PERFORMANCE EVALUATION OF A PILOT-SCALE PULSE-JET BAGHOUSE FOR OPERATION WITH AIRPOL'S GAS SUSPENSION ABSORPTION PROCESS AT TVA'S CENTER FOR EMISSIONS RESEARCH

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Executive Summary

Performance evaluation of a pulse-jet baghouse operating with AirPol's Gas Suspension Absorption (GSA) process was conducted at TVA's Center for Emissions Research (CER) facility. The baghouse filtered approximately 5000 acfm of flue gas and was operated in two different configurations: in parallel with the electrostatic precipitator (ESP) at an air-to-cloth of 4.0 acfm/ft^2 and in series with the ESP at an air-to-cloth of 12.0 acfm/ft^2.

The operation of the baghouse with the GSA process was very successful in both modes of operation. SO_2 removal was 3 to 5% higher for the baghouse operating in parallel with the ESP than with the ESP alone. For the baghouse operating in series with the ESP, the SO_2 removal was 0 to 2% higher than the ESP alone. The outlet emissions rate through the baghouse was very low for both configurations. Other baghouse performance parameters (tubesheet pressure drop, pulsing frequency, and collection efficiency) were within the preferred range of operation for pulse-jet baghouses.

Introduction

As part of the U.S. Department of Energy's (DOE) Clean Coal Technology (CCT) program, AirPol built a 10 MWe Gas Suspension Absorption (GSA) demonstration plant at TVA's CER. AirPol, Inc., located in Teterboro, NJ, is a U.S. subsidiary of the Danish company, FLS miljo a/s. The GSA process is a dry, lime-based flue gas desulfurization (FGD) system that was developed for removing acid gases from the flue gas generated by many industrial processes. The GSA process was expected to remove more than 90% of the sulfur dioxide (SO_2) from the flue gas, while achieving a relatively high utilization of reagent lime. The testing of the GSA demonstration unit was co-funded by an arrangement with AirPol, TVA, and the DOE. The testing at the CER is the first application of this technology in the U.S. and began in November 1992.

A pulse-jet baghouse system (1 MWe) was supplied by the Electric Power Research Institute (EPRI), as part of a program of evaluating the performance of pulse-jet baghouses on various process systems. EPRI owns four "transportable" 1 MWe pulse-jet baghouses that have been evaluated at nine installations since 1988.

Southern Research Institute (SRI) was sponsored by the EPRI to conducted an evaluation of the pulse-jet baghouse concurrent with an evaluation of the GSA process with an electrostatic precipitator (ESP). The parametric evaluation of the GSA process was conducted from December 1992 through September 1993.

Facilities

CER Test Facility

The test facility hosting the demonstration of the GSA process is located at the TVA Shawnee Fossil Plant in West Paducah, Kentucky. The facility has been in operation over the past three decades in the development of wet and dry FGD systems. The facility was designated as the Center for Emissions Research (CER) on October 27, 1992. The CER was established by TVA to evaluate, develop, and/or demonstrate new technologies or enhancements to existing technologies, which improve environmental performance for coal-fired boilers.

The GSA demonstration used a 10 MWe slipstream of flue gas (approximately 20,000 scfm) from the Shawnee Unit 9 (150 MWe) boiler, which typically burns a medium-sulfur (2.7 percent), western Kentucky coal. The test facility was operated for twenty-four hours per day, except for time periods caused by planned or forced outages.

AirPol's GSA Process

In the Gas Suspension Absorption (GSA) process, the flue gas enters the bottom of a vertical absorption vessel and flows upward through the vessel. A fresh lime slurry is sprayed into the vessel through a two-fluid nozzle and flows upward with the flue gas. The quantity of lime used is based on the actual level of SO_2 in the flue gas, and the amount of dilution water added to the lime slurry is controlled to cool the gas to the desired temperature. The lime in the slurry reacts with the acid gases and the water in the slurry evaporates to cool and humidify the flue gas.

After the lime reacts with the SO_2, the solids are separated from the gases and collected in a cyclone. About 99% of the solids are then recirculated back into the reactor inlet to achieve greater sorbent utilization. The flue gas from the cyclone passes to the final cleanup device, which can be either an electrostatic precipitator (ESP) or a baghouse.

Pulse-Jet Baghouse

The "transportable" pulse-jet baghouse (PJBH) was designed to filter 5000 acfm of flue gas at air-to-cloth of 4.0 acfm/ft^2; a scale equivalent to approximately 1.5 MW . This device is equipped with filter bags and pulse-cleaning equipment used in full-scale baghouses. The PJBH was configured to evaluate a low-pressure, high-volume pulse-cleaning system. In essence, this 48-bag baghouse could be compared to a small, single compartment of a full-scale (multi-compartment) baghouse. Therefore, this test scale is a practical size for evaluating baghouse performance on various processes and should produce results that would estimate full-scale baghouse performance.

Dirty flue gas enters the baghouse through the inlet plenum, which is located near the bottom of the filter bags. The bags are hung from the tubesheet and are attached to the tubesheet with a "snap-in" cuff. The bags are closed at the bottom and open at the top; therefore, the flue gas flows from the outside to the inside of the bags. The particulate matter is collected on the outside of the bags and the clean gas exits through the opening in the top of the bags. Clean flue gas exits the baghouse through the outlet plenum that is located just above the tubesheet.

The 48 bags are arranged in three concentric circles. The bags were fabricated from a homopolymer acrylic fabric. This fabric, specified as Dralon-T, has a temperature limit of 260 °F, and was selected due to the temperatures under evaluation with the GSA process. The bags are oval-shaped in cross section, 20 feet in length and 15.5 inches in circumference, and are supported by standard 14-wire carbon steel cages. The cages were treated with a proprietary epoxy coating to prevent corrosion due to the expected low temperature operation.

The flow of flue gas through the PJBH is controlled by a damper that is located in the baghouse outlet duct upstream of a flow measurement orifice meter and the baghouse induced draft (ID) fan. An electronic flow controller monitored and maintained a constant pressure drop across the orifice meter. On-site calibrations were performed to determine the orifice pressure drop sufficient to yield approximately 5000 acfm (4.0 acfm/ft^2).

Pulse cleaning is provided by a rotating cleaning manifold, equipped with three nozzles that are aligned with each circle of bags. The manifold is located above the bags in the clean gas outlet plenum and continuously rotates at 1 rpm. Pulse cleaning air is supplied to the manifold from a reservoir that is pressurized to approximately 7 to 9 psi by a dedicated positive displacement blower. The blower is energized prior to each cleaning pulse. The air is discharged from the reservoir into the manifold through a diaphragm valve, and then subsequently injected through the nozzles into the bags. Due to the circular bag arrangement and the rotating manifold, bag cleaning occurs on a somewhat random basis since a pulse nozzle was not always perfectly aligned with a bag. However, on a time-averaged basis, all the bags are cleaned equivalently.

Ash that is removed from the bags during pulse cleaning, or ash material that falls out without reaching the filter bags is collected in an ash hopper, located directly under the bags. The fly ash is continuously discharged through a rotary valve into an ash disposal line. Ash is conveyed through the disposal line by a continuously operating blower motor that discharges the ash to a waste silo.

Pulse cleaning can be performed either on a timed or pressure drop initiated / terminate method. Tubesheet pressure drop, flue gas flow rate, pulse cleaning rate, inlet and outlet temperatures, and various SO_2 and O_2 values through the system were the major parameters that were continuously monitored and recorded by a computer data acquisition system.

SRI wrote an operational manual of the pulse-jet baghouse specific to the CER installation to serve as a reference guide for the facility personnel. SRI conducted training classes to instruct the facility operators on the operation of the baghouse system.

Test Plan

TVA designed a test plan to evaluate the role of various parameters on the removal of sulfur dioxides in the flue gas. These major parameters were evaluated at two or three different levels. The test plan followed a half-factorial design with a full set of replicates. This selection procedure reduced the total number of tests required to evaluate the range of test variables. The replication of tests would possibly identify outlier results and improve the statistical significance of the evaluation. The half-factorial test matrix was essentially performed twice, although there were some alternate tests selected for the second half of the factorial testing. This test plan also allowed the pulse-jet baghouse to operate in a different configuration in each half of the test program.

During the test program, each test condition was typically maintained for a period of 2 to 3 days. At the beginning of each test, a lineout period allowed stable operation to be achieved. After the lineout period, a "test period" for typically one day was designated for which the test data were analyzed.

The first half of the factorial test program was conducted from February 1 through May 27, and the second half of the factorial test program was conducted from May 29 through September 30.

Matrix of Variables

During November and December 1992, a series of tests was conducted to define the practical operating limits of the various test parameters. These tests determined the ranges over which the variables would be evaluated. The major test parameters and the selected ranges are shown in the following table.

Test Parameter	*Range of Parameters*		
Calcium to Sulfur Ratio	1.0	1.3	
Approach Temperature (°F)	8	18	28
Flue Gas Flow Rate (kcfm)	14	20	
Fly Ash Loading (gr/acf)	0.5	2.0	
Coal Chloride Level (%)	0.02	0.12	
Recycle Screw Speed (rpm)	30	45	

Baghouse Configurations

The PJBH installation at the CER was designed with the flexibility to receive flue gas from either the inlet or the outlet of the ESP. The test program specified that the baghouse would be configured to receive flue gas from the ESP inlet (operating in parallel with the ESP) for the first half of the factorial test program and at the ESP outlet (operating in series with the ESP) for the second half of the factorial test program.

With the baghouse operating in parallel with the ESP, the baghouse would actually divert ~5000 acfm of the potential ~22000 acfm of flue gas from the ESP. With the baghouse operating in series with the ESP, there would be no change in flow rate through the ESP as a result of the baghouse operation. A schematic of the functional layout of the pulse-jet baghouse system and the associated ducting to the ESP system is presented in Figure 1.

For both of these configurations, the baghouse was operated at an approximate flow rate of 5000 acfm. For baghouse operation in parallel with the ESP, the baghouse operated with all 48 filter bags, yielding an effective air-to-cloth value of 4.0 acfm/ft^2. (This air-to-cloth value is typical of full-scale pulse-jet baghouses operating on coal-fired boilers.)

For baghouse operation in series with the ESP, it was possible for the baghouse to be operated at a higher air-to-cloth ratio due to the low mass loading at the outlet of the ESP. The air-to-cloth value was increased from 4.0 to 12.0 acfm/ft^2. To achieve the higher air-to-cloth value, two-thirds of the filter bags were removed and the holes in the tubesheet were sealed with temporary blank-off plates. The concept of operating a baghouse in series with an ESP, and operating the baghouse at a higher air-to-cloth ratio was patented by the EPRI, and is referred to as "COHPAC" (COmpact Hybrid PArticulate Collector).

GSA Test Identifications

Test identifications were assigned systematically by CER personnel. For the majority of the baghouse tests, these test identifications had the prefix of 2-AP or 3-AP. A two-digit number followed the prefix, and was a sequential designation of the test. Tests with the baghouse operating at the inlet to the ESP were designated as "3-AP" series tests. Tests with the baghouse operating at the outlet of the ESP or with the baghouse out of service were designated as "2-AP" series tests. Two special series of tests, high-sulfur coal tests and Air Toxics tests were designated as "1-HS" and "1-AT", respectively.

The baghouse was operated in series with the ESP during the second half of the factorial test program from May 26 through September 30. The baghouse operated for a total of 2417 hours during this period. During the week of September 24-29, the baghouse and ESP operated with "flue gas only", as requested by the AirPol test plan for the measurements of air toxics. The temperature of the flue gas was maintained such that the inlet to the ESP was less than 260 °F, the maximum operating temperature for the Dralon T filter bags.

Following the "flue gas only" tests, the PJBH was reconfigured for operation in parallel with the ESP for further testing. The 16 existing bags and cages were removed. As before, the filter bags had a good general appearance and retained a very light dust cake. A new set of 48 homopolymer acrylic bags were installed in the baghouse.

Baghouse Operating Periods

The total hours that the baghouse operated during each month is summarized in the table below. A chronological summary of the tests for which the PJBH was in operation is presented in Table 1. This table details the test identification, the start date, total hours of baghouse operation, and the operating configuration for the baghouse.

Month	PJBH in Parallel with ESP	PJBH in Series with ESP	Total Hours of Operation
January	125.2	5.2	130.4
February	315.1	22.7	337.9
March	92.8		92.8
April	420.8		420.8
May	242.8	74.9	317.7
June		561.4	561.4
July		644.7	644.7
August		580.6	580.6
September		555.3	555.3
Total	**1196.7**	**2444.7**	**3641.5**

Evaluation Procedures / Results

We evaluated the PJBH performance by several operational variables. The most important indicators of performance were the pulse cleaning frequency, SO_2 removal, and particulate collection efficiency. Each of these variables addressed a different characteristic that would quantify the performance of the baghouse operating with the GSA process. We also monitored several temperatures throughout the baghouse to assess the baghouse performance during operation at close approach-to-saturation temperatures.

Table 1. PJBH Operation Summary

Test ID	Start Date	Operating at ESP		Total Hours of PJBH Operation
		Inlet	Outlet	
2-AP-19	2/04		X	14.80
3-AP-08	2/05	X		26.75
3-AP-21	2/06	X		24.00
3-AP-03	2/07	X		20.15
3-AP-26	2/09	X		27.92
3-AP-27	2/10	X		24.00
3-AP-20	2/11	X		8.66
3-AP-19	2/12	X		36.33
3-AP-18	2/13	X		24.00
3-AP-02	2/14	X		24.00
3-AP-13	2/15	X		17.00
3-AP-12	2/20	X		51.82
3-AP-14	2/24	X		13.50
2-AP-05	2/25	X		17.00
2-AP-15	3/09	X		1.93
3-AP-24	3/23	X		45.37
3-AP-22	3/25	X		37.33
3-AP-23	3/31	X		70.96
3-AP-29	4/08	X		58.95
3-AP-20	4/18	X		115.90
3-AP-42	4/20	X		46.00
3-AP-44	4/22	X		48.25
3-AP-45	4/24	X		70.17
3-AP-58	4/30	X		64.54
3-AP-56	5/05	X		20.16
3-AP-59	5/06	X		27.00
3-AP-60	5/07	X		20.50
3-AP-11	5/08	X		24.25
3-AP-61	5/10	X		37.67
3-AP-62	5/11	X		34.04
3-AP-15	5/12	X		21.12
2-AP-71	5/28		X	73.00
2-AP-88	6/03		X	26.07
2-AP-17	6/07		X	94.89
2-AP-91	6/11		X	99.62
2-AP-92	6/17		X	66.55
2-AP-93	6/20		X	44.75
2-AP-84	6/22		X	54.75
2-AP-90	6/24		X	48.00

Table 1 (cont.) PJBH Operation Summary

Test ID	Start Date	Operating at ESP		Total Hours of PJBH Operation
		Inlet	Outlet	
2-AP-82	6/26		X	54.75
2-AP-94	6/29		X	72.00
2-AP-85	6/30		X	41.00
2-AP-75	7/02		X	48.25
2-AP-74	7/07		X	69.00
2-AP-79	7/10		X	49.50
2-AP-95	7/13		X	56.67
2-AP-96	7/15		X	48.75
2-AP-80	7/17		X	47.25
2-AP-86	7/19		X	50.50
2-AP-73	7/21		X	47.75
2-AP-72	7/23		X	46.00
2-AP-97	7/25		X	47.75
2-AP-81	7/27		X	40.00
2-AP-78	7/29		X	68.50
2-AP-87	8/01		X	77.75
2-AP-77	8/06		X	47.25
2-AP-83	8/08		X	51.00
1-HS-05	8/10		X	45.50
1-HS-09	8/12		X	48.50
1-HS-10	8/14		X	47.00
1-HS-06	8/16		X	90.83
1-HS-04	8/21		X	70.75
1-HS-02	8/27		X	47.50
1-HS-01	8/29		X	68.75
1-HS-03	9/02		X	52.75
1-HS-07	9/05		X	46.75
1-HS-08	9/07		X	49.00
1-HS-11	9/09		X	45.50
1-HS-12	9/11		X	31.75

We determined the average performance for each test condition for a specified test period based on the start and end times as designated by CER personnel. This test period excluded data obtained during the lineout period, during which the GSA and ESP systems were stabilizing.

We reviewed the graphical trends of each test variable during the test period to determine if there were obvious "upset" conditions that would warrant exclusion of data in determining average performance. There were situations, such as, loss of the slurry flow for a short time period, that would be evident from the SO_2 concentrations and the temperature profiles. Other conditions were more subtle, such as, problems with specific hardware that would produce excessive carryover of materials. These situations would influence the pulse cleaning frequency. The objective of the data review was to determine periods that the GSA / baghouse systems were not operating properly and exclude these data from analyses.

A tabular summary of the test parameters and baghouse performance data is presented in Table 2. This comprehensive summary is arranged by similar test conditions which allows the reader a means to visually compare data with respect to the major test parameters.

We compared the PJBH operation at the CER to an extensive database of pulse-jet baghouse evaluations.[1] Figure 3 presents comparisons of tubesheet pressure drop, pulse cleaning frequency, inlet mass loadings, and emission rates and is referred to in each of the pertinent sections of the report.

We also compared pulse-jet baghouse operation in the COHPAC mode with the GSA process to three other COHPAC operations reported in recent studies by the EPRI.[2,3] Although the demonstration of COHPAC at the CER is an application to a novel FGD process, comparison to these other processes provides a base of reference. A summary of these evaluations are presented in Table 3 and graphically in Figure 4.

Tubesheet Pressure Drop

The tubesheet pressure drop was a fixed parameter during the entire test program. The baghouse cleaning system was operated according to a ΔP-initiate and a ΔP-terminate mode for which the pressure drop across the fabric was maintained between two discrete pressure values. For example, during initial baghouse operation, pulse cleaning was initiated when the tubesheet pressure drop reached 5.0 in. H_2O, and pulsing continued until the pressure drop was reduced to below 4.0 in. H_2O.

When the filter bags were new and the PJBH was operating in parallel with the ESP, the tubesheet pressure drop was set between 4.5 and 5.0 in. H_2O. We attempted to operate at these settings, but after a couple of months as the fabric became more "seasoned", we increased these setpoint values to 5.0 and 6.0 in. H_2O.

Table 2. GSA Test Parameters and Baghouse Performance Results
(Baseline Tests: 2-AP and 3-AP Series, Ca/S of 1.3)

Test ID	Ca/S Ratio	Approach Temp (°F)	Flue Gas Flowrate (scfm)	Recycle Screw Speed (rpm)	Reactor Fly Ash Injection (lb/min)	Reactor Product Chloride (%)	PJBH Tubesheet ΔP (in. H2O)	PJBH Pulse Cleaning		Total SO2 Removal through (%)			
								In series with ESP (pulse/hr)	In parallel with ESP (pulse/hr)	GSA reactor	ESP	PJBH: in series with ESP	PJBH: in parallel with ESP
2-AP-19	1.3	28	20,000	30	7.1	0				61.9	67.1		
3-AP-19	1.3	28	20,000	30	7.4	0	4.74		38.9	69.9	74.2		79.7
2-AP-97	1.3	28	20,000	30	0.0	0	5.70			68.1	74.8	75.0	
2-AP-57	1.3	28	19,500	30	7.1	0				73.3	78.8		
3-AP-56	1.3	28	14,000	30	0.0	0	5.31		36.0	82.8	(86.7)		(90.2)
3-AP-20	1.3	28	14,000	45	0.0	0	4.76		25.6	83.2	86.5		89.2
3-AP-20	1.3	28	14,000	45	0.0	0.03	5.26		37.4	84.3	86.6		91.0
3-AP-13	1.3	28	14,000	45	0.0	0	4.77		36.3	79.8	84.8		86.9
2-AP-86	1.3	28	14,000	45	0.0	0.03	5.77	3.95		75.6	79.5	80.6	
3-AP-45	1.3	28	14,000	45	5.2	0	5.63		39.5	80.3	82.6		85.1
3-AP-14	1.3	18	20,000	45	7.1	0	5.12		27.6				88.1
2-AP-63	1.3	18	20,000	45	7.2	0.04				76.1	81.1		
2-AP-63	1.3	18	20,000	45	7.2	0.03				75.4	79.1		
2-AP-95	1.3	18	20,000	45	0.0	0.05	5.98	1.55		78.2	85.9	86.4	
2-AP-96	1.3	18	20,000	45	0.0	0.21	5.99	2.64		83.1	87.2	86.8	
2-AP-14	1.3	18	18,200	45	6.7	0.12				80.4	85.5		
3-AP-26	1.3	18	14,000	12	4.7	0	4.77		23.2	73.1	78.4		80.9
3-AP-27	1.3	18	14,000	30	4.7	0	4.78		23.1	81.1	84.9		87.5
3-AP-02	1.3	18	14,000	45	5.1	0	4.75		37.0	84.9	88.9		92.2
3-AP-03	1.3	18	14,000	45	5.0	0	4.78		28.5	78.3	82.3		85.4
2-AP-73	1.3	18	14,000	45	5.1	0	5.70	2.42		82.2	85.8	85.9	
2-AP-03	1.3	18	14,000	45	0.0	0				88.4	91.0		
3-AP-44	1.3	18	14,000	45	0.0	0.02	5.62		33.8	86.8	89.9		93.4
2-AP-10	1.3	8	20,000	45	0.0	0				88.0	91.4		
2-AP-80	1.3	8	20,000	45	0.0	0.09	5.96	0.77		87.5	88.9	89.3	
2-AP-11	1.3	8	14,000	30	5.0	0				88.4	92.1		
3-AP-11	1.3	8	14,000	30	5.2	0	5.30		36.9	98.1	(99.2)		(99.7)
2-AP-81	1.3	8	14,000	30	5.2	0	5.81	1.46		86.0	90.7	90.5	
3-AP-42	1.3	8	14,000	30	0.0	0	5.40		18.1	96.2	98.3		99.8

Table 2 (cont.) GSA Test Parameters and Baghouse Performance Results
(Baseline Tests: 2-AP and 3-AP Series, Ca/S of 1.0)

Test ID	Ca/S Ratio	Approach Temp (°F)	Flue Gas Flowrate (scfm)	Recycle Screw Speed (rpm)	Reactor Fly Ash Injection (lb/min)	Reactor Product Chloride (%)	PJBH Tubesheet ΔP (in. H2O)	PJBH Pulse Cleaning		Total SO2 Removal through (%)			
								In series with ESP (pulse/hr)	In parallel with ESP (pulse/hr)	GSA reactor	ESP	PJBH: in series with ESP	PJBH: in parallel with ESP
3-AP-21	1.0	28	20,000	45	7.3	0	4.74		28.1	54.7	60.7		69.2
2-AP-87	1.0	28	20,000	45	7.3	0	5.84	4.77		59.3	67.7	68.4	
3-AP-59	1.0	28	14,000	30	5.2	0	5.32		60.3	66.9	(72.9)		(79.4)
3-AP-18	1.0	28	14,000	30	0.0	0	4.80		26.6	63.3	66.7		69.7
2-AP-88	1.0	28	14,000	30	0.0	0.04	5.49	1.73		63.9	66.3	70.2	
3-AP-08	1.0	18	20,000	30	7.0	0	3.77		19.9	57.2	61.1		-----
2-AP-78	1.0	18	20,000	30	7.2	0	5.82	1.25		63.2	70.3	70.2	
2-AP-74	1.0	18	20,000	45	0.0	0	5.87	2.06		68.7	73.6	75.2	
2-AP-04	1.0	18	19,000	45	0.0	0				66.0	67.7		
3-AP-60	1.0	18	14,000	30	5.3	0	5.31		47.6	75.9	(81.2)		(84.3)
2-AP-01	1.0	18	14,000	30	0.0	0				67.1	70.6		
3-AP-62	1.0	18	14,000	30	0.0	0.13	5.29		40.0	71.8	76.2		77.2
2-AP-71	1.0	18	14,000	30	0.0	0.02				73.9	78.0		
2-AP-72	1.0	8	20,000	45	7.3	0	5.76	1.74		68.2	74.4	74.6	
2-AP-16	1.0	8	20,000	45	0.0	0				74.1	76.2		
2-AP-09	1.0	8	14,000	30	0.0	0				70.6	76.2		
2-AP-79	1.0	8	14,000	30	0.0	0	5.75	0.55		82.5	85.2	85.9	
3-AP-12	1.0	8	14,000	30	0.0	0	5.15		22.7	73.4	77.2		81.3
3-AP-58	1.0	8	14,000	30	0.0	0	5.27		34.1	87.7	(92.1)		(95.5)

Table 2 (cont.) Test Parameters and Baghouse Performance Results
(Chloride Spiking Tests: 2-AP and 3-AP Series)

Test ID	Ca/S Ratio	Approach Temp (°F)	Flue Gas Flowrate (scfm)	Recycle Screw Speed (rpm)	Reactor Fly Ash Injection (lb/min)	Reactor Product Chloride (%)	PJBH Tubesheet ΔP (in. H2O)	PJBH Pulse Cleaning		Total SO2 Removal through (%)			
								In series with ESP (pulse/hr)	In parallel with ESP (pulse/hr)	GSA reactor	ESP	PJBH: in series with ESP	PJBH: in parallel with ESP
2-AP-83	1.3	28	20,000	30	7.3	0.26	5.83			71.5	79.9	-----	
3-AP-23	1.3	28	19,200	45	7.4	0.26	5.22		54.2	79.2	83.4		89.2
2-AP-24	1.3	28	14,000	30	0.0	0.41				82.3	85.5		
3-AP-24	1.3	28	14,000	30	0.0	0.46	5.34		31.7	81.9	86.1		89.5
2-AP-84	1.3	28	14,000	30	0.0	0.60	5.98	0.90		79.4	85.1	87.0	
2-AP-91	1.3	18	20,000	45	6.3	0.32	5.91	1.62		87.8	89.7	91.3	
2-AP-92	1.3	18	20,000	45	0.0	0.72	5.92	1.06		89.1	92.4	93.5	
2-AP-06	1.3	18	19,000	45	0.0	0.47				88.8	93.8		
2-AP-93	1.3	18	18,300	45	6.7	0.30	5.95	1.38		93.2	94.3	95.2	
2-AP-15	1.3	18	17,100	45	6.3	0.44				94.2	98.9		
2-AP-07	1.3	18	14,000	30	5.4	0.29				91.0	95.0		
2-AP-77	1.3	18	14,000	30	5.0	0.30	5.80	2.19		88.3	94.5	94.5	
3-AP-29	1.3	18	14,000	45	5.3	0.31	5.26		33.4	84.6	86.8		91.5
2-AP-85	1.0	28	20,000	30	7.4	0.31	5.95	1.85		64.3	68.5	69.6	
2-AP-94	1.0	28	20,000	30	0.0	0.81	5.93	1.48		65.4	68.9	71.4	
2-AP-25	1.0	28	18,600	30	6.8	0.28				60.8	67.0		
3-AP-22	1.0	28	14,000	45	0.0	0.57	5.45		31.4	76.7	80.1		86.8
2-AP-90	1.0	28	14,000	45	0.0	0.86	5.96	1.58		69.0	72.7	75.4	
2-AP-17	1.0	18	20,000	30	0.0	0.75	5.92	3.27		76.8	80.7	83.6	
2-AP-82	1.0	18	20,000	30	0.0	0.87	5.90	0.81		76.5	80.6	82.5	
2-AP-28	1.0	18	14,000	40	5.0	0.39				77.6	82.9		
2-AP-75	1.0	18	14,000	45	4.3	0.45	5.97	1.34		76.3	82.5	83.1	

Table 2 (cont.) Test Parameters and Baghouse Performance Results
(High-Sulfur Coal Tests: 1-HS Series)

Test ID	Ca/S Ratio	Approach Temp (°F)	Flue Gas Flowrate (scfm)	Recycle Screw Speed (rpm)	Reactor Fly Ash Injection (lb/min)	Reactor Product Chloride (%)	PJBH Tubesheet ΔP (in. H2O)	PJBH Pulse Cleaning		Total SO2 Removal through (%)			
								In series with ESP (pulse/hr)	In parallel with ESP (pulse/hr)	GSA reactor	ESP	PJBH: in series with ESP	PJBH: in parallel with ESP
1-HS-10	1.6	28	20,000	45	7.3	0.26	5.80	4.70				90.7	
1-HS-08	1.6	28	20,000	45			5.67	----				87.0	
1-HS-06	1.6	18	20,000	45	7.3	0.25	5.78	0.97				97.9	
1-HS-04	1.6	18	20,000	45	7.5	0	5.69	(11.8)				93.1	
1-HS-02	1.6	8	20,000	45	7.4	0	5.63	----				-----	
1-HS-11	1.6	8	20,000	45			5.63	4.65				96.9	
1-HS-09	1.3	28	20,000	45	7.2	0.27	5.80	5.75				82.4	
1-HS-07	1.3	28	20,000	45			5.81	(16.9)				78.6	
1-HS-05	1.3	18	20,000	45	7.2	0.20	5.79	1.87				90.2	
1-HS-03	1.3	18	20,000	45			5.75	11.7				85.9	
1-HS-01	1.3	8	20,000	45			5.58	----				93.7	
1-HS-12	1.3	8	20,000	45			5.78	----				-----	

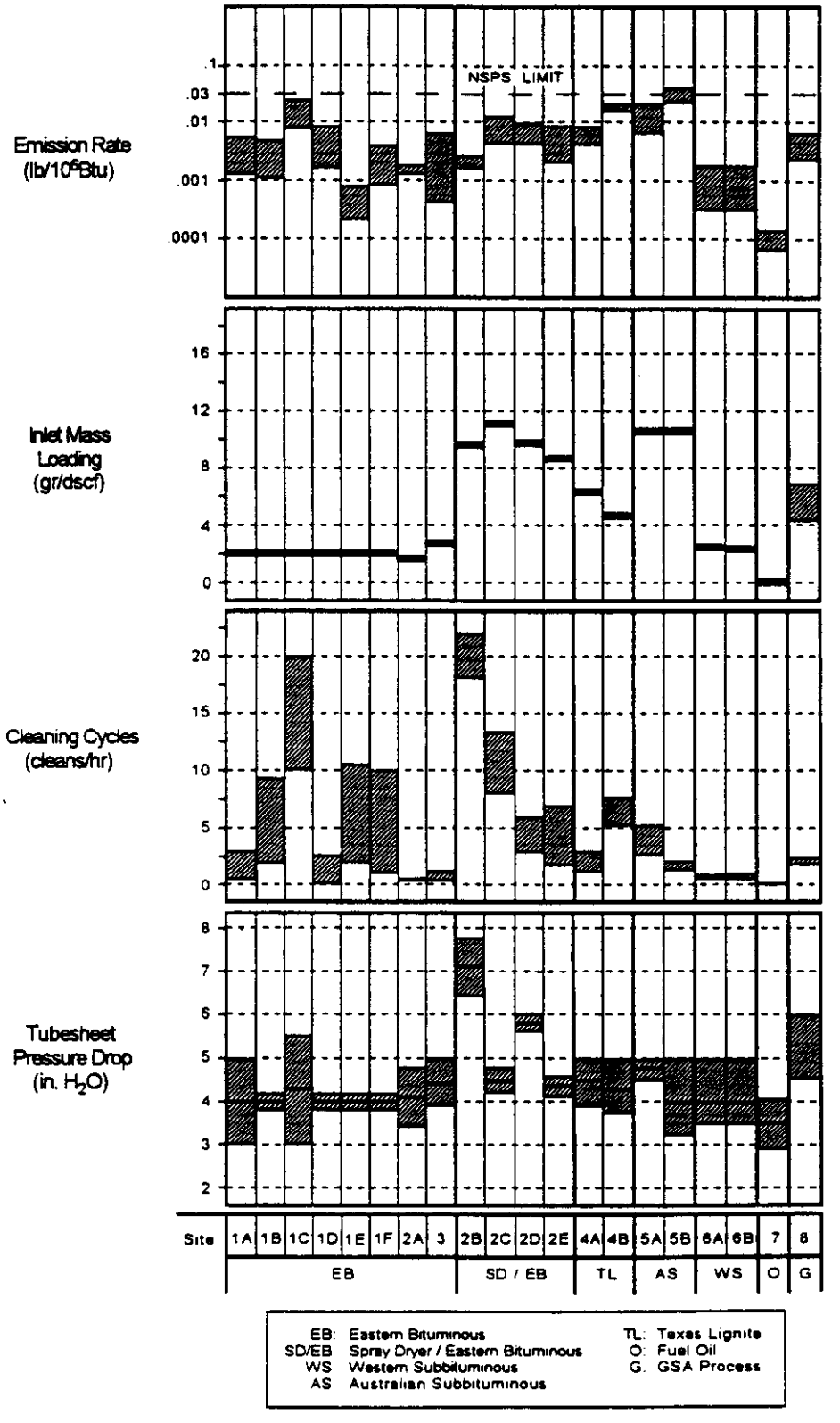

Figure 3. Pulse-jet baghouse pilot plant performance data.

Table 3. Performance Summary of COHPAC Collectors

Location	Big Brown	Marshall	Comanche	Shawnee
Coal / Process	Lignite	SO3	Sodium	FGD
Cleaning Type* / Pressure (psi)	LP (8-12)	LP (9-12)	IP (20-30)	LP (7-9)
Number of Filter Bags	2496	48	36	16
Hours of Operation	3726	1280	1550	2445
Flowrate (acfm)	735,000	5000	5880	5000
A/C Ratio (acfm/ft^2)	13.5	10	14	12
Tubesheet ΔP (in. H_2O)	4.5	6.5	5.4	5.5
Cleaning Rate (pulses/hr)	2.5	3.0	3.0	0.13
Inlet Mass (gr/dscf)	0.072			0.0073
Outlet Mass (gr/dscf)	0.0059			0.00034
Emissions (lbs/10^{6}Btu)	0.012			0.00085
Collection Efficiency (%)	91.8			95.4

* LP: Low pressure
IP: Intermediate pressure

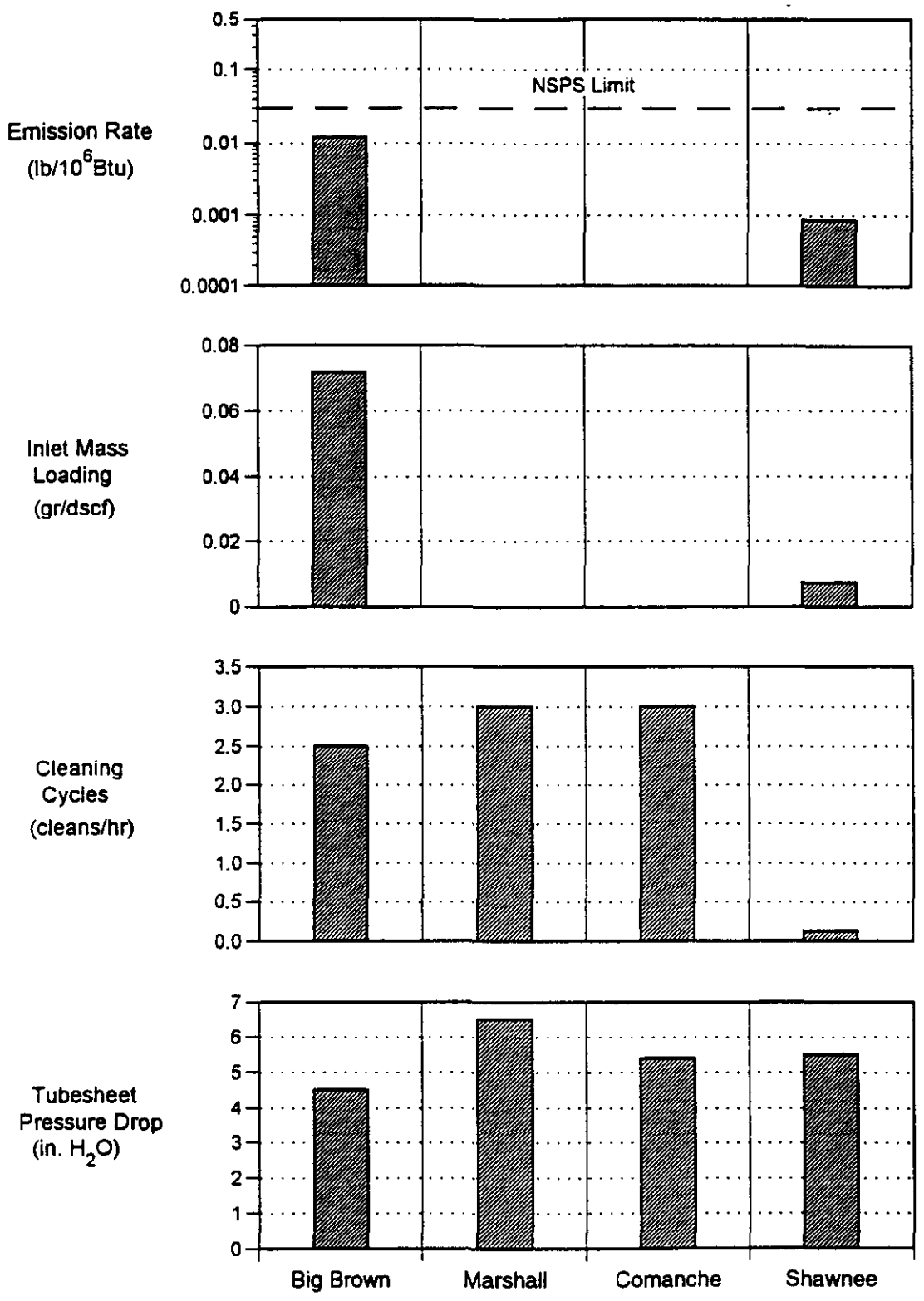

Figure 4. COHPAC Pulse-Jet Baghouse performance data.

For baghouse operation in series with the ESP, the tubesheet pressure drop was maintained between 5.0 and 6.0 in. H_2O. Due to the increased face velocity through the fabric (12.0 acfm/ft^2 instead of 4.0 acfm/ft^2), we determined that the minimum tubesheet pressure drop was ~4.5 in. H_2O. This minimum value may have increased slightly for long-term baghouse operation in this configuration.

For both PJBH configuration modes (with the PJBH operating in parallel and series with the ESP), the tubesheet pressure drop was maintained between approximately 4.5 and 6.0 in. H_2O. This pressure drop range is considered to be a normal range of operation for pulse-jet baghouses. A summary of the average tubesheet pressure drop values for each test condition is shown in Table 2. Figure 5 presents the history of the average tubesheet pressure drop for each test over the duration of the baghouse operation at the CER.

Comparisons to Reverse-Gas Baghouse

Pulse-jet baghouses can operate at higher air-to-cloth ratios for similar tubesheet pressure drops, compared with conventional (reverse-gas) baghouses, due to the more energetic cleaning method. Historically, reverse-gas baghouses are operated at air-to-cloth ratios around 2.0 acfm/ft^2, whereas pulse jet baghouses typically operate at twice this value.[4] Therefore, at a given tubesheet ΔP the "drag" for a pulse-jet baghouse is approximately half that of reverse-gas baghouses. (Drag is defined as pressure drop across the fabric divided by the flow rate through the fabric.) In other words, a pulse-jet baghouse would only have to be half the size of a reverse-gas baghouse to filter the same quantity of flue gas at the same tubesheet pressure drop.

Comparisons to other Pulse-Jet Baghouses

For the PJBH operation in parallel with the ESP at the CER (A/C of 4.0 acfm/ft^2), the baghouse fabric pressure drop was operated between approximately 4.5 and 6.0 in. H_2O. In reference to Figure 3, the operating tubesheet ΔP at the CER was near the high end of the range for pulse-jet baghouses. Considering the other relevant factors (low pulse cleaning rate and high inlet mass loading), a higher fabric pressure drop would be expected.

Comparison to other COHPAC Collectors

For the PJBH operation in series with the ESP at the CER (A/C of 12.0 acfm/ft^2), the baghouse was operated between approximately 5.0 and 6.0 in. H_2O. This was equivalent to the other COHPAC collectors as shown in Figure 4.

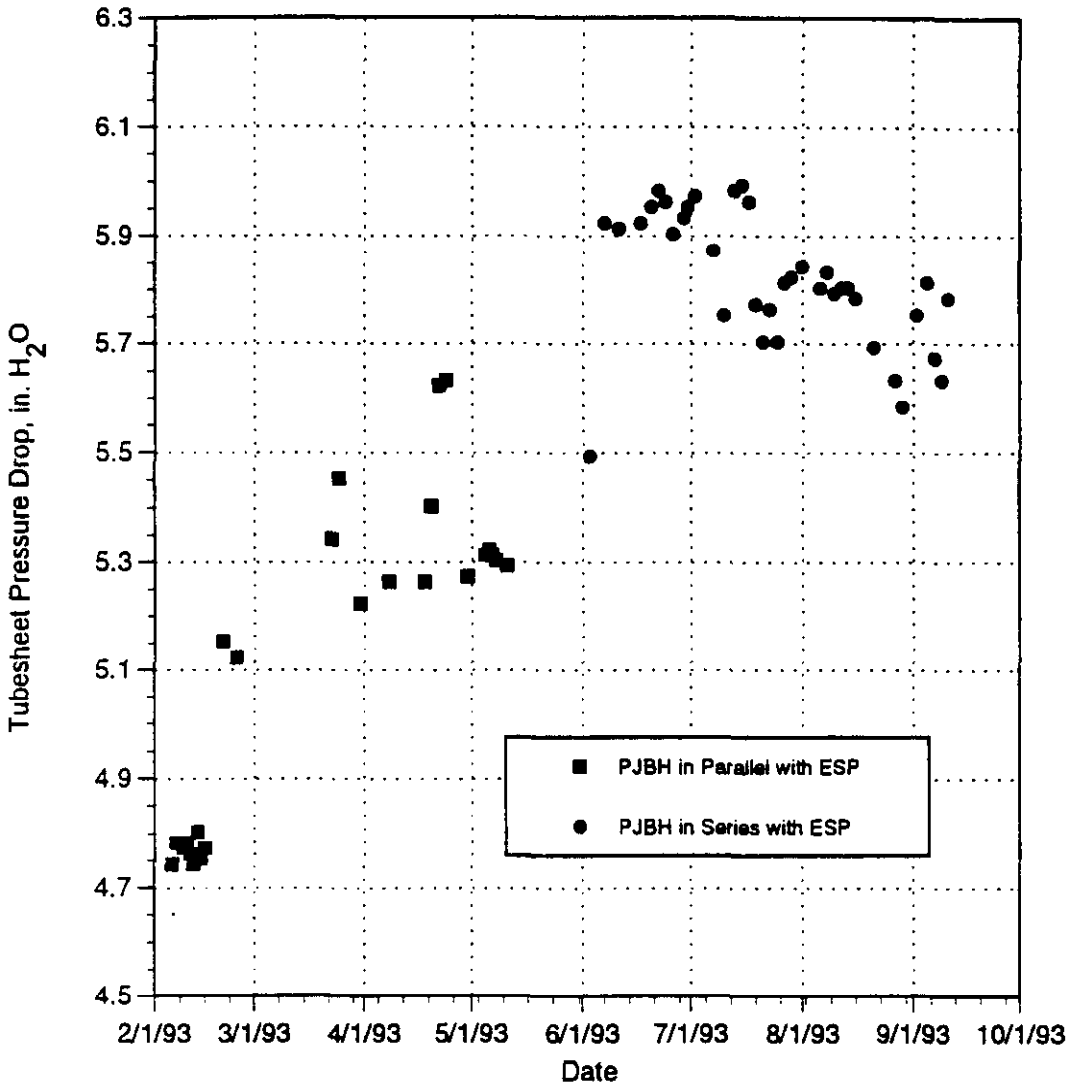

Figure 5. Pulse-Jet Baghouse Tubesheet Pressure Drop History, February through October, 1993.

Pulse Cleaning

Since the air-to-cloth ratio was held constant and the tubesheet pressure drop was operated between two discrete values, the primary parameter that was used to evaluate the dynamic properties of the filter bags (development of the dustcake and the cleanability of the bag fabric) was the pulse cleaning rate.

A summary of pulse cleaning frequencies for the GSA tests are presented in Table 2. The data are presented in separate columns for the two baghouse operating configurations. A comparison to other pilot plant and full scale performance data for pulse-jet baghouses is shown in Figure 3 and comparison of the PJBH operating in the COHPAC mode is presented in Figure 4.

For PJBH operation in parallel with the ESP, the pulse cleaning frequency increased slightly as the bags became more "seasoned", although for the majority of tests, the pulse rate was between ~30 and 40 pulses per hour. For PJBH operation in series with the ESP, the pulse cleaning rate was between ~1 and 5 pulses per hour due to the much lower mass loading at the PJBH inlet, despite the increase in air-to-cloth ratio.

In order to compare different pulse-jet baghouse installations, the way pulses are counted was standardized. The variable "cleaning cycles (cleans/hr)" shown in Figure 3 refers to the effective number of times that <u>each</u> <u>bag</u> was cleaned per hour. An assumption was made that each pulse port of the pulse manifold was cleaning one bag per pulsing period. At the CER, the pulse manifold has three pulse ports. Therefore, with 48 bags installed (for PJBH operation in parallel with the ESP), it would take 16 pulses/hour to equal 1 clean/hour. Therefore, 30 to 40 pulses/hour would be equivalent to 1.9 to 2.5 cleans/hour.

For both configurations of PJBH operation, there was not a strong relationship between pulse cleaning and any particular test parameter. Since the pulse cleaning rate was a truly dependent variable, it incorporated the effects of other independent parameters. There were many factors that could influence the pulsing rate (major test variables as well as baghouse operational factors). The interaction of these different parameters may have obscured the effect of any one parameter on the pulse cleaning rate.

There were relationships that were generally true; such as, the pulsing rates were higher for some of the tests with chloride spiking and typically lower pulsing rates for the tests at the 8-degree approach-to-saturation temperature. Although there were indications of these trends, additional studies would have to be performed to determine the relationship between pulse cleaning and these various test parameters.

Temperature Profile

With the GSA process, system temperatures were controlled to yield temperatures at the reactor outlet at a specific approach-to-saturation temperature (8°, 18°, or 28° F). The actual approach temperature was dependent on various parameters, but was between 125 and 131 °F. Consequently, temperatures at the baghouse inlet ranged from 133 to 159 °F depending on operating conditions.

The baghouse computer system recorded temperatures at the PJBH inlet duct, outlet duct, outlet plenum, and the ash hopper. The temperature of the flue gas measured at the PJBH inlet was generally within 1 to 2 degrees of the gas temperature at the ESP inlet or outlet, depending on the source of the flue gas. The temperature at the ESP outlet was generally 5 °F higher than the ESP inlet due to the electrical input to the ESP plates and the reactions occurring in the ESP. A summary of the temperature history concerning the baghouse operation is presented in Table 4. This table is presented in a chronological order.

Temperature loss across the PJBH ranged from approximately 4 to 15 °F over the duration of the test program. The minimum temperature loss across the baghouse was 4 to 5 °F, therefore larger temperature losses indicated potential sources of inleakages. After the inleakage sources were identified and eliminated, the temperature loss would be reduced. Generally, the increase in the oxygen content from the PJBH inlet to outlet was 0.4 to 1.0 %.

During tests in which the GSA was operating at an 8 °F approach-to-saturation temperature, the temperature at the PJBH outlet was near or below the saturation temperature. The baghouse generally performed at a lower pulsing frequency at these conditions. During a particular test at an 8 °F approach-to-saturation temperature, an inspection found that the surface of the bag exterior exhibited signs of being close to saturation, although no tubesheet ΔP or bag pulsing problems were documented. There were a few problems with the conveyance of ash through the baghouse hopper at the low operating temperatures, although we think these problem could be successfully resolved with more effective hopper heaters and hopper vibrators.

The only other observation with respect to baghouse temperature was made when the bags were removed to prepare for the PJBH operation at the ESP outlet. At the top 12 to 18 inches of each bag (directly under the tubesheet), there were crusty, nodular formations which were approximately 1/4- to 1/2-inch in diameter. The nodules decreased in size and virtually disappeared at the bottom of the 12- to 18-inch section. The nodular formations were suspected to have been caused by the bags being exposed to the "cool" pulse air during cleaning. This phenomena has been documented at other pilot-scale pulse-jet installations for which the pulse air is injected at near ambient temperatures.

Table 4. PJBH Temperature Profile
(PJBH Operating in Parallel with ESP)
(All data in °F)

Test ID	GSA Operational Parameters			PJBH Operational Parameters		
	GSA Inlet Wet Bulb	Approach Temp	GSA Inlet + Approach	PJBH Inlet	PJBH Outlet	PJBH Loss
3-AP-08	126.5	18.0	144.5	144.3	136.4	7.9
3-AP-21	128.4	28.0	156.4	156.2	146.8	9.4
3-AP-03	127.4	18.0	145.4	145.8	137.9	7.9
3-AP-26	120.0	18.0	138.0	139.1	134.4	4.7
3-AP-27	120.3	18.0	138.3	138.3	131.3	7.0
3-AP-20	126.3	28.0	154.3	154.2	141.6	12.6
3-AP-19	125.8	28.0	153.8	153.6	141.2	12.4
3-AP-18	126.5	28.0	154.5	154.6	142.5	12.1
3-AP-02	129.3	18.0	147.3	146.8	135.0	11.8
3-AP-13	127.0	28.0	155.0	154.9	141.0	13.9
3-AP-12	127.2	8.0	135.2	—	—	—
3-AP-12	127.2	8.0	135.2	135.2	125.1	10.1
3-AP-12	127.2	8.0	135.2	134.1	122.6	11.5
3-AP-14	(127)	18.0	(145)	144.0	129.3	14.7
3-AP-14	(127)	18.0	(145)	150.8	135.2	15.6
3-AP-24	126.4	28.0	154.4	152.5	145.2	7.3
3-AP-22	125.0	28.0	153.0	151.9	145.2	6.7
3-AP-23	125.8	28.0	153.8	152.2	142.8	9.4
3-AP-29	126.4	18.0	144.4	145.6	138.2	7.4
3-AP-20	126.4	28.0	154.4	155.0	147.4	7.6
3-AP-42	125.4	8.0	133.4	133.0	125.4	7.6
3-AP-44	125.9	18.0	143.9	145.1	139.4	5.7
3-AP-45	128.2	28.0	156.2	156.9	149.5	7.4
3-AP-58	129.5	8.1	137.6	138.4	133.2	5.2
3-AP-56	129.8	28.0	157.8	158.8	153.5	5.3
3-AP-59	130.5	28.0	158.5	159.4	152.9	6.5
3-AP-60	128.1	18.0	146.1	147.5	143.5	4.2
3-AP-11	129.3	8.0	137.3	138.4	134.1	4.3
3-AP-61	128.2	18.0	146.2	145.5	140.6	4.9
3-AP-62	127.3	18.0	145.3	145.1	140.9	4.2

Table 4 (cont.). PJBH Temperature Profile
(PJBH Operating in Series with ESP)
(All data in °F)

Test ID	GSA Operational Parameters			PJBH Operational Parameters		
	GSA Inlet Wet Bulb	Approach Temp	GSA Inlet + Approach	PJBH Inlet	PJBH Outlet	PJBH Loss
2-AP-88	127.3	28.0	157.3	160.5	146.8	13.7
2-AP-17	128.3	18.0	146.3	152.6	143.5	9.1
2-AP-91	129.1	18.0	147.1	153.3	144.0	9.3
2-AP-92	128.0	18.0	146.0	152.2	143.2	9.0
2-AP-93	129.6	18.0	147.6	154.1	143.4	10.7
2-AP-84	128.8	28.0	156.8	164.3	153.9	10.4
2-AP-90	128.6	28.0	157.6	163.4	150.7	12.7
2-AP-82	128.3	18.0	146.3	152.1	142.3	9.8
2-AP-94	130.0	28.0	158.0	163.6	151.7	11.9
2-AP-85	128.9	28.0	156.9	164.4	152.4	12.0
2-AP-75	131.7	18.0	149.7	158.4	148.3	10.1
2-AP-74	128.2	18.0	146.2	154.7	145.0	9.7
2-AP-79	129.7	8.0	137.7	145.6	138.8	6.8
2-AP-95	130.9	18.0	148.9	155.4	150.5	4.9
2-AP-96	130.1	18.0	148.1	155.7	150.4	5.3
2-AP-80	129.8	8.0	137.8	145.9	141.4	4.4
2-AP-86	129.5	28.0	157.5	165.3	159.4	5.9
2-AP-73	131.6	18.0	149.6	158.7	152.7	6.0
2-AP-72	130.7	8.0	138.7	146.5	141.9	4.6
2-AP-97	130.7	28.1	158.8	165.6	159.6	6.0
2-AP-81	130.4	8.0	138.4	148.6	145.0	3.6
2-AP-78	129.2	18.0	147.2	154.6	148.8	5.8
2-AP-87	128.4	28.0	156.4	162.4	156.4	6.0
2-AP-77	129.0	18.0	147.0	152.2	147.1	5.1
2-AP-83	129.4	28.0	157.4	161.4	155.7	5.7
1-HS-05	130.4	18.0	148.4	152.4	146.8	5.6
1-HS-09	129.7	28.0	157.7	161.2	155.2	6.0
1-HS-10	129.5	28.0	157.5	162.0	157.2	4.8
1-HS-06	129.8	18.0	147.8	152.0	147.8	4.2
1-HS-04	130.5	18.0	148.5	152.2	147.6	4.6
1-HS-02	130.0	8.0	138.0	142.4	139.5	2.9
1-HS-01	130.4	8.0	138.4	142.8	139.1	3.7
1-HS-03	130.0	18.0	148.0	149.9	145.4	4.5
1-HS-07	128.6	28.0	156.6	158.7	152.4	6.3
1-HS-08	128.7	28.0	156.7	160.5	153.8	6.7
1-HS-11	129.7	8.0	137.7	140.9	135.6	5.3
1-HS-12	128.8	8.0	136.8			

Particulate Mass Loadings / Collection Efficiency Measurements

TVA performed multiple total mass measurements at the inlet and the outlet of the PJBH from April 18 through September 11. For testing with the baghouse operating in parallel with the ESP, a thimble filter holder was used at the PJBH inlet and a 47 mm filter was used at the PJBH outlet for sample collection. A run time of 18 minutes was specified for measurements at the inlet and 90 minutes at the outlet location. For the tests when the baghouse was operating in series with the ESP (after May 28), a 47 mm filter was used at each location. A run time of 72 minutes was used for measurements at the PJBH inlet and 360 minutes at the PJBH outlet location. The samplers were operated at a flow rate of approximately 0.5 acfm.

There were several problems encountered with the execution of the mass measurements at the baghouse test ports. Due to the small sized sampling ports (3-inch) installed at the PJBH inlet and outlet test locations, there was minimal clearance of the filter holder assembly in the sampling port, which increased the potential of scraping the sample nozzle during the performance of the sampling traverses. Eventually, the sampling method was changed from the EPA Method 17 to EPA Method 5 procedure. Method 5 prescribes that the filter assembly is located out-of-stack in a heated enclosure.

As a qualitative check on the baghouse efficiency, routine baghouse inspections were performed. The tubesheet floor was always clean of any ash deposition, that would probably be evident if the baghouse was performing poorly (<99% efficient). Tests were performed to confirm that the baghouse emissions were representative of filtration properties and not due to bag leaks. The use of Visolite™, a bag leak-detecting agent, found no broken bags or problems at the tubesheet.

All of the particulate mass measurements performed since April 18 are presented as Appendix A. This data summary is grouped by test condition and contains the results of the individual mass concentrations measurements at the inlet and outlet to the PJBH and the ESP. There were typically two or three replicate tests for each location for an individual test condition. As evidenced by the data in Appendix A, there were some data sets for which there were significant variations between individual runs. Attempts were made to form meaningful average mass concentrations for each test condition. For some data sets, individual runs have been deleted from the average because of extreme variations from the other runs. In some cases, averages are not shown due to the large variation within a test condition.

A condensed summary of data for the particulate mass measurements is presented in Table 5. This table presents the data for the PJBH operating in parallel with the ESP separately from the data for the PJBH operating in series with the ESP. Data shown in parentheses are excluded from averages, but are shown for completeness. A graphical summary of the collection efficiencies for the various configurations is presented in Figure 6.

Table 5. PJBH / ESP Mass Measurements
(PJBH Operation in Parallel with ESP)

Test ID	ESP			PJBH			Ratio: ESP Inlet/ PJBH Inlet
	Inlet Loading (Gr/DSCF)	Outlet Loading (Gr/DSCF)	Collection Efficiency (%)	Inlet Loading (Gr/DSCF)	Outlet Loading (Gr/DSCF)	Collection Efficiency (%)	
3-AP-20	5.21	0.00612	99.908	4.84	0.00091	99.980	1.08
3-AP-42	4.97	0.00531	99.919	4.03	0.00143	99.966	1.23
3-AP-44		0.00324		4.95	0.00161	99.965	
3-AP-45	8.03	0.00246	99.970	7.15			1.12
3-AP-56				4.59	0.00244	99.944	
3-AP-59				6.85	0.00305	99.954	
3-AP-60				6.09	0.00324	99.944	
3-AP-11				7.36	0.00121	99.983	
3-AP-62				3.61	0.00135	99.963	
3-AP-15				5.72	0.00043	99.992	
2-AP-63	6.88	0.00318	99.954				
2-AP-71	3.99	0.00183	99.954				
Average	**5.82**	**0.00369**	**99.941**	**5.52**	**0.00174**	**99.966**	**1.14**
1 STD	**1.62**	**0.00167**	**0.026**	**1.32**	**0.00096**	**0.017**	

Table 5 (cont.). PJBH / ESP Mass Measurements
(PJBH Operation in Series with ESP)

Test ID	ESP			PJBH			Ratio: PJBH In/ ESP Out
	Inlet Loading (Gr/DSCF)	Outlet Loading (Gr/DSCF)	Collection Efficiency (%)	Inlet Loading (Gr/DSCF)	Outlet Loading (Gr/DSCF)	Collection Efficiency (%)	
2-AP-88	3.56	0.00469	99.868				
2-AP-16	7.11	0.00250	99.965				
2-AP-91	6.39	0.00278	99.956	0.00928	(0.00143)		3.34
2-AP-93	9.32	0.00500	99.951				
2-AP-84	3.80	0.00076	99.984	0.00636	0.00052	99.9863	8.37
2-AP-90	3.47	0.00299	99.932	(0.03410)	0.00023	99.9934	
2-AP-82				0.00802	0.00037		
2-AP-94	3.55	0.00390	99.890	0.00603	0.00027	99.9924	1.03
2-AP-85	4.68	0.00262	99.952				
2-AP-75	6.47	0.00163	99.980	0.00631	0.00023	99.9964	3.87
2-AP-74				0.00897	0.00041		
2-AP-95	3.52	0.00251	99.929	0.00435	0.00009	99.9974	1.73
2-AP-96	3.17	0.00304	99.904				
2-AP-80	4.80	0.00177	99.973	0.00713	0.00039	99.9919	4.02
2-AP-86	4.57	0.00344	99.930	0.00523			1.52
2-AP-73	6.63	0.00502	99.924	0.00549			1.09
2-AP-72	5.67	0.00266	99.960	0.00728	(0.00142)		2.74
2-AP-97	4.26			0.00991			1.57
2-AP-81	4.94	0.00171	99.965	0.00705			4.12
2-AP-78	3.85	0.00330	99.914	0.00675	0.00043	99.9888	2.05
2-AP-87	4.30	0.00245	99.943	0.00789	0.00040	99.9907	3.22
2-AP-77	4.95	0.00231	99.961	0.00533	0.00039	99.9921	2.31
2-AP-83	5.14	0.00344	99.933				
1-HS-05				(0.02219)	0.00049	99.9924	
1-HS-09				0.00709	0.00036	99.9940	2.54
1-HS-10				0.00841	0.00014	99.9978	2.04
1-HS-06				0.00931	0.00039	99.9946	2.75
1-HS-02				(0.02451)	(0.00024)	99.9970	1.15
1-HS-01				(0.03637)			1.40
1-HS-03							
1-HS-07				0.01237	0.00025	99.9947	3.03
1-HS-11				0.00519	0.00038	99.9946	1.73
Average	**5.36**	**0.00314**	**99.940**	**0.00732**	**0.00034**	**99.9934**	**2.33**
1 STD	**1.53**	**0.00108**	**0.027**	**0.00192**	**0.00012**	**0.0026**	

PJBH Operating in Parallel with the ESP

Both collection devices operated with a high particulate collection efficiency. The PJBH averaged marginally higher efficiency than the ESP (99.966% vs. 99.941%). The ESP collection should have been very efficient, since the ESP was operated at a relatively high specific collection area (SCA). Mass concentrations at the outlet of the PJBH are compared with other pulse-jet baghouses in Figure 3. The collection efficiency of the PJBH was in the range that is typical for pulse-jet baghouses.

An overview of all measurements for the PJBH operating in parallel with the ESP is shown in the following table. To account for the variations in the results, the data are presented as a range of one standard deviation (95% confidence limits).

Location	Inlet Concentration (gr/DSCF)	Outlet Concentration (gr/DSCF)	Collection Efficiency (%)
ESP	4.20-7.44	0.00202-0.00536	99.915-99.967
PJBH	4.20-6.84	0.00078-0.00270	99.949-99.983

These results suggest that the PJBH was sampling a representative flue gas stream from the ESP inlet duct, since the mass concentrations at the PJBH and ESP inlet ducts were similar (The ratio of the mass concentrations at the ESP inlet to the PJBH inlet showed a difference of 14% as shown in Table 5.)

There was no obvious relationship between the major test parameters and the mass loadings at the inlet to the baghouse due to the scatter in the data. More data would be require to adequately define these relationships.

PJBH Operating in Series with the ESP

For the PJBH operating in series with the ESP, the collection efficiency is calculated with the outlet of the PJBH compared to the inlet of the ESP, rather than the inlet of the PJBH. Therefore, the collection efficiency reported for the PJBH is for the combination of the ESP and PJBH. This average collection efficiency of the PJBH / ESP combination was 99.9934 %.

Average mass concentrations at the inlet to the PJBH ranged from 0.005 to 0.009 gr/DSCF. This level of emissions (representing the outlet of the ESP) was only a small fraction of what would be expected at a "poorly performing ESP" for which the COHPAC concept was intended. Therefore, for the test conditions evaluated at the CER, the baghouse operating as a COHPAC collector was not seriously challenged.

Average mass concentration at the outlet to the PJBH was 0.00034 gr/DSCF. This result was compared with other COHPAC collectors in Figure 4. Unfortunately, mass emission measurements were performed for only one of these evaluations.

An overview of the measurements made for the PJBH operating in series with the ESP is shown in the following table.

Location	Inlet Concentration (gr/DSCF)	Inlet / Outlet Concentration (gr/DSCF)	Outlet Concentration (gr/DSCF)	Collection Efficiency (%)
ESP	3.83-6.89	0.00206-0.00422		99.913-99.967
PJBH		0.00540-0.00924	0.00022-0.00046	99.991-99.996

For the PJBH operating in series with the ESP, data analyses have indicated that the measurement of mass loadings was very difficult. The main reason for these difficulties is that the measured concentrations were so low. Some of these difficulties are evident in the measurements made at the outlet to the ESP and the inlet to the PJBH. Ideally, the mass concentrations at each of these locations should have been the same, since it was the same flue gas stream. However, measurements were made at both of these locations for 23 test conditions, and there was never good agreement. (The concentrations at the PJBH inlet for all of these test averaged 2.3 times higher than the concentrations at the ESP outlet, as shown in Table 5.) Variations among mass concentrations measured for a single test condition were often unexplainably large.

SO_2 Removal

A major objective of the parametric baghouse evaluation was to compare the SO_2 removal efficiency for the two baghouse configurations to the SO_2 removal efficiency for the ESP operating alone.

In design of the baghouse test program, we selected 8 values from the CER Foxboro computer system for monitoring by the SRI baghouse data acquisition system. These values were the SO_2 and O_2 concentrations for each of four locations; the GSA system inlet, ESP inlet, ESP outlet, and the PJBH outlet. TVA installed dedicated sampling and conditioning hardware and separate gas analyzers (SO_2 and O_2) for each of these locations.

For each test condition, we calculated average SO_2 removals for various reference points; across each collection device and across each system of devices. For these calculations, we adjusted the SO_2 concentrations to equivalent oxygen levels. This method should correct for any dilution of the flue gas and allow comparisons of SO_2 concentrations on equivalent bases.

CER personnel calculated SO_2 removals on a molar basis, which normalized the SO_2 concentration based on flue gas conditions (temperature, pressure, moisture, oxygen, etc.). Correction of the SO_2 concentrations to a common oxygen basis (as performed by SRI) should yield SO_2 removals that are equivalent to calculations on a molar basis. The equations that we used for the SO_2 removals calculations are shown in Table 6. These equations are analogous to the ones used by CER personnel for similar calculations.

There were small differences in the SO_2 removals in the results reported by SRI and TVA, which is presumed to be due to the different methods used for calculation. The SO_2 removal generally differed by less than 2% (on a total SO_2 removal basis) between the two calculated results. Since the two methods of calculation used different test parameters, the variations in these parameters could cause these differences in the SO_2 removal results.

A summary of the SO_2 removal efficiencies for the PJBH and ESP is presented in Table 2. SO_2 removals are presented together with the test variables to facilitate comparisons of the results.

Figures 7A and 7B present a comparison of total SO_2 removal for the three configurations of particulate collection devices. (The two figures are identical except that figure 7A shows data points for the baghouse operating in parallel with the ESP, and figure 7B shows data points for the baghouse operating in series with the ESP.) For reference purposes, total SO_2 removal through the PJBH in parallel with the ESP and in series with the ESP are plotted versus the SO_2 removal through the ESP. A reference line is shown for comparing the PJBH performance. As the data indicate, the SO_2 removal for the two PJBH configurations produced results that were distinguishable from the SO_2 removal data for the ESP, and the PJBH operating in parallel with the ESP produced the highest SO_2 removal results.

Figures 7A and 7B shows that the removal through the PJBH operating in parallel with the ESP was consistently 3 to 5% higher on an absolute basis than through the ESP for like test conditions. The removal through the PJBH operating in series with the ESP exhibits a 0 to 2% absolute increase in SO_2 removal compared with removal through the ESP alone.

Another perspective is presented in Figures 8A, 8B, and 8C, which shows the incremental amount of SO_2 removal through the particulate collection system versus the level of SO_2 removal through the GSA reactor. (The three figures are identical except that figure 8A shows data points for the baghouse operating in parallel with the ESP, figure 8B shows data points for the baghouse operating in series with the ESP, and figure 8C shows data for the ESP.) As would be expected, the amount of SO_2 removal through the particulate devices is a function of how much SO_2 remains at the exit of the GSA reactor. Higher SO_2 concentrations at the exit of the GSA reactor were consistent with higher removals through the subsequent particulate collection devices. As shown in this figure, the pulse-jet baghouse operating in parallel with the ESP (baghouse operating alone) yielded the highest SO_2 removal.

Table 6. SO_2 Removal Equations

PJBH SO_2 Removal Efficiency

$$\Delta R_b = \frac{(S_e - S_{b'})\dfrac{20.9 - A_e}{20.9 - A_{b'}}}{S_e}$$

ESP SO_2 Removal Efficiency

$$\Delta R_e = \frac{(S_e - S_{e'})\dfrac{20.9 - A_e}{20.9 - A_{e'}}}{S_e}$$

Total System SO_2 Removal Efficiency Through PJBH

$$R_b = \frac{(S_i - S_{b'})\dfrac{20.9 - A_i}{20.9 - A_{b'}}}{S_i}$$

Total System SO_2 Removal Efficiency Through ESP

$$R_e = \frac{(S_i - S_{e'})\dfrac{20.9 - A_i}{20.9 - A_{e'}}}{S_i}$$

in which

S_i = SO_2 Concentration at System Inlet
S_e = SO_2 Concentration at ESP Inlet
$S_{e'}$ = SO_2 Concentration at ESP Outlet
$S_{b'}$ = SO_2 Concentration at PJBH Outlet
A_i = O_2 Concentration at System Inlet
A_e = O_2 Concentration at ESP Inlet
$A_{e'}$ = O_2 Concentration at ESP Outlet
$A_{b'}$ = O_2 Concentration at PJBH Outlet
ΔR_b = SO_2 Removal Across PJBH
ΔR_e = SO_2 Removal Across ESP
R_e = Total SO_2 Removal Through ESP
R_b = Total SO_2 Removal Through PJBH

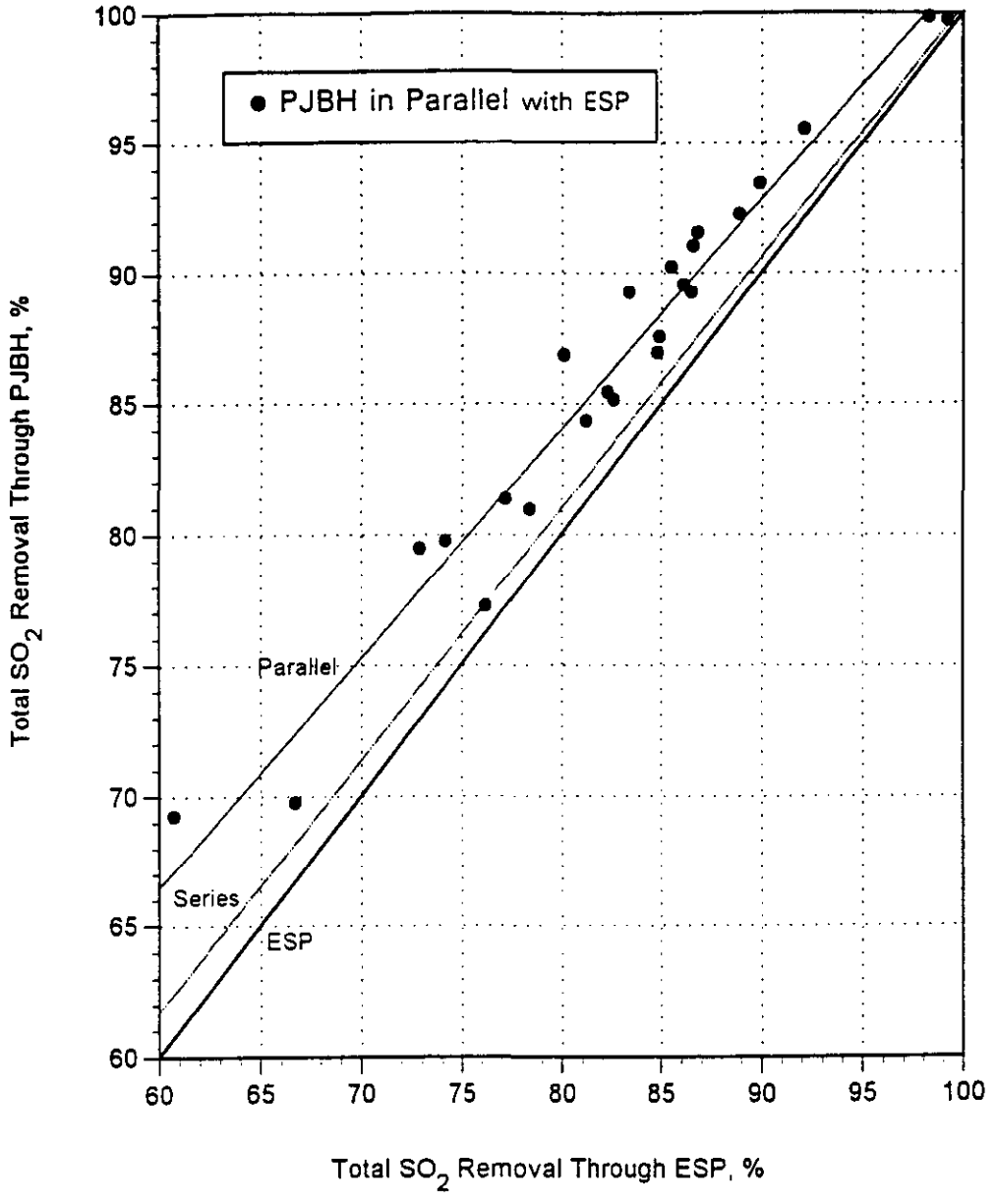

Figure 7A. Total System SO_2 Removal Through PJBH Versus ESP. Data shown for PJBH in parallel with ESP.

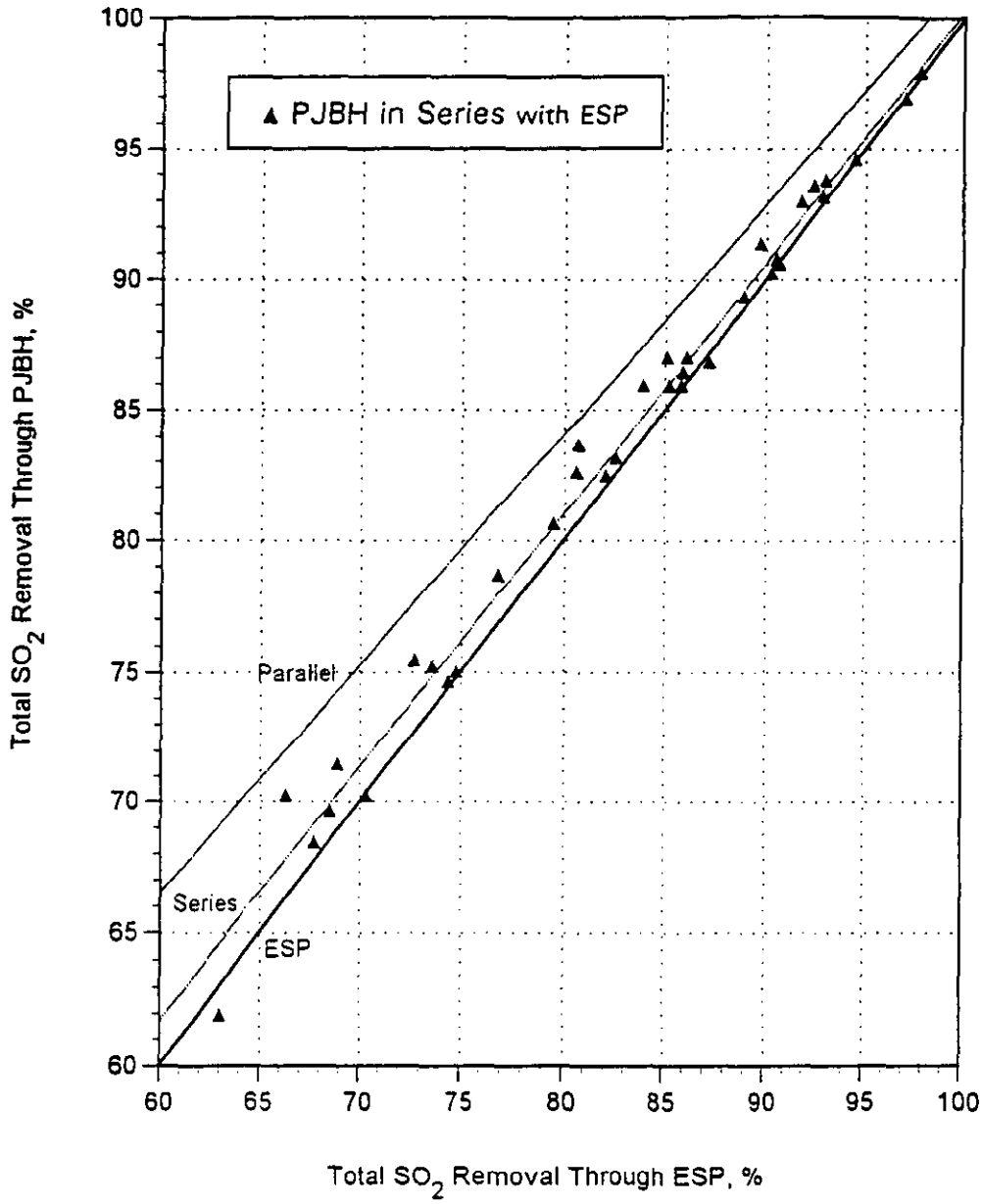

Figure 7B. Total System SO_2 Removal Through PJBH Versus ESP. Data shown for PJBH in series with ESP.

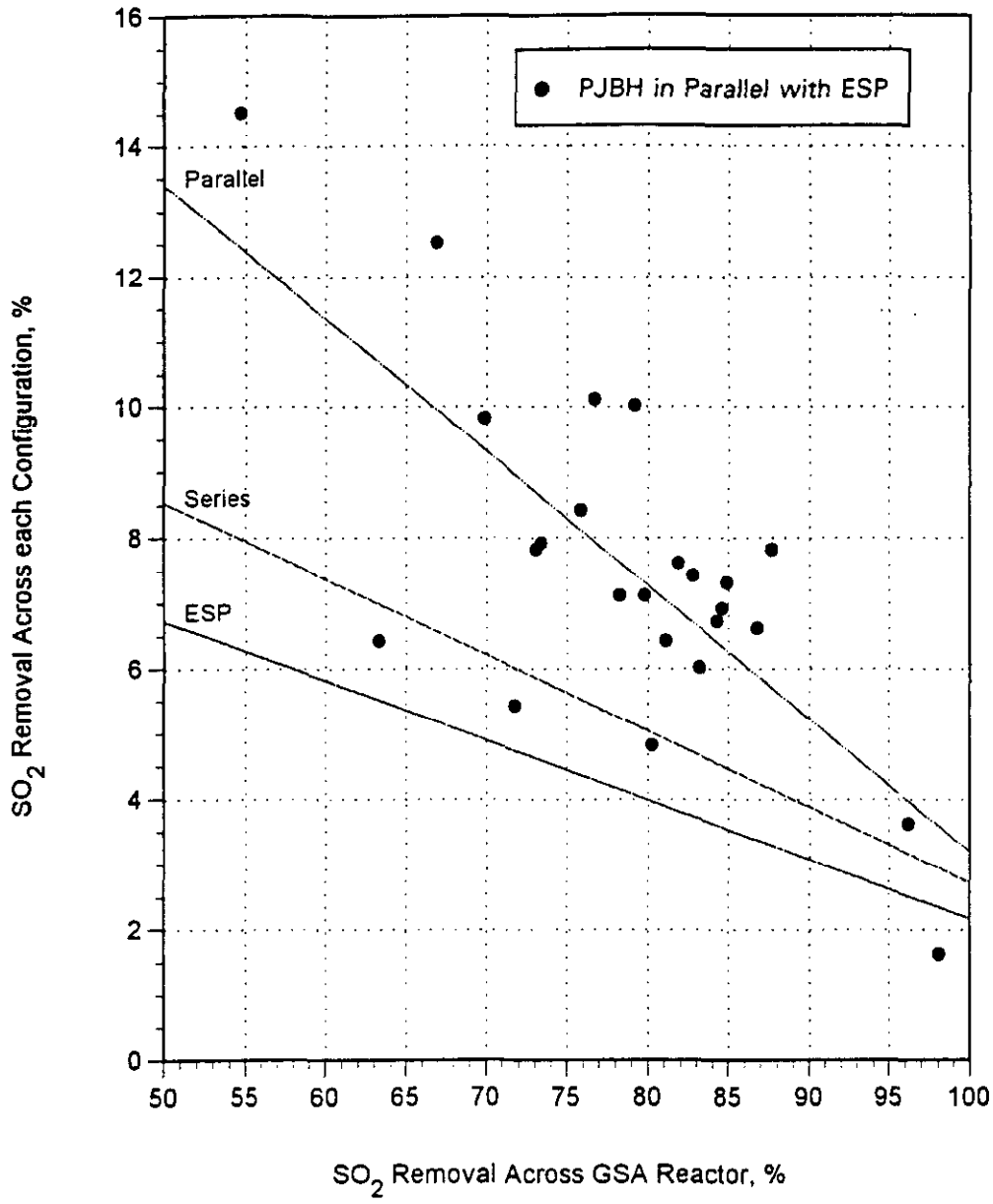

Figure 8A. Percentage of SO_2 Removed by each Configuration of the Particulate Control Devices as a Function of SO_2 Removal Across the GSA Reactor. Data shown for PJBH in parallel with ESP.

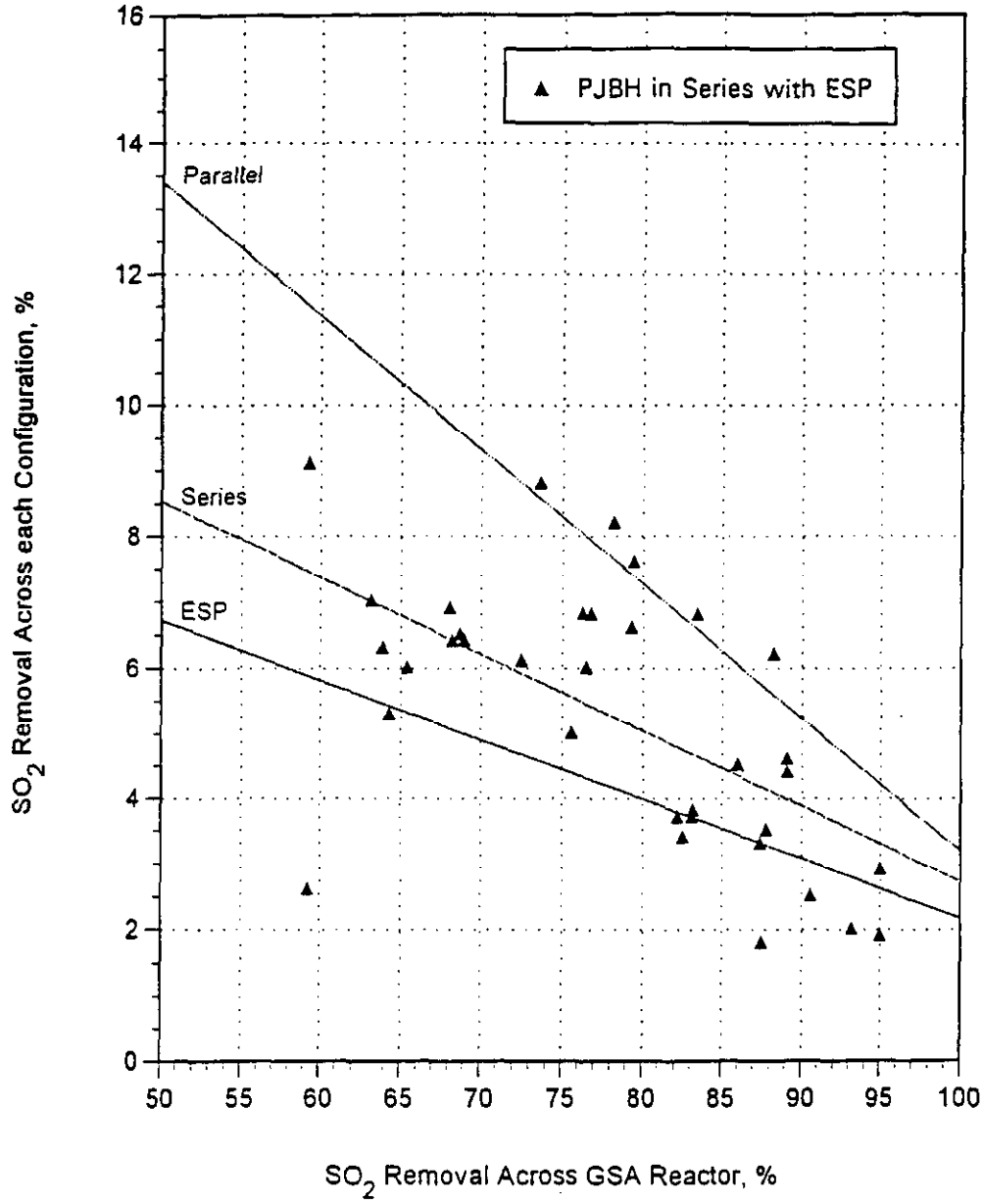

Figure 8B. Percentage of SO_2 Removed by each Configuration of the Particulate Control Devices as a Function of SO_2 Removal Across the GSA Reactor. Data shown for PJBH in series with ESP.

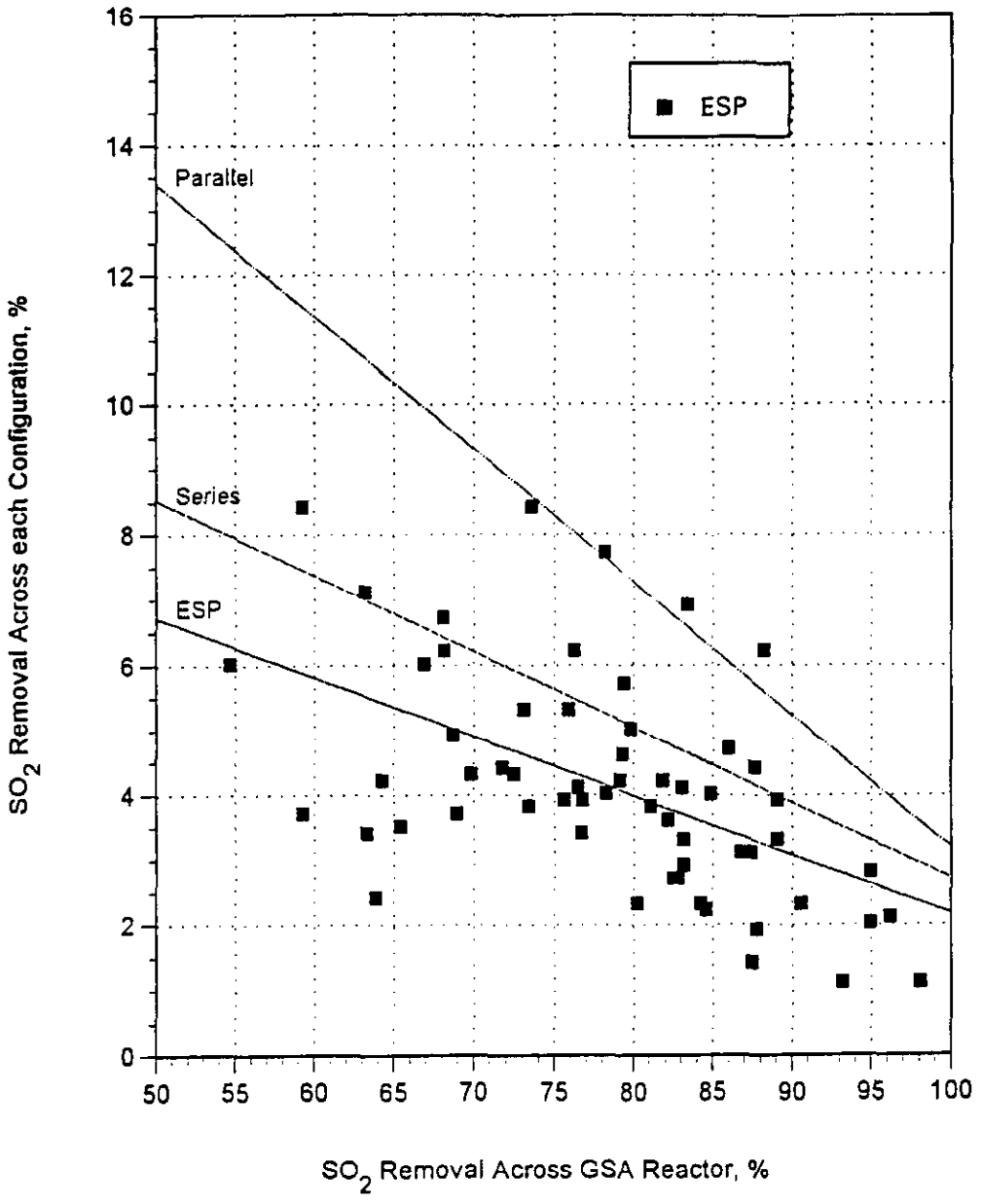

Figure 8C. Percentage of SO_2 Removed by each Configuration of the Particulate Control Devices as a Function of SO_2 Removal Across the GSA Reactor. Data shown for ESP.

Data analyses by CER personnel has shown that reasonable trends exist between the major test variables (lime stoichiometry, approach temperature, coal chloride content) and SO_2 removal through the ESP. Since a relationship between the SO_2 removal for the various parameters has been established, it was therefore unnecessary to show detailed relationships between SO_2 removal and the major test parameters for the PJBH configurations.

Tests conducted from April 27 through May 13 (3-AP-11, 3-AP-56, 3-AP-58, 3-AP-59, and 3-AP-60) produced SO_2 removals (through the ESP and PJBH) that were significantly higher than were expected when compared with similar tests. These SO_2 removal data for these tests are shown in parentheses. Since these tests occurred during the period that the boiler was operated with continuous soot blowing of the air heaters, this atypical boiler operation was suspected to have caused the higher SO_2 removals. TVA personnel investigated possible causes for the higher SO_2 removals during this period which included elevated moisture levels, coal analyses for chloride content and ash analyses for calcium utilization. It is also possible that some operational parameter was not being measured correctly during this period (calcium stoichiometry, flue gas wet bulb temperature). (We are not aware that any reason was determined that would explain the data from these five tests.)

Conclusions

The operation of a pulse-jet baghouse with the GSA process was very successful in both modes of operations; as a "standard" pulse-jet baghouse in parallel with the ESP and also as a "COHPAC" collector, in series with the ESP. A summary of the operating parameters and results are shown in the following table.

Operating Mode	PJBH in Parallel with ESP	PJBH in Series with ESP
Air-to-cloth Ratio (acfm/ft^2)	4.0	12.0
Tubesheet ΔP (in. H_2O)	4.0 - 6.0	5.0 - 6.0
Pulsing Rate (pulses/bag/hr)	1.9 - 2.5	0.06 - 0.31
Inlet Mass Loading (gr/DCSF)	5.52 $\pm$ 1.32	0.0073 $\pm$ 0.0019
Outlet Mass Loading (gr/DSCF)	0.0017 $\pm$ 0.00096	0.00034 $\pm$ 0.00012
Collection Efficiency (%)	99.966 $\pm$ 0.017	99.9934 $\pm$ 0.0026
SO2 Removal (% > ESP)	3 - 5	0 - 2

Operation in Parallel with the ESP:

The PJBH operated for 1197 hours in this configuration. The pulse cleaning rate was as low as any of the other pulse-jet baghouse in the EPRI database of pilot-scale and full-scale pulse-jet baghouse operation, although the inlet mass loading to the baghouse was reasonably high (4 to 7 gr/DSCF). This low pulsing rate is partially attributed to the good filtration properties of the sorbent / ash product being handled by the baghouse. The outlet emissions rate was very low, certainly below any existing regulations. SO_2 removal was 3 to 5% higher for the baghouse operating in parallel with the ESP than with the ESP alone. This configuration yielded the highest total SO_2 removal for the GSA process.

Operation in Series with the ESP:

The PJBH operated for 2445 hours in this configuration. Although the baghouse operating in the COHPAC mode was not seriously challenged, due to the low inlet mass loading, the baghouse compared favorably with the other relevant COHPAC operating histories. The tubesheet pressure drop was within the acceptable range of operation for the high air-to-cloth value. The pulse cleaning rate was very low, practically an order of magnitude lower than the other comparable data from COHPAC units. SO_2 removal was only slightly better, approximately 0 to 2%, than through the ESP alone.

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Appendix A. Particulate Mass Measurements

Test ID	Date	Location/ID	Inlet Mass (Gr/DSCF)	Outlet Mass (Gr/DSCF)	Collection Efficiency (%)
3-AP-20	4/18	PJBH #1	4.71	0.00078	99.983
3-AP-20	4/18	PJBH #2	4.94	0.00355	99.892
3-AP-20	4/19	PJBH #1	6.24		
3-AP-20	4/19	PJBH #2	4.42		
Average			**5.08**		
3-AP-20	4/20	PJBH #1	5.06	0.00114	99.976
3-AP-20	4/20	PJBH #2	4.47	0.00065	99.985
3-AP-20	4/20	PJBH #3	4.28	0.00094	99.980
Average			**4.60**	**0.00091**	**99.980**
3-AP-20	4/19	ESP #1	5.26	0.02090	99.653
3-AP-20	4/19	ESP #2	5.10	0.00555	99.915
3-AP-20	4/19	ESP #3	5.27	0.00668	99.900
Average			**5.21**	**0.00612**	**99.908**
3-AP-42	4/21	PJBH #1	3.92	0.00272	99.928
3-AP-42	4/21	PJBH #2	4.19	0.00154	99.962
3-AP-42	4/21	PJBH #3	3.97	0.00131	99.970
Average			**4.03**	**0.00143**	**99.966**
3-AP-42	4/22	ESP #1	5.23	0.00463	99.934
3-AP-42	4/22	ESP #2	4.83	0.00615	99.905
3-AP-42	4/22	ESP #3	4.85	0.00515	99.919
Average			**4.97**	**0.00531**	**99.919**
3-AP-44	4/23	PJBH #1	4.96	0.00188	99.958
3-AP-44	4/23	PJBH #2	4.94	0.00133	99.971
Average			**4.95**	**0.00161**	**99.965**
3-AP-44	4/24	ESP #1	3.41	0.01516	99.668
3-AP-44	4/24	ESP #2	0.93	0.00387	99.701
3-AP-44	4/24	ESP #3	0.69	0.00261	99.720
Average					
3-AP-45	4/25	PJBH #1	5.89	0.01023	99.820
3-AP-45	4/25	PJBH #2	7.15	0.00753	99.870
3-AP-45	4/27	PJBH #1	7.04	0.01271	99.819
3-AP-45	4/27	PJBH #2	7.25	0.00138	99.979
Average			**7.15**		
3-AP-45	4/26	ESP #1	8.32	0.00403	99.952
3-AP-45	4/26	ESP #2	7.74	0.00185	99.976
3-AP-45	4/26	ESP #3	8.02	0.00151	99.981
Average			**8.03**	**0.00246**	**99.970**

Appendix A. (cont.) Particulate Mass Measurements

Test ID	Date	Location/ID	Inlet Mass (Gr/DSCF)	Outlet Mass (Gr/DSCF)	Collection Efficiency (%)
3-AP-58	5/01	PJBH #1	2.23	0.00151	99.930
3-AP-58	5/01	PJBH #2	4.79	0.00865	99.812
3-AP-58	5/01	PJBH #3	3.77	0.00239	99.933
Average					
3-AP-58	5/02	ESP #1	4.93	0.00531	99.921
3-AP-56	5/06	PJBH #1	4.45	0.00316	99.926
3-AP-56	5/06	PJBH #2	4.79	0.00155	99.963
3-AP-56	5/06	PJBH #3	4.52	0.00260	99.942
Average			**4.59**	**0.00244**	**99.944**
3-AP-59	5/07	PJBH #1	6.70	0.00365	99.945
3-AP-59	5/07	PJBH #2	6.81	0.00338	99.948
3-AP-59	5/07	PJBH #3	7.03	0.00213	99.968
Average			**6.85**	**0.00305**	**99.954**
3-AP-60	5/08	PJBH #1	5.99	0.00403	99.929
3-AP-60	5/08	PJBH #2	6.18	0.00244	99.959
Average			**6.09**	**0.00324**	**99.944**
3-AP-11	5/09	PJBH #1	7.91	0.00126	99.983
3-AP-11	5/09	PJBH #2	6.80	0.00116	99.983
Average			**7.36**	**0.00121**	**99.983**
3-AP-62	5/12	PJBH #1	3.97	0.00391	99.898
3-AP-62	5/12	PJBH #2	3.61	0.00135	99.963
Average			**3.79**		
3-AP-15	5/13	PJBH #1	5.33	0.00212	99.958
3-AP-15	5/13	PJBH #2	5.72	0.00043	99.992
Average			**5.53**		

Appendix A. (cont.) Particulate Mass Measurements

Test ID	Date	Location/ID	Inlet Mass (Gr/DSCF)	Outlet Mass (Gr/DSCF)	Collection Efficiency (%)
2-AP-63	5/20	ESP #1	7.63	0.00342	99.959
2-AP-63	5/20	ESP #2	7.22	0.00276	99.970
2-AP-63	5/20	ESP #3	7.27	0.00151	99.978
Average			**7.37**	**0.00256**	**99.969**
2-AP-63	5/21	ESP #1	7.26	0.00491	99.938
2-AP-63	5/21	ESP #2	6.35	0.00258	99.962
2-AP-63	5/21	ESP #3	6.19	0.00381	99.942
Average			**6.60**	**0.00377**	**99.947**
2-AP-63	5/25	ESP #1	6.40	0.00352	99.947
2-AP-63	5/25	ESP #2	6.46	0.00386	99.944
Average			**6.43**	**0.00369**	**99.946**
2-AP-63	5/27	ESP #1	6.98	0.01461	99.790
2-AP-63	5/27	ESP #2	7.28	0.00845	99.890
2-AP-63	5/27	ESP #3	7.04	0.00268	99.960
Average			**7.10**		
2-AP-71	5/30	ESP #1	4.10	0.01302	99.757
2-AP-71	5/30	ESP #2	4.07	0.00175	99.966
2-AP-71	5/30	ESP #3	3.72	0.00151	99.968
Average			**3.96**	**0.00163**	**99.967**
2-AP-71	5/31	ESP #1	3.96	0.00636	99.877
2-AP-71	5/31	ESP #2	3.86	0.00138	99.971
2-AP-71	5/31	ESP #3	4.21	0.00265	99.951
Average			**4.01**	**0.00202**	**99.961**
2-AP-88	6/03	ESP #1	3.72	0.00379	99.896
2-AP-88	6/03	ESP #2	3.80	0.00405	99.893
Average			**3.76**	**0.00392**	**99.895**
2-AP-88	6/04	ESP #1	3.47	0.00662	99.808
2-AP-88	6/04	ESP #2	3.28	0.01010	99.686
2-AP-88	6/04	ESP #3	3.30	0.00429	99.891
Average			**3.35**	**0.00546**	**99.837**

Appendix A. (cont.) Particulate Mass Measurements

Test ID	Date	Location/ID	Inlet Mass (Gr/DSCF)	Outlet Mass (Gr/DSCF)	Collection Efficiency (%)
2-AP-16	6/06	ESP #1	8.33	0.00396	99.952
2-AP-16	6/06	ESP #2	7.17	0.00248	99.966
Average			**7.75**	**0.00322**	**99.959**
2-AP-16	6/07	ESP #1	6.21	0.00256	99.958
2-AP-16	6/07	ESP #2	6.75	0.00139	99.979
2-AP-16	6/07	ESP #3	6.41	0.00135	99.978
Average			**6.46**	**0.00177**	**99.972**
2-AP-91	6/12	PJBH #1	0.01110	0.00143	
2-AP-91	6/12	PJBH #2	0.00745	0.00143	
Average			**0.00928**	**0.00143**	
2-AP-91	6/13	ESP #1	6.19	0.00265	99.967
2-AP-91	6/13	ESP #2	6.12	0.00351	99.952
Average			**6.16**	**0.00308**	**99.959**
2-AP-91	6/14	ESP #1	6.37	0.00208	99.971
2-AP-91	6/14	ESP #2	6.75	0.00223	99.971
2-AP-91	6/14	ESP #3	6.74	0.00299	99.961
Average			**6.62**	**0.00243**	**99.968**
2-AP-91	6/15	ESP #1	4.31	0.00258	99.947
2-AP-91	6/15	ESP #2	6.53	0.00306	99.958
2-AP-91	6/15	ESP #3	4.69	0.00528	99.903
Average				**0.00282**	
2-AP-93	6/21	ESP #1	7.73	0.00455	99.952
2-AP-93	6/21	ESP #2	9.41	0.00545	99.949
2-AP-93	6/21	ESP #3	9.22	0.00165	99.985
Average			**9.32**	**0.00500**	**99.951**
2-AP-84	6/23	PJBH #1	0.00706	0.00052	
2-AP-84	6/23	PJBH #2	0.00566	0.00052	
Average			**0.00636**	**0.00052**	
2-AP-84	6/24	ESP #1	3.80	0.00068	99.985
2-AP-84	6/24	ESP #2	3.88	0.00084	99.982
2-AP-84	6/24	ESP #3	3.71	0.00384	99.916
Average			**3.80**	**0.00076**	**99.984**

Appendix A. (cont.) Particulate Mass Measurements

Test ID	Date	Location/ID	Inlet Mass (Gr/DSCF)	Outlet Mass (Gr/DSCF)	Collection Efficiency (%)
2-AP-90	6/25	PJBH #1	0.03346	0.00023	
2-AP-90	6/25	PJBH #2	0.03474	0.00023	
Average			**0.03410**	**0.00023**	
2-AP-90	6/26	ESP #1	3.35	0.00198	99.952
2-AP-90	6/26	ESP #2	3.74	0.00351	99.927
2-AP-90	6/26	ESP #3	3.32	0.00347	99.917
Average			**3.47**	**0.00299**	**99.932**
2-AP-82	6/27	PJBH #1	0.00824	0.00037	
2-AP-82	6/27	PJBH #2	0.00779	0.00037	
Average			**0.00802**	**0.00037**	
2-AP-94	6/29	PJBH #1	0.00489	0.00027	
2-AP-94	6/29	PJBH #2	0.00716	0.00027	
Average			**0.00603**	**0.00027**	
2-AP-94	6/30	ESP #1	3.60	0.00526	99.877
2-AP-94	6/30	ESP #2	3.54	0.00254	99.942
2-AP-94	6/30	ESP #3	3.52	0.00974	99.775
Average			**3.55**	**0.00390**	**99.890**
2-AP-85	7/02	ESP #1	4.94	0.00297	99.947
2-AP-85	7/02	ESP #2	4.50	0.00227	99.956
2-AP-85	7/02	ESP #3	4.60	0.00570	99.888
Average			**4.68**	**0.00262**	**99.952**
2-AP-75	7/03	PJBH #1	0.00605	0.00023	
2-AP-75	7/03	PJBH #2	0.00656	0.00023	
Average			**0.00631**	**0.00023**	
2-AP-75	7/04	ESP #1	6.33	0.00180	99.977
2-AP-75	7/04	ESP #2	6.70	0.00146	99.982
2-AP-75	7/04	ESP #3	6.37	0.00885	99.883
Average			**6.47**	**0.00163**	**99.980**
2-AP-74	7/08	PJBH #1	0.01090	0.00041	
2-AP-74	7/08	PJBH #2	0.00703	0.00041	
Average			**0.00897**	**0.00041**	

Appendix A. (cont.) Particulate Mass Measurements

Test ID	Date	Location/ID	Inlet Mass (Gr/DSCF)	Outlet Mass (Gr/DSCF)	Collection Efficiency (%)
2-AP-79	7/12	ESP #1	3.48	0.00114	99.973
2-AP-79	7/12	ESP #2	3.27	0.00011	99.997
2-AP-79	7/12	ESP #3	3.35	0.00035	99.989
Average			**3.37**		
2-AP-95	7/14	PJBH #1	0.00399	0.00009	
2-AP-95	7/14	PJBH #2	0.00470	0.00009	
2-AP-95	7/14	PJBH #3	0.00743	0.00009	
Average			**0.00435**	**0.00009**	
2-AP-95	7/15	ESP #1	3.58	0.00290	99.931
2-AP-95	7/15	ESP #2	3.52	0.00128	99.969
2-AP-95	7/15	ESP #3	3.47	0.00211	99.949
Average			**3.52**	**0.00251**	**99.929**
2-AP-96	7/16	ESP #1	3.10	0.00238	99.936
2-AP-96	7/16	ESP #2	3.20	0.00245	99.935
Average			**3.15**	**0.00242**	**99.923**
2-AP-96	7/17	ESP #1	3.25	0.00376	99.899
2-AP-96	7/17	ESP #2	3.13	0.00376	99.899
2-AP-96	7/17	ESP #3	4.68	0.00344	99.941
Average			**3.19**	**0.00365**	**99.886**
2-AP-80	7/18	PJBH #1	0.00878	0.00039	
2-AP-80	7/18	PJBH #2	0.00726	0.00039	
2-AP-80	7/18	PJBH #3	0.00534	0.00039	
Average			**0.00713**	**0.00039**	
2-AP-80	7/19	ESP #1	4.72	0.00068	99.988
2-AP-80	7/19	ESP #2	5.40	0.00177	99.973
2-AP-80	7/19	ESP #3	4.28	0.00025	99.995
Average			**4.80**		

Appendix A. (cont.) Particulate Mass Measurements

Test ID	Date	Location/ID	Inlet Mass (Gr/DSCF)	Outlet Mass (Gr/DSCF)	Collection Efficiency (%)
2-AP-86	7/20	PJBH #1	0.00844		
2-AP-86	7/20	PJBH #2	0.00300		
2-AP-86	7/20	PJBH #3	0.00424		
Average			**0.00523**		
2-AP-86	7/20	ESP #1		0.00320	
2-AP-86	7/20	ESP #2		0.00441	
2-AP-86	7/20	ESP #3		0.00346	
Average				**0.00369**	
2-AP-86	7/21	ESP #1	4.80	0.00288	99.949
2-AP-86	7/21	ESP #2	4.53	0.00174	99.970
2-AP-86	7/21	ESP #3	4.37	0.00499	99.904
Average			**4.57**	**0.00320**	**99.930**
2-AP-73	7/22	PJBH #1	0.00407		
2-AP-73	7/22	PJBH #2	0.00669		
2-AP-73	7/22	PJBH #3	0.00571		
Average			**0.00549**		
2-AP-73	7/22	ESP #1		0.00413	
2-AP-73	7/22	ESP #2		0.00323	
2-AP-73	7/22	ESP #3		0.00256	
Average				**0.00331**	
2-AP-73	7/23	ESP #1	6.02	0.00805	99.893
2-AP-73	7/23	ESP #2	7.43	0.00277	99.969
2-AP-73	7/23	ESP #3	6.45	0.00933	99.880
Average			**6.63**	**0.00672**	**99.899**
2-AP-72	7/24	PJBH #1	0.00753	0.00142	
2-AP-72	7/24	PJBH #2	0.00703	0.00142	
Average			**0.00728**	**0.00142**	
2-AP-72	7/25	ESP #1	5.86	0.00306	99.955
2-AP-72	7/25	ESP #2	5.47	0.00225	99.964
Average			**5.67**	**0.00266**	**99.960**

Appendix A. (cont.) Particulate Mass Measurements

Test ID	Date	Location/ID	Inlet Mass (Gr/DSCF)	Outlet Mass (Gr/DSCF)	Collection Efficiency (%)
2-AP-97	7/26	PJBH #1	0.01078		
2-AP-97	7/26	PJBH #2	0.00674		
2-AP-97	7/26	PJBH #3	0.01220		
Average			**0.00991**		
2-AP-97	7/26	ESP #1		0.00799	
2-AP-97	7/26	ESP #2		0.00628	
2-AP-97	7/26	ESP #3		0.00468	
Average				**0.00632**	
2-AP-97	7/27	ESP #1	4.29	0.01032	99.791
2-AP-97	7/27	ESP #2	1.24	0.01593	98.911
2-AP-97	7/27	ESP #3	4.23	0.01340	99.661
Average			**4.26**	**0.01322**	**99.690**
2-AP-81	7/28	PJBH #1	0.00807		
2-AP-81	7/28	PJBH #2	0.00602		
Average			**0.00705**		
2-AP-81	7/28	ESP #1		0.01165	
2-AP-81	7/28	ESP #2		0.00327	
Average					
2-AP-81	7/29	ESP #1	4.92	0.00183	99.964
2-AP-81	7/29	ESP #2	4.91	0.00209	99.958
2-AP-81	7/29	ESP #3	4.98	0.00122	99.976
Average			**4.94**	**0.00171**	**99.965**
2-AP-78	7/30	PJBH #1	0.00758	0.00043	
2-AP-78	7/30	PJBH #2	0.00592	0.00043	
Average			**0.00675**	**0.00043**	
2-AP-78	7/31	ESP #1	3.85	0.00282	99.936
2-AP-78	7/31	ESP #2	3.76	0.00232	99.945
2-AP-78	7/31	ESP #3	3.93	0.00808	99.816
Average			**3.85**	**0.00441**	**99.886**
2-AP-78	8/01	ESP #1	4.68	0.00240	99.954
2-AP-78	8/01	ESP #2	4.90	0.00195	99.965
Average			**4.79**	**0.00218**	**99.955**

Appendix A. (cont.) Particulate Mass Measurements

Test ID	Date	Location/ID	Inlet Mass (Gr/DSCF)	Outlet Mass (Gr/DSCF)	Collection Efficiency (%)
2-AP-87	8/02	PJBH #1	0.00750	0.00040	
2-AP-87	8/02	PJBH #2	0.00827	0.00040	
Average			**0.00789**	**0.00040**	
2-AP-87	8/06	ESP #1	4.02	0.00221	99.954
2-AP-87	8/06	ESP #2	4.28	0.00264	99.947
2-AP-87	8/06	ESP #3	4.59	0.00249	99.954
Average			**4.30**	**0.00245**	**99.943**
2-AP-77	8/07	PJBH #1	0.00589	0.00039	
2-AP-77	8/07	PJBH #2	0.00476	0.00039	
Average			**0.00533**	**0.00039**	
2-AP-77	8/08	ESP #1	4.95	0.02274	99.629
2-AP-77	8/08	ESP #2	4.99	0.02525	99.575
2-AP-77	8/08	ESP #3	4.91	0.00231	99.961
Average			**4.95**		
2-AP-83	8/09	ESP #1	5.21	0.00304	99.950
2-AP-83	8/09	ESP #2	5.34	0.00262	99.958
2-AP-83	8/09	ESP #3	5.48	0.00356	99.942
Average			**5.34**	**0.00307**	**99.943**
2-AP-83	8/10	ESP #1	4.99	0.00442	99.922
2-AP-83	8/10	ESP #2	5.08	0.00365	99.940
2-AP-83	8/10	ESP #3	4.72	0.00333	99.939
Average			**4.93**	**0.00380**	**99.923**
1-HS-05	8/11	PJBH #1	0.02545	0.00049	
1-HS-05	8/11	PJBH #2	0.01893	0.00049	
Average			**0.02219**	**0.00049**	
1-HS-05	8/12	ESP #1	6.69	0.00448	99.942
1-HS-05	8/12	ESP #2	6.35	0.00651	99.909
1-HS-05	8/12	ESP #3	6.43	0.00298	99.959
Average			**6.49**	**0.00466**	**99.928**

Appendix A. (cont.) Particulate Mass Measurements

Test ID	Date	Location/ID	Inlet Mass (Gr/DSCF)	Outlet Mass (Gr/DSCF)	Collection Efficiency (%)
1-HS-09	8/13	PJBH #1	0.00689	0.00036	
1-HS-09	8/13	PJBH #2	0.00728	0.00036	
Average			**0.00709**	**0.00036**	
1-HS-09	8/14	ESP #1	5.94	0.00322	99.953
1-HS-09	8/14	ESP #2	5.94	0.00249	99.957
1-HS-09	8/14	ESP #3	6.23	0.00266	99.963
Average			**6.04**	**0.00279**	**99.954**
1-HS-10	8/15	PJBH #1	0.00667	0.00014	
1-HS-10	8/15	PJBH #2	0.01015	0.00014	
Average			**0.00841**	**0.00014**	
1-HS-10	8/16	ESP #1	6.30	0.00289	99.963
1-HS-10	8/16	ESP #2	6.52	0.00432	99.944
1-HS-10	8/16	ESP #3	6.44	0.00517	99.934
Average			**6.42**	**0.00413**	**99.936**
1-HS-06	8/21	ESP #1	7.20	0.00366	99.954
1-HS-06	8/21	ESP #2	7.00	0.00318	99.960
1-HS-06	8/21	ESP #3	7.43	0.00330	99.960
Average			**7.21**	**0.00338**	**99.953**
1-HS-06	8/22	PJBH #1	0.00842	0.00039	
1-HS-06	8/22	PJBH #2	0.01020	0.00039	
Average			**0.00931**	**0.00039**	
1-HS-04	8/23	ESP #1	5.74	0.00642	99.901
1-HS-04	8/23	ESP #2	6.79	0.01007	99.867
1-HS-04	8/23	ESP #3	6.74	0.01593	99.802
Average			**6.42**	**0.01081**	**99.832**
1-HS-02	8/28	PJBH #1	0.02641	0.00024	
1-HS-02	8/28	PJBH #2	0.02260	0.00024	
Average			**0.02451**	**0.00024**	
1-HS-02	8/29	ESP #1	8.52	0.01714	99.812
1-HS-02	8/29	ESP #2	7.56	0.01782	99.805
1-HS-02	8/29	ESP #3	7.95	0.02891	99.670
Average			**8.01**	**0.02129**	**99.734**

Appendix A. (cont.) Particulate Mass Measurements

Test ID	Date	Location/ID	Inlet Mass (Gr/DSCF)	Outlet Mass (Gr/DSCF)	Collection Efficiency (%)
1-HS-01	8/31	PJBH #1	0.03637		
Average					

1-HS-01	9/02	ESP #1	6.10	0.02640	99.608
1-HS-01	9/02	ESP #2	6.44	0.02283	99.696
1-HS-01	9/02	ESP #3	6.34	0.02894	99.623
Average			**6.29**	**0.02606**	**99.586**

1-HS-03	9/05	ESP #1	4.28	0.00452	99.911
1-HS-03	9/05	ESP #2	4.76	0.00992	99.822
1-HS-03	9/05	ESP #3	4.72	0.00396	99.930
Average			**4.59**	**0.00424**	**99.908**

1-HS-07	9/06	PJBH #1	0.00925	0.00025	
1-HS-07	9/06	PJBH #2	0.01548	0.00025	
Average			**0.01237**	**0.00025**	

1-HS-07	9/07	ESP #1	4.41	0.00288	99.941
1-HS-07	9/07	ESP #2	4.93	0.00415	99.931
1-HS-07	9/07	ESP #3	4.72	0.00522	99.911
Average			**4.69**	**0.00408**	**99.928**

1-HS-08	9/09	ESP #1	5.68	0.01148	99.829
1-HS-08	9/09	ESP #2	5.27	0.01217	99.804
1-HS-08	9/09	ESP #3	5.38	0.01180	99.817
Average			**5.44**	**0.01182**	**99.817**

1-HS-11	9/10	PJBH #1	0.00486	0.00038	
1-HS-11	9/10	PJBH #2	0.00552	0.00038	
Average			**0.00519**	**0.00038**	

1-HS-11	9/11	ESP #1	1.20	0.00325	99.781
1-HS-11	9/11	ESP #2	7.56	0.00274	99.967
1-HS-11	9/11	ESP #3	6.47	0.00130	99.983
Average			**7.01**	**0.00300**	**99.957**