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

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Abstract

This quarterly report describes the activities that have taken place during the first full quarter of the Phase II project “Investigation and Demonstration of Dry Carbon-Based Sorbent Injection for Mercury Control”. Modifications were completed and sampling began at the 600 acfm pilot-scale particulate control module (PCM) located at the Comanche Station in Pueblo, CO. The PCM was configured as an electrostatic precipitator for these tests. A Perkin-Elmer flue gas mercury analyzer was installed on-site and operated. Initial test results using both manual sampling methodology and the mercury analyzer are presented herein.

Preparations were made during this period for full-scale mercury testing of several PSCo units. A site visit was made to Arapahoe and Cherokee Generating Stations to determine sample locations and to develop a test plan.

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Executive Summary

PSCo is conducting a two-year Phase II program which will significantly advance the technical basis for application of carbonaceous sorbents to mercury control on coal-fired utility boilers. The approach in Phase I was to fabricate a pilot facility and perform tests using dry carbon-based sorbent injection for mercury control on an actual coal-fired flue gas slipstream. Phase II is designed to move carbon injection technology towards commercial application on coal-fired power plants by addressing key reliability and operability concerns. Phase II includes testing carbon injection at another site, as well as making mercury measurements on several of PSCo's coal-fired units.

In this quarter, modifications and upgrades to the pilot facility at Comanche Station continued. Testing of the pilot in the ESP configuration began initially without carbon injection, and comparisons were made between measurements made using manual sampling and a batch-sampling mercury analyzer manufactured by Perkin-Elmer.

Concurrently, numerous modifications were made to the 600 acfm pilot-scale particulate control module (PCM) installed at Comanche Station in Pueblo, CO. This pilot-scale facility is being used to conduct carbon injection tests during the Phase II work. Most of the modifications were made to better control and maintain stable gas temperatures throughout the PCM. Sorbent mercury capacity is very temperature dependent and therefore temperature control is crucial in sorbent investigations. Much effort was also given to the techniques for sampling particulate-laden gas. This is an important issue since ADA will attempt to more accurately quantify the total vapor-phase and particulate-phase mercury. Phase I data suggest that further refinement of testing procedures and equipment may be required to increase the confidence in the data. Isokinetic particulate sample trains were built for the Comanche pilot-scale facility for the representative capture of particulate matter. One target of the improved measurement technique was to quantify the mercury removal by Comanche's ash separately from an injected sorbent. An alternative measurement method was installed during this quarter, a Perkin-Elmer MERCER analyzer was tested for comparison alongside the manual, isokinetic sampling system. In total, these modifications should improve the quality and reduce the variation in the data derived from the carbon injection tests.

Data from testing in the ESP configuration using these test methods is presented herein. All ESP results are presented, these tests took place from May 14 to August 3, 1998.

Introduction

The overall objective of this two-phase program is to investigate the use of carbonaceous sorbents to control mercury emissions in coal-fired utility boiler flue gas. This information is important to the utility industry in anticipation of pending regulations. During Phase I of the program, a 600 cubic foot per minute (cfm) pilot-scale test facility was engineered, constructed, and integrated into Public Service Company of Colorado (PSCo) Comanche Station in Pueblo, Colorado to test various carbon sorbents under different operating conditions. The flexibility of the test facility allowed investigators to study mercury removal with the particulate control module (PCM) configured as an electrostatic precipitator, a pulse-jet baghouse, or a reverse-gas baghouse. Carbon-based sorbents were injected upstream of the PCM and mercury concentration measurements were made to determine the mercury removal efficiency for each sorbent. Details of the Phase I program were presented in the draft final report which includes a full description of the equipment and analytical procedures used as well as the data and conclusions from the tests.

Phase II is designed to move carbon injection technology towards commercial application on coal-fired power plants by addressing key reliability and operability concerns. The approach is to establish repeatable results in the pilot unit, and to obtain sufficient information to confidently scale up the technology. The same PCM used in Phase I is being used in Phase II for further mercury control evaluations. In this phase, selected sorbents will be tested with the PCM configured as an electrostatic precipitator, a pulse-jet baghouse, TOXECON, and a reverse-gas baghouse. A description of the test facility is included below.

Measurements of mercury will also be performed at several of PSCo's coal-fired units. The as-found mercury emissions will be measured at the inlet and outlet of each particulate collector to quantify how much mercury is collected without sorbent injection.

In addition to further tests at the existing pilot facility at Comanche, a carbon injection system will be installed and tested at a pilot-scale ESP operated at another utility site. This pilot ESP is owned by ABB and is a wire-plate design, treating up to 5,000 cfm of flue gas. This testing will provide information on whether the characteristics seen at Comanche are representative of other sites.

The impact of carbon injection on ash disposability and sale will also be examined in Phase II. Recycling will be evaluated by re-injecting ash into the pilot with and without processing.

The final deliverable of Phase II will be a comprehensive report and database on the applicability of carbon injection for mercury control on PSCo's units.

Equipment Description

The pilot-scale test facility is designed to permit significant control over the operating conditions during sorbent evaluation tests. In addition to changing the particulate control configurations, operating parameters such as flue gas flow rate, duct temperature, flue gas moisture content, in-duct sorbent residence time, and flue gas mercury concentration can be controlled and varied. In Phase II sorbent effectiveness will be evaluated over a temperature range from 230° F to 350° F. This broad temperature range is targeted because of the dependence of sorption characteristics on temperature of the flue gas, and the need to better understand this relationship. When necessary, the flue gas can be heated using an in-line immersion gas heater. Sorbents are introduced to the system through ports located in the injection section. Ports are located such that in-duct sorbent residence times of 0.75 to 1.5 seconds are available to evaluate the impact of duct residence time of a sorbent on its effectiveness.

The PCM is designed with interchangeable collection members allowing configurations such as an ESP, pulse-jet baghouse, reverse-gas baghouse or TOXECON. The ESP was tested this quarter, and its description is provided below.

Electrostatic Precipitator

The ESP pilot fabricated for these tests is a 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 ESP 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.

Results and Discussion

Task 21 - Comanche Pilot-Scale Modifications and Testing

Modifications to the unit included moving the in-duct gas heater upstream of the inlet sample port, adding a static mixer, and reworking the unit's skin heaters to better control temperature. These upgrades have allowed ADA to test up to 350°F with constant temperature (within 5°F) throughout the unit, which has enhanced the precision of data collection.

ESP Startup. The PCM unit was configured as a tube ESP on April 14, 1998. Initial performance was poor, which was attributable to two primary causes. Ash produced at Comanche is inherently problematic for ESPs due to the high resistivity typical of Powder River Basin coal ash. This was compounded by the inability of the pilot ESP's rapping system to remove sufficient ash from the tubes. Future use of the ESP will require a reworking of this system.

Shortly after start-up ADA experienced a major problem with the high voltage supply system. The problem, initially thought to be a failed T/R, was eventually traced to a faulty gauge in the AVC (automatic voltage controller). This problem delayed carbon injection testing for approximately two weeks. However, the unit was operational for testing of the Perkin-Elmer MERCEM analyzer and ADA's isokinetic sampling system.

Several maintenance and operational issues were addressed as needed during the quarter. Items such as an unstable flow controller, the pilot fan coming loose from its foundation, problems with the Campbell data logger, and periodic manual cleaning required to keep the ESP running well, took time out from testing.

MERCEM Analyzer. ADA took delivery of and installed the MERCEM analyzer on April 16, 1998. The equipment included probes, filter boxes and hot lines. Bob Peters (Aldora) and Walter Trippel (Perkin-Elmer) arrived on site May 11, 1998 to start up the instrument. Once it was operational, ADA performed a calibration test using a mercury generator (permeation tube) as a mercury source and iodated carbon traps for mercury measurements. Gaseous mercury was fed from the mercury generator into a stainless steel header via a heated line. The gas was sampled by the MERCEM and with carbon traps (triplicate samples). These tests are identified in Table 1 as 1-cal to 3-cal, "calibrator to analyzer check." Table 1 also shows the analyzer readings for the first 25 test runs, including tests conducted using the mercury doper to obtain higher mercury concentrations in the gas stream. The level in the flue gas was set using the analyzer

reading as a guideline, targeting levels around 5, 25, and 50 $\mu\text{g}/\text{Nm}^3$. The iodated carbon trap measurements showed much higher levels, however, of approximately 15, 75, and almost 200 $\mu\text{g}/\text{Nm}^3$, respectively. These results are depicted on Figure 1.

Figure 1. Correlation of IC trap measurements to MERCER analyzer readings.

During the first few weeks of operation, the instrument was plagued by two problems. Two or three times daily the instrument would place itself in “standby” mode, thus halting data collection. Fortunately this never happened during a test. The analyzer was also incapable of storing data for downloading onto a PC. Both problems were solved by making software changes suggested by Bob Peters of Aldora. The data files collected by the instrument have been compared to the files collected by ADA’s data logger, and were found to be functionally identical.

There were problems with operation of the MERCER analyzer that were not successfully resolved in this quarter. The power supply to the computer failed, and was replaced on-site. The instrument was then returned to service. Shortly thereafter the instrument began to show a “low lamp energy” alarm. ADA responded by cleaning the cell, which helped only slightly. The lamp energy was still approximately one-half of the normal value (40% vs. 85%). After consultation with Aldora, the lamp was changed by ADA personnel. The lamp energy increased slightly, but exhibited a substantial amount of noise. In addition, the lamp energy was oscillating rapidly between 46% and 72%.

Manual Mercury Measurement Procedures. To improve our confidence in the sample recovery procedures that are being used for measuring total mercury, Frontier Geosciences

performed a laboratory test to evaluate the effectiveness of using acetone for recovering particulate matter from the sampling train. Frontier used an ash sample from 4/97 to do this experiment. The results show an average measurement of 1135 ng/g with a standard deviation of 36.22 (%RSD=3.2%). The original analysis of the same sample last year was 1035 ng/g (%RSD with this sample is 9.25%). These results give us confidence that acetone recovery of our sample trains is not significantly biasing our mercury results.

Field procedures were modified to include using HCl to clean glassware rather than HNO₃ because HCl is more effective for recovering mercury. Acetone was used to recover particulate matter from sample train surfaces. HCl was then used to clean the surfaces after each triplicate run. The HCl rinses from these initial tests were analyzed for mercury to determine whether it was necessary to rinse the glassware with HCl in order to get complete sample recovery. These results are somewhat scattered, showing that the HCl rinse contained small amounts of mercury in some tests, and almost none in others. This data will be reviewed further and presented in detail next quarter.

Sample recovery included collecting an ash sample (cyclone and filter recovery) and a vapor-phase sample for each inlet test. Isokinetic sampling at both the inlet and outlet to the ESP showed that very little ash, and hence particle-bound mercury, existed at the outlet. Thus further testing was conducted with isokinetic sampling at the inlet only, and IC traps only at the outlet.

ADA has been collecting a sample of hopper ash during each test in an effort to perform a mass balance for mercury. This procedure has not produced useful information to date. ADA will continue to collect the samples, but will not analyze them until a new data analysis approach is agreed upon.

Test Results without Carbon Injection. Testing of the pilot began in May. Triplicate samples were collected using isokinetic sampling at both the inlet and outlet locations. The following conditions were tested for comparison: ESP power off with and without using the in-duct heater to elevate the pilot temperature (skin heaters were used to maintain constant temperature throughout the pilot), and the same two heater conditions with the ESP power on. The measurements were each made at each location with an isokinetic particulate sample (oven box held at duct temperature) combined with a vapor-phase mercury sample using an iodated carbon trap. Results of these tests are summarized in Table 1.

Test #	Description	Date	Inlet vapor-phase Hg	Inlet ash Hg	Total Inlet Hg	Outlet vapor-phase Hg	Outlet ash Hg	Total Outlet Hg	Total Hg removal, %	Host Load, MW	Pilot Inlet T, F	PCM Inlet T, F	Pilot flow, acfm	T/R Voltage, kV	MERCEM Inlet Hg	MERCEM Outlet Hg
1-cal	Calibrator to analyzer check	5/14/98	4.0		4.0										3.5	
2-cal	Calibrator to analyzer check	5/14/98	2.9		2.9										3.5	
3-cal	Calibrator to analyzer check	5/14/98	2.7		2.7										3.5	
1	ESP Off, Duct Heater Off, "Natural Temp"	5/15/98	0.2	6.1	6.3	0.2	6.0	6.2	2.0	348	260	253	509	0	2.4	2.3
4	ESP Off, Duct Heater Off, "Natural Temp"	5/19/98	5.1	2.4	7.5	4.0	2.9	6.9	7.7	364	281	273	546	0	4.4	4.2
5	ESP Off, Duct Heater Off, "Natural Temp"	5/20/98	2.9	4.4	7.3	3.0	7.6	10.6	-45.1	303	256	255	572	0	3.6	3.5
6	ESP Off, Duct Heater Off, "Natural Temp"	5/20/98	3.2	4.1	7.3	3.7	1.3	5.0	31.5	312	261	262	545	0	3.8	3.4
7	ESP Off, Duct Heater Off, "Natural Temp"	5/20/98	3.6	4.9	8.5	3.3	7.6	10.9	-28.9	356	276	270	511	0	4.7	4.5
8	ESP Off, Duct heater on, heat to 300F	5/21/98	5.8	1.5	7.3	5.2	1.9	7.2	1.9	369	284	292	615	0	4.2	3.7
9	ESP Off, Duct heater on, heat to 300F	5/21/98	6.6	1.3	7.8	6.8	0.3	7.1	8.8	356	281	292	612	0	4.9	4.8
10	ESP Off, Duct heater on, heat to 300F	5/21/98	7.4	0.9	8.3	6.4	1.1	7.5	9.5	319	275	293	598	0	4.8	5.1
11	ESP ON, Duct Heater Off, "natural Temp"	5/28/98	3.5	4.3	7.7	5.0	0	5.0	35.9	361	293	289	638	33	4.0	3.5
12	ESP ON, Duct Heater Off, "natural Temp"	5/28/98	4.0	3.7	7.7	4.9	0.11	5.0	35.3	363	291	288	639	28	4.1	3.4
13	ESP ON, Duct Heater Off, "natural Temp"	5/28/98	6.3	1.7	7.9	6.0	0.03	6.0	24.4	305	281	282	616	29	4.1	4.1
14	ESP ON, Heat to 300 deg. F	6/1/98	11.9	2.3	14.2	9.4	0.02	9.4	33.7	359	279	297	619	39	4.7	5.6
15	ESP ON, Heat to 300 deg. F	6/1/98	11.6	1.9	13.5	8.4	0.02	8.4	37.9	362	280	297	614	38	5.1	5.4
16	ESP ON, Heat to 300 deg. F	6/1/98	6.9	1.4	8.4	7.5	0.03	7.5	10.2	360	284	298	605	35	4.9	5.0
17	ESP off, heat to 300 deg F, doping Hg	6/15/98	18.0		18.0	18.9		18.9	-4.8	356	280	297	597	0	5.7	5.7
18	ESP off, heat to 300 deg F, doping Hg	6/15/98	14.2		14.2	15.9		15.9	-12.3	356	282	297	598	0	5.2	5.3
19	ESP off, heat to 300 deg F, doping Hg	6/15/98	15.0		15.0	17.0		17.0	-13.5	356	283	297	596	0	4.8	5.2
20	ESP off, heat to 300 deg F, doping Hg	6/16/98	72.7		72.7	77.8		77.8	-6.9	351	277	298	608	0	23.7	24.0
21	ESP off, heat to 300 deg F, doping Hg	6/16/98	77.9		77.9	81.0		81.0	-3.9	357	282	298	617	0	24.9	25.0
22	ESP off, heat to 300 deg F, doping Hg	6/16/98	79.8		79.8	81.4		81.4	-2.0	356	286	298	618	0	25.2	26.1
23	ESP off, heat to 300 deg F, doping Hg	6/18/98	162.7		162.7	193.5		193.5	-18.9	357	293	300	620	0	55.7	58.7
24	ESP off, heat to 300 deg F, doping Hg	6/18/98	183.9		183.9	201.9		201.9	-9.8	358	294	300	629	0	54.0	56.3
25	ESP off, heat to 300 deg F, doping Hg	6/18/98	191.5		191.5	199.3		199.3	-4.1	358	295	300	630	0	57.3	60.9

Table 1. Summary of measurement method comparison tests. All mercury measurements in $\mu\text{g}/\text{Nm}^3$ @ 3%O₂.

The first sixteen tests were performed to establish “baseline” mercury removal by the pilot and to determine ESP particulate control efficiency. Figure 2 shows the particulate loading during ESP tests prior to carbon injection. The particulate control efficiency ranged from 85 to 100%, with an average of 92%. These ash removal numbers are lower than what would be expected for a well-performing ESP. This is probably related to the problems with cleaning the ESP mentioned above.

Figure 2. Ash loading with ESP on and off.

Tests 17 to 25 were conducted to check MERCEM analyzer measurements vs. the manual IC trap method. These results are presented in Table 1 and Figure 1.

Table 2 shows the data for all the remaining ESP tests. These results are discussed in the following sections.

Test Results with No Carbon Injection. Mercury removal by the ESP without any carbon injection was tested several times at several different temperatures. All these baseline test results are shown on Figure 3. Although a trend with temperature can be seen (i.e., higher removal rates at lower temperatures), there is a wide variability in the data. Test results at the extremes of temperature (spray cooling at ~230°F and maximum heating at ~350°F) show tight patterns, but at the intermediate temperatures of 270-310°F, the results are more variable. Mercury removal by the flyash in these tests falls into the following ranges: 53 to 61% at 230°F, 10 to 39% at 271 to 306°F, and -2 to 26% at 350°F. The broad ranges are not seen within sets of triplicate test runs, which are fairly tightly grouped in most cases, but between different sets of triplicates taken on different days.

Test #	Description	Date	Carbon inj, lb/MMacf	Total Inlet Hg	Total Outlet Hg	Total Hg removal, %	Host Load, MW	Pilot Inlet T, F	PCM Inlet T, F	Pilot flow, acfm	T/R Voltage, kV	MERCEM Inlet Hg	MERCEM Outlet Hg
26	"natural Temp", No Carbon Inj	6/24/98	0.0	8.2	6.5	21.5	357	279	271	621	37	3.9	3.2
27	"natural Temp", No Carbon Inj	6/24/98	0.0	8.7	6.7	23.0	357	281	273	621	36	4.1	3.6
28	"natural Temp", No Carbon Inj	6/24/98	0.0	8.6	7.5	12.7	357	283	276	624	35	4.2	4.0
29	"natural Temp", C @ 1.0	6/25/98	1.0	10.4	5.9	42.8	359	285	276	646	37	4.2	3.3
30	"natural Temp", C @ 1.0	6/25/98	1.1	10.4	5.7	45.2	359	289	280	647	35	4.5	3.4
31	"natural Temp", C @ 1.0	6/25/98	1.0	10.5	5.4	49.0	357	292	284	651	31	4.6	3.3
32	"natural Temp", C @ 4.0	6/26/98	4.5	13.1	4.4	66.7	360	286	280	598	36	4.3	3.2
33	"natural Temp", C @ 4.0	6/26/98	4.4	10.8	4.3	60.2	360	288	282	613	35	4.4	3.1
34	"natural Temp", C @ 4.0	6/26/98	4.3	10.7	3.9	63.0	361	291	284	632	34	5.0	2.7
35	"natural Temp", C @ 0.5	6/29/98	0.5	11.1	8.1	26.9	358	313	307	631	36	3.7	3.8
36	"natural Temp", C @ 0.5	6/29/98	0.5	11.3	8.1	28.3	359	323	313	643	33	5.9	4.3
37	"natural Temp", C @ 0.5	6/29/98	0.5	12.8	8.9	30.9	361	328	317	648	26	6.0	4.4
38	Heater to 350 F, NO Carbon Inj	6/30/98	0.0	11.9	11.8	0.8	369	298	347	663	37	4.1	4.0
40	Heater to 350 F, NO Carbon Inj	6/30/98	0.0	11.3	11.5	-2.4	369	295	349	672	37	5.9	4.6
41	Heater to 350 F, NO Carbon Inj	6/30/98	0.0	11.3	11.3	0.3	352	294	349	677	36	6.1	4.9
42	Heater to 350 F, C @ 4.0	7/1/98	3.4	10.6	5.3	49.8	373	289	346	667	37	3.2	3.3
43	Heater to 350 F, C @ 4.0	7/1/98	3.3	12.0	5.8	51.9	371	295	350	685	37	4.9	3.3
44	Heater to 350 F, C @ 4.0	7/1/98	3.2	12.1	5.6	53.6	370	297	350	699	36	5.3	3.5
45	"natural temp", C @ 1.0, RT=0.5 sec	7/13/98	1.2	8.4	4.0	52.3	362	294	285	625	30	1.1	1.2
46	"natural temp", C @ 1.0, RT=0.5 sec	7/13/98	1.2	7.8	4.1	48.1	368	296	290	627	27	1.2	1.4
48	Spray cool to 230F, NO Carbon Inj.	7/14/98	0.0	4.9	2.3	53.1	347	231	230	616	28	0.8	0.9
49	Spray cool to 230F, NO Carbon Inj.	7/14/98	0.0	4.8	2.0	57.7	350	228	226	606	31	1.0	1.0
50	Spray cool to 230F, NO Carbon Inj.	7/14/98	0.0	4.8	1.9	60.9	330	230	228	610	30	1.3	1.2
51	Spray cool to 230F, C @ 1.0	7/14/98	1.1	4.2	1.8	57.1	353	234	228	615	30	0.6	1.0
52	Spray cool to 230F, C @ 1.0	7/14/98	1.1	4.7	1.8	61.4	352	236	228	623	30	0.6	0.9
53	Spray cool to 230F, C @ 1.0	7/14/98	1.1	4.4	1.9	55.8	355	234	228	614	31	0.7	1.0
54	Heater to 310 F, C @ 1.0	7/15/98	1.1	5.6	2.8	50.6	354	284	306	621	32	0.9	0.9
55	Heater to 310 F, C @ 1.0	7/15/98	1.1	6.5	3.1	52.9	356	285	307	615	28	1.0	1.0
56	Heater to 310 F, C @ 1.0	7/15/98	1.1	6.7	2.8	58.5	356	287	307	607	28	0.9	1.0
57	Heater to 310 F, NO Carbon Inj	7/16/97	0.0	5.9	3.9	34.6	321	258	302	579	32	0.4	0.2
58	Heater to 310 F, NO Carbon Inj	7/16/97	0.0	6.3	4.0	36.9	334	271	305	619	38	0.4	0.4
59	Heater to 310 F, NO Carbon Inj	7/16/97	0.0	6.9	4.2	39.2	338	274	306	622	36	0.4	0.5
60	Heater to 310 F, C @ 4.0	7/16/97	4.1	7.6	2.7	64.0	358	281	307	617	30	0.8	1.0
61	Heater to 310 F, C @ 4.0	7/16/97	4.2	7.5	3.0	59.7	358	286	308	606	26	0.9	1.4
62	Heater to 310 F, C @ 4.0	7/16/97	4.3	7.1	2.6	64.1	359	288	308	598	25	0.8	1.2
63	Heater to 310 F, C @ 4.0, RT=0.5 sec	7/17/97	4.1	7.6	3.1	59.5	352	281	306	630	39	0.0	0.5
64	Heater to 310 F, C @ 4.0, RT=0.5 sec	7/17/97	4.0	8.3	2.8	66.3	341	282	307	644	38	0.2	0.7
65	Heater to 310 F, C @ 4.0, RT=0.5 sec	7/17/97	4.0	7.9	2.6	67.3	350	283	305	650	36	0.3	1.4
66	Heater to 350 F, NO Carbon Inj	7/31/98	0.0	10.2	7.6	25.6	331	278	344	601	36	0.9	1.0
67	Heater to 350 F, NO Carbon Inj	7/31/98	0.0	10.4	7.8	24.8	341	284	346	606	36	1.7	1.3
68	Heater to 350 F, NO Carbon Inj	7/31/98	0.0	10.9	9.3	14.5	351	288	345	604	36	2.1	1.7
69	Heater to 350 F, C @ 1.0	7/31/98	1.1	11.2	6.3	43.2	339	287	345	598	34	2.3	2.4
70	Heater to 350 F, C @ 1.0	7/31/98	1.1	10.1	6.0	40.1	317	281	344	599	34	1.7	2.2
71	Heater to 350 F, C @ 1.0	7/31/98	1.1	10.0	5.6	43.8	333	279	343	595	35	1.2	2.0
72	Heater to 350 F, C @ 4.0	8/3/98	3.9	10.5	5.1	51.7	344	288	344	600	34	1.3	2.1
73	Heater to 350 F, C @ 4.0	8/3/98	3.9	11.4	5.5	52.1	354	295	345	603	34	1.3	2.1
74	Heater to 350 F, C @ 4.0	8/3/98	4.0	11.0	4.8	56.1	355	294	345	589	34	1.4	3.2

Table 2. ESP Tests 26 through 74. All mercury measurements in $\mu\text{g}/\text{Nm}^3$ @ 3%O₂.

Figure 3. All ESP baseline tests.

Test Results with Carbon Injection. Carbon injection testing in the ESP configuration took place at the same target temperatures as baseline tests. Several tests at 350°F were repeated based on the scattered results seen from initial testing. It was desirable to repeat tests at 310°F since these results showed some inconsistencies, but we determined that it would require extensive additional testing to get reliable data. We deferred further testing to other PCM configurations, or possibly to a final ESP test towards the end of the program.

Figure 4 shows a graph of the results of all carbon injection and baseline tests.

Figure 4. All carbon injection test results in ESP configuration.

The following observations are made from this graphed data:

- At all temperatures tested, mercury control of greater than 50% is attainable with carbon injected at greater than 3.5 lb/MMacf.
- Mercury control seems to level off with increased carbon concentration, resulting in diminishing returns from increased carbon consumption. It would probably require much more carbon to achieve consistent control levels as high as 80% in the ESP configuration.
- Mercury control is achieved with carbon injection at about 1 lb/MMacf, with the higher control levels within this bracket being achieved at lower temperatures.
- Spray cooling the flue gas to 230°F has about the same mercury removal effect as injecting about 1 lb/MMacf carbon into 300°F flue gas.
- Residence time variation from 0.5 to 1.0 seconds does not impact the result measurably in these few tests.

Task 22 - Comparison of Pilot and Full-Scale Mercury Emissions

Measurements of mercury will be performed at several of PSCo's coal-fired units. The as-found mercury emissions will be measured at the inlet and outlet of each particulate collector to quantify how much mercury is collected without sorbent injection. During the quarter a plan for these tests was outlined in a draft management plan. The units that will be sampled are: Arapahoe 1, Arapahoe 4, Cherokee 3, Comanche, and Hayden. These units were selected because of the variety of coal types that they fire and the variety of particulate collectors. Comanche is selected because of the comparison with pilot data.

In July much of the preparatory work for full-scale mercury measurements was completed. This included site visits, coordinating with PSCo personnel and Frontier Geosciences, writing a test plan, obtaining drawings of the test locations, and fine-tuning test procedures. The tests are scheduled to take place in August and will be discussed in the next quarterly report.

Task 23 - Scale-Up ESP Tests

The pilot facility owned and operated by ABB will be installed in the spring at Waukegan Station in Illinois. The station fires a Powder River Basin coal, and the pilot slipstream will be extracted upstream of the host unit's ESP. A carbon injection system will be installed and tested on the wire-plate pilot-scale ESP. This pilot ESP is capable of treating up to 5,000 cfm of flue gas. This testing will provide information on whether the characteristics seen at Comanche are representative of other sites.

In this quarter very little work was done on this task. Construction delays at Waukegan station have resulted in the schedule for these tests being pushed back until 1999.

Task 24 - Carbon Separation from Flyash

The impact of carbon injection on ash disposability and sale will be examined during Phase II. Recycling will be evaluated later in the program by re-injecting processed and unprocessed ash into the pilot.

Task 25 - Database Survey and Modeling Comparison

There were no activities on this task during this quarter.

Task 26 - Waste Characterization

There were no activities on this task during this quarter.

Task 27 - Economics and Design Issues

There were no activities on this task during this quarter.

Task 28 - Program Management and Reporting

The FETC contractor meeting was held July 21-23 in Morgantown, WV. PSCo was asked to write and present a paper at this meeting. Sheila Haythornthwaite attended this meeting and presented Phase I results as well as the Phase II plans. The final paper is due to FETC in August for publication on CD-ROM. A draft of the paper was distributed in July for review by PSCo, EPRI, and DOE.

Ongoing coordination and monthly reporting to PSCo continued this quarter.