Evaluation of Carbon Injection for Mercury Control at Coal-Fired Power Plants

Sheila M. Haythornthwaite (SheilaH@adatech.com; 303 792-5615)
Justin Smith (JustinS@adatech.com; 303 792-5615)
Jason Ruhl (JasonR@adatech.com; 303 792-5615)
ADA Technologies, Inc.
304 Inverness Way South, Suite 365
Englewood, CO 80112

Mark Fox (MarkFox@msp.psco.com; 303 571-7047)
New Century Energies
Terry Hunt (TerryH@ueplaza.com; 303 571-7113)
Utility Engineering
550 15th Street
Denver, CO 80202

Ramsay Chang (RChang@EPRI.com; 650 855-2535)
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94304

Tom Brown, FETC Contracting Officer Representative
DOE Contract DE-AC22-95PC95256
10/1/95 to 5/1/00
Prime Contractor: Public Service Company of Colorado
Subcontractor: ADA Technologies, Inc.

Abstract

The Department of Energy is sponsoring investigation of the applicability of activated carbon sorbents for control of mercury emissions from coal-fired power plants. There is a significant level of interest in controlling these emissions because coal-fired power plants make up approximately 30% of anthropogenic mercury emissions. DOE used data from this and other programs to support EPA's December 1997 "Mercury Study Report to Congress," which evaluated the current state-of-the-art in power plant mercury control from technical and cost standpoints. EPA decided in April 1998 that although current technologies are not sufficiently developed to require implementation today, the results of further study and testing will determine regulatory direction within three to five years. DOE is funding Public Service Company of Colorado (PSCo) to perform pilot testing and field measurements to evaluate carbon injection as a mercury control technology.

Mercury removal is difficult to quantify or scale-up confidently. Data interpretation is challenging because of complicating effects including measurement difficulties, mercury

speciation, adsorption of mercury by flyash, and sensitivity to temperature. In this phase of the program, PSCo and ADA Technologies are investigating these issues by performing three field test programs emphasizing waste analysis and scalability as key components.

Promising results were found for the carbon injection technology during Phase I of this program. Testing will continue on the 600-acfm pilot-scale particulate control module (PCM) that is installed at PSCo's Comanche Station in Pueblo, CO. The PCM was fabricated, installed, and tested during Phase I, and is configurable as an ESP, a reverse-gas baghouse, or a pulse-jet baghouse. Initial Phase II testing is designed to improve the measurement methodology, followed by testing in each of the PCM configurations.

Measurements of mercury emissions from several PSCo units without carbon injection will also be made. It is important to determine the ability of the pilot to match full scale performance. This will be determined by injecting ash collected from the full-scale units into the pilot and then comparing the ash-only mercury removal to the full-scale results. More detailed comparisons will be made between pilot results and Comanche's full-scale reverse-gas baghouse since flue gas composition may affect results.

Another component of the field testing will include carbon injection into a 3,000 acfm pilot ESP owned by ABB. This larger-scale, wire-plate ESP will be installed at another PRB-fired power plant and will provide further evaluation data for comparison with Comanche test results.

Carbon injection is the mercury control technology that is closest to commercialization on coal-fired power plants. This program is directed towards demonstrating the feasibility and limitations of its application.

Introduction and Summary of Phase I

The primary objective of this two-phase program is to demonstrate, optimize, and engineer dry sorbent injection for mercury control for coal-fired utility power plants. Phase I focused on evaluating mercury removal performance of carbon sorbents using actual flue gas at a field test facility, assessing the impact of the sorbent and the injection system on existing power plant equipment, and analyzing collected sorbent/ash to develop disposal options. Phase II of the program will gather additional data to further develop carbon injection in preparation for future full-scale testing. Phase I was completed by PSCo under a cost-share contract with the U.S. DOE. The Electric Power Research Institute (EPRI) provided technical assistance and additional funding for the work. ADA Technologies performed the pilot design, installation and testing, data analysis, and reporting.

The project team demonstrated the applicability of carbon injection for mercury control on coal-fired power plants in Phase I of this program. Many questions were brought to light, due to the difficulties encountered in measuring and understanding mercury trends. In Phase I the team accomplished:

1. Design, fabrication, and installation of a 600 acfm pilot system at PSCo's Comanche

generating station. This pilot could be configured as an ESP, a reverse-gas baghouse, a conventional pulse-jet baghouse, or a high air-to-cloth ratio pulse-jet baghouse. The temperature, flue gas mercury concentration, flue gas particulate loading (normal or low), and sorbent injection rate could each be controlled independently.

2. Operation and testing of the pilot over a 12-month period. Each particulate control configuration was tested. Mercury sampling methodology evolved and was improved over the course of testing.

3. Demonstration of mercury control by carbon injection as a function of temperature, three different sorbents, concentration of sorbent in the flue gas, and type of particulate control. Some of this data is qualitative because of the difficulty in separating sorbent effects from that of Comanche's fly ash. Our experience showed that the ash tends to sorb mercury under some conditions.

4. Established process conditions for 70% to 95% mercury control, using carbon sorbents, on different particulate collectors, on actual coal-fired flue gas.

5. Progressed towards reliable equipment integration by evaluating impacts of carbon injection on particulate collectors, interactions with NO_x and SO_2 controls, and regulatory ash disposal criteria.

6. Examined the variables affecting costs of implementing carbon injection technology.

Phase I succeeded in showing that carbon injection works on this scale. It also brought to our attention some limitations of the pilot testing that provide direction for the Phase II program. Specifically, the scalability of removal data from pilot to full-scale needs to be ascertained. The mercury removal effectiveness of carbon needs to be separated from that of the fly ash. Longer-term impacts on particulate collector performance as well as on the generated waste should also be investigated.

Sampling challenges in Phase I testing led to difficulty in data interpretation. Over the course of the year of pilot testing, both the pilot operation and sampling methodology were upgraded. However, some measurements obtained late in the Phase I program still showed high mercury removals even without sorbent injection and little additional removal with sorbent injection.

Phase I results indicate that carbon injection can obtain from 30 to 97% mercury removal at this site depending on operating conditions. The removal is strongly dependent on flue gas temperature and sorbent injection rate. Baseline mercury concentrations are so low that sampling methods are very important to collect accurate data, and one of the outcomes of Phase I has been an improved approach to mercury sampling. Another interesting result is that significant mercury removal is obtained with no carbon injection due to the properties of Comanche's flyash and other operating conditions. This affects test methodology, since the ash collected on a pre-filter within the sampling system may sorb mercury as the sample passes through it. To alleviate this variable and to account for the mercury taken up in the flyash, the sampling approach was modified to include isokinetic collection of the ash. The sampling system has been described previously (Haythornthwaite et al, 1997). With this approach an isokinetic particulate sample can be extracted simultaneously with the gaseous sample. The particulate is separated from the gas stream by the cyclone collector, and each fraction (particulate and vapor) can be analyzed individually. This approach was very effective and resulted in significantly improved mercury measurements.

Specific trends for mercury control by carbon injection with injection rate and temperature were identified or confirmed through Phase I field testing. These trends are shown on Figures 1 through 3 and described briefly below.

Figure 1 shows that increased carbon injection ratio (mass carbon : mass mercury) results in increased mercury removal efficiency. A wide range of pulse-jet baghouse data is shown on this figure, including temperatures from 220 to 300 ^{o}F, inlet mercury values from 2 to 18 μg/Nm^3, and tests on both normal-ash and low-ash flue gas. The overall trend is still clear, although some data scatter is seen. The scatter is attributable to a combination of the influence of other variables than injection ratio and difficulty in separating the effect of carbon sorbent from the effect of Comanche's ash in removing mercury. The effect of Comanche's ash is indicated on the figure by the zero injection rate values, ranging from 5% to almost 70%. These data points fall into groups by temperature, another parameter that substantially influences mercury removal.

Figure 1. Carbon Injection Ratio Impact on Percentage Mercury Removal at Comanche Pilot

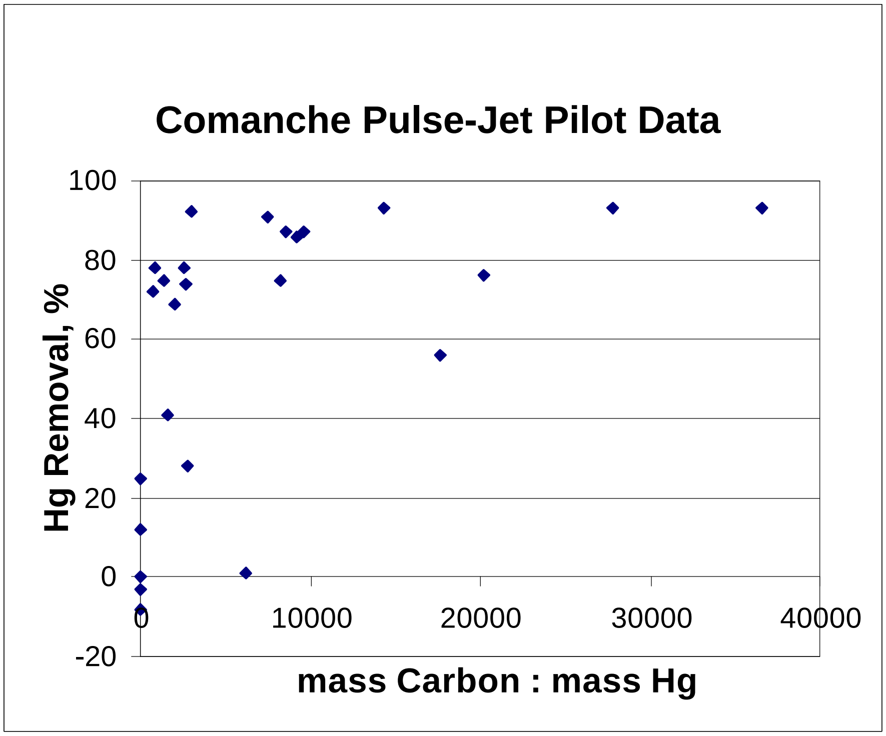


Figure 2 shows the removal of mercury by Comanche's flyash, and the effect of temperature on both ash and sorbent-based mercury removal. The open circles show results with Norit carbon injection and without fly ash present. The sorbent concentration in the flue gas for each open circle is about the same, the only major change between test conditions is the temperature. At 250 ^{o}F mercury removal is greater than 90%. However, as temperature increases towards 300 ^{o}F, mercury removal drops to 60-75%. There is some scatter in the data, but the trend with temperature is again seen in results of "baseline" tests, measurements made with normal flyash loading but no sorbent injection. The solid diamonds on Figure 2 show these results. Below 250 ^{o}F, greater than 65% mercury removal can be realized by the flyash alone. At higher temperatures, baseline tests showed less than 20% mercury removal. This strong temperature dependence for mercury removal by a sorbent, either the flyash or an injected carbon, was seen throughout Phase I testing. The temperature cutoffs were not consistent, however, and the amount of mercury removed by flyash alone varied greatly. These two variables; temperature for effective adsorption, and potential mercury removal by the native flyash, will be further investigated in the Phase II testing.

Figure 2. Trend Graph for Decreasing Mercury Removal with Increasing Temperature at Comanche Pilot

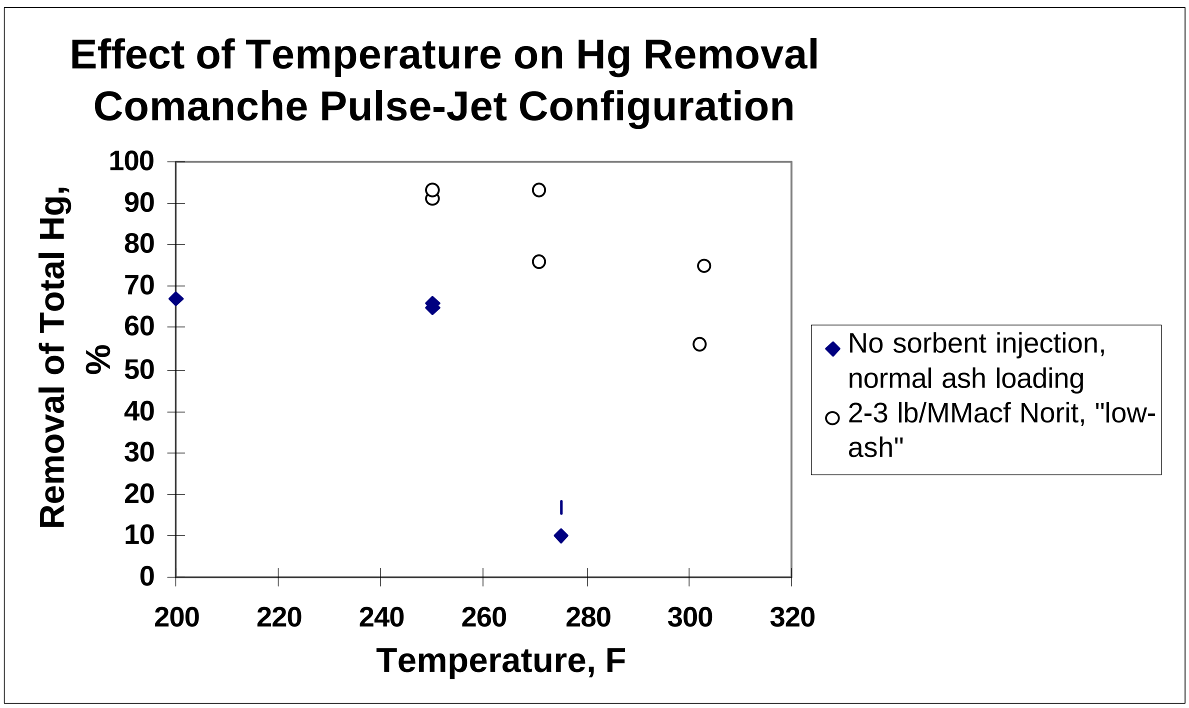
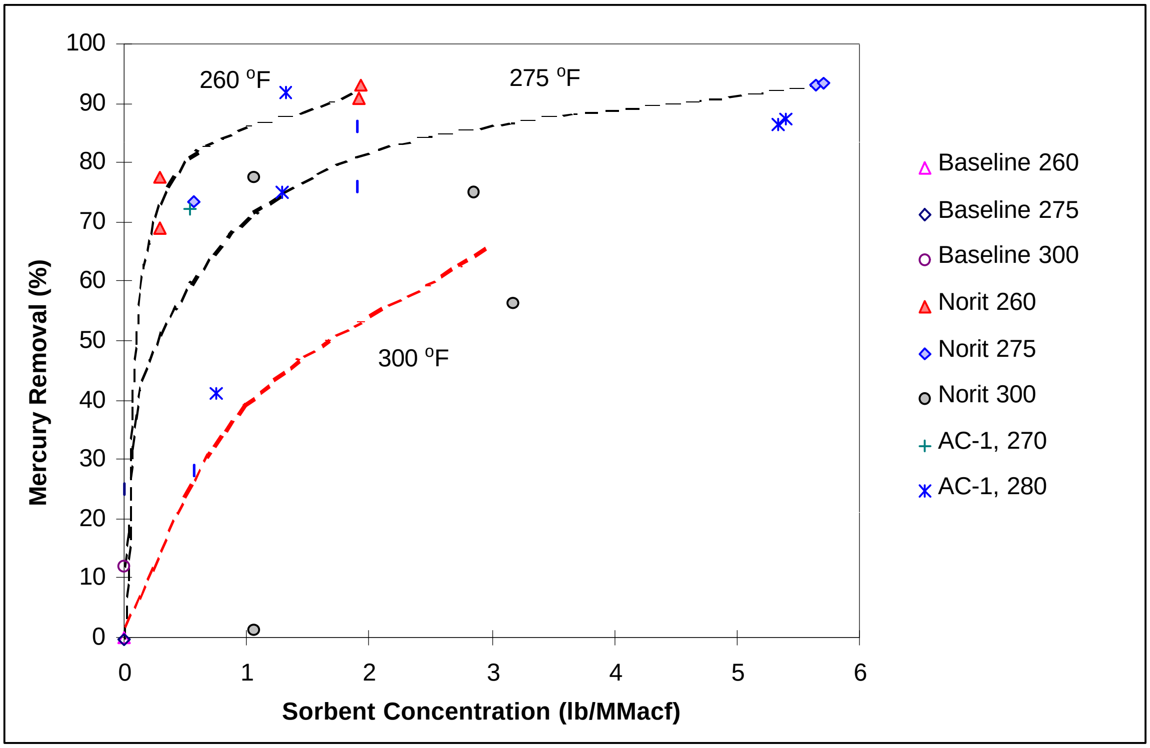


Figure 3 shows the temperature trend for mercury removal in a different way. The tests shown are on the pilot in the pulse-jet baghouse configuration with low-ash flue gas (extracted downstream from Comanche's full-scale reverse-gas baghouse).

Figure 3. Temperature Trend for Mercury Removal by Injected Carbon at Comanche Pilot: Pulse-Jet Configuration, Low-Ash Flue Gas



High (70 to 80%) mercury control efficiencies by activated carbon were measured at temperatures under 275 °F and carbon concentrations in the flue gas of less than 2 lb/MMacf. Under these conditions the removal efficiency improvement is small with higher quantities of carbon, and lowering the flue gas temperature yields the same improvement. At higher flue gas temperature of 300 °F, mercury removal was less than for lower temperatures at similar injection rates, and data needs to be gathered to determine how much carbon is needed to obtain high mercury removal. The exact cutoff temperature for high mercury removals with the lower injection rates will also be investigated in Phase II. In some cases it may be more economical to cool flue gas than to inject additional carbon, these parameters need to be defined more clearly to determine economics for a given site.

Phase II Approach

The utility industry is very conservative and demands high reliability and predictability for any new plant equipment. Concerns voiced by utilities about new technologies include long-term performance issues, balance-of-plant impacts, storage or generation of waste materials, and minimization of costs. Ideally, a utility would like to see a full-scale installation of a new technology operating for several years before committing to the purchase of the technology. To get to this point, reliability issues must be addressed to minimize risks associated with a full-scale demonstration. This Phase II program is designed to address these reliability concerns, moving carbon injection technology closer to commercial availability.

The sampling difficulties in Phase I have led us to develop a test matrix at the beginning of Phase II that will provide insight into the sampling methodology. We will use both the isokinetic sampling method with an iodated carbon trap for vapor-phase mercury collection, similar to Phase I, and a Perkin-Elmer batch-sampling analyzer (MERCEM™) as the mercury measurement methods at Comanche. The remainder of testing at Comanche will use a method as developed from this initial matrix.

Other field work that will be performed in Phase II includes comparison tests between pilot results and full-scale measurements at Comanche, measurements on other PSCo units to determine the mercury-removal capability of the existing particulate collectors, and carbon-injection testing on a larger-scale pilot ESP at another coal-fired power plant site. Measurements for these tests will include a variety of sampling approaches, summarized in Table 1. Each method has been selected as appropriate for the specific application. For example, isokinetic ash sampling will be employed for testing upstream of particle collectors, and where access makes it possible, the filter and iodated carbon trap will be in-situ. In-situ sampling ensures that the ash and the iodated carbon trap are held at duct temperature. Analysis of backup traps will be used for one in three samples to check for mercury breakthrough.

The above methods all measure either total mercury or total vapor-phase mercury. During one series of tests at Comanche station, mercury speciation will be performed using the Ontario-Hydro test method. Particulate-bound, elemental, and oxidized forms of mercury will all be measured at the inlet and outlet to the host unit baghouse and at the pilot inlet and outlet while in the reverse-gas baghouse configuration. These measurements will be compared to evaluate whether the pilot is representative of full-scale.

Table 1. Measurement Methods for Quantifying Mercury Concentration at Comanche Pilot

Method	Sample Location	Purpose	Site
Iodated carbon sorbent trap	Particulate collector outlet	Total vapor-phase Hg	Comanche Pilot Other PSCo units
Iodated carbon trap with out-of-stack isokinetic ash collection	Inlet and outlet	Validation of test method and quantify ash effects	Comanche Pilot
Iodated carbon trap with in-stack isokinetic ash collection	Inlet	Total Hg	Other PSCo units
MERCEM™ Analyzer	Inlet and outlet	On-site vapor-phase Hg results, but must be validated	Comanche Pilot
Ontario Hydro	Inlet and outlet	Hg speciation and comparison to host	Comanche host and pilot

Comanche Pilot Testing

The first step in Phase II work at Comanche has been to make some upgrades to the pilot. These are shown on Figure 4. The layout of the pilot for prior testing included temperature control, and when heating was required above host temperatures, the duct heater downstream of the inlet port was used. This may have changed the vapor-phase mercury concentration by its cycled temperature operation. The modified inlet section to the pilot makes all changes to the flue gas temperature and composition (e.g. doping with mercury or injecting ash) upstream of the inlet sample port. Temperature control through the pilot has been substantially improved since early Phase I testing and is now maintained within about 5 ^{o}F from the inlet to the outlet.

To accomplish improved mercury quantification, approximately four weeks at the beginning of the Phase II Comanche testing are dedicated to conducting tests to validate mercury measurements. By measuring total mercury (ash-bound plus vapor-phase) at both the inlet and the outlet of the system with identical test procedures, we can determine whether it is possible to control the system well enough to preserve the mercury concentration through the pilot. This would allow sampling without the need to preserve the ash bound/vapor phase equilibrium that may be altered by overexposing the gas to an ash with affinity for mercury.

Isokinetic sampling will be performed at the inlet and outlet in the ESP configuration without power to the ESP, initially. A tentative mass balance will be obtained by analyzing hopper samples. This approach will provide a value for total mercury at both the inlet and the outlet. Several tests will be run with the ESP turned off to determine the extent to which loss of mercury takes place across the unit (ideally zero). Further testing with the ESP at full power will determine what shift in mercury vapor- and particulate-phases is caused by collection of the ash alone, and determine the control efficiency of the pilot ESP. Tests with sorbent injection should further shift the deposition of mercury to the particulate measurement taken from the ash collection hopper. This shift towards particulate deposition and collection will be the measurement of sorbent efficiency. Regular hopper samples and lab analysis will also provide data on waste characterization.

In addition a Perkin Elmer mercury analyzer will be available for this initial test series. This analyzer has functioned well in tests at UNDEERC, with results within 25% of impinger-based methods. The analyzer measures total gaseous mercury. The sample probe includes a heated filter box outside the stack which contains two sintered metals filters in series. These two filters remove the majority of the particulate before the gas is extracted through a heated (360 ^{o}F) sample line to the analyzer. In the analyzer a $SnCl_2$ solution is used to reduced any oxidized mercury to elemental mercury. After drying, the sample gas is then sent through a gold trap for amalgamation. Periodically, the trap is heated to vaporize the mercury, which is analyzed by cold vapor atomic absorbence spectroscopy (CVAAS) (Laudal, et al 1996). Results from the analyzer (both inlet and outlet) will be compared with manual (iodated carbon with isokinetic ash collection at the inlet) samples to determine the reliability of analyzer data for on-the-fly testing decisions.

Refinement of sampling procedures will precede the test matrix planned for each particulate control module. The testing plan for all PCMs is summarized in Table 2. Long-term carbon injection tests are planned for several days so that impacts on collection performance can be better quantified. Re-injection of flyash refers to operating the pilot on a low-ash slipstream while injecting ash from Comanche or another PSCo unit. These tests will be performed at operating conditions as similar as possible to the operation of the source-ash unit.

After a useable sampling system has been selected, testing will be conducted in the ESP configuration. Tests at three temperatures and three injection rates, and two residence times will be used to verify results obtained in the Phase I program. It is possible that tests with alternate sorbents will also be performed in this configuration, this will be determined as sorbents are made available to ADA through EPRI, DOE, or other sources.

Table 2. Test Matrix Summary for Comanche Pilot

	Injection Rate	Temperature	Residence Time	Sodium Injection	Sorbent Recycling	Long Term Carbon-Inj.	Ontario-Hydro	Re-Inject Flyash
ESP	X	X	X					X
Pulse-Jet baghouse	X	X		X		X		
Reverse-Gas baghouse	X	X		X		X	X	X
TOXECON	X	X			X	X		

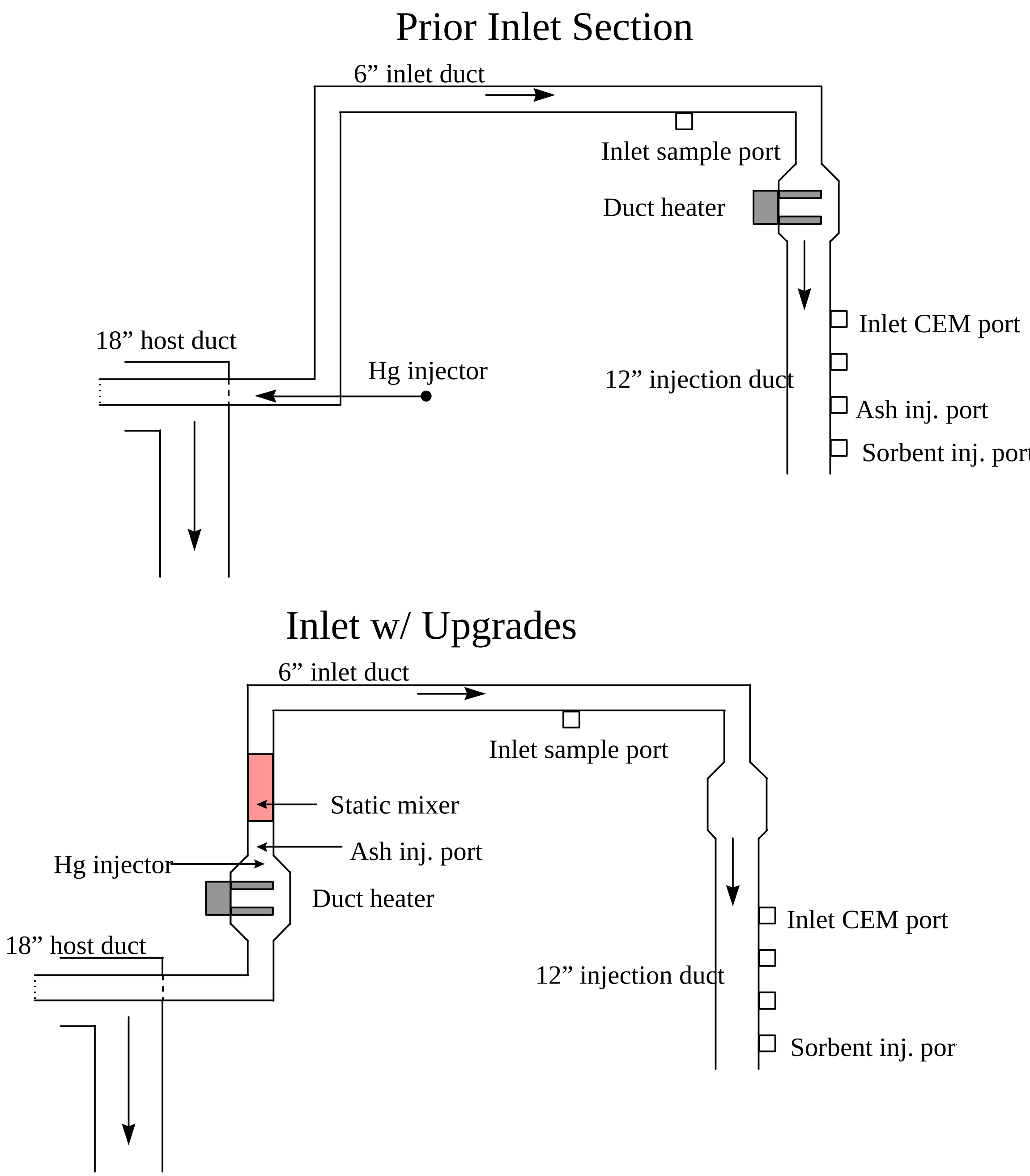


Figure 4. Pilot Inlet Section Before and After Upgrades

PSCo Power Plant Survey

Pilot data from Phase I identified strong trends indicating sorption of mercury by the flyash. This sorption has also been seen by others in a concurrent DOE program (Devito 1997). This task is focused on evaluating the applicability of these results to full-scale. It is important to determine whether the flyash sorption seen at Comanche and other units occurs at other PSCo sites with various particulate collectors, and at what temperature range this sorption occurs. The potential of removing mercury by controlling temperatures instead of injecting carbon is of significant interest. Characterizing a full-scale unit’s emissions at different temperatures will provide information on the necessity of carbon injection or whether flyash alone will be sufficient. To this end, total mercury testing across four particulate collectors will be performed. Three of those units will be tested twice, once in the summer (higher temperatures) and once in the winter (lower temperatures). The sampling methods shown in Table 1 will be used, in-stack isokinetic sampling at the inlets and iodated carbon traps at the outlet.

In addition to the tests for total mercury on other units, mercury will be speciated upstream and downstream of Comanche’s reverse-gas baghouse. These tests will be conducted by Consol using the Ontario-Hydro method with addition of a preservative upon sample completion. Consol will also consult on the recovery of ash and coal samples to obtain a mass balance for mercury on the unit. Ontario-Hydro is a draft ASTM method that has been established as the preferred field method for accurate mercury speciation. Results from speciation testing on the full-scale Comanche reverse-gas baghouse will be compared with pilot tests in the reverse-gas configuration conducted under similar operating conditions to those found during the full-scale measurements. Table 3 summarizes the planned full-scale mercury measurements.

Table 3: Mercury Testing of PSCo Units

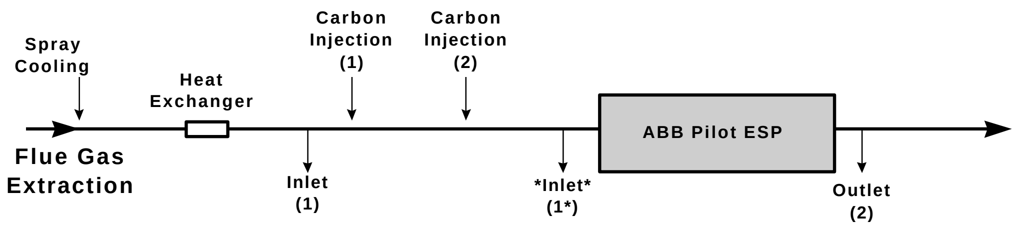
Site	Particulate Collector	Coal Type	Test Method
Arapahoe 1	Electrostatic Precipitator	Powder River Basin or Colorado (spot market)	In-stack isokinetic inlet (total Hg); iodated carbon trap outlet (vapor Hg)
Arapahoe 4	Reverse-Gas Baghouse	Powder River Basin or Colorado (spot market)	same
Cherokee 3	Reverse-Gas Baghouse	Colorado	same
Hayden	Spray Dryer (To be operating by spring ’99)		same
Comanche	Reverse-Gas Baghouse	Powder River Basin	Ontario-Hydro (total and speciated Hg)

Larger-Scale Pilot ESP Testing (ABB Pilot)

Scaling up carbon injection on an electrostatic precipitator to obtain data more representative of full-scale operation is the goal of this task. ABB has a 10,000 lb/hr pilot-scale ESP that will be installed on a coal-fired power plant slipstream. This ESP is a wire-plate design and has a proprietary switched integrated rectifier power supply. The electrical performance of the pilot is tightly controlled and logged. ADA specified a carbon injection system for this pilot, and will perform mercury control testing using the system.

The testing parameters that can be varied at ABB’s pilot facility include heating or cooling of the flue gas by heat exchanger or by spray cooling, in-duct residence time of the carbon, carbon injection rate and sample location. Variable sample location tests include sampling across the inlet ducting only to determine any duct effect on mercury removal.

Figure 5 shows a schematic of the ABB ESP pilot layout. Two series of carbon-injection tests will be completed at ABB's pilot-scale ESP. Both test series will be conducted on flue gases from powder river basin coal, providing a comparison point for Comanche results. If possible, the second series of tests will be performed while firing coal from a different mine than the first series.



Variables:
•Temperature
•Moisture
•Residence Time (by injection location)
•Carbon Injection Rate
•Sample Location

Figure 5. Schematic of ABB Pilot ESP and Test Variables

Preliminary testing will be done using the draft Ontario-Hydro method, simultaneously with the an iodated-carbon trap manual sample, at two temperature conditions. This will provide data on the split between elemental and oxidized forms of vapor-phase mercury, and particulate-bound mercury. A criteria of 15% of the total mercury as particulate-bound mercury will be used to decide what test method to use for the balance of testing. If the particulate-bound mercury is less than 15%, the balance of the test series will be conducted using the iodated carbon traps for vapor-phase mercury only. This method is preferred in terms of efficiency. Should the particulate-bound mercury be greater than 15% of the total, it is important to use isokinetic testing so that the particulate fraction is accurately represented. In this case the balance of the test series will be conducted using an in-stack filter and iodated carbon trap.

If a second PRB coal is fired during the second series, the Ontario-Hydro method will be again employed to document the speciated-vapor and particle-bound fractions of mercury. Testing two coals burned at the same plant will provide valuable information about the degree of impact varying fuel has on mercury speciation and removal efficiency. Since we will have preliminary data on removal efficiencies at this site from the first test series, testing parameters may be fine-tuned. This may include testing at optimum sorbent injection rates based on a desired removal efficiency, or further testing to determine the effects of spray cooling on mercury removal efficiencies.

Additionally, the effect of long-term carbon injection on the pilot ESP performance will be evaluated. Continuous carbon injection for several days is planned, during which mercury and particulate tests will be run periodically to evaluate whether mercury- or particulate-removal efficiency is affected by carbon injection. Electrical parameters and opacity will be monitored closely to determine any degradation in ESP performance. The sequence for this test series is shown in Table 4.

Table 4. Sequence for Mercury Control Testing at ABB's Pilot ESP

Test Description	Method	Purpose
Series 1 Preliminary	Ontario-Hydro	Ascertain vapor/particulate split
Series 1 Full matrix	IC Trap*	Impact of variables
Series 2 Preliminary	Ontario-Hydro	Only if second coal
Series 2 Full matrix	IC Trap*	Impact of variables
Long-Term	IC Trap*	Long-term impacts

* Inlet location IC (iodated carbon) trap tests will utilize either isokinetic in-stack sampling, or iodated-carbon trap only. This will be determined based on preliminary test results.

Summary/Conclusions

In Phase I of this program, field mercury measurements were made of mercury control by carbon injection into a pilot-scale particulate collector installed at Comanche Station. Mercury removal by activated carbon was not optimized, but trends were identified and the ranges of certain variables were bracketed. Specific results relative to mercury control by sorbents and measurement methodology are:

- Comanche fly ash adsorbs mercury under some operating conditions.
- Decreasing flue gas temperature yields higher mercury removal efficiency by sorbents, whether an injected sorbent or Comanche's native fly ash.
- Increasing carbon injection ratio improves mercury removal to a point. Injection ratio and flue gas temperature can be optimized together.
- Mercury measurements in the presence of fly ash at Comanche require quantification of the particulate-phase mercury.

In Phase II the technology of carbon injection for mercury control will be further investigated and optimized by the following:

- Improve data reliability from Phase I.
    - Improve confidence in measurements by performing triplicate, independent tests with individual quantification of particulate-bound mercury.
    - Repeat conditions at the Comanche pilot under all particulate control module configurations, including identifying operating conditions with incomplete or conflicting data from Phase I testing.
    - Identify operating conditions (temperature, other) under which Comanche ash sorbs mercury.
    - Demonstrate comparison of pilot to full-scale operation at Comanche with the pilot in the reverse-gas configuration, under operating conditions as close as possible to the full-scale baghouse.

- Define accurate operating costs for economic projections applicable to a variety of utility units and particulate collectors.
    - Measure mercury emissions and control efficiency across different particulate collectors and boilers.
    - Project full-scale costs for an example case.
- Determine the long-term stability of mercury in ash.
- Determine whether carbon separation can offset the costs or provide useful products.
- Develop a useful database of mercury control via carbon injection to assist evaluation of the applicability of the technology to a given unit.

References

Haythornthwaite, S.M., S. Sjostrom, T. Ebner, J. Ruhl, R. Slye, J. Smith, T. Hunt, R. Chang, T. Brown, "Demonstration of Dry Carbon-Based Sorbent Injection for Mercury Control in Utility ESPs and Baghouses," presented at the EPRI-DOE-EPA Combined Utility Air Pollutant Control Symposium, Washington, D.C., August 25-29, 1997.

Laudel, D.L., K.C. Galbreath, M.K.Heidt, S.K.Joines, T.D. Brown, "A State-of-the-Art Review of Flue Gas Mercury Speciation Methods," EPRI Report TR-107080, November 1996.

DeVito, M.S., "Mercury Emissions at FGD-Equipped Coal-Fired Utilities," Proceedings of the U.S. DOE Advanced Coal-Based Power and Environmental Systems '97 Conference, July 22-24, 1997.