.01 | 1.83 | | 1.73 | 42.4 |
| 14 Norit | 1 | 326 | 272 | 256 | 249 | 224 | | 575 | 1.92 | 8044 | 4.85 | 0.27 | 5.12 | 1.34 | 0.03 | 1.34 | | 1.27 | 73.8 |
| 15 Norit | 1 | 331 | 279 | 301 | 288 | 240 | | 550 | 1.20 | 5150 | 5.22 | 0.08 | 5.30 | 1.91 | 0.09 | 1.91 | | 2.21 | 57.7 |
| 17 AC-1F | 1 | 307 | 259 | 255 | 247 | 233 | | 619 | 1.07 | 4292 | 4.87 | 0.47 | 5.35 | 1.54 | 0.03 | 1.54 | | 1.53 | 68.5 |
| 18 AC-1C | 1 | 338 | 284 | 259 | 252 | 231 | 359 | 638 | 1.73 | 6787 | 5.41 | 0.09 | 5.50 | 2.25 | 0.31 | 2.57 | | 2.18 | 59.7 |
| 19 AC-1C | 1 | 330 | 283 | 290 | 279 | 243 | 355 | 617 | 1.07 | 4634 | 5.03 | 0.15 | 5.18 | 2.65 | 0.15 | 2.8 | | 2.59 | 48.5 |
| 20 AC-1C | 1 | 327 | 281 | 289 | 278 | 243 | 352 | 611 | 1.81 | 7338 | 5.34 | 0.17 | 5.51 | 2.53 | 0.25 | 2.77 | | 2.61 | 51.1 |
| 21 AC-1C | 1.5-2 | 251 | 230 | 251 | 239 | 226 | 220 | 615 | 1.08 | 4881 | 4.17 | 0.50 | 4.67 | 3.15 | 0.03 | 3.18 | | 2.67 | 36.0 |
| 23 Norit | 1.5-2 | 283 | 253 | 252 | 246 | 231 | 274 | 587 | 1.13 | 6154 | 2.97 | 0.95 | 3.92 | 2.15 | 0.03 | 2.18 | | 1.97 | 33.6 |
| 24 Baseline | | 291 | 249 | 268 | 211 | 199 | 349 | 663 | 0.00 | 0 | 2.04 | 0.84 | 2.88 | 1.60 | 0.01 | 1.61 | | 1.39 | 31.9 |
| 26 Norit | 1 | 284 | 244 | 234 | 205 | 194 | 318 | 611 | 1.08 | 5265 | 2.63 | 1.52 | 4.15 | 1.55 | 0.00 | 1.55 | | 1.39 | 47.1 |
| 27 Norit | 1 | 285 | 243 | 238 | 204 | 195 | 339 | 629 | 1.05 | 4649 | 3.37 | 1.19 | 4.56 | 1.30 | 0.02 | 1.31 | | 1.18 | 64.9 |

* Particulate collected non-isokinetically and may not be representative of duct flyash.

** % Hg removal calculated for tests without simultaneous samples using closest inlet in time.

*** Overall Hg removal includes removal from sorbent and also by the flyash and are not accurate for sorbent only removal.

**** The PCM does have some inleakage. As O2 or CO2 measurements are not available, the data was correct using the change in flow across the PCM using existing flue gas flow meters located on PCM.

Mercury Removal- Pulse-Jet Configuration

Pulse-jet testing was begun this quarter and initial mercury measurements have been made. Data is not yet available. Data has been collected with the revised sampling procedure which is believed to provide a more accurate total mercury measurement. This should allow more accurate representative of the sorbents ability to remove mercury than was possible with the ESP data.

Activities Scheduled for Next Quarter (January 1 - March 31, 1997)

Task 3. Field Evaluations of Sorbents for Mercury Control

Carbon injection in the pulse-jet configuration is scheduled through the second week in January. The mercury doping system will be operational by early February to allow two weeks for testing of the no ash configuration with mercury doping. The PCM will then be configured as a reverse-gas baghouse. Results from the no-ash plus doping tests and the isokinetic ash sampling tests will be evaluated to determine an appropriate plan for reverse-gas testing.

Task 6. Management and Reporting

The budget and schedule will be reviewed in conjunction with reviewing technical data to determine the most efficient method for completing the remaining work scope on time and on budget.

Preliminary Conclusions

The data gathering process is still underway for this program and a number of data analysis and sampling concerns exist, thus conclusions have not been formulated. The significant observations included in this report are summarized below.

- 1) Comanche's flyash appears to adsorb mercury at all tested temperatures. An average removal of approximately 30% has been observed although significant variations between tests have been noted.
- 2) Due to the low temperatures available on the host unit and the belief that artificial heating and cooling effect the mercury removal, insufficient data is available to determine if adsorption changes significantly at different operating temperatures.
- 3) Adsorption of mercury by the flyash significantly increases the importance of accurate particulate measurements to determine the total mercury concentration and the ability to determine a sorbent mercury removal efficiency.
- 4) Overall vapor phase mercury removal of 15% to 70% have been observed with the ESP configuration of the PCM. Note that the removals listed include the Hg removal obtained from the flyash which is believed to be significant and in the range of 30% at Comanche at the tested temperatures.
- 5) Mercury removal increases with increasing carbon injection up to the maximum injection ratio tested, 2 lb/Macf.
- 6) Any improvements in mercury removal in the ESP due to increase sorbent residence time is uncertain.

References

- Laudel, et. al. "Bench- and Pilot-Scale Evaluation of Mercury Speciation Measurement Methods," *Proceedings, First Joint Power and Fuel Systems Contractors Conference*, July 9-11, 1996.
- Lengyel, J., M. DeVito, and R. Bilonick. "Interlaboratory and Intralaboratory Variability in the Analysis of Mercury in Coal," *Journal of the American Waste Management Association*, April 1996, 46:317-326.