Tennessee Valley Authority
Technology Advancements

10-MW Demonstration of the Gas Suspension Absorption Process at TVA's Center for Emissions Research

Final Report
March 1995

Tennessee Valley Authority
AirPol, Inc.
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FINAL REPORT

Tennessee Valley Authority
AirPol Inc.
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Prepared by

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Technology Advancements
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ABSTRACT

The Tennessee Valley Authority (TVA) in cooperation with AirPol Inc., and the U.S. Department of Energy (DOE), has recently completed a successful 17-month test program with the AirPol Gas Suspension Absorption (GSA) flue gas desulfurization (FGD) process at TVA's Center for Emissions Research (CER). This project was selected by DOE for funding in the third round of the Clean Coal Technology Program. This 10-MW demonstration of the GSA FGD system at the CER was the first application of this technology in the U.S.

The GSA test program, which was cofunded two-thirds by TVA and one-third by DOE/AirPol, was completed over a 17-month period from November 1, 1992 to March 31, 1993. This test program demonstrated that the GSA FGD technology could achieve high SO_2 removal efficiencies (90+ percent) for a 2.7 percent sulfur (as-fired) coal application, while maintaining particulate emissions below the New Source Performance Standards (NSPS), i.e., 0.03 lb/MBtu, in a four-field electrostatic precipitator. The reliability and operability of this system was also demonstrated in a 28-day, 24 hour/day, continuous run during which the GSA unit simultaneously achieved high SO_2 removal efficiencies (90+ percent) and maintained particulate emissions below the NSPS. Also, the air toxics removal capabilities of the GSA system were determined in a series of tests.

A 1-MW pulsejet baghouse (PJBH) pilot plant was also tested in conjunction with this GSA test program. This PJBH testing was initially cofunded by TVA and the Electric Power Research Institute, who were later joined by AirPol and DOE in sponsoring this PJBH testing. A 14-day PJBH demonstration run was also completed to confirm the reliability of this system.

ACKNOWLEDGEMENTS

The planning of the 10-MW Gas Suspension Absorption test program was a cooperative effort of various people in several organizations, both inside and outside TVA. The major TVA participants were: T. A. Burnett, A. T. Hagood, T. M. Little, and E. J. Puschaver. Other people and organizations involved in the planning of this test program were: F. E. Hsu of AirPol; S. K. Marchant of the U.S. Department of Energy; L. R. Lepovitz of Radian Corporation; R. Merritt of Southern Research Institute; and R. F. Altman of the Electric Power Research Institute.

The execution of the test program was the result of efforts by K. M. Schuppert, E. J. Puschaver, T. M. Little, B. F. Smith, L. R. Lepovitz, and the entire onsite staff at TVA's Center for Emissions Research. The data review and analysis were primarily the result of efforts by T. A. Burnett, S. R. Hunter, and T. M. Little, of TVA; and L. R. Lepovitz of Radian Corporation.

This report was principally prepared by T. A. Burnett of TVA and L. R. Lepovitz of Radian Corporation.

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List of Abbreviations

	Abbreviation
actual cubic feet per minute	acfm
air-to-cloth ratio	A/C
atmospheric fluidized bed combustion	AFBC
British thermal units	Btu
calcium-to-sulfur ratio	Ca/S
carbon dioxide	CO_2
Center for Emissions Research	CER
continuous wet-bulb monitor	CWBM
cubic feet	ft^3
degrees (Fahrenheit)	^oF
Department of Energy	DOE
diameter	dia.
Electric Power Research Institute	EPRI
electrostatic precipitator	ESP
feet	ft
flue gas desulfurization	FGD
Gas Suspension Absorption	GSA
grains per actual cubic foot	gr/acf
gram	g
horsepower	hp
hydrogen chloride	HCl
inches	in.
induced draft	ID
kilovolt	kV
milliamp	mA
million	M
New Source Performance Standards	NSPS
pounds	lb
pounds per square inch gauge	psig
pulsejet baghouse	PJBH
revolutions per minute	rpm

List of Abbreviations

	Abbreviation
second	sec
Shawnee Fossil Plant	SHF
slaked lime	$Ca(OH)_2$
specific collection area	SCA
spray dryer	SD
square feet	ft^2
square meter	m^2
stainless steel	SS
standard cubic feet per minute	scfm
sulfur dioxide	SO_2
sulfur trioxide	SO_3
Technology Advancements	TA
Tennessee Valley Authority	TVA
transformer/rectifier	T/R

EXECUTIVE SUMMARY

As part of the U.S. Department of Energy's (DOE) Clean Coal Technology Program, AirPol Inc., a U.S. subsidiary of the Danish company, FLS miljo a/s, installed a 10-MW Gas Suspension Absorption (GSA) demonstration plant at the Tennessee Valley Authority's (TVA's) Center for Emissions Research (CER). The CER is located at TVA's coal-fired Shawnee Fossil Plant near Paducah, Kentucky. The 17-month test program, which began on November 1, 1992 and was completed on March 31, 1993, was funded two-thirds by TVA and one-third by DOE/AirPol.

AirPol requested that TVA act as the host site and provide operating, maintenance, and technical support for this demonstration project because of TVA's background and experience with other dry, lime-based flue gas desulfurization (FGD) systems at the CER and the availability of the existing infrastructure at this facility (1-3). TVA's Technology Advancements (TA) staff accepted AirPol's proposal and agreed to participate in this demonstration project for several reasons. The most important reasons were that the GSA process was very similar to other dry, lime-based FGD technologies that TA had evaluated and found to be both technically and economically attractive and second, the GSA process appeared to fulfill the electric utility industry's need for an FGD technology that was not a "chemical plant".

The GSA technology was developed by FLS miljo a/s in Europe for removing acid gases from the flue gas generated by many industrial processes. It is being used at several municipal waste incinerator plants in Europe to remove hydrogen chloride (HCl), sulfur dioxide (SO_2), and some air toxics materials from the flue gas. In this first application of this technology in the U.S., the GSA FGD system is treating a 10-MW slipstream of flue gas resulting from the combustion of a high-sulfur (2.7 percent, as-fired basis) eastern bituminous coal.

The major objectives of the demonstration were to: (1) optimize the GSA process operating variables; (2) determine the calcium-to-sulfur ratio

(Ca/S) required for various SO_2 removal efficiencies; (3) demonstrate 90 percent or greater SO_2 removal efficiency in the GSA/electrostatic precipitator (ESP) system; (4) determine the impact of the GSA process on the operability and performance of an ESP; (5) evaluate the performance of a 1-MW pulsejet baghouse (PJBH) used in conjunction with a slipstream from the GSA system; (7) evaluate the air toxics removal capabilities of the GSA system with the ESP and with the PJBH; (8) compare the SO_2 removal efficiency achieved in the GSA/ESP system with that in the GSA/PJBH system; (9) complete a 28-day, around-the-clock demonstration run; (10) compare the GSA performance with that of the conventional spray dryer (SD) process; (11) evaluate equipment erosion and corrosion at various locations in the GSA/ESP system; and (12) compare the relative economics of the GSA process with other competing technologies, including the SD process.

PROCESS DESCRIPTION

A simplified GSA process flow diagram, as installed at TVA's CER, is shown in Figure S-1. The SO_2-laden flue gas from the boiler air preheater passes through a preheater/precooler and then to the GSA reactor where it enters the bottom of the reactor and flows upward through a venturi-type section before entering the cylindrical section of the reactor. A freshly-slaked lime slurry is injected into the cylindrical section of the reactor through a single, two-fluid nozzle and the resulting atomized slurry also flows upward, co-currently with the flue gas. The quantity of lime slurry used is based on the SO_2 content of the inlet flue gas and the required SO_2 removal efficiency. Trim water is added to the lime slurry to cool the flue gas to the design approach-to-adiabatic-saturation temperature (hereafter referred to as the approach-to-saturation temperature) in the reactor. The freshly-slaked lime slurry atomized into the reactor coats the surface of the dry recycle solids entrained in the flue gas. This results in the dispersion of the fresh lime slurry over a very large surface area and enhances the mass and heat transfer in the reactor. The resulting thin layer of lime slurry absorbs the SO_2 and HCl, as well as the sulfur trioxide (SO_3) and carbon dioxide (CO_2), from the flue gas and these absorbed acid gases then react with the slaked lime ($Ca(OH)_2$) to form a mixture of reaction products; i.e., calcium

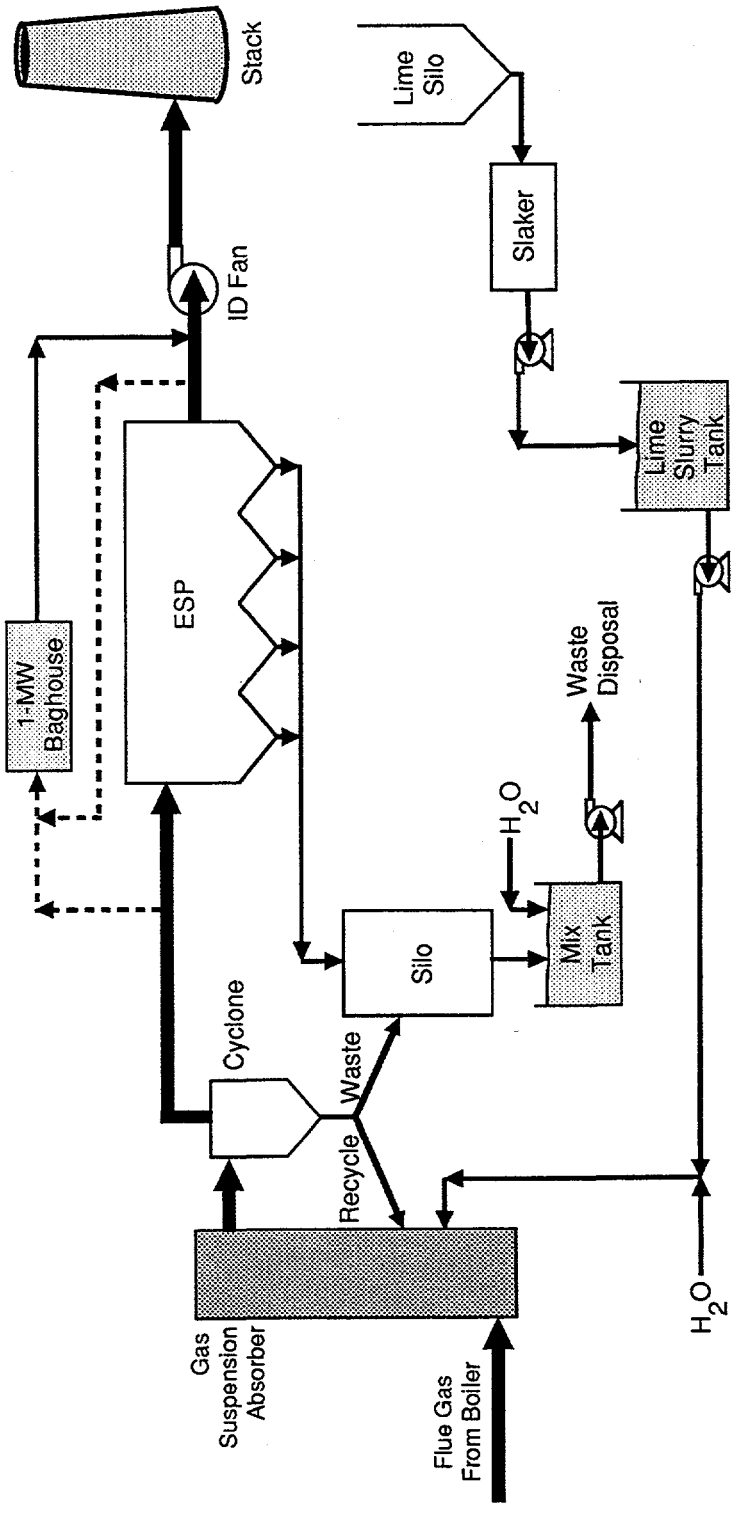


FIGURE S-1. GSA DEMONSTRATION PLANT FLOW DIAGRAM

sulfite, sulfate, carbonate, and chloride. The primary overall reactions in the GSA system are:

$$Ca(OH)_2\ (aq) + SO_2\ (g) \longrightarrow CaSO_3 * 1/2\ H_2O\ (s) + 1/2\ H_2O\ (g)$$

$$Ca(OH)_2\ (aq) + SO_3\ (g) + H_2O\ (aq) \longrightarrow CaSO_4 * 2H_2O\ (s)$$

$$Ca(OH)_2\ (aq) + CO_2\ (g) \longrightarrow CaCO_3(s) + H_2O\ (g)$$

$$Ca(OH)_2\ (aq) + 2HCl\ (g) + 4H_2O\ (aq) \longrightarrow CaCl_2 * 6H_2O\ (s)$$

These reactions are thought to take place primarily in the thin layer of fresh lime slurry coating the dry recycle solids. (The reaction products are shown in the fully hydrated form, even though a mixture of hydration levels would be expected.)

Simultaneously, the sensible heat in the hot flue gas evaporates most of the water from this slurry, thus, cooling and humidifying the flue gas while producing dry solids. The resulting dry solids are entrained in the flue gas along with fly ash from the boiler and flow up through the reactor and exit out the top into a cyclone-type mechanical collector. The cyclone removes most of the particles from the flue gas (90+ percent) and nearly all of these solids are recycled to the reactor to provide the fluidizing bed material. The flue gas from the cyclone then passes to a 10-MW, four-field ESP for final particulate removal. The flue gas from the ESP is reheated, passed to an induced draft fan, and discharged to the atmosphere through a stack. (The reheat system at the CER is required because of the constrained site; most GSA installations will probably not be required to have a reheat system.)

Most of the solids collected in the cyclone are fed back to the reactor via a recycle feeder box that provides temporary, in-process storage. The solids are pulled from the recycle feeder box by screw conveyors, which feed the solids back to the inlet of the reactor, thereby maintaining a high concentration of solids in the reactor. The recycle solids provide the surface area that is covered by the injected lime slurry. The high

concentration of solids is also thought to continuously clean the inner surface of the reactor.

The solids collected in the ESP are moved by mechanical conveyors and a bucket elevator into a by-product storage silo. Also, some of the cyclone catch is moved by this bucket elevator to the storage silo. At the CER, for TVA's convenience, these dry by-product solids are reslurried and the resulting slurry is pumped to the existing ash pond for final disposal. In a commercial GSA installation, these dry by-product solids would be mixed with lesser amounts of water (20-30 percent by weight) and laid down in an onsite landfill. Since this by-product material contains unreacted lime and fly ash, water is the only remaining reactant thought to be needed for the material to undergo a pozzolanic reaction and "set up" into a low-grade concrete.

The lime slurry is prepared from a high-calcium, pebble lime in a conventional, paste-type slaker. The resulting lime slurry is pumped to a storage tank and then to the process feed tank. The slurry is pumped from the feed tank to the single, two-fluid nozzle in the bottom of the cylindrical section of the reactor as needed in the process. The flow of the lime slurry is controlled by the continuous measurement of the flue gas SO_2 content either upstream of the reactor or downstream of the dust collector. Also, trim water is mixed with the lime slurry that is pumped to the nozzle to lower the flue gas temperature to the required operating temperature in the reactor, which is typically 145-155°F. (These flue gas temperatures correspond to an approach-to-saturation temperature of 18-28°F at the reactor outlet.)

The PJBH pilot plant, which was installed at the CER (see Figure S-1) as part of a joint TVA/Electric Power Research Institute (EPRI) program, treats a 1-MW slipstream of flue gas from the main GSA/ESP plant. The flue gas slipstream for the PJBH can be removed from either the ESP inlet or outlet and the treated flue gas is returned to the main GSA plant ductwork downstream of the ESP. The solids collected in the PJBH are pneumatically conveyed to the by-product storage silo in the GSA/ESP process for disposal with the other GSA by-product material.

GSA TEST PROGRAM

The 13 month GSA test program was composed of five parts as shown in Figure S-2. The first part was the preliminary or startup tests, which were completed in November and December 1992. The second part was the factorial tests, which were completed between January and August 1993. The third part was the air toxics testing, which was completed between mid-September and mid-October 1993. The fourth part was the 28-day GSA demonstration run, which was completed in late October and November 1993. The fifth and final part was the 14-day PJBH demonstration run. This PJBH run was originally scheduled to be run simultaneously with the final two weeks of the 28-day GSA demonstration run in November 1993, but could not be completed until March 1994. Only the factorial tests and the two demonstration runs are discussed in any detail in this report.

Preliminary Testing

The purpose of the preliminary tests was to investigate the operating limits of the 10-MW GSA system as installed at the CER. The results from several of these preliminary tests were very interesting. The discussion of these tests is basically limited to those tests and results that impacted the selection of variable levels for the factorial test plan.

During one of the preliminary tests, the approach-to-saturation temperature in the reactor was gradually decreased over the course of several days and the overall system (reactor/cyclone and ESP) SO_2 removal efficiency was monitored. The overall system SO_2 removal efficiency increased from about 65 percent to more than 99 percent as the approach-to-saturation temperature decreased from 40 to 5°F, as shown in Figure S-3. The other test conditions, which remained constant throughout the test, were: 320°F inlet flue gas temperature, 1.40 moles $Ca(OH)_2$/mole inlet SO_2 for the Ca/S level, and essentially no chloride in the system. Even though this test was run at a very close approach-to-saturation temperature (5°F) on the final day, there was no indication of plugging in the system and the moisture level in the reactor/cyclone by-product material was very low (<1.0 percent).

DOE/AirPol/TVA Test Program

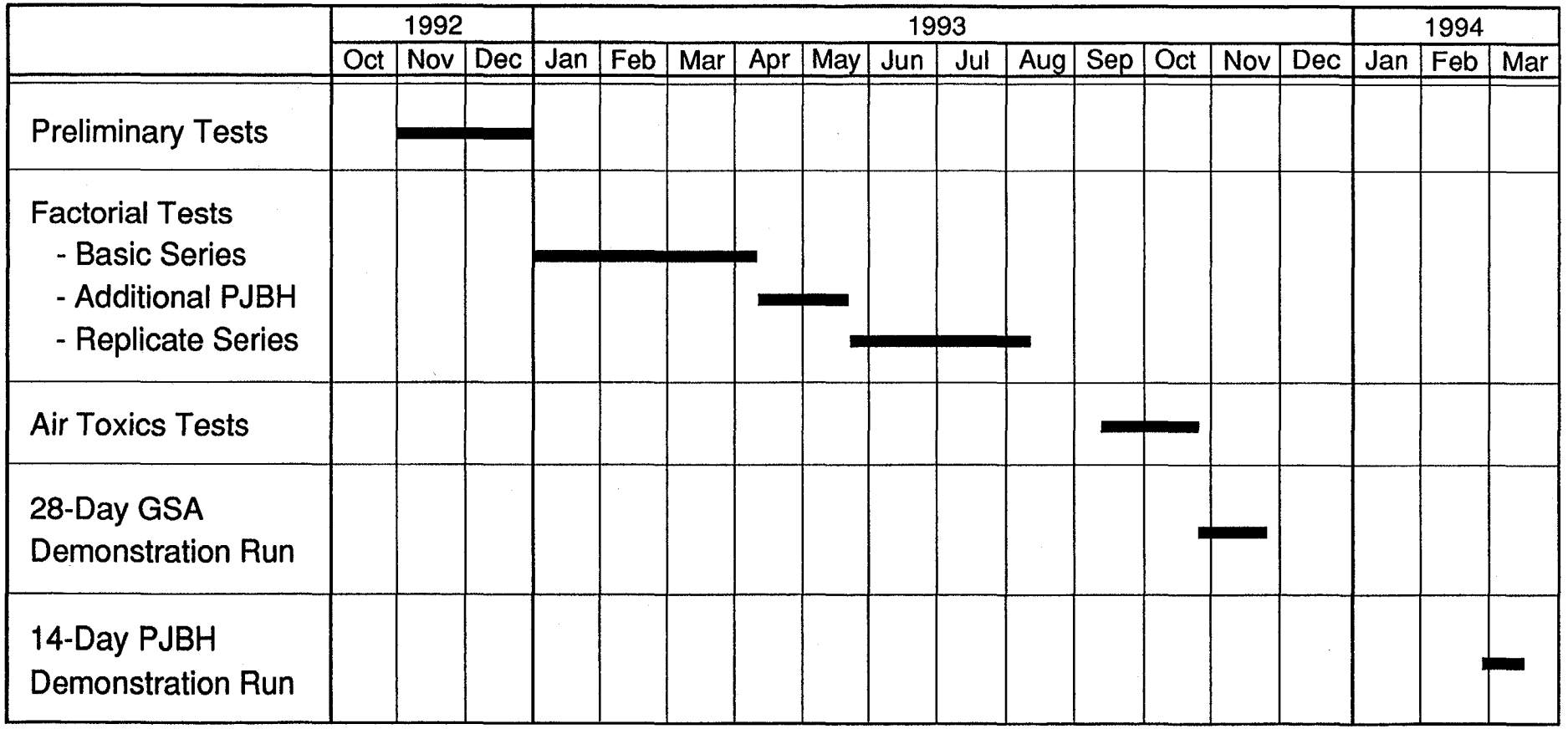


FIGURE S-2. DOE/AIRPOL/TVA TEST PROGRAM

A second, extended, preliminary test was run at the same conditions as the previous test, except that in this test, calcium chloride was added to the GSA system to simulate the combustion of a high-chloride (0.30 percent) coal. In keeping with the purposes of these preliminary GSA tests, the simulated coal chloride level was set at this unusually high level (0.30 percent) to cover most of the expected range for this variable. Again, the approach-to-saturation temperature was gradually decreased with all other conditions held constant and the overall system SO_2 removal efficiency was monitored. The results from this second test are also shown in Figure S-3. The overall system SO_2 removal efficiency in this test increased from about 75 percent at the high approach-to-saturation temperature condition (40°F) to about 100 percent at the lowest approach-to-saturation temperature tested (23°F). In addition, there was no indication of plugging and the moisture level in the reactor/cyclone solids remained very low (< 1.0 percent).

Another series of startup tests involved evaluating the SO_2 removal efficiency as a function of the recycle screw speed, which is an indirect measure of the recycle rate in the system. The initial design range for the recycle screw speed was 10 to 22 rpm and the results from these tests indicated that the overall system SO_2 removal efficiency increased as the recycle screw speed was increased over this range. Therefore, the system was modified to double the maximum recycle screw speed to 45 rpm, which was the upper level for this variable in the factorial test program.

Factorial Testing

Most of the GSA test results discussed in this report were obtained from the statistically-designed test plan that was completed in August 1993. This test plan was a half-factorial design with a full set of replicates to reduce the effects of variability in the data on the results. This design also allowed the PJBH to treat the flue gas from the ESP inlet during the basic tests and from the ESP outlet during the replicate tests. The primary purpose of this factorial test program was to determine the

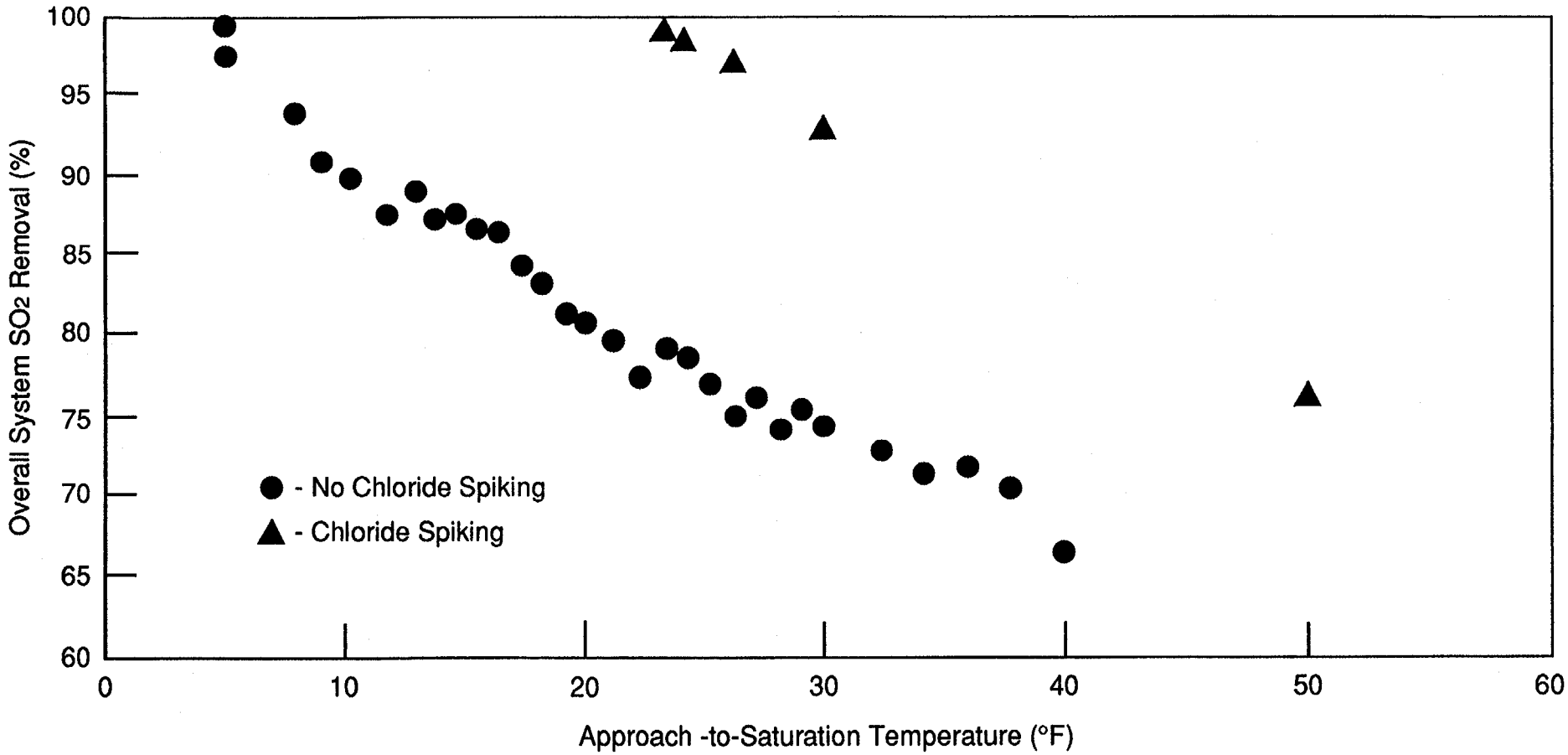


FIGURE S-3. RESULTS FROM PRELIMINARY AIRPOL GSA TEST PROGRAM

effect of the process design variables on the SO_2 removal efficiency in the reactor/cyclone, the ESP, and the overall system.

Based on the results from the preliminary testing, the major process design variables were determined, levels for each of these variables were defined, and the test plan was prepared. The major process design variables were: approach-to-saturation temperature, Ca/S level, inlet fly ash loading, coal chloride level, flue gas flow rate, and recycle screw speed. Two levels were determined for nearly all of the variables and these variables and levels are shown in Table S-1. The exception was the approach-to-saturation temperature where three levels were defined (8, 18, and 28°F), but the lowest approach-to-saturation temperature (8°F) was only run for those tests at the lower coal chloride level. The maximum Ca/S level tested was only 1.30 moles $Ca(OH)_2$/mole inlet SO_2, even though higher levels were technically feasible. This lower maximum Ca/S level was selected because the relative economics of these dry, lime-based processes for a high-sulfur coal application dictate that the Ca/S level be minimized.

SO_2 Removal Efficiency - The overall system SO_2 removal efficiencies during these factorial tests ranged from slightly more than 60 percent to nearly 95 percent, depending on the specific test conditions. The higher SO_2 removal efficiency levels were achieved at the closer approach-to-saturation temperatures (8 and 18°F), the higher Ca/S level (1.30 moles $Ca(OH)_2$/mole inlet SO_2), and the higher coal chloride level (0.12 percent) for the 18°F approach-to-saturation temperature level. The data from the factorial tests completed at these conditions are shown in Figure S-4. The slight scatter in the data in this figure is due to the variation in the levels for the other major variables in these tests (i.e., flue gas flow rate, recycle screw speed, etc.). The lower SO_2 removal efficiency levels were achieved at the opposite conditions, i.e., the highest approach-to-saturation temperature (28°F), the lower Ca/S level (1.00 mole $Ca(OH)_2$/mole inlet SO_2), and the lower coal chloride level (0.02-0.04 percent).

Most of the SO_2 removal in the GSA system occurs in the reactor/cyclone, with only about 2-5 percentage points of the overall system SO_2 removal

Table S-1

Major Variables and Levels
in the GSA Factorial Testing

Variable	Level
Approach-to-saturation temperature, ^{o}F	8[a], 18, and 28
Ca/S, moles $Ca(OH)_2$/mole inlet SO_2	1.00 and 1.30
Fly ash loading, gr/acf	0.5 and 2.0
Coal chloride level, %	0.02 and 0.12
Flue gas flow rate, kscfm	14 and 20
Recycle screw speed, rpm	30 and 45

a. $8^{o}F$ level only run at the low-chloride level.

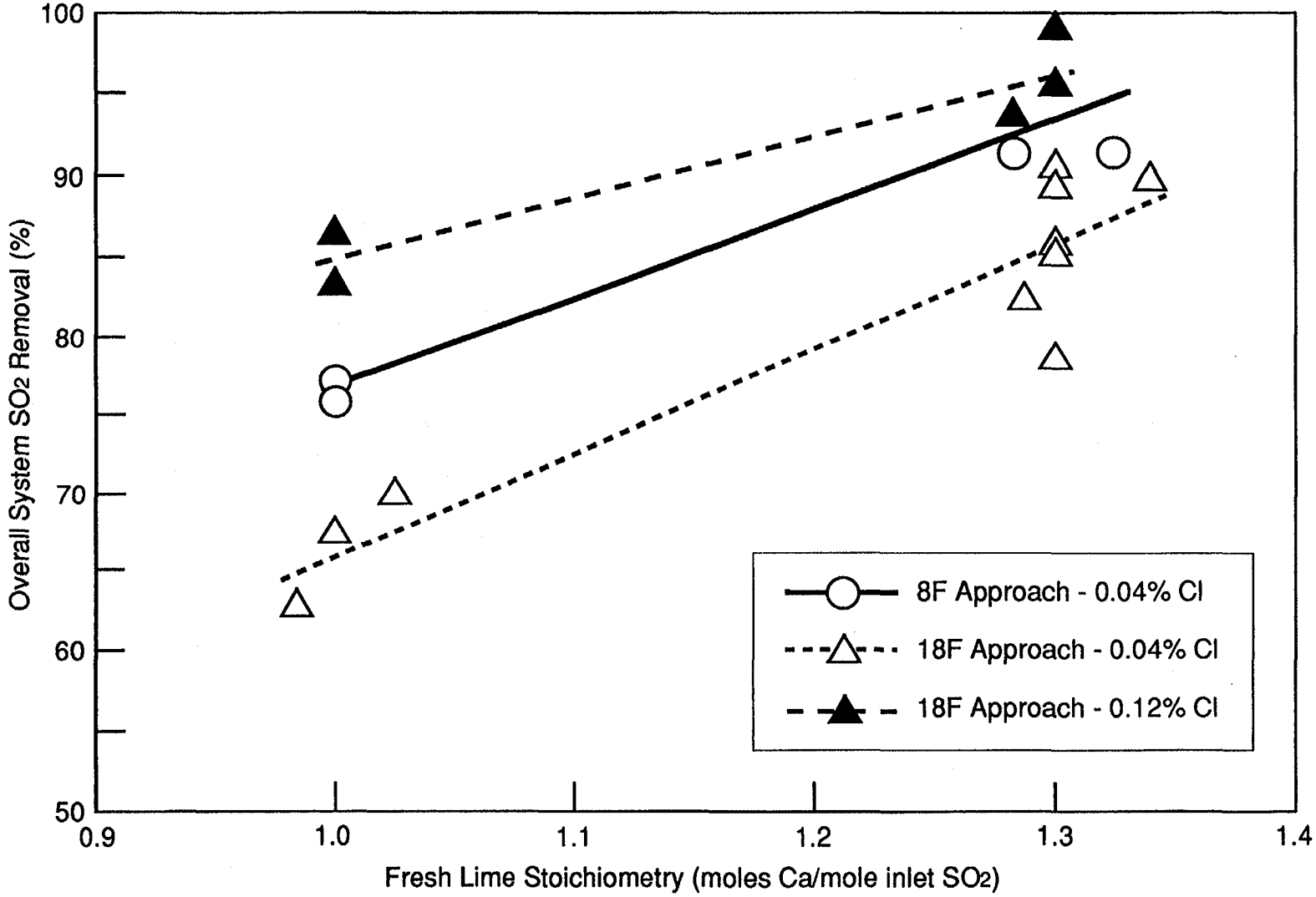
occurring in the ESP. This is substantially less SO_2 removal in the ESP than in the previous SD/ESP testing at the CER. The lower SO_2 removal efficiency in the ESP in the GSA system is hypothesized to be due to both the very low moisture level in the particulates and the lower grain loading entering the ESP.

These overall system SO_2 removal efficiency results from the factorial tests were similar to those achieved in the previous testing of SD/ESP system. In general, the major variables had the expected effects. First, increasing the Ca/S level, increasing the coal chloride level, or lowering the approach-to-saturation temperature, each had a significant positive effect on the SO_2 removal efficiency in the GSA system. The recycle feed rate, as measured by the recycle screw speed, and the flue gas flow rate, individually, have a minor effect on the SO_2 removal efficiency in the GSA system. These two variables have opposite effects on the SO_2 removal efficiency, i.e., increasing the recycle screw speed or decreasing the flue gas flow rate results in higher SO_2 removal efficiencies. The inlet fly ash loading also had a minor, negative effect on SO_2 removal efficiency over the range tested.

The overall system SO_2 removal efficiency data from these factorial tests were modeled. The result of this modeling was a linear equation that predicted the overall system SO_2 removal efficiency based on the major variable levels. The coefficient of determination for this model is 0.93, indicating that this model is very good at explaining the variability in the test data. The mean square error term for this model was +/- 2.5 percentage points meaning that the 95 percent confidence bands lie within +/- 5.0 percentage points of the model predictions.

The resulting projected overall system SO_2 removal efficiencies as a function of the Ca/S level and the approach-to-saturation temperature are shown in Figure S-4, along with the data from some of the factorial tests. These data indicate a good match between the model predictions and the test data.

Operability - One of the most surprising results of this testing was the ability of the GSA system to operate at close approach-to-saturation



Notes: All tests conducted at a 320°F inlet flue gas temperature

FIGURE S-4. OVERALL SYSTEM SO_2 REMOVAL RESULTS FROM THE AIRPOL GSA DEMONSTRATION

temperatures without incurring any operating problems. This is even more impressive given the very low flue gas residence time in the reactor/cyclone. During the factorial testing, the GSA system was able to operate at an approach-to-saturation temperature of 8°F at the low coal chloride level and an approach-to-saturation temperature of 18°F at the higher coal chloride level. No operating problems were encountered in the factorial tests completed at either condition. In fact, the moisture level in the by-product solids remained below 1.0 percent in all of these factorial tests, even at the higher coal chloride level.

The analysis of the solids from the GSA system appeared to support the theory that the dry recycle solids are coated with a thin layer of fresh lime slurry on each pass through the reactor. Figure S-5 shows a photomicrograph of the cross-section of one of the large particles removed from the recycle stream. This photograph shows a central core surrounded by a series of rings similar to tree rings. Spectral analysis of these layers determined that the central core of this particle is fly ash, while the surrounding rings are composed of calcium-sulfur compounds.

Lime Utilization - The lime utilization in the GSA system, which is calculated by dividing the overall system SO_2 removal efficiency by the Ca/S level, was relatively high, ranging from 60 to 80 percent depending on the specific test conditions. The highest lime utilization rates were achieved in those tests completed at the lower Ca/S level (1.00 mole $Ca(OH)_2$/mole inlet SO_2), lower approach-to-saturation temperature (18°F), and higher coal chloride level (0.12 percent). These calculated lime utilization rates were also compared with the lime utilization rates determined in the laboratory by analysis of the recycle solids and the ESP solids. In general, the calculated reactor/cyclone lime utilization rate matched the laboratory-determined rate for the recycle solids quite well. Since the calculated values were based on the average test results, while the laboratory analyses reflected an average value for a much shorter period of time, some variability would be expected in a comparison of these two values.

Cyclone Performance - Although the particulate removal efficiency in the cyclone was not determined during this testing, the removal efficiency was

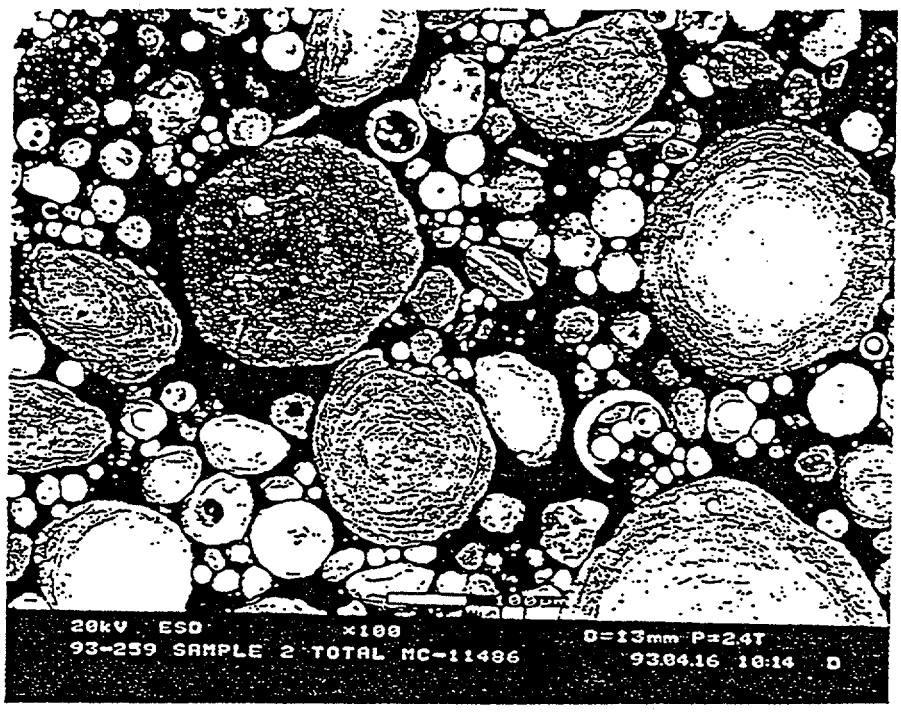


Figure S-5. Cross-Sectional Area of Larger GSA Particles.

estimated to be very high (>90 percent). The basis for this estimate is the relatively modest grain loadings at the ESP inlet, relative to the grain loading in the reactor itself. The cyclone achieved this high removal efficiency presumably because of the number of relatively large particles in the flue gas stream.

The main purposes of the cyclone in the GSA system were to: (1) provide the dry recycle material for the reactor and (2) reduce the inlet grain loading to the ESP. Previous work at the CER had shown that high removal efficiencies in the ESP might not be good enough to achieve the emission standards, if the ESP inlet grain loading was too high. By reducing the ESP inlet grain loading to 3-5 gr/acf, the cyclone allowed the ESP to meet the emission rate standards, as discussed further below.

ESP Performance - The ESP installed at the CER is a relatively modern, four-field unit with 10 in. plate spacing, similar in design to several full-scale ESPs installed on the TVA power system. This unit has 23 ft high plates with 8 parallel gas passages. The specific collection area (SCA) of this ESP is about 440 ft^2/kacfm under the cooled, humidified flue gas conditions downstream of the reactor/cyclone. (For the untreated flue gas at 300°F, i.e., in a fly-ash-only application, the SCA of this ESP is about 360 ft^2/kacfm.)

The particulate performance of the ESP was determined for each of the factorial tests. The most important result of this particulate testing was that the emission rate from the ESP was well below the New Source Performance Standards (NSPS) for particulates, i.e., 0.03 lb/million British thermal units (MBtu), at all of the test conditions evaluated, as shown in Figure S-6. In fact, with the exception of two tests, the emission rate was in the range of 0.005 to 0.015 lb/MBtu. The particulate removal efficiency in the ESP was above 99.9 percent for most of these tests and the outlet grain loadings were below 0.005 gr/acf.

One surprising result of this testing was that there was no significant improvement in the ESP performance at the relatively low flue gas flow rates encountered when the GSA system was operating at the lower flue gas flow rate and the PJBH was operating and pulling flue gas from the ESP

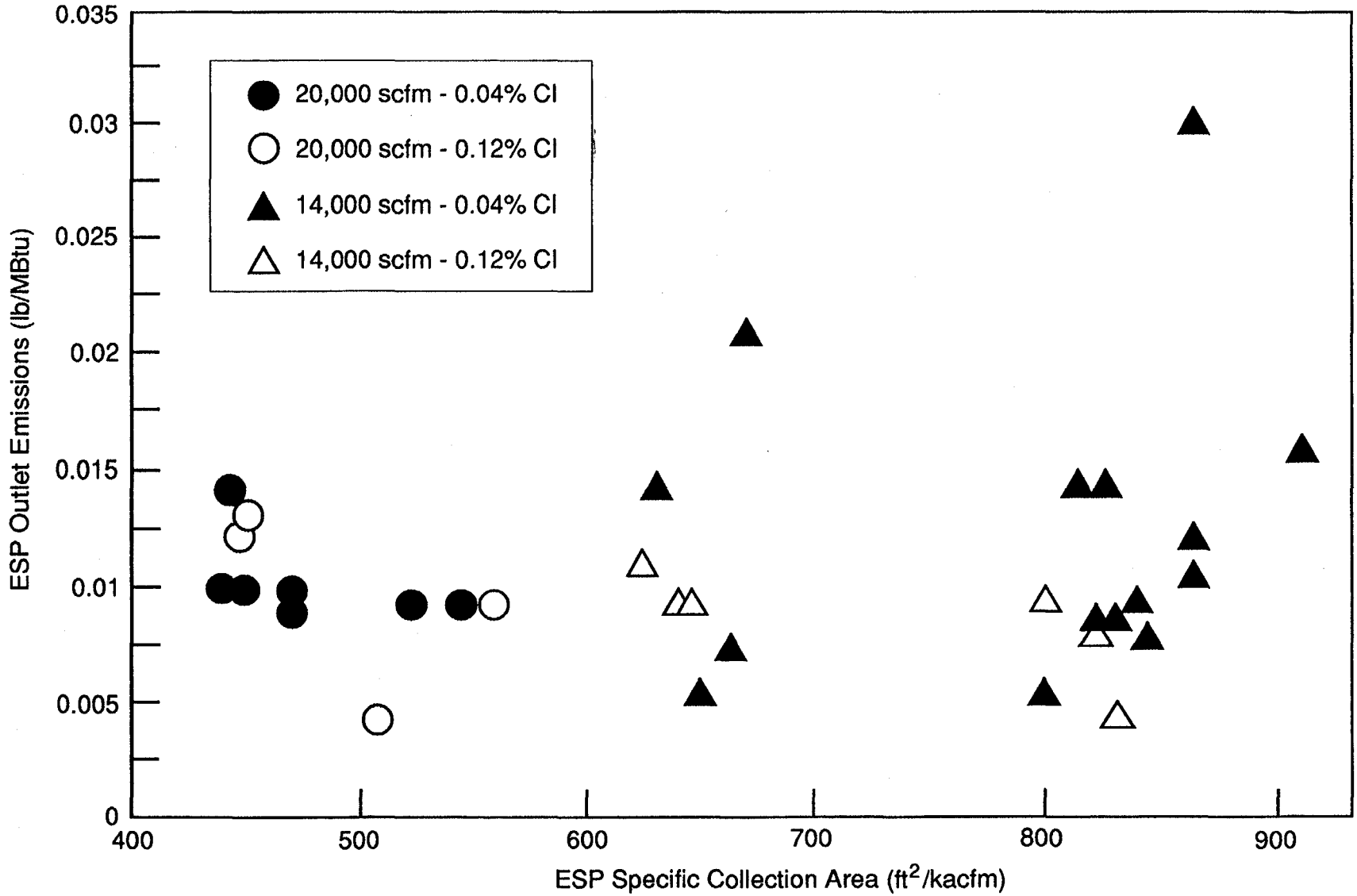


FIGURE S-6. ESP PERFORMANCE RESULTS FROM THE AIRPOL GSA DEMONSTRATION

inlet. For some of these tests with both the GSA system operating at the low flue gas flow rate (14,000 scfm) and the 1-MW PJBH pilot plant operating and pulling 5,000 acfm of flue gas from the ESP inlet, the SCA in the ESP was effectively doubled and approached 900 ft^2/kacfm. The flue gas velocity in the ESP also dropped below 2.0 ft/sec in these tests. However, the emission rate remained in the same range as in the other tests, i.e., 0.010 lb/MBtu, as previously shown in Figure S-6. Thus, significantly increasing the effective SCA in the ESP had no major effect on the emission rate over the SCA range tested.

Comparison with SD Results - The overall system SO_2 removal efficiency in the GSA system was comparable to the performance previously achieved in the 10-MW SD testing at similar test conditions. The SO_2 removal efficiencies in the reactor/cyclone were higher than that achieved in the SD vessel, but the SO_2 removal efficiency in the ESP was lower in the GSA testing than for the comparable SD testing. The net effect was that the overall system SO_2 removal efficiencies for the two FGD systems were essentially the same.

The ESP performance in the GSA testing was also comparable to that achieved in the previous SD testing. The particulate removal efficiencies were typically 99.9+ percent in both systems. However, the lower ESP inlet grain loadings in the GSA tests resulted in a slightly lower emission rate.

PJBH Performance - Although not part of the original GSA project, TVA and EPRI cofunded the installation of a 1-MW PJBH pilot plant at the CER to be operated in conjunction with the existing GSA demonstration. Later, DOE and AirPol joined in sponsoring this PJBH pilot plant program. This PJBH contained 48 bags arranged in three concentric rings. The bags used in this testing were fabricated from a low-cost, acrylic material because of the low temperature application. The PJBH pilot plant was started up in January 1992 and operated during the factorial test program, the air toxics tests, and the 14-day PJBH demonstration run.

During the basic factorial tests, the PJBH operated with the full complement of 48 bags and was treating flue gas from the ESP inlet, which contained the full particulate loading (3-5 gr/acf) from the GSA reactor/

cyclone. The inlet flue gas flow rate was about 5,000 acfm, which corresponds to an air-to-cloth ratio (A/C) of 4.0 acfm/ft^2 in the PJBH. The cleaning of the bags in the PJBH was pressure-drop-initiated during this testing, with the cleaning cycle begun whenever the tubesheet pressure drop reached 6 in. of water. The cleaning continued until the tubesheet pressure drop had declined to 4.5 in. of water.

During the replicate factorial testing, the PJBH was pulling flue gas from the ESP outlet. The inlet flue gas flow rate was again 5,000 acfm, but the A/C was 12.0 acfm/ft^2 for these tests since about two-thirds of the bags had been removed from the PJBH prior to this replicate factorial testing. This dramatic increase in the A/C was possible because the inlet grain loading to the PJBH was typically only 0.02 gr/acf or less. The PJBH was again operated in the pressure-drop-initiated cleaning mode.

During the factorial tests, the SO_2 removal efficiency in the PJBH was typically about 3-5 percentage points higher than that achieved in the ESP at the same test conditions. Thus, as expected, the reactor/cyclone/PJBH system achieved a higher overall system SO_2 removal efficiency than the reactor/cyclone/ESP system. This higher SO_2 removal efficiency in the PJBH system was not unexpected given the intimate contact as the SO_2-laden flue gas passed through the filtercake and the bags before being discharged to the stack. The approach-to-saturation temperature was also lower in the PJBH, which would be a major contributor to the higher SO_2 removal efficiency in the PJBH.

However, it should be noted that most of the SO_2 removal still occurred in the reactor/cyclone and the PJBH SO_2 removal efficiency, based on the inlet SO_2 to the reactor, contributed less than 8 percentage points to the overall system SO_2 removal efficiency during this testing. This PJBH SO_2 removal efficiency is lower than that generally seen in a SD application, probably because of the low moisture levels in the particles.

During the replicate factorial testing, the PJBH was pulling flue gas from the ESP outlet and the inlet SO_2 concentration was very low. Thus, although the SO_2 removal efficiency across the PJBH may have been high,

the PJBH contribution to the overall system (reactor/cyclone/ESP/PJBH) SO_2 removal efficiency was very low at only 2-4 percentage points.

The particulate removal efficiencies in the PJBH were 99.9+ percent for all of the tests completed with the full dust loading from the GSA reactor/cyclone. The emission rate for all of these tests was well below the NSPS for particulates and was typically in the range of 0.010 lb/MBtu. The filtercake on the bags was relatively easy to dislodge and no problems with cleaning the bags were encountered.

The particulate removal efficiencies in the replicate factorial tests with the PJBH pulling flue gas from the ESP outlet were "only" 90-95 percent. However, since the inlet grain loading was very low, this "low" particulate removal efficiency was not unexpected and the outlet grain loadings from the PJBH were extremely low. The emission rates from the PJBH for these tests were more than an order of magnitude below the NSPS for particulates. These results would seem to confirm that a high A/C PJBH can be installed downstream of an existing, high-efficiency ESP as a relatively low-cost, final-stage, particulate cleanup device. For some retrofit applications where the existing ESP is relatively small and the inlet grain loading to the PJBH may be higher, additional testing would need to be completed. (There was not sufficient test time available to evaluate the number of energized ESP fields as a major variable.)

28-Day GSA Demonstration Run

A long-term, 28-day GSA demonstration run was successfully completed in late November 1993. The purpose of this run was to demonstrate that the GSA system (reactor/cyclone/ESP), as installed at the CER, could operate reliably and continuously, 24 hours/day, seven days/week for a four-week period, while simultaneously achieving 90+ percent SO_2 removal and maintaining the ESP emissions below the NSPS for particulates. There was one interruption during this run when the boiler came off-line for 40 hours to repair a tubeleak. However, since this outage was not caused by the GSA system, the run was simply extended for 40 hours to compensate for the lost test time.

The overall system SO_2 removal efficiency averaged slightly more than 90 percent during the entire 28-day demonstration run. There was only one 24-hour period when the SO_2 removal was below this target level and this was due to a lime slurry flowmeter calibration problem. The specific test conditions for this demonstration run were selected based on the results from the factorial testing that had been completed earlier. An overall system SO_2 removal efficiency setpoint of 91 percent was input to the computer control system and the Ca/S level was adjusted by the control system to maintain this setpoint. The most surprising result of this run was that the average Ca/S level required to achieve the SO_2 removal setpoint (1.45 moles $Ca(OH)_2$/mole inlet SO_2) was higher than that expected based on the previous factorial testing.

The ESP performance was relatively good throughout the 28-day demonstration run and the emission rate remained well below the NSPS. However, there was an abrupt step increase in the emission rate, from 0.007 to 0.015 lb/MBtu, about halfway through the run. This step increase in the emission rate coincided with a problem with the double-dump valve and screw conveyor that remove the solids from the ESP first field hopper. This mechanical problem was resolved without bringing the ESP off-line, but the increased dust loading entering the second field of the ESP and the overflow from the first field hopper led to a buildup of solids in the second field. This solids buildup caused the average secondary current level in the second field to plummet and to remain at very low levels for the remainder of the run. This dramatic decline in the average secondary current in the second field also coincided with the step increase in the emission rate from the ESP. As previously noted, however, the emission rate only increased to about one-half of the NSPS for particulates.

The GSA system operated reliably during the entire 28-day demonstration run, even though the test conditions included an 18°F approach-to-saturation temperature and the higher coal chloride level. There were no plugging or solids handling problems due to damp solids. In fact, the moisture level in the by-product solids remained at about 0.5 percent.

The reactor and ESP were inspected at the end of this demonstration run. The reactor had some deposits on the walls, but most of the deposits were

of no significance. There were some heavier-than-normal deposits on the wall above the nozzle elevation, however. No suitable explanation for these deposits was determined, although the suspicion was that the nozzle may need to be changed out more frequently. There were also solid deposits in the ESP. Those ESP deposits of most concern were on the hopper ridges between the first and second field hoppers and between the second and third field hoppers. Because of the high angle of repose for the GSA material at these test conditions and the unusual, site-specific design of the ESP hoppers in the first and second fields at the CER, these deposits are thought to have caused the low average secondary current levels in the first and second fields of the ESP during the final two weeks of the GSA demonstration run.

14-Day PJBH Demonstration Run

A long-term, 14-day PJBH demonstration run was successfully completed in March 1994. This run was originally planned to coincide with the last two weeks of the 28-day GSA demonstration run in November, but a problem with the PJBH prevented its operation. The purpose of this 14-day run was to demonstrate that the GSA system (reactor/cyclone/PJBH), as installed at the CER, could operate reliably and continuously, 24 hour/day, seven days/week for a two-week period, while simultaneously achieving 90+ percent SO_2 removal and maintaining the PJBH outlet emissions below the NSPS for particulates. There was one interruption during this demonstration run when the boiler was unable to fire the design coal and was switched to the low-sulfur compliance coal. The PJBH demonstration run was suspended until the higher sulfur coal was again available. However, since this outage was not caused by the GSA system or the PJBH, the demonstration run was simply extended to compensate for the lost test time.

The overall system (reactor/cyclone/PJBH) SO_2 removal efficiency averaged more than 96 percent during the entire 14-day PJBH demonstration run. The specific design test conditions for this run were the same as those used in the previous GSA demonstration run, except that the fly ash addition rate was reduced slightly from about 1.5 to 1.0 gr/acf. An overall system (reactor/cyclone/ESP) SO_2 removal efficiency setpoint of

91 percent was input to the computer control system to be consistent with the previous GSA demonstration run. The Ca/S level was adjusted by the control system to maintain this SO_2 removal setpoint. The average Ca/S level during this run ranged from about 1.34 to 1.43 moles $Ca(OH)_2$/mole inlet SO_2, which was lower than that required in the 28-day GSA demonstration run.

The PJBH particulate removal efficiency was very good during this run, averaging 99.99+ percent. The emission rate was about one order of magnitude below the NSPS for particulates at 0.001 to 0.003 lb/MBtu.

CONCLUSIONS

The completion of the 13-month GSA test program at the 10-MW scale at TVA's CER indicated the following:

1. The GSA/ESP process can achieve high SO_2 removal efficiencies (90+ percent) at modest Ca/S levels (1.30 moles $Ca(OH)_2$/mole inlet SO_2) and a close approach-to-saturation temperature (8°F) when treating flue gas resulting from the combustion of a 2.7 percent sulfur (as-fired), low-chloride (0.02-0.04 percent) coal;

2. The GSA/ESP process can also achieve high SO_2 removal efficiencies (90+ percent) at a modest Ca/S level (1.30 moles $Ca(OH)_2$/mole inlet SO_2) and a higher approach-to-saturation temperature (18°F) with slightly higher levels of chlorine in the coal (0.12 percent);

3. Most of the SO_2 removal efficiency occurs in the reactor/cyclone with relatively low SO_2 removals (2-5 percentage points) in the ESP.

4. The enhanced mass and heat transfer characteristics of the GSA reactor allows high SO_2 removal efficiencies to be achieved at a very low flue gas residence time in the reactor/cyclone. The GSA reactor also operates at a high flue gas velocity (20-25 ft/sec). Thus, the GSA reactor is only one-third to one-fourth the size of the conventional SD vessel;

5. The expected enhancing effect of chlorine on the SO_2 removal efficiency in the GSA/ESP process was documented over the narrow range tested. Even modest coal chloride levels (0.12 percent), which are typical of many coals, can provide this enhanced SO_2 removal effect;

6. The SO_2 removal efficiencies achieved in the GSA/ESP system are essentially the same as those achieved at comparable conditions during the previous testing of the SD/ESP system at the CER;

7. The GSA/ESP process has very low particulate emission rates, i.e., well below the NSPS for particulates, when a four-field ESP with an SCA > 440 ft^2/kacfm is used;

8. The SO_2 removal efficiency in the GSA/PJBH system was typically about 3-5 percentage points higher than that achieved in the GSA/ESP system at the same test conditions; and

9. The GSA system produces a by-product material containing very low moisture levels. This material contains both fly ash and unreacted lime and thus, with the addition of water, undergoes a pozzolanic reaction and can be disposed of in a landfill.

FUTURE ACTIVITIES

The planned future activities are to continue the development of the GSA process at TVA's CER. This work is being funded by TVA. Some of these planned activities include:

1. Continue to monitor and evaluate the performance of the ESP to ensure that the GSA process will not have an adverse impact on this particulate control device;

2. Conduct tests at lower SCA by deenergizing one or more fields in the ESP to determine the resulting effect on particulate emissions;

3. Evaluate the effect of other limes on the performance of the GSA system;

4. Evaluate the effect of higher coal chloride levels on the performance of the GSA/ESP system; and

5. Evaluate the potential for using the by-product material from the atmospheric fluidized bed combustion unit as a source of lime to displace some of the fresh lime feed to the system.

Section 1

INTRODUCTION

The Tennessee Valley Authority (TVA) has had an active research and development program in the flue gas desulfurization (FGD) area for many years at the Center for Emissions Research (CER), formerly the Shawnee Test Facility (1-3). Initially, this FGD development program focused primarily on wet-scrubbing technologies, particularly the wet limestone scrubbing technology in the mid-to-late 1970's. Later, TVA's efforts evolved into the development of other, potentially more cost-effective technologies in the dry scrubbing area. In the early-to-mid 1980's these efforts focused on developing the spray dryer (SD) technology for medium- to high-sulfur coal applications with the installation of two small, 1-MW SD/baghouse pilot plants. The final 1-MW SD test program involved the installation of a relatively small electrostatic precipitator (ESP) downstream of the SD for particulate control.

In the mid-1980's, TVA installed a larger 10-MW SD/ESP at the CER in cooperation with the Electric Power Research Institute (EPRI) and Ontario Hydro. This plant was designed and constructed with the express purpose of testing this technology for potential application to existing coal-fired utility boilers, which had an ESP for particulate control. (A new coal-fired boiler with a SD FGD system would typically have a baghouse for particulate control because of the higher sulfur dioxide (SO_2) removal in the baghouse.) The results of this 10-MW SD/ESP testing have been previously reported (2,3).

Another dry, lime-based, FGD system was tested at CER for about one year following the completion of the 10-MW SD/ESP test program. During this year of other testing, the detailed design for the 10-MW Gas Suspension Absorption (GSA) demonstration plant was completed and the equipment was procured and installed at the CER. The dry, lime-based, GSA FGD system was started up in November 1992 for a planned one-year test program. This test program was cofunded two-thirds by TVA and one-third by the U.S.

Department of Energy (DOE) and AirPol Inc., a U.S. subsidiary of the Danish company, FLS miljo a/s. The DOE funding for this project was provided under the Clean Coal Technology Program. This project had been selected by DOE in the third round of the Clean Coal Technology Program in December 1989.

AirPol requested that TVA act as the host site for this project because of TVA's background and experience with dry, lime-based, FGD systems at the CER and the availability of the existing infrastructure at this facility. With the existing infrastructure, AirPol only needed to install their reactor, cyclone, recycle loop, and some ductwork to have a complete 10-MW demonstration plant. Thus, the CER provided a very low cost facility to test the GSA technology.

TVA's Technology Advancements (TA) staff accepted AirPol's proposal and agreed to participate and cofund this project for several reasons. The most important reasons were that the GSA process: (1) is very similar to other dry, lime-based, FGD technologies that TA had evaluated and found to be both technically and economically attractive and (2) appears to fulfill the U.S. electric utility industry's need for an FGD technology that is not a "chemical plant." For nearly two decades, electric utility personnel have been looking for an FGD technology that did not require chemical analyses for either routine operation or understanding the erosion/corrosion problems in the system. The routine operation and maintenance of the GSA system requires neither chemical analyses nor an understanding of chemistry.

The GSA technology was developed by FLS miljo a/s in Europe for removing acid gases from the flue gas generated by many industrial processes. It has been installed at several municipal incinerator applications in Europe to remove hydrogen chloride (HCl), SO_2, and hazardous air pollutants from flue gas. The testing at the CER was the first application of this technology in the U.S. In this application, the GSA system was treating a 10-MW slipsteam of flue gas resulting from the combustion of a high-sulfur (2.7 percent, as-fired basis), Western Kentucky bituminous coal. The GSA system was expected to remove more than 90 percent of the SO_2 from the

flue gas, while achieving a relatively high utilization of the reagent lime.

Later, in collaboration with the EPRI, TVA installed a 1-MW pulsejet baghouse (PJBH) at the CER. This PJBH was designed to treat 5,000 acfm of flue gas, which could be removed from either the ESP inlet or the ESP outlet. The flue gas treated in the PJBH was returned to the main flue gas duct downstream of the ESP. DOE and AirPol agreed to cosponsor this PJBH test program and it was incorporated into the GSA test program in early 1993.

The major objectives of the GSA demonstration were to: (1) optimize the process design variables; (2) determine the lime stoichiometry required for various SO_2 removal efficiencies; (3) demonstrate 90+ percent SO_2 removal efficiency in the GSA/ESP system; (4) evaluate the effect of retrofitting the GSA process on the particulate performance of an existing ESP; (5) evaluate the SO_2 and particulate removal performance of a 1-MW PJBH treating a flue gas slipstream from the GSA system; (6) evaluate the hazardous air pollutants, or air toxics, removal capabilities of the GSA system with the ESP and with the PJBH; (7) compare the overall system SO_2 removal efficiency achieved with an ESP and with the PJBH; (8) complete a 28-day, around-the-clock, GSA/ESP demonstration run; (9) complete a 14-day, around-the-clock, GSA/PJBH demonstration run; (10) compare the performance of the GSA system with that of the SD process, which had previously been tested at the CER; and (11) evaluate equipment erosion/corrosion at various locations in the overall system.

Section 2

CER SYSTEM DESCRIPTION

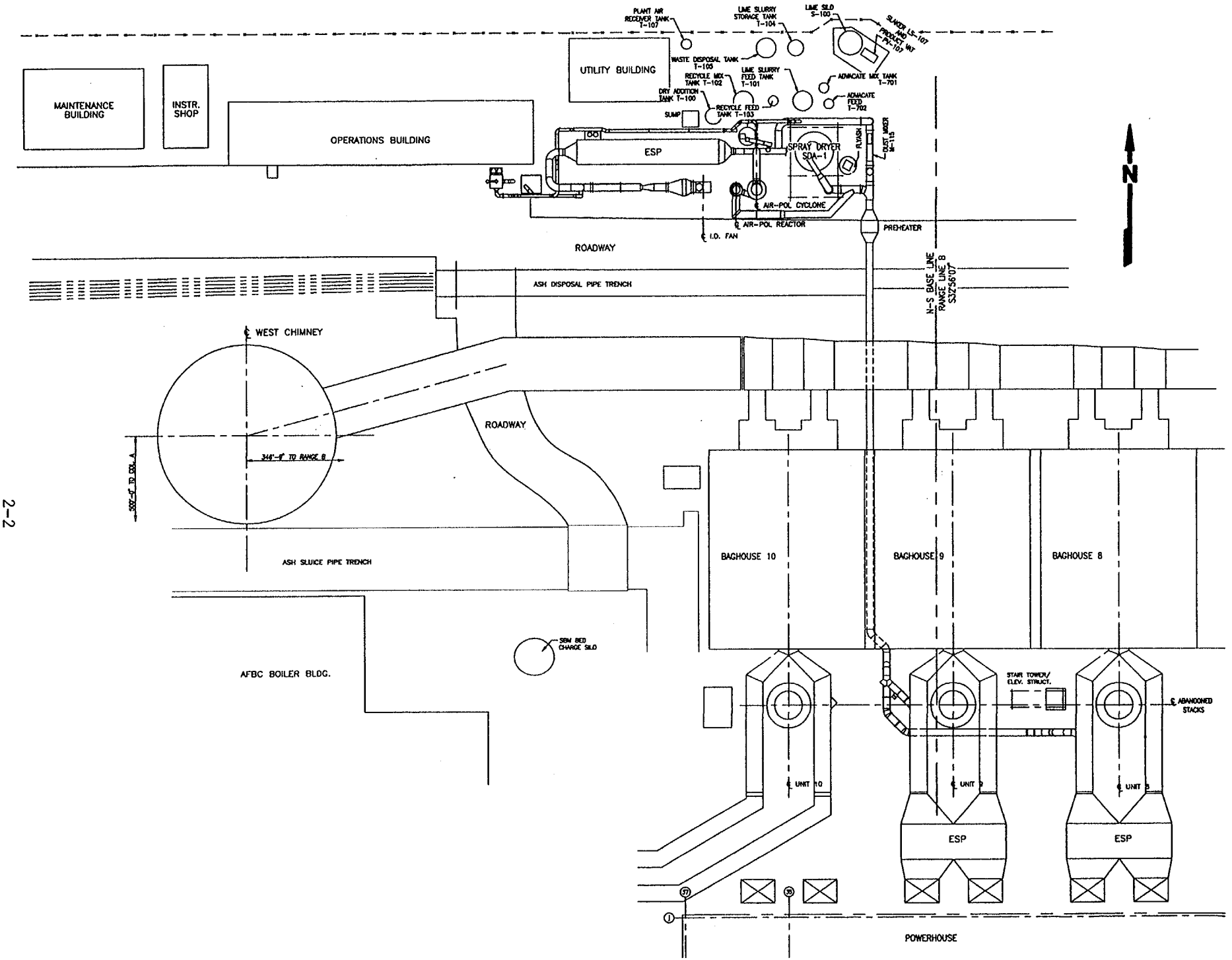
A general description of the Shawnee Fossil Plant and the CER is included in this section. Also included in this section is a process description for the GSA FGD system, including a general overview of the process chemistry.

FACILITY LOCATION

The Shawnee Fossil Plant (SHF) is located on the Kentucky bank of the Ohio River about 10 miles northwest of Paducah, Kentucky. The plant originally consisted of 10 identical, front-fired, Babcock & Wilcox units, each with a nameplate rating of 175 MW. The boilers were built in the early 1950's. In the mid-to-late 1980's, the Unit 10 boiler was replaced by an atmospheric fluidized bed combustion (AFBC) boiler.

Each of the nine remaining units burns pulverized coal to produce about 1.0 million (M) lb/hr of steam at 1,800 psig and 1,000°F at full load. The coal consumption rate for each unit at full load is about 60 tons/hr. Units 1-8 at the SHF are fired with a low-sulfur (1.2 lb SO_2/MBtu), compliance coal, while Unit 9 burns a high-sulfur (4.0-5.0 lb SO_2/MBtu) coal to supply flue gas for the CER.

The CER is located adjacent to Units 9 and 10, about 250 ft north of the main power plant. A plan view of the CER in relation to the power plant is shown in Figure 2-1. All utilities for the CER are obtained from the power plant. The flue gas slipstream for the CER is removed from the "A" duct of Unit 9, downstream of the boiler mechanical collectors. (Unit 9 has two parallel flue gas ducts, the "A" side and the "B" side.) The flue gas temperature at this point ranges from 270-290°F depending on both the boiler load and the ambient weather conditions and is at a pressure of about -18 in. of water because the flue gas take-off point is upstream of both the induced draft (ID) fan and the reverse-air baghouse for Unit 9.


MAINTENANCE BUILDING
INSTR. SHOP
OPERATIONS BUILDING
UTILITY BUILDING
PLANT AIR RECEIVER TANK T-107
WASTE DISPOSAL TANK T-105
LIME SLURRY STORAGE TANK T-104
LIME SILO S-100
SLAKER LS-107 AND PRODUCT PT-107 WT
RECYCLE MIX TANK T-102
LIME SLURRY FEED TANK T-101
ADVACATE MIX TANK T-701
DRY ADDITION TANK T-100
RECYCLE FEED TANK T-103
ADVACATE FEED T-702
SUMP
ESP
SPRAY DRYER SDA-1
FLYASH
DUST MIXER M-115
℄ AIR-POL CYCLONE
℄ AIR-POL REACTOR
PREHEATER
℄ I.D. FAN
ROADWAY
ASH DISPOSAL PIPE TRENCH
N-S BASE LINE RANGE LINE 8 S3256'07"
℄ WEST CHIMNEY
344'-9" TO RANGE 8
302'-9" TO COL. A
ROADWAY
ASH SLUICE PIPE TRENCH
BAGHOUSE 10
BAGHOUSE 9
BAGHOUSE 8
SBM BED CHARGE SILO
AFBC BOILER BLDG.
STAIR TOWER/ ELEV. STRUCT.
℄ ABANDONED STACKS
℄ UNIT 10
℄ UNIT 9
℄ UNIT 8
ESP
ESP
POWERHOUSE
N

PLOT P

The flue gas from Unit 9 is routed through a 39 in. dia., insulated duct to the CER. The flue gas is pulled through this ductwork by the ID fan at the CER. The CER also has the capability of removing a slipstream of flue gas from Unit 8 during major maintenance outages on Unit 9, although this capability was not needed during the GSA testing. (Under these conditions Unit 8 would be fired with the high-sulfur coal normally burned in Unit 9.)

COAL COMPOSITION

The Unit 9 boiler burned several different high-sulfur (4.0-5.0 lb SO_2/MBtu), low-chloride (0.02-0.04 percent), Western Kentucky bituminous coals during the GSA test program. The first coal was purchased from the Peabody Coal Company and the original source was their Martwick mine. This coal was burned during the preliminary or startup tests and the first two months of the factorial testing. The second coal was purchased from Emerald Energy and the original source was their Pleasant Valley mine. This coal was burned during most of the remainder of the factorial testing. The third coal was purchased from the Warrior Coal Company and was used during the last few replicate factorial tests. The fourth coal was supplied by the Andalex Coal Company and the original source was their Cimarron mine. This coal was burned during the air toxics testing, the 28-day GSA demonstration run, and the 14-day PJBH demonstration run. All of these coals were washed prior to delivery.

The typical ultimate analysis compositions of the Peabody, Emerald Energy, and Andalex coals, on a dry basis, are shown in Table 2-1 and the proximate analyses are shown in Table 2-2. All three of these coals had a high-sulfur level (ranging from 2.61 to 3.06 percent on a dry-basis) and very low chloride level (0.02 to 0.04 percent). The ash levels ranged from about 7 to slightly more than 11 percent, again on a dry-basis. The alkalinity in these coal ashes was very low.

CER DESCRIPTION

The CER was originally designed and built in the mid-1980s to test the SD/ESP technology at the 10-MW scale. The design of the facility and the results of these previous SD/ESP evaluations have been reported elsewhere (2,3).

TABLE 2-1

TYPICAL COAL AND ASH COMPOSITIONS FOR THE HIGH-SULFUR COALS

Coal Component	Percent, dry-basis		
	Peabody	Emerald Energy	Andalex
Carbon	72.99	76.26	69.42
Hydrogen	4.92	5.72	5.03
Oxygen[a]	7.65	6.83	9.91
Nitrogen	1.65	1.26	1.39
Sulfur	3.05	2.61	3.06
Chlorine	0.02	0.04	0.04
Ash	9.72	7.28	11.15
TOTAL	100.00	100.00	100.00
Ash Component	**Percent**		
SiO_2	53.96	54.02	52.46
Al_2O_3	18.84	20.87	20.97
Fe_2O_3	19.67	13.44	14.11
CaO	0.33	3.61	3.12
MgO	0.83	0.86	0.80
Na_2O	0.38	0.38	0.33
K_2O	2.39	2.29	2.59
SO_3	2.19	2.57	1.84
Ti_2	1.04	1.35	1.32
Other[a]	0.37	0.61	2.46
TOTAL	100.00	100.00	100.00

a. By difference.

TABLE 2-2

PROXIMATE COAL ANAYLSES FOR THE
HIGH-SULFUR COALS

	Peabody Martwick	Emerald Energy	Andalex
Moisture, %	11.3	10.1	8.9
Volatiles, %	35.8	37.6	35.4
Fixed Carbon, %	44.3	45.8	45.5
Ash, %	8.6	6.5	10.2
TOTAL	100.0	100.0	100.0
Heating Value, Btu/lb			
Wet	12,800	12,910	12,420
Dry	13,117	13,420	12,870

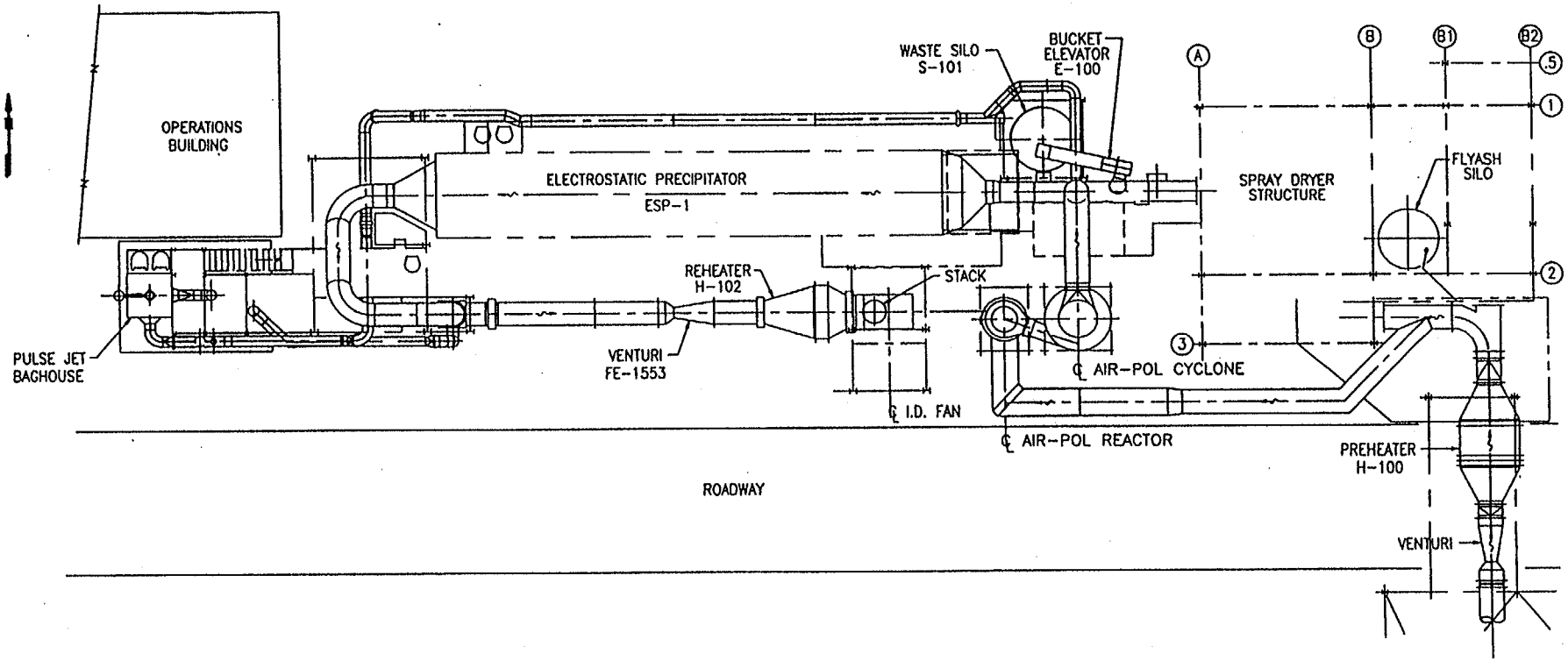
However, some flexibility was provided in the original design to accommodate other test options. In early 1992, the existing SD/ESP plant was modified to incorporate the equipment needed for the testing of another dry, lime-based, FGD process. This test equipment was installed on the north side of the SD structure such that the SD was simply bypassed and the flue gas reentered the ductwork at the ESP inlet downstream of the SD.

In a similar manner, the GSA equipment was installed on the south side of the SD structure, such that the flue gas from the boiler passed through the preheater/precooler and entered the new ductwork to the GSA equipment, passed through the GSA equipment, and then reentered the existing ductwork upstream of the ESP inlet. The plan and elevation drawings for this GSA equipment, as installed at the CER, are shown in Figure 2-2 and 2-3.

The design of the 10-MW GSA plant began soon after the DOE contract award in 1990, but the construction was delayed for one year because of other TVA commitments. The construction of the GSA plant finally began in April 1992 and was completed in August 1992. This GSA construction proceeded while another test program was underway. To reduce the overall cost for the GSA system, as much of the original SD/ESP process equipment as possible was incorporated into the design of the GSA system. Simultaneously with the installation of the GSA equipment, the 1-MW PJBH pilot plant was installed downstream of the ESP.

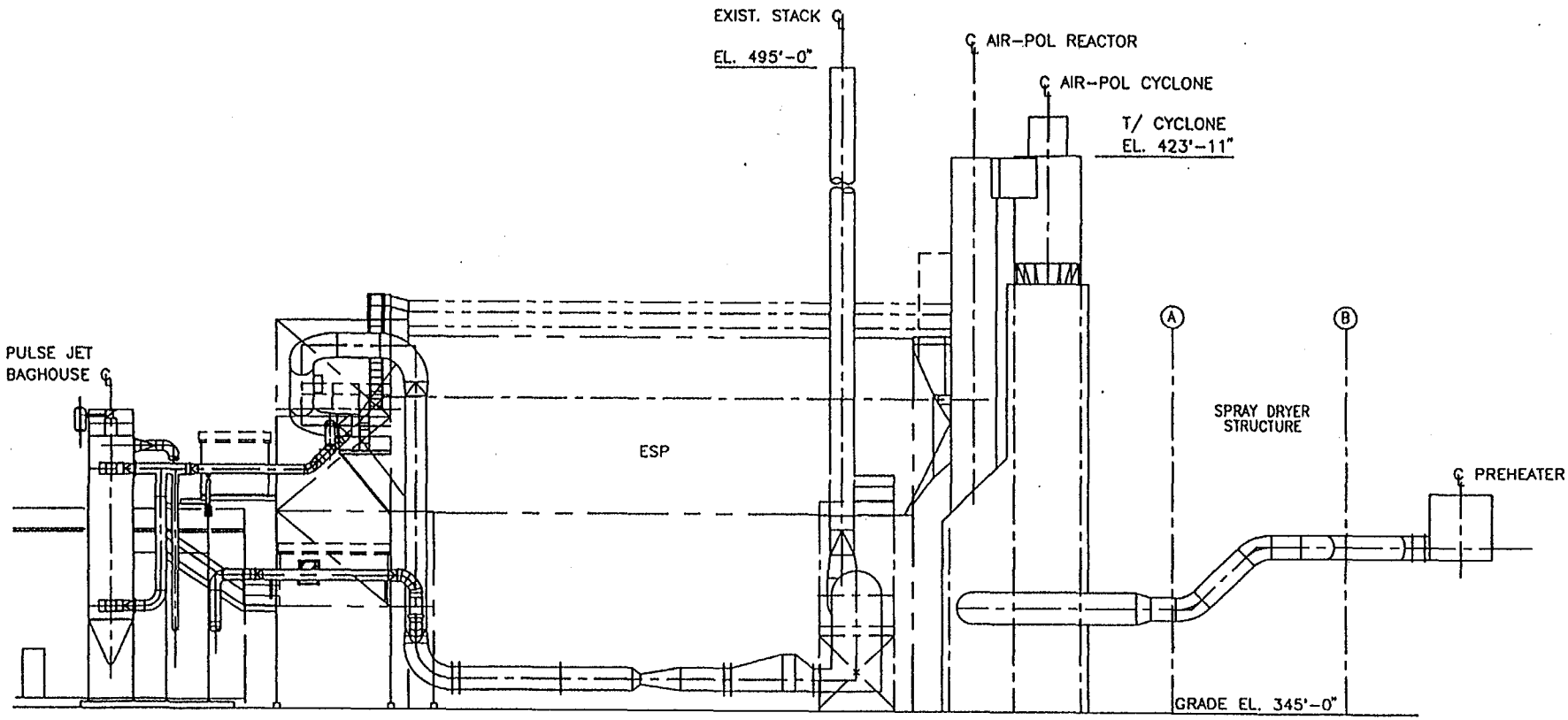
The flue gas from the boiler passes through a long duct run to the CER and then through a preheater/precooler system, which controls the inlet flue gas temperature at the CER to the desired setpoint. The heat exchange medium in this system is condensate from Unit 9. The water loop is pressurized with nitrogen gas and opertes at about 180 psig. The temperature of this high-pressure water is controlled with two separate, smaller (100-150 ft^2 of tube area) heat exchangers, one using steam from the boiler to heat the pressurized water and the other using water from the river to cool it. The flow rate of the pressurized water through each of these heat exchangers is controlled to achieve the desired inlet flue gas temperature.

The preheater/precooler is a shell-and-tube heat exchanger, which originally contained 2,700 ft^2 of tube area in three separate banks of tubes. However,



PLAN

FIGURE 2-2. PLAN VIEW OF GSA EQUIPMENT



ELEVATION – LOOKING NORTH

FIGURE 2-3. ELEVATION OF GSA EQUIPMENT

during the previous SD/ESP testing, a number of the 304 stainless steel (SS) tubes developed leaks and had to be plugged. (Most of these plugged tubes were in the third bank.) The 304 SS tubes failed due to stress corrosion cracking. This heat exchanger is about 16 ft long, 8 ft wide, and 6 ft. high. From the preheater/precooler, the SO_2-laden flue gas passes directly to the inlet of the GSA reactor.

GSA Process Description

In the GSA FGD process, which is shown in Figure 2-4, the flue gas from the preheater/precooler passes through the inlet ductwork to the GSA reactor, where the flue gas enters the bottom of the reactor and flows upward through a venturi-type section into the cylindrical body of the reactor. The purpose of the venturi section is to boost the flue gas velocity at the bottom of the reactor. The increased velocity is required to suspend the bed of circulating solids. Some large particles do fall down through this venturi section and into the bottom of the inlet elbow. There is small clean-out valve installed in the inlet elbow, below the venturi section, to allow the removal of any oversized solids that are sufficiently large to fall out of the reactor. Above the venturi section, the reactor is a simple cylindrical vessel with no internal parts. The inlet duct and reactor are constructed from carbon steel.

A freshly-slaked lime slurry is injected into the reactor through a single, two-fluid nozzle, which is installed in the venturi section of the reactor. The resulting atomized slurry from the two-fluid nozzle also flows upward, co-currently with the flue gas in the reactor. The quantity of lime slurry fed to the nozzle is controlled based on the SO_2 content of the inlet flue gas and the SO_2 removal efficiency that is required. Trim water is added to the lime slurry to cool the flue gas to the design approach-to-adiabatic-saturation temperature (hereafter referred to as the approach-to-saturation temperature).

Dry recycle solids are reinjected into the reactor via a simple chute from the recycle feeder box. The recycle screws remove the dry solids from the recycle feeder box and these solids fall by gravity, entering the reactor just above the venturi section. Upon entering the reactor, these solids are reentrained by the flue gas flowing up through the reactor and form a

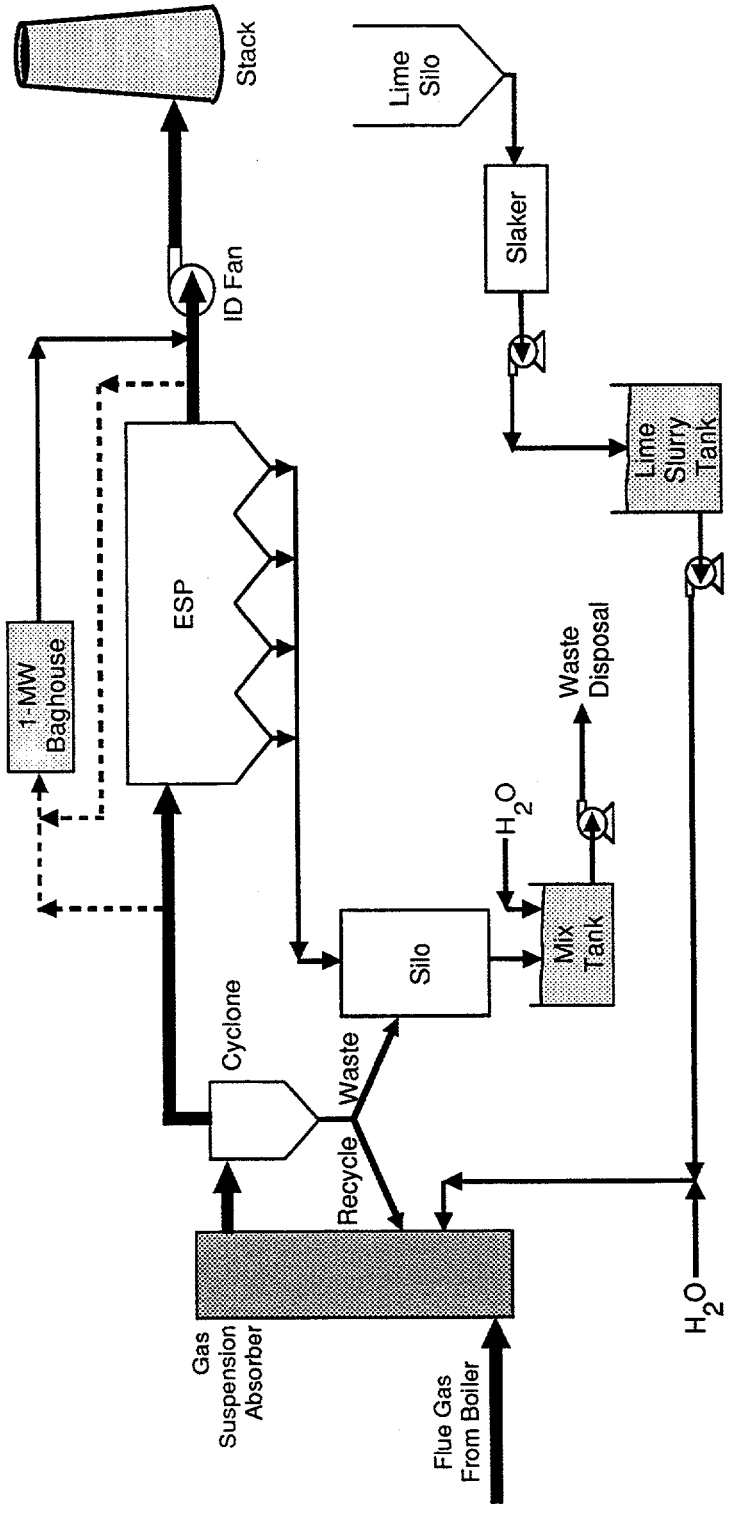


FIGURE 2-4. GSA DEMONSTRATION PLANT FLOW DIAGRAM

circulating bed of small particles. The fresh lime slurry, which is atomized into this circulating bed of solids, coats the surface of these solids with a thin layer of lime slurry.

This thin layer of freshly-slaked lime slurry coating the recycle solids provides a large surface area in the reactor for the absorption of the acid gases, i.e., SO_2, sulfur trioxide (SO_3), carbon dioxide (CO_2), and HCl from the flue gas. Once absorbed into the thin slurry layer, these acid gases then react with the slaked lime ($Ca(OH)_2$) to generate a mixture of reaction products; i.e., calcium sulfite, sulfate, carbonate, and chloride. Thus, the primary overall reactions occurring in the GSA reactor are:

$$Ca(OH)_2\ (aq) + SO_2\ (g) \rightarrow CaSO_3{*}1/2\ H_2O\ (s) + 1/2\ H_2O\ (g)$$

$$Ca(OH)_2\ (aq) + SO_3\ (g) + H_2O\ (aq) \rightarrow CaSO_4{*}2H_2O\ (s)$$

$$Ca(OH)_2\ (aq) + CO_2\ (g) \rightarrow CaCO_3\ (s) + H_2O\ (g)$$

$$Ca(OH)_2\ (aq) + 2HCl\ (g) + 4H_2O\ (aq) \rightarrow CaCl_2{*}6H2O\ (s)$$

These reactions are thought to take place primarily in the thin layer of fresh lime slurry coating the dry recycle solids. (The reaction products are shown in the fully hydrated form, even though a mixture of hydration levels would be expected.)

Simultaneously, the sensible heat in the hot flue gas evaporates most of the water from this thin layer of lime slurry coating the particles. The evaporation of the water cools and humidifies the flue gas. Essentially all of the moisture in the lime slurry is evaporated, leaving only some residual surface moisture. The resulting "dry" solids are entrained in the flue gas along with the fly ash from the boiler and pass up through the reactor. The dry solids exit from the top of the reactor along with the flue gas and enter a cyclone-type mechanical collector. The cyclone, which is constructed of carbon steel, removes most of the particles from the flue gas (90+ percent).

The solids removed in the cyclone fall by gravity through a chute connecting the base of the cyclone with the recycle feeder box. This recycle feeder box

provides in-process storage and was originally designed to have a solids residence time of about three minutes. Recycle screws are installed in the bottom of the recycle feeder box to pull the solids into the chute that feeds the solids back into the reactor. Nearly all of these solids that are collected in the cyclone are recycled to the reactor to provide the circulating bed of solids. Some of the solids from the top of the recycle feeder box are removed by an overflow screw and are fed to the by-product disposal system.

The flue gas from the cyclone passes to the ESP inlet. The existing ESP is an ABB-Flakt design that is typical of the newer ESPs in the utility industry in general and within TVA in particular. The ESP has four fields containing 13,528 ft^2 of collecting plate area arranged such that the ESP has eight parallel gas passages. These collector plates are fabricated from Corten and the plate spacing is 10 in. At the design ESP inlet flue gas flow rate of 30,300 acfm at 145°F, this plate area corresponds to a specific collection area (SCA) of 446 ft^2/kacfm and a face velocity of 3.3 ft/sec. For fly-ash-only testing, the higher flue gas flow rate (because of the higher flue gas temperature) decreases the SCA to about 360 ft^2/kacfm and increases the face velocity to about 3.8 ft/sec. The aspect ratio for this ESP is 1.60. The ESP housing, which is constructed of carbon steel (ASTM A588, grade A), contains room for a fifth field; however, this fifth field is currently empty with no plates, wires, hopper, or associated equipment installed.

The charging electrodes are spiral SS wires mounted in a rigid frame. Both the discharge electrodes and the plates are rapped by tumbling hammers installed on rotating shafts. A microprocessor-based system controls the voltage to the transformer/rectifier (T/R) sets and also the rapping sequence and frequency. All four T/R sets (one for each field) are identical and are rated at 50 kilovolts (kV) and 200 milliamps (mA).

From the ESP, the flue gas passes to a reheater, the ID fan, and the CER stack. The reheater is also a shell-and-tube heat exchanger with about 560 ft^2 of tube area. The tubes are fabricated from 316 SS while the rest of the heat exchanger is constructed from carbon steel. The reheater is approximately 8 ft long by 6 ft wide and uses steam from the boiler to boost the flue gas temperature to 200°F. (A reheat system may or may not be needed

in a commercial GSA application, but is required at the CER to provide plume buoyancy at this congested site.)

The ID fan is rated at 44,600 acfm and has a 400-hp motor. It is constructed of 316L SS and is installed downstream of the reheater to protect it from corrosion damage. The flue gas flow rate is controlled using a louver-type damper installed upstream of the ID fan. The flue gas from the ID fan is discharged into the base of the 150 ft CER stack.

The lime slurry is prepared from a high-calcium pebble lime in a paste-type slaker (i.e., the grit is removed from the slurry). Two different high-calcium limes were used during the testing, one from Mississippi Lime Company and one from Tenn Luttrell Company. The lime slurry is pumped first to a storage tank and then to a lime feed tank from which it is metered to the two-fluid nozzle in the bottom of the cylindrical section of the reactor.

During the factorial testing of the GSA system, the lime slurry flow rate was controlled by the continuous measurement of the flue gas SO_2 concentration upstream of the reactor. (The lime slurry flow rate could also be controlled to maintain a specific SO_2 level in the flue gas downstream of the ESP.) Also, trim water is mixed with lime slurry to lower the flue gas temperature at the cyclone outlet to the required operating temperature, which is typically 145-155°F. These temperatures correspond to an approach-to-saturation temperature in the reactor of 18-28°F.

PJBH Pilot Plant

The 1-MW PJBH pilot plant, which was installed adjacent to the ESP at the CER (see Figure 2-2), treated a 5,000 acfm slipstream of flue gas from the main GSA/ESP plant. The flue gas slipstream for the PJBH could be removed from either the ESP inlet (the "in-parallel" mode) or the ESP outlet (the "in-series" mode) through an 18 in. dia., insulated duct. The flue gas entered the bottom of the PJBH, passed through the bags, and was discharged from the top of the PJBH back to the GSA/ESP ductwork downstream of the ESP.

The PJBH had 48 bags arranged in three concentric rings. The acrylic bags installed for the GSA factorial testing were fabricated from Draylon T, which

was a relatively low-cost material suitable for this low temperature application. The bags were oval-shaped in cross-section, 20 ft. in length and 15-1/2 in. in circumference, and were supported by standard 14-wire carbon steel cages. The cages were coated to prevent rusting due to the expected low-temperature operation.

With the full complement of bags and the PJBH pulling flue gas from the ESP inlet with the full particulate loading, the air-to-cloth ratio (A/C) was approximately 4.0 acfm/ft^2. During the "in-series" testing with the PJBH pulling flue gas from the ESP outlet with the resulting very low particulate loading, only one-third of the bags were installed and the PJBH operated at an A/C of 12.0 acfm/ft^2.

The solids, which were collected on the outside of the bags in the PJBH, were periodically dislodged by a high-volume, low-pressure flow of ambient air distributed by a rotating manifold. This rotating manifold was equipped with three nozzles that were aligned with each ring of bags and was located above the bags in the "clean" outlet gas plenum. The manifold continuously rotated at 1 rpm. The pulses of cleaning air were supplied through the manifold from a reservoir that was pressurized to about 9 psi by a dedicated positive displacement blower. The low-pressure air was discharged from the reservoir into the manifold through a diaphragm valve and then subsequently injected through the nozzles into the bags to dislodge the filtercake. These solids fell into the PJBH hopper and were removed through a rotary valve at the base of the hopper. From the rotary valve, the solids dropped into a pneumatic conveying system, which moved the solids to the by-product disposal area in the GSA/ESP process.

The cleaning of the bags in the PJBH was pressure-drop-initiated during this GSA testing with the cleaning cycle begun whenever the tubesheet pressure drop reached 6 in. of water. The bag cleaning cycle continued until the tubesheet pressure drop had decreased to 4-1/2 in. of water.

As previously discussed, the PJBH pilot plant was installed at the same time as the GSA equipment. However, the PJBH pilot plant was not started up until late December 1992. The objective of the 1-MW PJBH project at CER was to evaluate the performance of this type of fabric filter with the GSA/ESP

system. The test program involved the evaluation of the PJBH performance in two configurations: (1) as a stand-alone particulate control device, which could be compared with the performance of an ESP and (2) as a retrofit device installed in series with an ESP as the final stage in the particulate control system. The latter arrangement was sowewhat analogous to the EPRI-patented technology called the Compact Hybrid Particulate Collector (COHPAC).

LIME COMPOSITION

Most of the testing was completed using a high-calcium pebble lime supplied by Mississippi Lime Company. A typical composition for this lime is shown in Table 2-3. The bulk density for this pebble lime averaged about 57 lb/ft^3 and the surface area ranged from 0.5 to 3.0 m^2/g.

Table 2-3

TYPICAL LIME COMPOSITION

Component	Percent
CaO	93.2
MgO	1.0
$CaCO_3$	1.0
Acid insolubles	4.8

Section 3

GSA TEST PROGRAM

The overall test program for the GSA process consisted of five major phases: (1) the preliminary or startup tests, (2) the factorial tests, (3) the air toxics tests, (4) the 28-day GSA demonstration run and (5) the 14-day PJBH demonstration run. The GSA system was started up in November 1992 and the final task was completed in March 1994. A timeline for the GSA test program is shown in Figure 3-1. (The blank areas in this test program were reserved for tests that were not part of the GSA test program and are not discussed in this report.)

The purpose of the preliminary tests, which were completed in November and December 1992, was to investigate the limits of the 10-MW GSA system as installed at the CER. During these tests, the major process variables were evaluated at the extremes of the ranges planned for the later factorial test program. Some of these initial variable levels were based on TVA's previous experience with other dry, lime-based, FGD systems. These preliminary or startup tests were the subject of a separate report that was prepared by AirPol (4) and will not be discussed further. Similarly, the air toxics tests, which were completed in September and October 1993, were also the subject of a separate report (5) that was prepared by the air toxics contractor, Energy and Environmental Research Corporation, and also will not be discussed in this report.

The three remaining test phases: the factorial testing, the 28-day GSA demonstration run, and the 14-day PJBH demonstration run are discussed in more detail in the following sections.

FACTORIAL TESTS

The GSA factorial testing was completed during the period from January to early August 1993, as shown in Figure 3-1. The purpose of this statistically-designed factorial test program was to determine the effect

DOE/AirPol/TVA Test Program

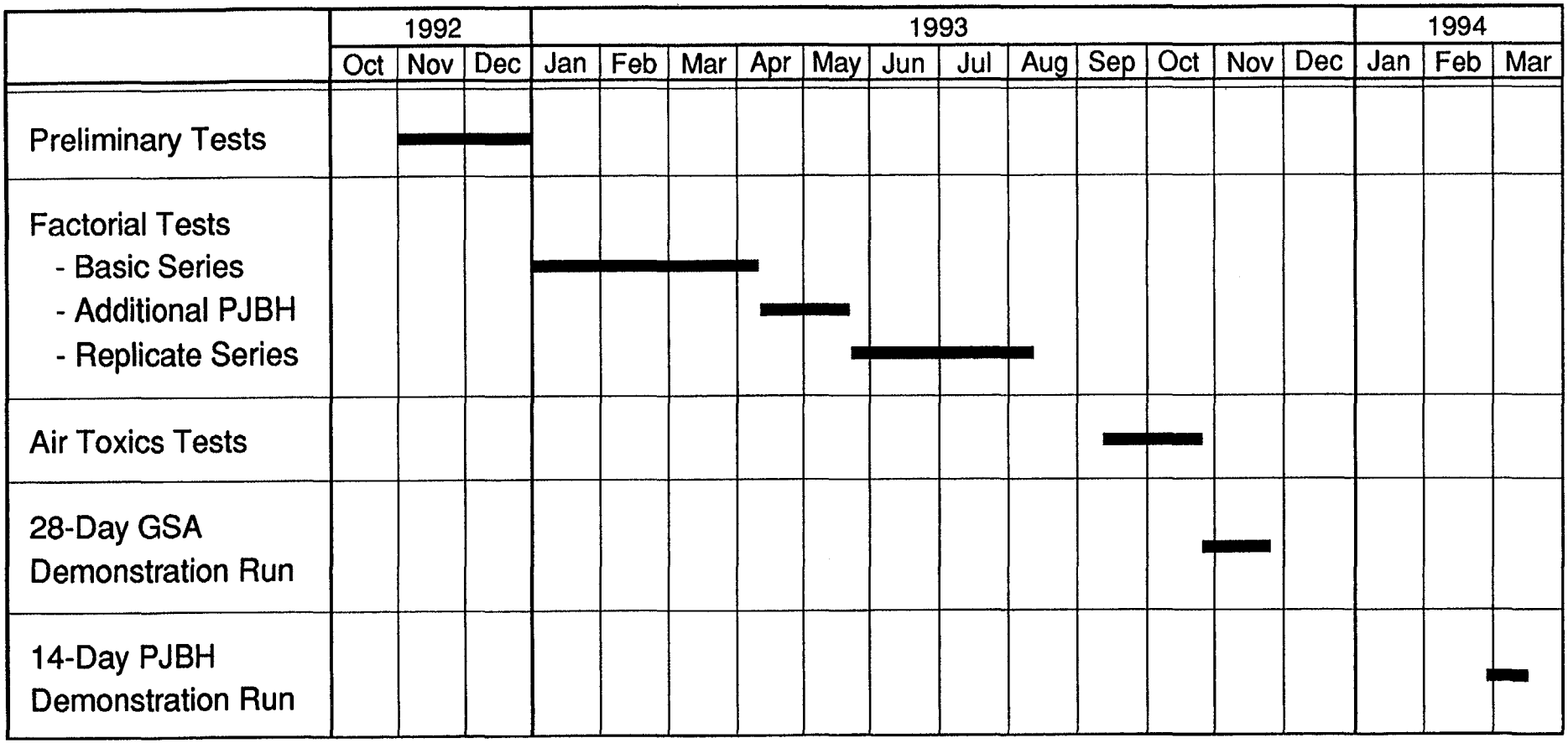


FIGURE 3-1. DOE/AIRPOL/TVA TEST PROGRAM

of the major process variables on the SO_2 removal efficiency in the reactor/cyclone, the ESP, the PJBH, and the overall system. In these factorial tests, the major process design variables were the independent variables and the SO_2 removal efficiency, lime utilization, and ESP performance were all dependent variables.

Given the large number of major process design variables and the limited amount of test time available, only two levels for most of the variables were included in the original test plan design. These two variable levels were selected to cover the range of primary interest for a utility FGD application. To further reduce the length of the factorial test plan, but still retain the quality control on the test results, a half-factorial design with a full set of replicate tests was used for the GSA testing.

With the inclusion of the PJBH testing into the overall GSA test program, this half-factorial design with a full set of replicate tests provided an additional advantage. The PJBH could be tested at each test condition in each of the two operating modes, i.e., in-series and in-parallel with the ESP. The basic factorial tests were completed with the PJBH operating in the "in-parallel" mode, i.e., pulling flue gas from the ESP inlet. This operating mode allowed a comparison of the ESP and the PJBH performance at the same test condition on the same day. The replicate factorial tests were completed with the PJBH operating in the "in-series" mode, i.e., pulling flue gas from the ESP outlet. This arrangement allowed the PJBH performance to be determined at each test condition as a final-stage, particulate control device. Since the reactor/cyclone would be operating at the same conditions for both the basic and the replicate tests and essentially all of the SO_2 removal was occurring in the reactor/cyclone portion of the GSA system, this test plan design allowed the quality control on the SO_2 removal data, i.e., two separate tests completed at each condition, and yet also provided the opportunity for both PJBH operating scenarios to be evaluated at each of the test conditions.

A total of 63 tests were completed during the factorial test program. These tests, each of which was designed to be run for 48 hours, were run during the period from January to August 1993.

Major Variables and Levels

Based on TVA's previous experience with other dry, lime-based, FGD systems and the results from the preliminary GSA testing, the major process design variables in the GSA FGD system were determined to be: (1) inlet flue gas temperature, (2) approach-to-saturation temperature, (3) calcium-to-sulfur ratio (Ca/S), (4) inlet fly ash loading, (5) coal chloride level, (6) flue gas flow rate, and (7) recycle screw speed. However, only one level for the inlet flue gas temperature variable (320°F) was used in the factorial testing because of the limited test time available. Also, the results from the previous work with other dry, lime-based FGD system had indicated that this variable, although important, was not as important as some of the other major process variables.

Two levels were selected for all but one of the other major process variables. This exception was the approach-to-saturation temperature where three levels were defined, but the lowest approach-to-saturation temperature level (8°F) was only evaluated for those tests at the lower coal chloride level because of concerns about the operability of the system at the combined high chloride/close approach condition, based on the results from the preliminary testing.

The major process variables and the selected levels for each variable are shown in Table 3-1. The reasons for selecting each of these variables and levels for the GSA test program are discussed in more detail below.

Approach-to-Saturation Temperature - This variable has two major effects in these dry, lime-based, FGD processes. First, the approach-to-saturation temperature level determines the magnitude of the driving force for the evaporation of water from the lime slurry that is injected into the flue gas in the reactor. The presence of liquid water on the solids is required for SO_2 removal to occur at a rapid rate. At a high approach-to-saturation temperature, there is a large driving force for the evaporation of water in the reactor, particularly toward evaporating the last vestiges of moisture in the circulating solids. Consequently, the thin layer of lime slurry dries very quickly and the entrained solids have low residual

Table 3-1

MAJOR VARIABLES AND LEVELS FOR THE GSA FACTORIAL TESTING

Variable	Level
Approach-to-saturation temperature, ^{o}F	8, 18, 28[a]
Ca/S, moles $Ca(OH)_2$/mole inlet SO_2	1.00 and 1.30
Fly ash loading, gr/acf	0.50 and 2.0
Coal chloride level, %	0.02 and 0.12
Flue gas flow rate, kscfm	14 and 20
Recycle screw speed, rpm	30 and 45

a. $8^{o}F$ condition only run at the low coal chloride level.

moisture levels. Since the SO_2 removal in these dry, lime-based FGD systems requires the presence of liquid water to absorb the SO_2 as the first step in the overall removal of the SO_2 from the flue gas, too high an evaporation rate results in a low SO_2 removal efficiency in the system. Conversely, a close approach-to-saturation temperature in the reactor leads to a slower evaporation rate for the water and a higher overall system SO_2 removal efficiency. This effect of the approach-to-saturation temperature variable on the SO_2 removal efficiency in the GSA system is very important and is also one reason that three levels of this variable were selected for the GSA test program.

Second, in combination with the inlet flue gas temperature, this variable determines how much water can be injected into and evaporated by the flue gas. At the closer approach-to-saturation temperatures, more water has to be added to the flue gas to reach the desired reactor outlet temperature. The higher water injection rate at the closer approach-to-saturation temperatures is thought to spread the fresh lime slurry over more of the dry recycle particles, which in theory would increase the total wetted surface area available for the absorption, reaction, and removal of the acid gases in the reactor. However, this effect on the overall system SO_2 removal is expected to be of less importance than the previously discussed effect of this variable on the evaporation rate of the water from the lime slurry.

Although it is desirable to operate at a very close approach-to-saturation temperature to maximize the overall system SO_2 removal efficiency, this must be balanced by the need to maintain the operability of the system. At very close approach-to-saturation temperatures, the potential for wet operation in the reactor increases, such that the system is on the edge of operability and even minor problems could push the system over the brink and into an upset condition. Therefore, these dry, lime-based, FGD systems are typically operated sufficiently above the minimum approach-to-saturation temperature to provide a built-in safety margin to minimize the possibility of a minor problem sending the system into an upset mode and shutting the system down. For example, during the previous SD/ESP testing, the boiler soot-blowing was found to be one of these minor problems that could upset the system when it was operating at a very low approach-to-saturation temperatures.

The design operating level for the approach-to-saturation temperature in these dry, lime-based FGD systems is expected to be 18°F for a high-sulfur (4.0-5.0 lb SO_2/MBtu) coal application. This coal sulfur level requires a high SO_2 removal efficiency (90+ percent), which will necessitate a low approach-to-saturation temperature in the reactor. This 18°F approach-to-saturation temperature level maximizes the overall system SO_2 removal efficiency while maintaining some margin of safety. For a low-sulfur coal application where more modest SO_2 removal efficiencies (70 percent) are typically required, the "normal" approach-to-saturation temperature may be somewhat higher at 25-35°F to provide an additional margin of safety. Therefore, the second level for this variable, 28°F, was also included in the test plan to gather GSA performance data at this more conservative condition. The third level for this variable, 8°F, was included after the completion of the preliminary testing, which indicated that this level was technically feasible at the low coal chloride level. However, this low approach-to-saturation temperature condition was only run for the low-chloride tests. Given the current state-of-the-art in dry scrubbing technology and the utility concerns about upset conditions, the primary objective of the test program was to demonstrate that the GSA FGD system could operate reliably at an approach-to-saturation temperature of 18°F.

The approach-to-saturation temperature level in the reactor also has an effect on the ESP performance since this variable (in combination with the flue gas wet-bulb temperature) determines the flue gas temperature at the ESP inlet. The flue gas temperature is an important determinant of the resistivity of the solids entering the ESP, which in turn has an effect on the particulate control performance of the system. (The chemical composition of the solids, which is discussed below, is another important determinant of the resistivity of the particulates.) Based on the past work at the CER with other dry, lime-based, FGD systems, the resistivity of the FGD solids can vary significantly with even seemingly minor changes in the flue gas temperature at the ESP inlet.

Ca/S Level - The fresh lime stoichiometry or Ca/S level is probably the most important determinant of the overall system SO_2 removal efficiency in these dry, lime-based FGD systems. The Ca/S level is defined as the

moles of fresh lime injected per mole of SO_2 entering the system. With all of the other variables held constant, a higher Ca/S level in the system will achieve a higher overall system SO_2 removal efficiency. However, since the consumption of fresh lime is one of the major operating costs in these dry, lime-based, FGD systems, the Ca/S level must be held as low as possible to minimize the resulting process operating costs.

Since there are no "real" technical constraints on the Ca/S level at normal boiler operating conditions and this variable is thought to be a major determinant of SO_2 removal in the system, a wide range of this variable could have been tested to determine its effect on the overall system SO_2 removal efficiency. However, given the limited test time available, only two levels of the Ca/S variable could be tested. Since the results from previous economic evaluations had indicated that Ca/S levels substantially above 1.30 moles $Ca(OH)_2$/mole inlet SO_2 may result in high operating costs for a high-sulfur coal application, the decision was made to evaluate this variable at the levels of 1.00 and 1.30 moles $Ca(OH)_2$/mole inlet SO_2 during this initial factorial testing. The other major reason for selecting these two levels for the Ca/S variable was that these two Ca/S levels had been evaluated in the previous SD/ESP testing at the CER. By selecting two of the same levels for this variable in the GSA test program, direct comparisons between the performance of the GSA process and the SD/ESP technology would be possible, which was one of the major goals of the GSA test program.

The Ca/S level also has an effect on the performance of the ESP since this variable helps to determine the chemical composition of the solids entering the ESP. The chemical composition of the solids is a major determinant of the resisitivity of these solids. The resistivity of the solids, if outside the narrow "ideal" range, can cause increased ESP emissions.

Fly Ash Level - The fly ash level in the inlet flue gas was varied at two levels: 0.5 gr/acf, which is the normal level in the flue gas received at the CER, and 2.0 gr/acf, which is more typical of the level for a pulverized-coal-fired boiler. The boilers at the SHF, which were built in the 1950's, had multiclone-type collectors installed to reduce the fly ash loading in the flue gas. These multiclones reduce the fly ash loading from the more typical level of 2.0 gr/acf to only 0.5 gr/acf at the CER.

The capability to reinject the fly ash collected in the multiclones back into the flue gas entering the CER was installed before the GSA testing began. The decision was made to use this capability in the GSA testing to determine if the inlet fly ash loading had an effect on the system performance.

The fly ash level in the inlet flue gas was not expected to have a significant effect on the SO_2 removal performance in the GSA system since the fly ash contains very little or no alkalinity. Any effect of this variable on the GSA performance was expected to be due to the displacement effect of the fly ash, i.e., the higher levels of fly ash collected in the GSA system would reduce the amount of FGD by-product material that could be recycled to the reactor and potentially be reused.

Coal Chloride Level - The coal chloride level was also expected to be an important variable in the GSA FGD system based on the previous testing of other dry, lime-based, FGD systems at the CER. The coal chloride level determines the amount of HCl in the flue gas, which is almost completely removed in these dry, lime-based, FGD systems. The absorbed HCl reacts with the $Ca(OH)_2$ to form calcium chloride. The level of calcium chloride in the GSA system is important because of its effect on the water evaporation rate in the reactor and on the moisture level in the "dry" solids.

The calcium chloride, which is an ionic salt when dissolved in the lime slurry, depresses the vapor pressure of the water and thereby slows the evaporation rate of the water in the reactor. Thus, the slurry solids remain wetter longer, retaining a surface layer of liquid water, which is necessary for the absorption of the acid gases. This increases the reaction time available in the system and boosts the SO_2 removal efficiency. In addition, calcium chloride is a hygroscopic material, i.e., it has the ability to adsorb moisture from the humid flue gas, thereby maintaining a layer of residual surface moisture on the solids. This residual surface moisture may allow additional SO_2 removal even though the solids are "dry".

However, this ability to both slow the water evaporation rate and retain higher residual moisture levels on the surface of the solids also offers the increased potential for plugging and other operational problems in the system. Thus, the higher chloride levels offer a double-edged sword, the potential for higher SO_2 removal efficiencies, but also an increased potential for plugging. The increased moisture level with the higher chloride levels in the system were one reason that in this first round of factorial testing, the lowest approach-to-saturation temperature ($8^{o}F$) was not attempted at the higher coal chloride level.

Based on previous work at the CER, the chloride in the GSA system can come from either the HCl in the flue gas or through the injection of a calcium chloride solution. The coal chloride levels selected for evaluation in the original GSA test plan were 0.02 and 0.12 percent since the first high-sulfur coal burned during the test program contained a very low chloride level (0.02 percent). Thus, this low level became the baseline coal chloride level. With the later coal switch very early in the factorial test program, the baseline coal chloride level increased slightly to 0.04 percent, but the higher level of 0.12 percent was retained. The higher coal chloride level (0.12 percent) was achieved by spiking the trim water that was added to the lime slurry with a 32 percent calcium chloride solution to simulate the combustion of a higher chloride coal.

There were two reasons that the 0.12 percent coal chloride level was chosen as the second level for this variable. First, the statistical analysis of the data is easier when equal increments between the variable levels are selected and the future plans included tests at the 0.20-0.22 percent coal chloride level to cover the range of interest for this variable. Although some Illinois-basin coals contain higher chloride levels, the trend in the utility industry is to burn coals with lower chloride levels because of the concerns about increased boiler corrosion with the higher chloride coals. In some cases, the maximum chloride level allowed in the coal is specified as less than 0.3 percent and the trend in the utility industry appears to be for further reductions of this level in the future. Second, this higher coal chloride level (0.12 percent) was selected in an attempt to match, as closely as possible, one of the coal chloride levels that had been used in the previous SD/ESP FGD testing at the CER. The coal chloride levels in

the SD testing had been 0.10, 0.20, and 0.30 percent. This would facilitate the comparison of the results achieved at the CER between these two FGD systems.

During the previous SD/ESP testing, it was also found that increasing the coal chloride level from 0.02 to 0.10 percent provided a significant boost in the overall system SO_2 removal efficiency, as much as 10 percentage points for some test conditions. Further increasing the coal chloride level from 0.10 to 0.20 percent resulted in a more modest increase in the overall system SO_2 removal efficiency of about 5 percentage points, again depending on the other test conditions. Further increases in the coal chloride level above 0.20 percent did not seem to provide any further meaningful increase in overall system SO_2 removal efficiency in the SD/ESP system.

The coal chloride level can also have an effect on the ESP performance in these dry, lime-based, FGD systems. There were two effects noted in the previous SD/ESP testing. First, the presence of higher chloride levels will slightly change the chemical composition of the solids entering the ESP, which may change the resistivity of the solids. For example, the presence of chlorides will increase the SO_2 removal efficiency in the system, which will increase the sulfite levels and decrease the unreacted lime in the solids entering the ESP. This reduction in the unreacted lime should increase the resistivity in the solids. Second, the presence of the hygroscopic calcium chloride may lead to more sticky particles because of the resulting surface moisture. This increase in the cohesivity may reduce reentrainment losses and lower ESP emissions. It may also lead to solids deposits in the ESP.

Flue Gas Flow Rate - The decision was made to look at two levels of the flue gas flow rate: the design value of 20,000 scfm at the system inlet and a lower level of 14,000 scfm. The purpose of evaluating these two levels was to simulate both the full-load condition with the design value and also the reduced load condition with the 14,000 scfm flue gas flow rate. The original intention was to simulate a 50-60 percent load

condition for the lower flue gas flow rate, but the minimum setting on the louver damper upstream of the CER ID fan prevented operation at this lower flue gas flow rate and the 14,000 scfm value was selected as the minimum level.

The ultimate effect of changing the flue gas flow rate would be to vary the flue gas residence time in the reactor/cyclone. At the design flue gas flow rate, the flue gas residence time in the reactor/cyclone is only about 4 sec. At the reduced flue gas flow rate condition, this flue gas residence time is increased to about 5.5 sec. The change in the flue gas flow rate would also affect both the SCA and the face velocity in the ESP. At the lower flue gas flow rate, the SCA is higher and the face velocity is lower, both of which should enhance the ESP performance.

Recycle Screw Speed - The recycle screw speed was used as an indirect measure of the recycle rate in the GSA system. The higher recycle screw speed (45 rpm) provided a 50 percent increase in the recycle rate over that achieved at the lower recycle screw speed (30 rpm). The higher recycle rate, in theory, should provide more solids in the reactor. These higher solids levels would provide more surface area for mass and heat transfer between the injected slurry coating these recycle solids and the flue gas. However, the higher solids level in the reactor will also increase the pressure drop in the system and the optimum recycle screw speed will be determined by this tradeoff between the increased SO_2 removal efficiency and the pressure drop losses.

Originally, when the GSA system was installed, the design maximum recycle screw speed was about 22 rpm. However, during the preliminary testing it was found that increasing the recycle screw speed up to the maximum level of 22 rpm increased the SO_2 removal efficiency in the system. Therefore, the decision was made to modify the recycle screw motor to allow the recycle screw speed to be increased to a maximum rate of 45 rpm and the two values of 30 and 45 rpm were selected for the test program. (This change reduced the solids residence time in the recycle feeder box, which had important implications on the operability of the system at some test conditions, as discussed later in Section 5.)

Other Variables

There were several other, unintended variables that were introduced into the GSA test program. The first was the coal supply, and the second was the high-calcium, pebble lime.

Coal - The bituminous coal being burned in the boiler became an unintended variable in this GSA test program when the existing contract for the coal supply expired and a new, low-bid supplier was selected. The same coal specification was used during the procurement to try to minimize the impact of the coal switch, but subtle changes in the coal composition (e.g. sulfur, chloride, or ash) may have an effect on the GSA system performance. Unfortunately, there were two of these coal supply changes incurred during the factorial test program. Thus, three different coals were burned, although only a very few tests were completed with two of these coals and their impact on the results should be very minor, if detectable.

The preliminary tests and the first two months of the factorial testing, encompassing only about 15 of the basic factorial tests, were completed with the Peabody Martwick coal. The remainder of the basic factorial tests and most of the replicate factorial tests were completed with the Emerald Energy Pleasant Valley coal. There were approximately 12 of the replicate factorial tests completed while the boiler burned a Warrior coal, however.

Lime - The lime supply contract expired early in the factorial test program and a new supplier was selected during the competitive bid process. Thus, the high-calcium lime became the second unintended variable in the GSA test program. However, after several months of testing with this apparently similar high-calcium, pebble lime and the completion of most of the basic factorial tests, problems were noted with this lime and the contract was returned to the original lime supplier. This lime supply was continued throughout the replicate factorial testing (and the two demonstration runs).

28-DAY GSA DEMONSTRATION RUN

As part of the Clean Coal Technology Program, one of the requirements was to complete a long-term demonstration run with the GSA/ESP system. Through

negotiations between AirPol and DOE, the long-term GSA/ESP demonstration run for this project was specified to be 28 days of around-the-clock, continous operation. This demonstration run was to be completed at the end of the factorial testing after the "optimum" test conditions had been determined. Thus, the specific test conditions were not defined until later in the test program. These test conditions were later defined to be: 320°F inlet flue gas temperature; 18°F approach-to-saturation temperature; 2.0 gr/acf fly ash level; 0.12 percent coal chloride level; 20,000 scfm flue gas flow rate; 30 rpm recycle screw speed; and 91 percent overall system (reactor/cyclone/ESP) SO_2 removal efficiency. The Ca/S level was allowed to fluctuate to achieve this overall system SO_2 removal efficiency setpoint.

The three major objectives of this 28-day GSA demonstration run were to: (1) achieve an average overall system (reactor/cyclone/ESP) SO_2 removal efficiency of 90+ percent during the entire 28-day run, (2) maintain the particulate emissions from the ESP below the New Source Performance Standards (NSPS) for particulates, and (3) demonstrate the reliability and operability of the GSA/ESP system by remaining on-line for the entire 28-day period.

14-DAY PJBH DEMONSTRATION RUN

After the PJBH project was incorporated into the overall GSA test program, a further objective of the GSA demonstration run was included. This objective was to complete a 14-day PJBH demonstration run during the final two weeks of the GSA demonstration run. However, because of problems that were encountered during the initial attempt in November 1993, the 14-day PJBH demonstration run had to be postponed until March 1994. This demonstration run was completed at the same test conditions as previously used in the 28-day GSA/ESP demonstration run.

Section 4
RESULTS

The SO_2 removal and ESP particulate control results from the 10-MW GSA Clean Coal Technology demonstration project are discussed in this section. These discussions are organized according to the specific test series. The four test series that will be discussed are the two factorial test series (the basic and replicate tests), the 28-day GSA demonstration run, and the 14-day PJBH demonstration run.

SO_2 REMOVAL PERFORMANCE

Factorial Tests

The tests from the statistically-designed factorial test plan were performed in two parts: the basic series of tests and the replicate series of tests. These factorial tests were designated as either the 2-AP or 3-AP series depending on the orientation and operational status of the 1-MW PJBH, which was tested concurrently with the GSA/ESP system. The test designation 2-AP was used to denote when either the PJBH was not operating or was operating in series with the ESP (i.e., withdrawing a slipstream of flue gas from downstream of the ESP). All of the replicate series of factorial tests were designed to be completed with the PJBH operating in series with the ESP. However, some of the basic tests were also completed with the PJBH off-line and were designated as 2-AP series tests. The test designation 3-AP was used when the PJBH was operated in parallel with the ESP (i.e., withdrawing a slipstream of flue gas from upstream of the ESP). Most of the basic factorial tests were completed with the PJBH operating in this mode.

A total of 78 tests were performed during the factorial test phase. Not all of these tests, however, were part of the original factorial test plan. As an example, several tests were added during the factorial test phase to further evaluate the performance of the PJBH. Table 4-1 lists only these 2-AP and 3-AP series tests that were conducted at operating

TABLE 4-1

FINALIZED BASIC AND REPLICATE TESTS

Basic Test Numbers		Replicate Test Numbers	
Planned	Actual	Planned	Actual
2-AP-01	2-AP-01	2-AP-71	2-AP-71
	3-AP-62		
2-AP-04	2-AP-04	2-AP-74	2-AP-74
2-AP-05	3-AP-29	2-AP-75	2-AP-75
2-AP-08	3-AP-08	2-AP-78	2-AP-78
2-AP-03	2-AP-03	2-AP-73	2-AP-73
	3-AP-03		
	3-AP-02		
2-AP-07	2-AP-07	2-AP-77	2-AP-77
2-AP-06	2-AP-06	2-AP-76	2-AP-92
2-AP-09	2-AP-09	2-AP-79	2-AP-79
	3-AP-12		
2-AP-16	2-AP-16	2-AP-72	2-AP-72
2-AP-11	2-AP-11	2-AP-81	2-AP-81
	3-AP-11		
2-AP-10	2-AP-10	2-AP-80	2-AP-80
2-AP-17	2-AP-17	2-AP-82	2-AP-82
2-AP-18	3-AP-18	2-AP-88	2-AP-88
2-AP-19	2-AP-19	2-AP-89	2-AP-97
	3-AP-19		
	2-AP-57		
2-AP-20	3-AP-20	2-AP-86	2-AP-86
	3-AP-13		
	3-AP-20		
2-AP-21	3-AP-21	2-AP-87	2-AP-87
2-AP-22	2-AP-22	2-AP-90	2-AP-90
	3-AP-22		
2-AP-23	3-AP-23	2-AP-83	2-AP-83
2-AP-24	2-AP-24	2-AP-84	2-AP-84
	3-AP-24		
2-AP-25	2-AP-25	2-AP-85	2-AP-85

conditions specified in the original factorial test plan. These tests typically consisted of 12 to 24 hours of operation to reach steady-state conditions, followed by 24 to 48 hours of testing from which the test averages were developed. The data from 10 test segments will not be reported due to problems encountered during these tests (2-AP-05, 2-AP-10, 2-AP-14 (file 2), 2-AP-15 (files 1 & 2), 2-AP-16, 2-AP-93, 3-AP-15, 3-AP-60, and 3-AP-61). The problems encountered during these tests include equipment operation which interfered with the GSA system achieving steady-state conditions, calibration problems with process monitoring equipment, and/or an insufficient amount of test data to develop representative test averages for the specific operating conditions.

The SO_2 removal results for the tests conducted at the baseline chloride levels (0.02-0.04 weight percent coal chloride) are presented in Table 4-2 for the 2-AP series tests and in Table 4-3 for the 3-AP series tests. Similarly, the SO_2 removal results are presented in Tables 4-4 and 4-5 for the chloride spiking tests (0.12 weight percent coal chloride equivalent) for the 2-AP and 3-AP series, respectively.

As shown in all of these tables, the majority of the SO_2 removal occurs in the reactor/cyclone portion of the GSA FGD system. The ESP contribution to the total system (reactor/cyclone/ESP) SO_2 removal ranged from only 1 to 7 percent. This result was somewhat surprising given our previous experience with other dry, lime-based FGD systems where the ESP provided substantial amounts of SO_2 removal.

There are at least three possible explanations for the fact that most of the SO_2 removal in the GSA FGD system occurs in the reactor/cyclone. First, because of the enhanced heat transfer in the GSA reactor, the solids entrained in the flue gas leaving the reactor have very low residual moisture levels. The moisture level in these solids typically ranged from 0.2 to 0.6 percent, depending on the major variable levels. In no tests did the residual moisture level reach 1.0 percent. At these low moisture levels, the SO_2 removal reaction rate, which is a strong function of the liquid water level, is very slow and thus, the SO_2 removal in the ESP is very low.

AirPol GSA/ESP SO2 Removal Results Summary

2-AP Series - Baseline Tests

Test No.	Ca/S Ratio	Reactor Inlet Temp (F)	Approach Temperature (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Injection Rate (lb/min)	Reactor Product Chloride Content (%)	Reactor/ Cyclone SO2 Removal (%)	ESP SO2 Removal (%)	Total System SO2 Removal (%)
2-AP-09	1.0	320	8	14,000	30	0	0	70.6	5.6	76.2
2-AP-79	1.0	320	8	14,000	30	0	0	82.5	1.3	83.8
2-AP-72	1.0	320	8	20,000	45	7.3	0	66.9	4.1	71.0
2-AP-16	1.0	320	8	20,000	45	7.8	0.04	74.1	0.5	74.6
2-AP-11	1.3	320	8	14,000	30	5.0	0	88.4	3.7	92.1
2-AP-81	1.3	320	8	14,000	30	5.2	0	86.1	4.1	90.2
2-AP-10	1.3	320	8	20,000	45	0	0	88.0	3.4	91.4
2-AP-80	1.3	320	8	20,000	45	0	0.09	84.1	4.2	88.3
2-AP-01	1.0	319	18	14,000	30	0	0	67.1	3.5	70.6
2-AP-71	1.0	320	18	14,000	30	0	0.02	73.9	4.0	77.9
2-AP-78	1.0	320	18	20,000	30	7.2	0	63.6	4.1	67.7
2-AP-04	1.0	320	18	19,000	45	0	0	66.0	1.7	67.7
2-AP-74	1.0	320	18	20,000	45	0	0	69.1	2.1	71.2
2-AP-03	1.3	319	18	14,000	45	0	0	88.4	2.6	91.0
2-AP-73	1.3	320	18	14,000	45	5.1	0	82.2	2.3	84.5
2-AP-95	1.3	320	18	20,000	45	0	0.05	78.2	4.7	82.9
2-AP-96	1.3	322	18	20,000	45	0	0.21	83.2	3.4	86.6
2-AP-14	1.3	320	18	18,000	45	6.7	0.12	80.4	5.0	85.4
2-AP-63	1.3	320	18	20,000	45	7.2	0.04	76.1	5.9	82.0
2-AP-63	1.3	320	18	20,000	45	7.2	0.03	75.4	3.1	78.5
2-AP-88	1.0	320	28	14,000	30	0	0.04	63.9	2.2	66.1
2-AP-87	1.0	320	28	20,000	45	7.3	0	59.2	3.2	62.4
2-AP-86	1.3	320	28	14,000	45	0	0.03	75.5	2.0	77.5
2-AP-97	1.3	320	28	20,000	30	0	0	68.1	4.4	72.5
2-AP-19	1.3	320	28	20,000	30	7.1	0	61.9	5.2	67.1
2-AP-57	1.3	319	28	19,500	30	7.1	0	73.3	5.5	78.8

AirPol GSA/ESP SO2 Removal Results Summary
3-AP Series - Baseline Tests

Test No.	Ca/S Ratio	Reactor Inlet Temperature (F)	Approach Temperature (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Injection Rate (lb/min)	Reactor Product Chloride Content (%)	Reactor/ Cyclone SO2 Removal (%)	ESP SO2 Removal (%)	Total System SO2 Removal (%)
3-AP-12	1.0	320	8	14,000	30	0	0	73.4	3.8	77.2
3-AP-58	1.0	320	8	14,000	30	0	0	87.8	3.7	91.5
3-AP-42	1.3	320	8	14,000	30	0	0	96.4	2.0	98.4
3-AP-11	1.3	319	8	14,000	30	5.2	0	98.6	0.7	99.3
3-AP-62	1.0	319	18	14,000	30	0	0.13	71.8	1.9	73.7
3-AP-08	1.0	320	18	20,000	30	7.0	0	57.2	6.9	61.1
3-AP-44	1.3	319	18	14,000	45	0	0.02	86.8	3.2	89.9
3-AP-03	1.3	319	18	14,000	45	5.0	0	78.3	4.0	82.3
3-AP-26	1.3	260	18	14,000	12	4.7	0	73.1	5.3	78.4
3-AP-27	1.3	260	18	14,000	30	4.7	0	81.1	3.8	84.9
3-AP-02	1.3	319	18	14,000	45	5.1	0	84.9	4.0	88.9
3-AP-18	1.0	319	28	14,000	30	0	0	63.3	3.4	66.7
3-AP-59	1.0	320	28	14,000	30	5.2	0	66.9	3.1	70.0
3-AP-21	1.0	319	28	20,000	45	7.3	0	54.7	6.0	60.7
3-AP-56	1.3	320	28	14,000	30	0	0	82.8	2.7	85.5
3-AP-20	1.3	320	28	14,000	45	0	0	83.2	3.3	86.5
3-AP-20	1.3	320	28	14,000	45	0	0.03	84.3	2.3	86.6
3-AP-13	1.3	319	28	14,000	45	0	0	79.8	5.0	84.8
3-AP-45	1.3	320	28	14,000	45	5.2	0	80.3	2.4	82.7
3-AP-19	1.3	320	28	20,000	30	7.4	0	69.9	5.3	74.2

TABLE 4-3

AirPol GSA/ESP SO2 Removal Results Summary

2-AP Series - Chloride Spiking Tests

Test No.	Ca/S Ratio	Reactor Inlet Temperature (F)	Approach Temperature (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Inj. Rate (lb/min)	Reactor Product Chloride Content (%)	Reactor/ Cyclone SO2 Removal (%)	ESP SO2 Removal (%)	Total System SO2 Removal (%)
2-AP-28	1.0	320	18	14,000	40	5.0	0.39	77.6	5.1	82.7
2-AP-75	1.0	320	18	14,000	45	4.7	0.45	76.2	4.3	80.5
2-AP-17	1.0	320	18	20,000	30	0	0.75	76.8	2.6	79.4
2-AP-82	1.0	320	18	20,000	30	0	0.87	76.5	1.8	78.3
2-AP-07	1.3	320	18	14,000	30	5.4	0.29	91.0	3.9	94.9
2-AP-77	1.3	320	18	14,000	30	5.0	0.30	88.2	5.6	93.8
2-AP-98*	1.3	320	18	14,000	30	5.2	0.30	88.1	2.4	90.5
2-AP-06	1.3	320	18	20,000	45	0	0.47	88.8	4.9	93.9
2-AP-92	1.3	320	18	20,000	45	0	0.72	89.0	2.4	91.4
2-AP-91	1.3	320	18	20,000	45	7.2	0.32	87.6	2.1	89.7
2-AP-22	1.0	320	28	14,000	45	0	0.57	75.7	3.7	79.4
2-AP-90	1.0	320	28	14,000	45	0	0.86	68.9	1.0	69.9
2-AP-25	1.0	320	28	18,600	30	6.8	0.28	60.8	6.2	67.0
2-AP-94	1.0	320	28	20,000	30	0	0.81	65.4	0.7	66.1
2-AP-85	1.0	320	28	20,000	30	7.4	0.31	64.3	0.6	64.9
2-AP-84	1.3	320	28	14,000	30	0	0.60	79.4	3.0	82.4
2-AP-24	1.3	320	28	14,000	30	0	0.41	82.3	3.2	85.5
2-AP-83	1.3	320	28	20,000	30	7.3	0.26	70.2	9.7	79.9

* Test data has not been finalized.

TABLE 4-4

AirPol GSA/ESP SO2 Removal Results Summary
3-AP Series - Chloride Spiking Tests

Test No.	Ca/S Ratio	Reactor Inlet Temperature (F)	Approach Temperature (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Injection Rate (lb/min)	Reactor Product Chloride Content (%)	Reactor/ Cyclone SO2 Removal (%)	ESP SO2 Removal (%)	Total System SO2 Removal (%)
3-AP-29	1.0	320	18	14,000	45	5.2	0.31	84.0	2.2	86.2
3-AP-22	1.0	320	28	14,000	45	0	0.57	76.7	3.4	80.1
3-AP-24	1.3	320	28	14,000	30	0	0.46	81.9	4.4	86.3
3-AP-23	1.3	320	28	19,200	45	7.2	0.26	79.3	4.1	83.4

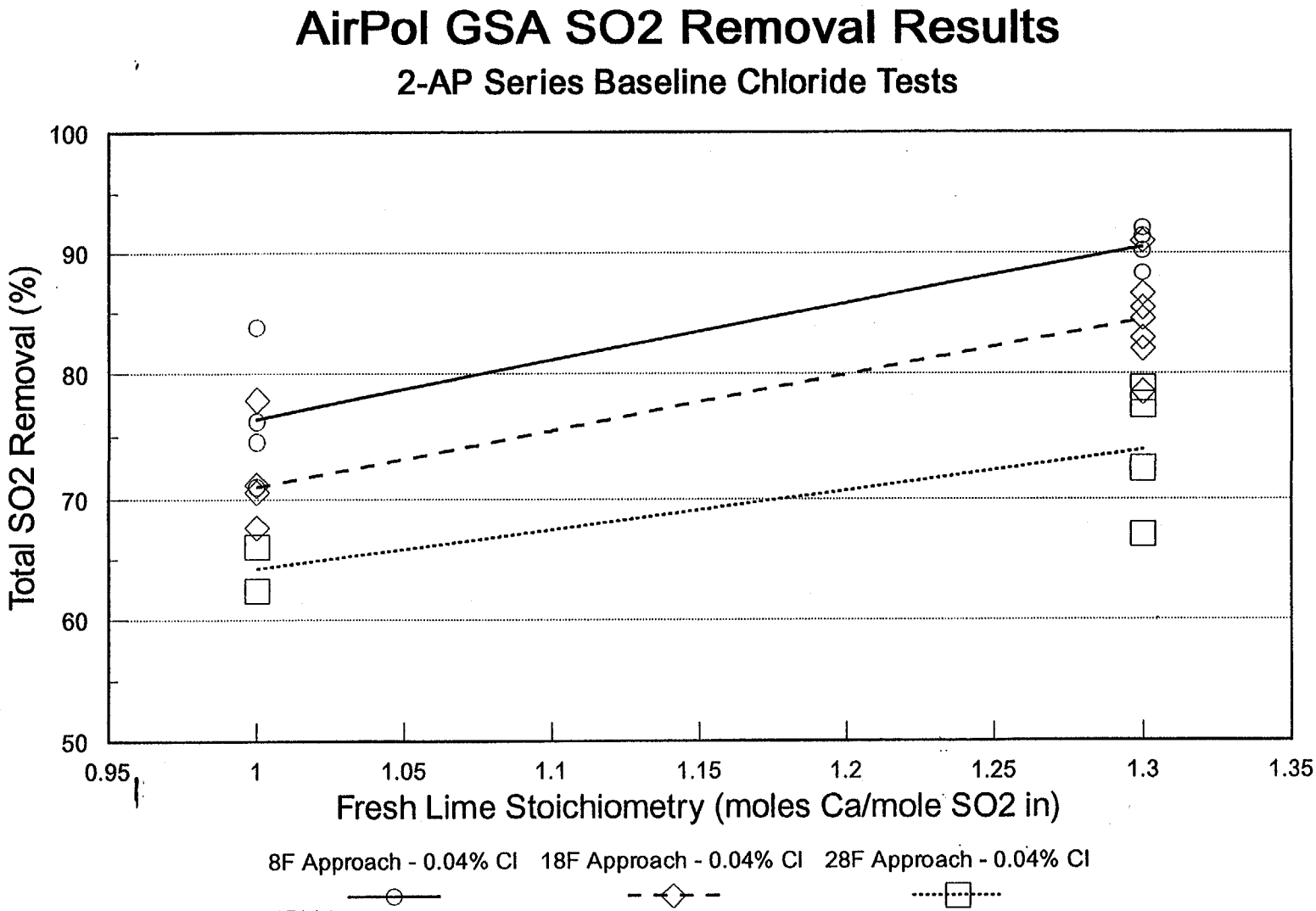
TABLE 4-5

Second, because of the enhanced mass transfer in the GSA reactor, a high SO_2 removal efficiency is achieved in the reactor/cyclone and the SO_2 concentration in the flue gas entering the ESP is dramatically reduced. Since the ESP does not provide intimate contact between the particles collected on the plates and the SO_2 in the flue gas flowing past the plates, the potential for additional SO_2 removal in the ESP is reduced.

Third, the cyclone installed between the reactor and the ESP removes most of the alkaline particulate matter from the flue gas before it can reach the ESP and thus, the internal lime stoichiometry in the ESP is significantly lower than that in the reactor/cyclone. Without the presence of these alkaline solids, the SO_2 removal in the ESP is reduced to low levels.

Effect of Lime Stoichiometry and Approach-to-Saturation Temperature - The SO_2 removal performance results from all of the 2-AP series tests conducted at baseline chloride levels (0.04 weight percent coal chloride) are presented in Figure 4-1. In the figure, the average total system (reactor/cyclone/ESP) SO_2 removal is plotted for each test as a function of the fresh lime stoichiometry with different symbols used to denote the three levels of approach temperature; 8, 18 and 28°F. Linear regression curves for each approach temperature are also plotted in the figure.

As shown in Figure 4-1, the total system SO_2 removal increases as the fresh lime stoichiometry is increased from 1.0 to 1.3 moles $Ca(OH)_2$/mole inlet SO_2 and the approach temperature is decreased from 28 to 8°F. The average total system SO_2 removal ranged from a low of approximately 62 percent at a 1.0 stoichiometry and a 28°F approach to a high of 92 percent at a 1.3 stoichiometry and an 8°F approach temperature. Based on the linear regression lines, the SO_2 removal increases approximately 9 to 13 percentage points as the stoichiometry is increased from 1.0 to 1.3. The increase in SO_2 removal as the approach temperature is reduced from 28 to 18°F is about 6 to 10 percentage points at the same fresh lime stoichiometry. A decrease in the approach temperature from 18 to 8°F results in a further increase in SO_2 removal of about 5 to 6 percentage points at the same fresh lime stoichiometry.



Notes: All tests conducted at a 320F inlet flue gas temperature and 25 wt % solids lime slurry.

FIGURE 4-1

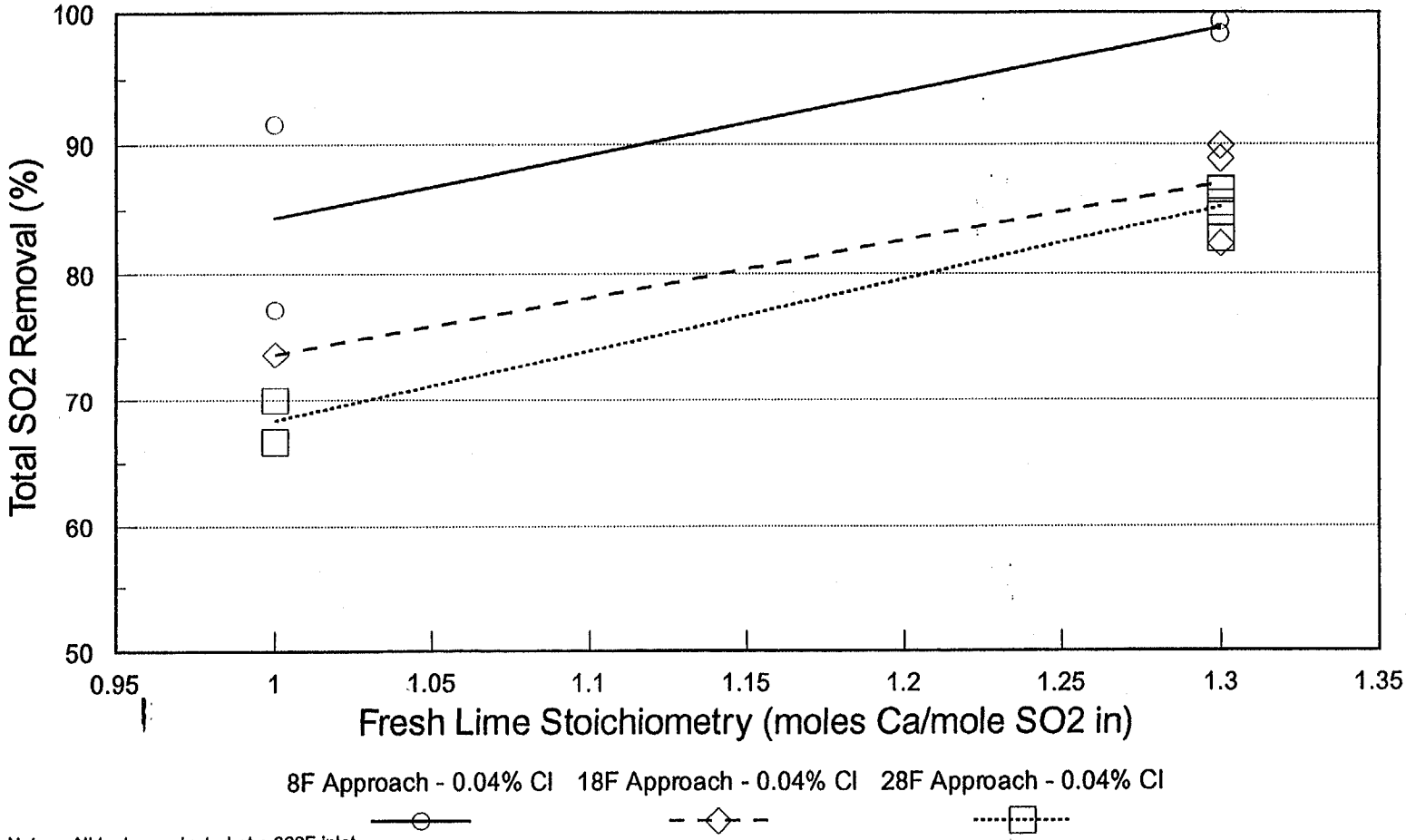
Figure 4-2 provides a similar plot of the data from the 3-AP series tests. In the figure, only the tests conducted at the lower flue gas flow rate of 14,000 scfm are plotted. Because only the 3-AP series tests at 14,000 scfm are plotted, the SO_2 removal performance is higher in these tests compared to the 2-AP series results presented in Figure 4-1. This higher SO_2 removal performance is presumably due to the increased flue gas residence time in the GSA reactor/cyclone at the lower flue gas flow rate. Unlike the prior figure, the increase in SO_2 removal is greater when the approach temperature is decreased from 18 to 8°F (10 percentage points) compared to the increase when reducing the approach temperature from 28 to 18°F (2 to 5 percentage points). This result would support the theory that the increased residence time in the reactor/cyclone allows more reaction time since the lower approach temperature corresponds to a reduced driving force for the evaporation of water and thus, liquid water would be present longer in the reactor/cyclone.

These figures show that the fresh lime stoichiometry and the approach temperature in the reactor/cyclone are two of the most important variables for determining the SO_2 removal efficiency in the GSA FGD system. These results were not unexpected based on our previous experience with the SD FGD system. Since the fresh lime stoichiometry determines the ratio of the two reactants ($Ca(OH)_2$ and SO_2), one would anticipate that this variable would be extremely important and have a major effect on the total system SO_2 removal efficiency. Thus, the higher SO_2 removal efficiency at the higher lime stoichiometry was expected.

The effect of the approach temperature on SO_2 removal efficiency is somewhat less straight forward. One of the keys to rapid absorption and reaction of the SO_2 in these dry scrubbing FGD systems is the presence of liquid water to facilitate the reaction between lime and SO_2. The approach temperature defines both how much liquid water can be injected into the flue gas and also the driving force for the evaporation of the water. At a close approach temperature, more water is injected into the flue gas and also the driving force for evaporating the last water is dramatically reduced. Thus, the liquid water is present in the solids longer and the SO_2 removal efficiency is increased.

AirPol GSA SO2 Removal Results

3-AP Series Baseline Chloride Tests



Notes: All tests conducted at a 320F inlet flue gas temperature, 25 wt % solids lime slurry and 14,000 scfm.

FIGURE 4-2

These results confirm that the GSA FGD is capable of achieving high SO_2 removal efficiencies (90 percent) at the relatively modest lime stoichiometry of 1.30 moles $Ca(OH)_2$/mole inlet SO_2 and with little or no chloride in the system. These factorial test results confirmed that high SO_2 removals are feasible, which was one of the major objectives of this test program. Prior to the start of the factorial testing there was some question whether the GSA FGD system could achieve 90 percent SO_2 removal at the lower lime stoichiometries included in the factorial test plan.

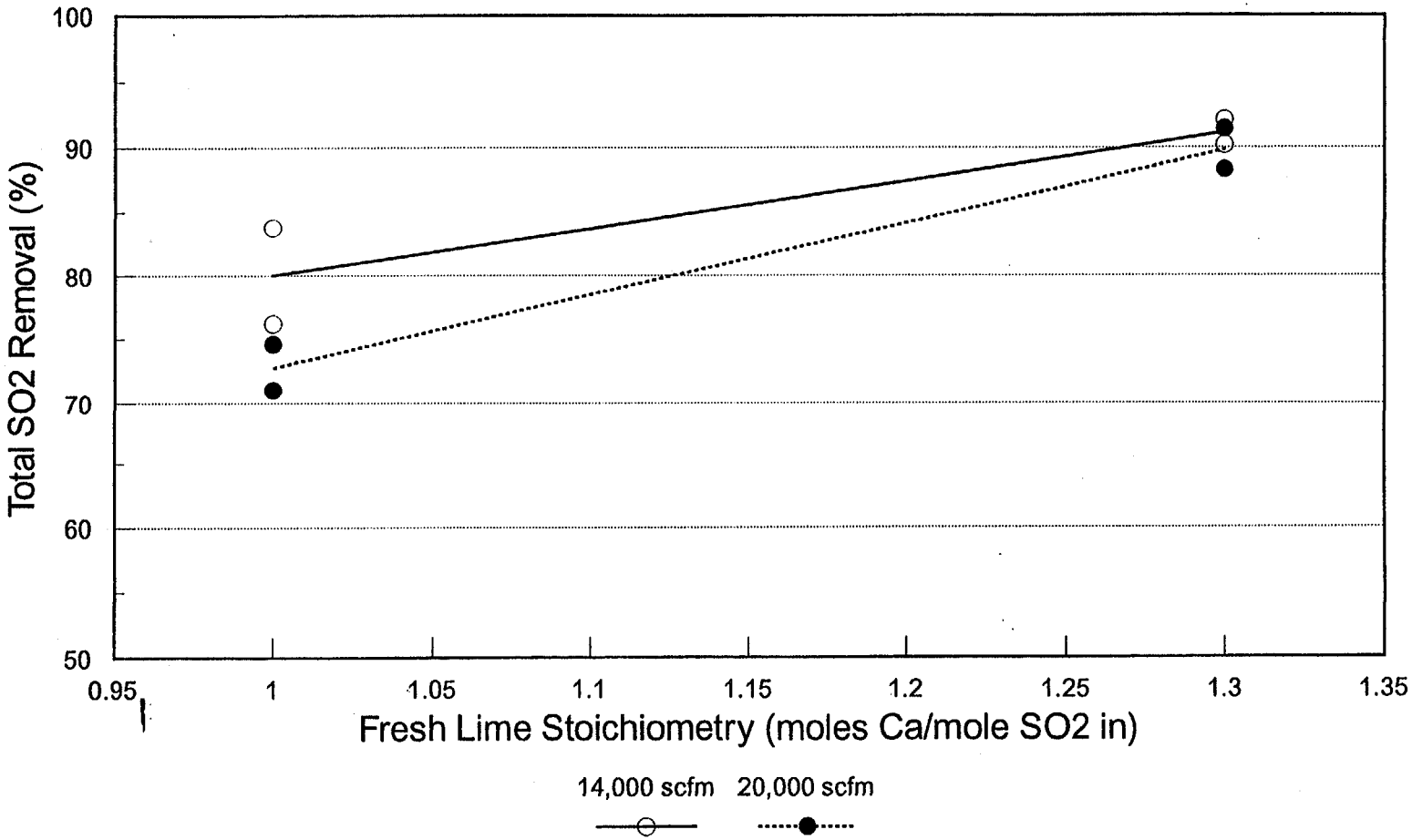
Effect of Flue Gas Flow Rate - The flue gas flow rate through the GSA system was also found to be a significant variable affecting the SO_2 removal performance. Figures 4-3, 4-4 and 4-5 present the results from the 2-AP series tests conducted at baseline chloride levels. In each figure, the average total SO_2 removal is plotted for each test as a function of fresh lime stoichiometry. The distinction is made in each figure for tests conducted at the two flue gas flow rate levels, 14,000 and 20,000 scfm. Linear regression lines are plotted for each flue gas flow rate. Figure 4-3 plots data for tests conducted at an 8°F approach temperature, while in Figures 4-4 and 4-5 the data for tests conducted at an 18 and 28°F approach temperatures, respectively, are plotted.

In all three figures, the SO_2 removal performance in the GSA system is lower at the higher flue gas flow rate, i.e., 20,000 scfm. The decrease in performance ranges from approximately 2 to 8 percentage points based on the linear regression lines. The lower SO_2 removal performance at the design flue gas flow rate (20,000 scfm) was also observed in the 2-AP series tests conducted with calcium chloride spiking. Figures 4-6 and 4-7 provide similar plots of the average total system SO_2 removal as a function of fresh lime stoichiometry for tests conducted at an 18 and 28°F approach temperature, respectively. Similar to the baseline chloride tests, the SO_2 removal in the GSA system decreased from approximately 2 to 9 percentage points as the flue gas flow rate increased from 14,000 to 20,000 scfm.

This same effect was also observed in the 3-AP series tests. Figure 4-8 plots the average total system SO_2 removal in the GSA system as a

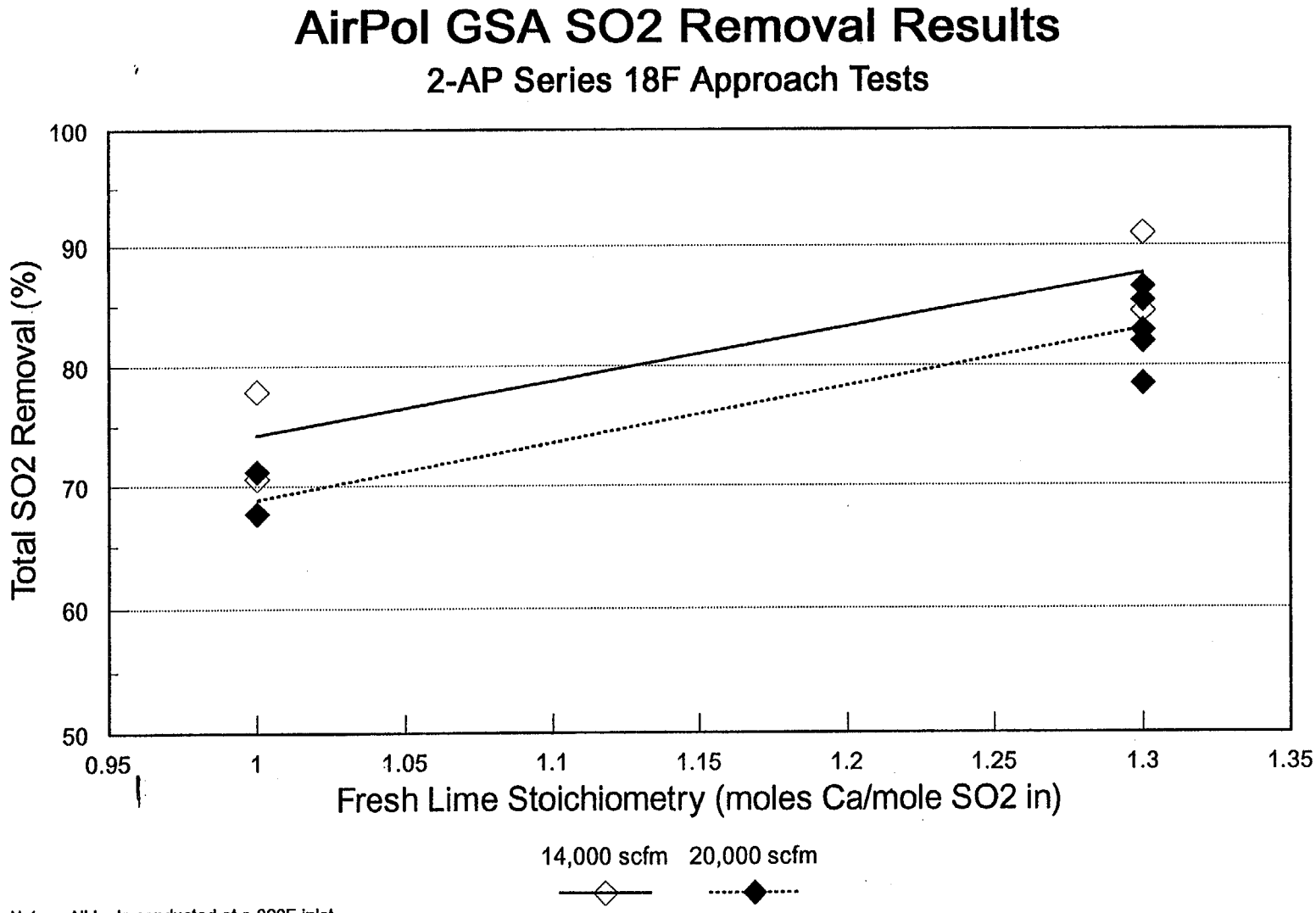
AirPol GSA SO2 Removal Results

2-AP Series 8F Approach Tests



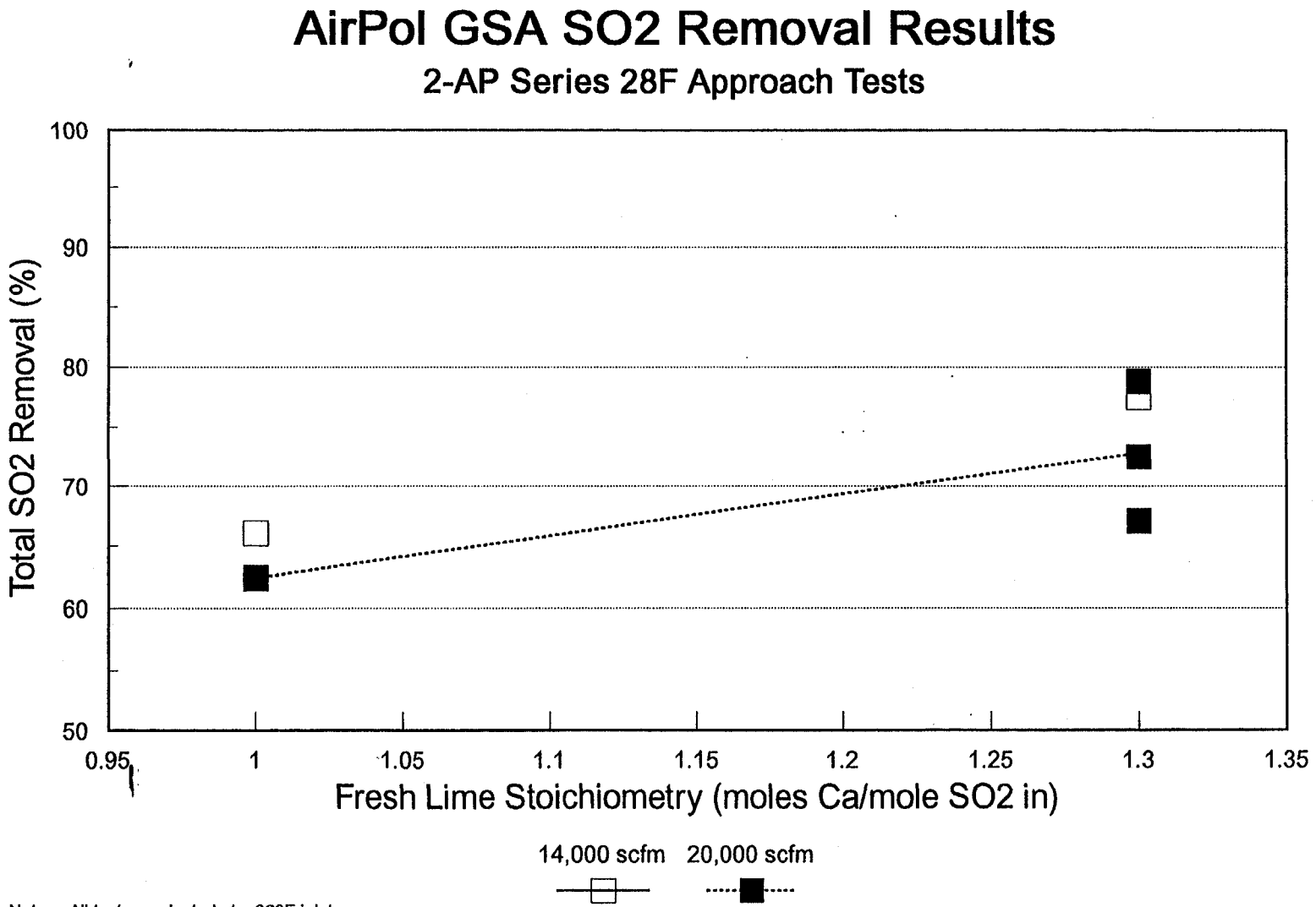
Notes: All tests conducted at a 320F inlet flue gas temperature, 8F approach temperature, and at a 0.04% coal Cl level.

FIGURE 4-3



Notes: All tests conducted at a 320F inlet flue gas temperature, 18F approach temperature, and at a 0.04% coal Cl level.

FIGURE 4-4

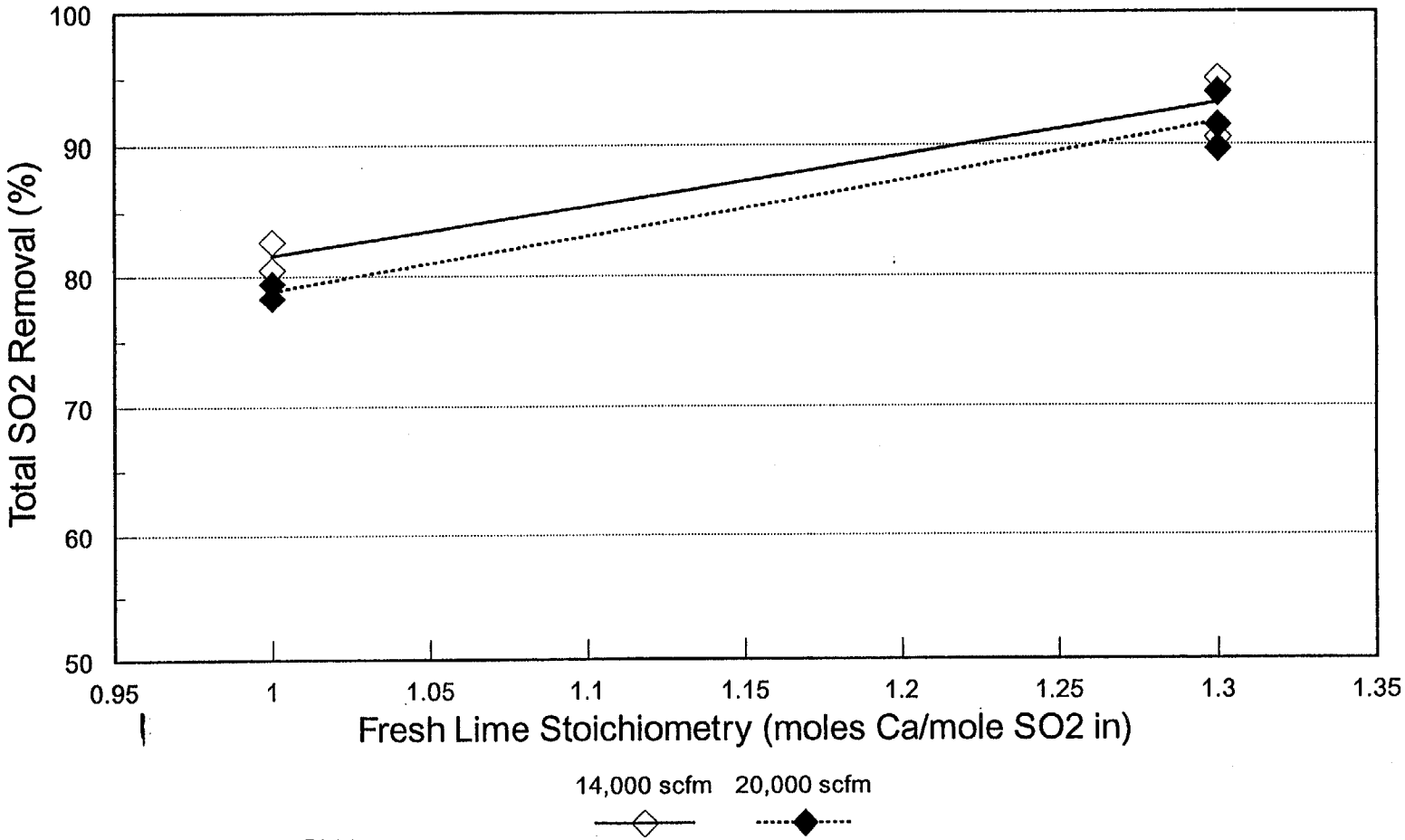


Notes: All tests conducted at a 320F inlet flue gas temperature, 28F approach temperature, and at a 0.04% coal Cl level.

FIGURE 4-5

AirPol GSA SO2 Removal Results

2-AP Series 18F Approach/Chloride Spiking Tests

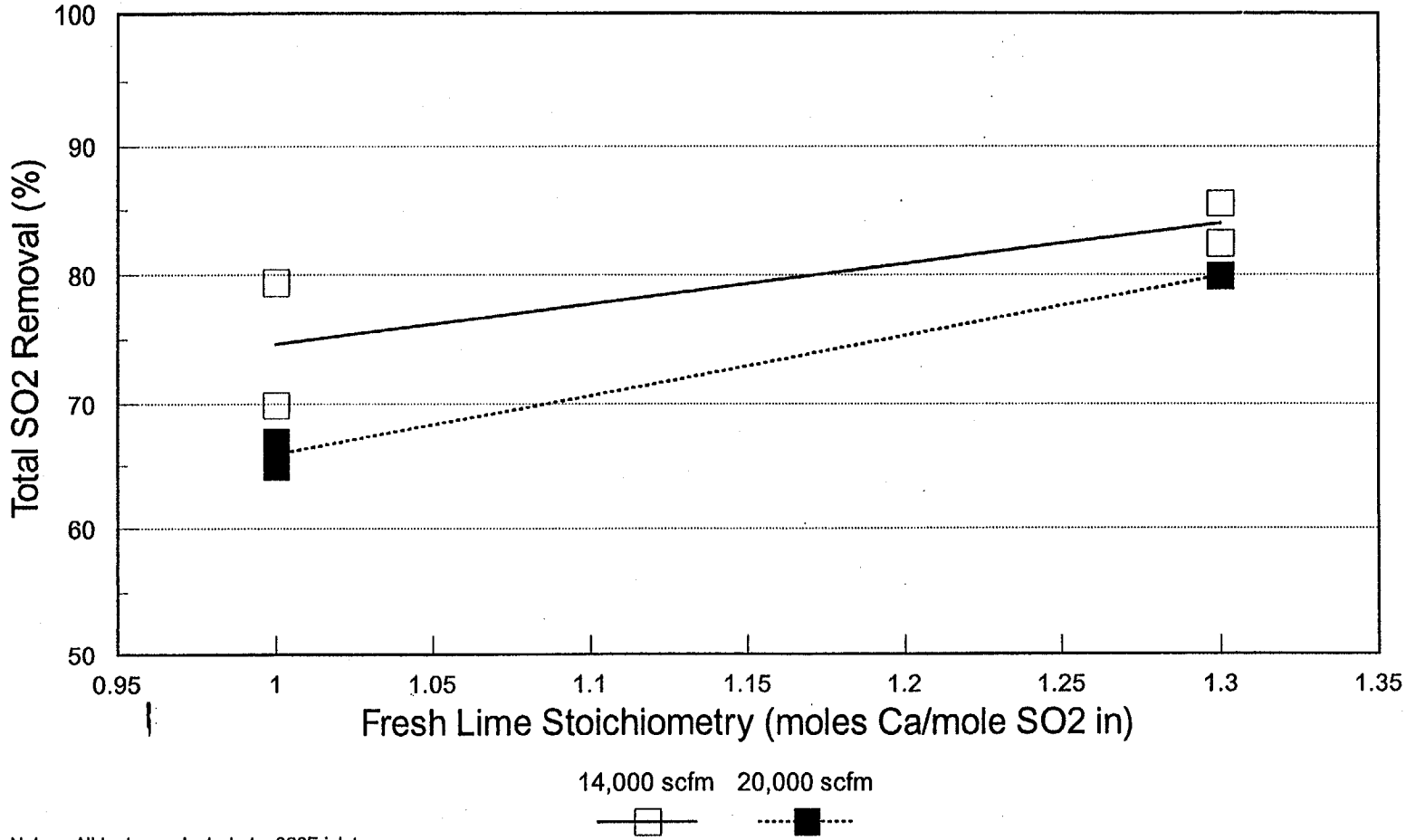


Notes: All tests conducted at a 320F inlet flue gas temperature, 18F approach temperature, and at a 0.12% coal Cl level.

FIGURE 4-6

AirPol GSA SO2 Removal Results

2-AP Series 28F Approach/Chloride Spiking Tests

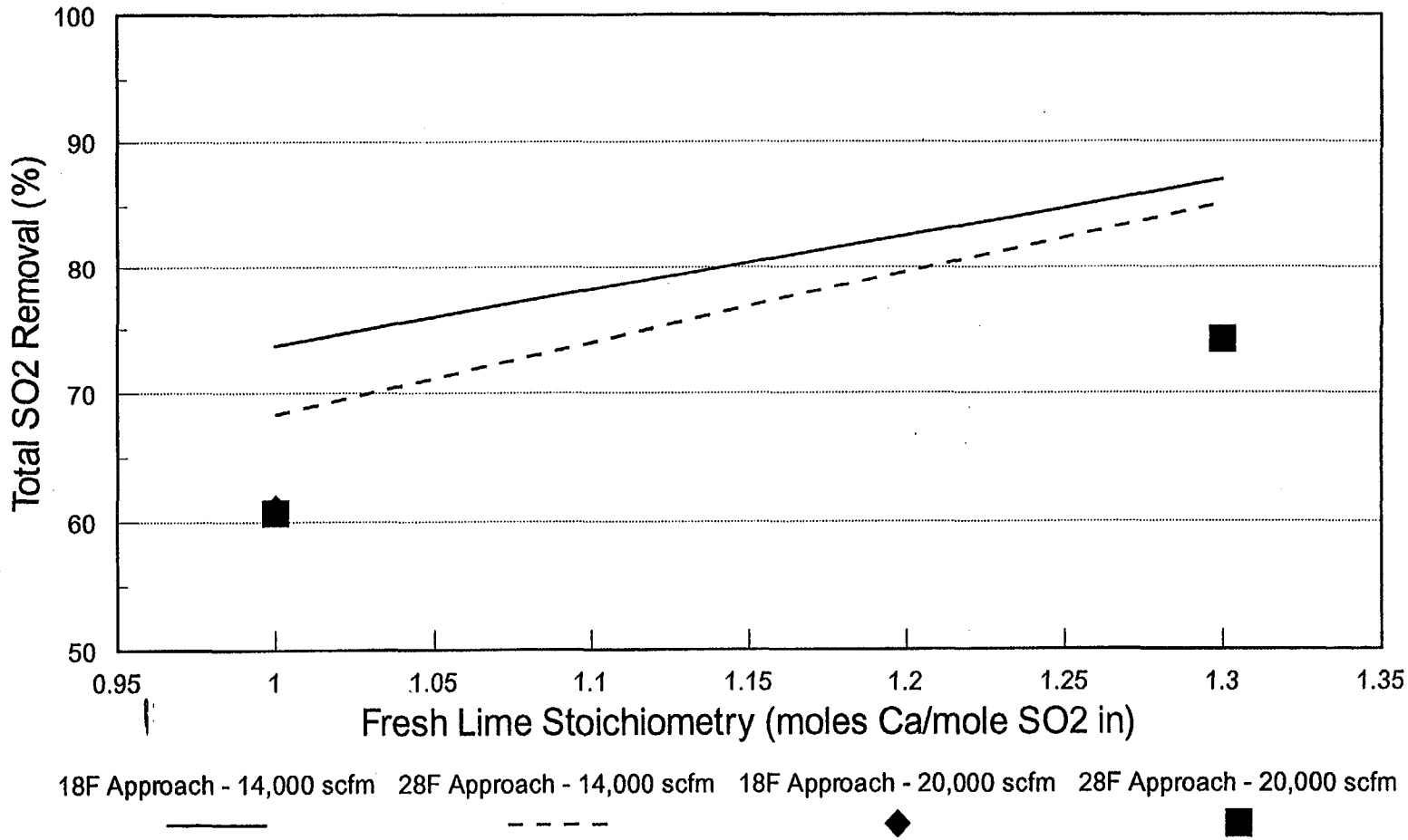


Notes: All tests conducted at a 320F inlet flue gas temperature, 28F approach temperature, and at a 0.12% coal Cl level.

FIGURE 4-7

AirPol GSA SO2 Removal Results

3-AP Series Baseline Chloride Tests



Notes: All tests conducted at a 320F inlet flue gas temperature and 25 wt % solids lime slurry.

FIGURE 4-8

function of the fresh lime stoichiometry for the 3-AP series tests conducted at baseline chloride levels. In the figure, the tests conducted at an 18 and 28°F approach temperature and at flue gas flow rates of 14,000 and 20,000 scfm are plotted. Only the regression lines are plotted for the test data at a flue gas flow rate of 14,000 scfm in order to more readily distinguish the data points from the tests conducted at 20,000 scfm. All three tests conducted at the higher flue gas flow rate resulted in decreased SO_2 removal performance. Based on the linear regression lines, the decrease in SO_2 removal was approximately 10 percentage points.

The increase in SO_2 removal in the GSA system at the lower flue gas flow rate is presumably due to the increased residence time in the GSA reactor/cyclone. The flue gas residence time increases from approximately 3.9 sec. at a flue gas flow rate of 20,000 scfm to 5.5 sec. at 14,000 scfm. Although this is only a 1.6 sec. differential, it represents a 41 percent increase in the flue gas residence time. The effect of residence time in the GSA reactor/cyclone, especially at these low residence times, may be more significant compared to other dry scrubbing technologies such as the SD FGD system because the cyclone downstream of the reactor removes over 90 percent of the solids/sorbent from the flue gas stream, thus minimizing the potential for further reaction of the sorbent with the flue gas SO_2 in the downstream ductwork and particulate control device.

The design flue gas flow rate through the system represents a trade-off between several factors. The higher flue gas flow rate condition results in a smaller reactor vessel size, which substantially reduces the capital cost for the system. Furthermore, if the design flue gas flow rate is reduced too far, at low boiler load conditions the flue gas velocity in the reactor may be too low to entrain the reinjected solids. However, this higher design flue gas flow rate results in a lower SO_2 removal efficiency in the system.

The lower flue gas flow rate of 14,000 scfm was specifically included in the factorial testing to evaluate the effect of lower boiler loads on the performance of GSA system. Based on the results of this factorial testing, it would appear that the SO_2 removal efficiency would increase

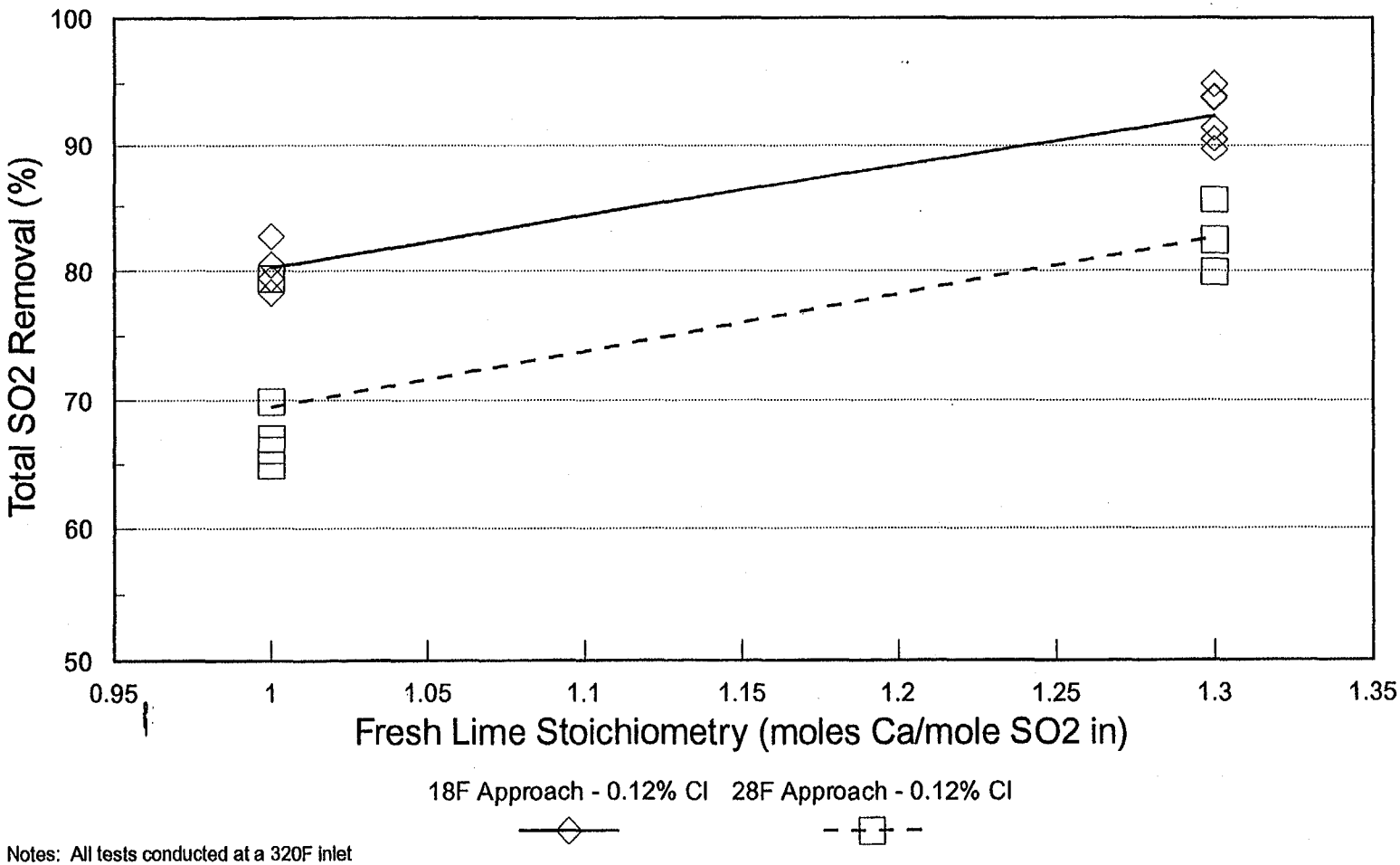
at lower boiler loads, although there are several other variables that may have an impact on the SO_2 removal efficiency at reduced boiler loads. However, because of time constraints, these other variables were not evaluated in this test program.

Effect of Chloride Spiking - Similar to prior dry scrubbing studies, calcium chloride spiking to simulate a higher coal chloride level was found to have a beneficial effect on SO_2 removal in the GSA system in this testing. Figure 4-9 presents the data from the 2-AP series tests conducted with calcium chloride spiking to simulate scrubbing flue gas resulting from the combustion of a 0.12 weight percent chloride coal. In this figure, the average total system SO_2 removal efficiency is plotted as a function of fresh lime stoichiometry for tests conducted at an 18 and 28°F approach temperature. The average total system SO_2 removal ranged from a low of approximately 65 percent at a 1.0 stoichiometry and a 28°F approach to a high of 94 percent at a 1.3 stoichiometry and an 18°F approach temperature. Based on the linear regression lines, the SO_2 removal increases approximately 12 percentage points as the lime stoichiometry is increased from 1.0 to 1.3 moles $Ca(OH)_2$/mole inlet SO_2. The increase in SO_2 removal as the approach temperature is reduced from 28 to 18°F is about 10 percentage points. No chloride spiking tests were completed below an 18°F approach temperature because of the potential for solids build-up/plugging problems.

The baseline chloride results for the 2-AP series tests are compared with the chloride spiking test results in Figures 4-10 and 4-11. Figure 4-10 presents the data at an 18°F approach temperature and Figure 4-11 presents the 28°F approach test results. The distinction is made in the figures for tests conducted at the flue gas flow rates of 14,000 and 20,000 scfm. Compared to the baseline chloride results, the higher chloride level improves SO_2 removal in the GSA system by about 4 to 10 percentage points at a stoichiometric ratio of 1.0 moles $Ca(OH)_2$/mole inlet SO_2. At a stoichiometric ratio of 1.3 moles $Ca(OH)_2$/mole inlet SO_2, the increase in SO_2 removal is comparable, ranging from about 4 to 9 percentage points.

AirPol GSA SO2 Removal Results

2-AP Series Chloride Spiking Tests



Notes: All tests conducted at a 320F inlet flue gas temperature and 25 wt % solids lime slurry.

FIGURE 4-9

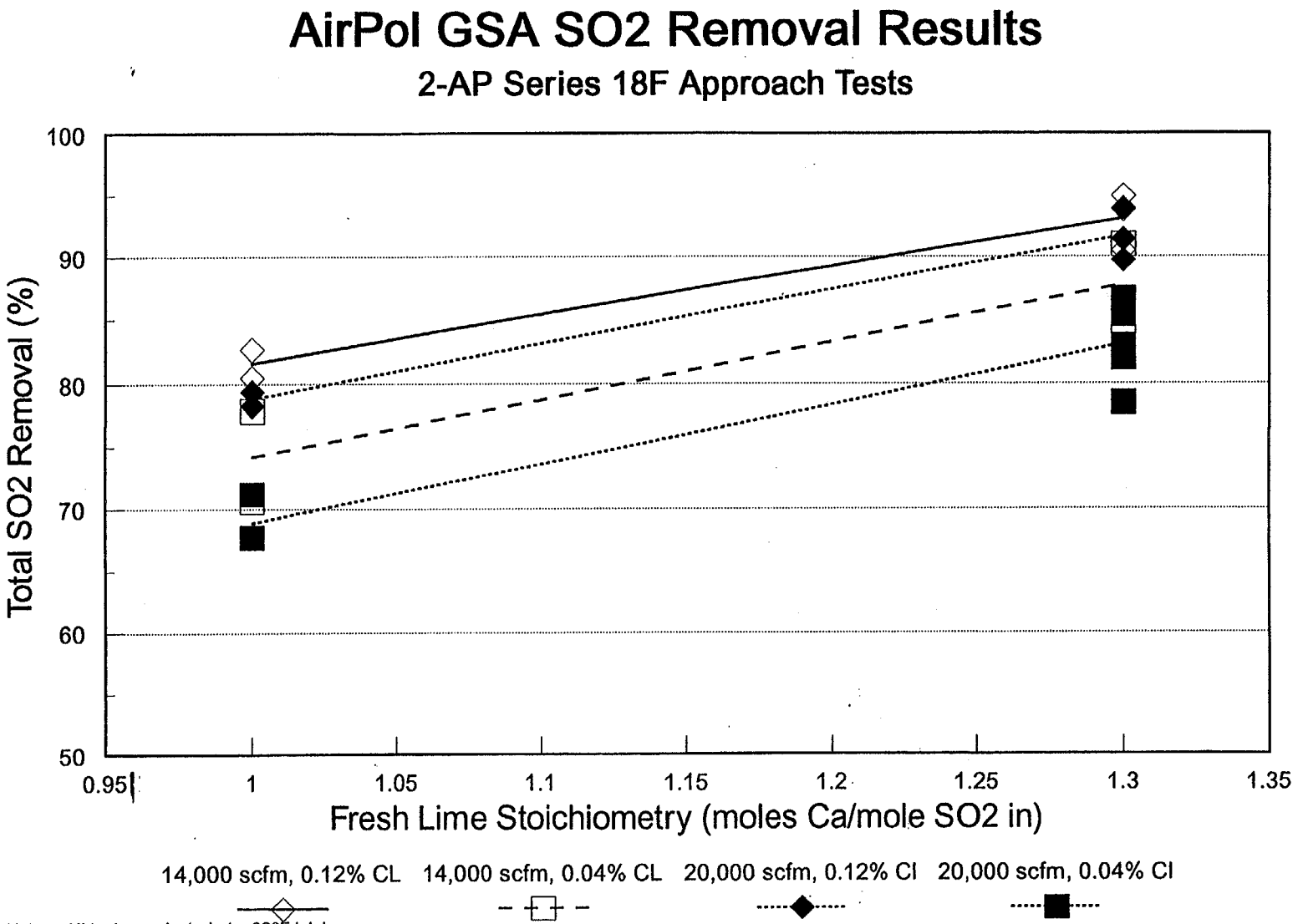
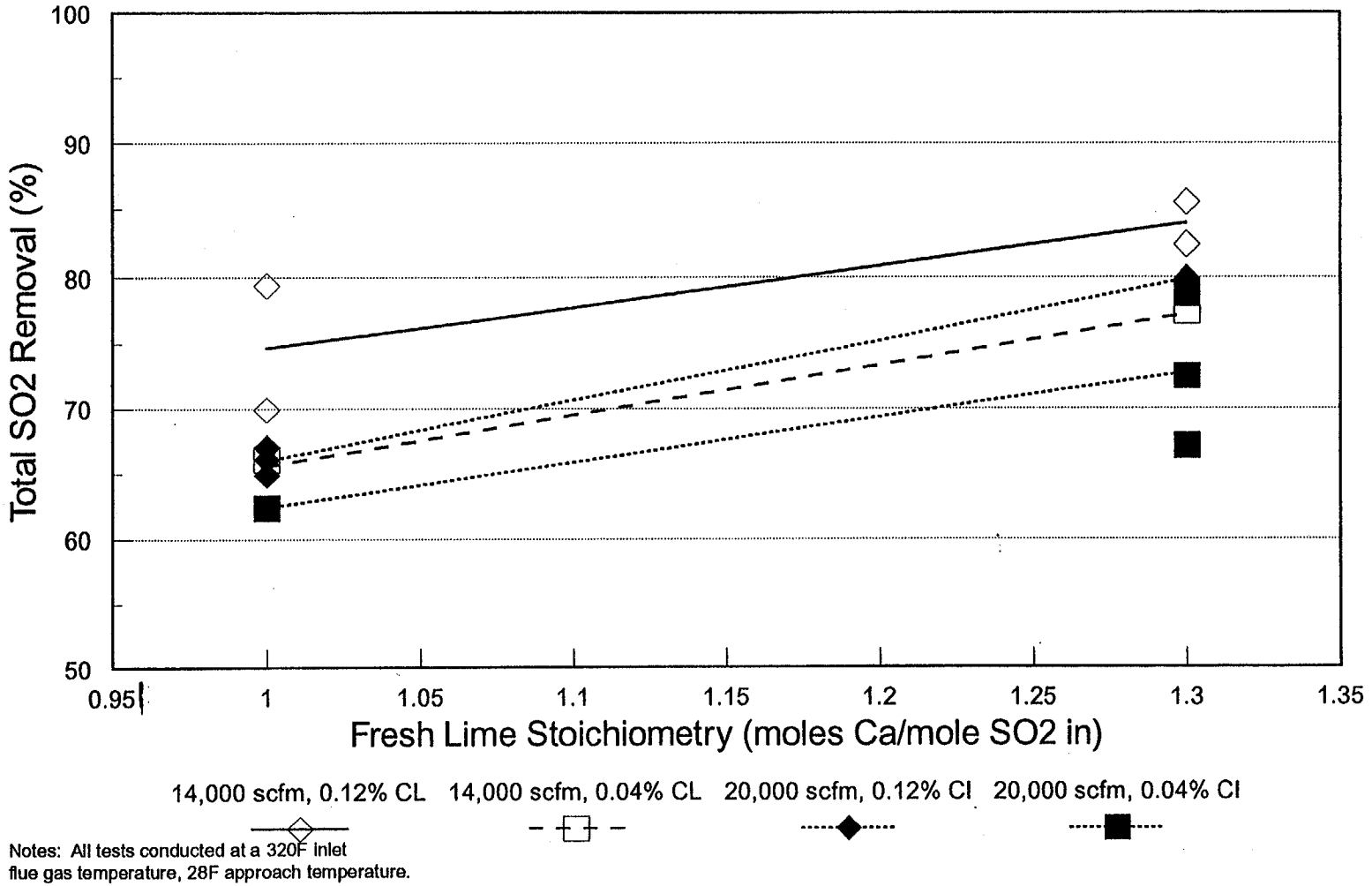

AirPol GSA SO2 Removal Results
2-AP Series 18F Approach Tests
Total SO2 Removal (%)
100
90
80
70
60
50
0.95
1
1.05
1.1
1.15
1.2
1.25
1.3
1.35
Fresh Lime Stoichiometry (moles Ca/mole SO2 in)
14,000 scfm, 0.12% CL
14,000 scfm, 0.04% CL
20,000 scfm, 0.12% Cl
20,000 scfm, 0.04% Cl
Notes: All tests conducted at a 320F inlet
flue gas temperature, 18F approach temperature.

FIGURE 4-10

AirPol GSA SO2 Removal Results

2-AP Series 28F Approach Tests



Notes: All tests conducted at a 320F inlet flue gas temperature, 28F approach temperature.

FIGURE 4-11

An increase in SO_2 removal with calcium chloride addition was also observed in the 3-AP series tests. Figure 4-12 presents the data for tests conducted at an 18 and 28°F approach temperature. Only the regression lines are plotted for the baseline chloride test data in order to more readily distinguish the data points from the chloride spiking tests. The tests conducted at a 1.0 stoichiometry exhibited approximately 12 to 13 percentage point increase in total system average SO_2 removal. The one test conducted at a 1.3 stoichiometry, however, did not show any improvement. This latter result is somewhat unexpected and a suitable explanation for this test result is not available.

Effect of Other Operational Variables - The other operational variables, such as recycle screw speed and inlet fly ash loading, also had an effect on the total system SO_2 removal efficiency. The influence of these variables, however, was much less than the effect of lime stoichiometry, approach temperature, coal chloride level, and flue gas flow rate (residence time).

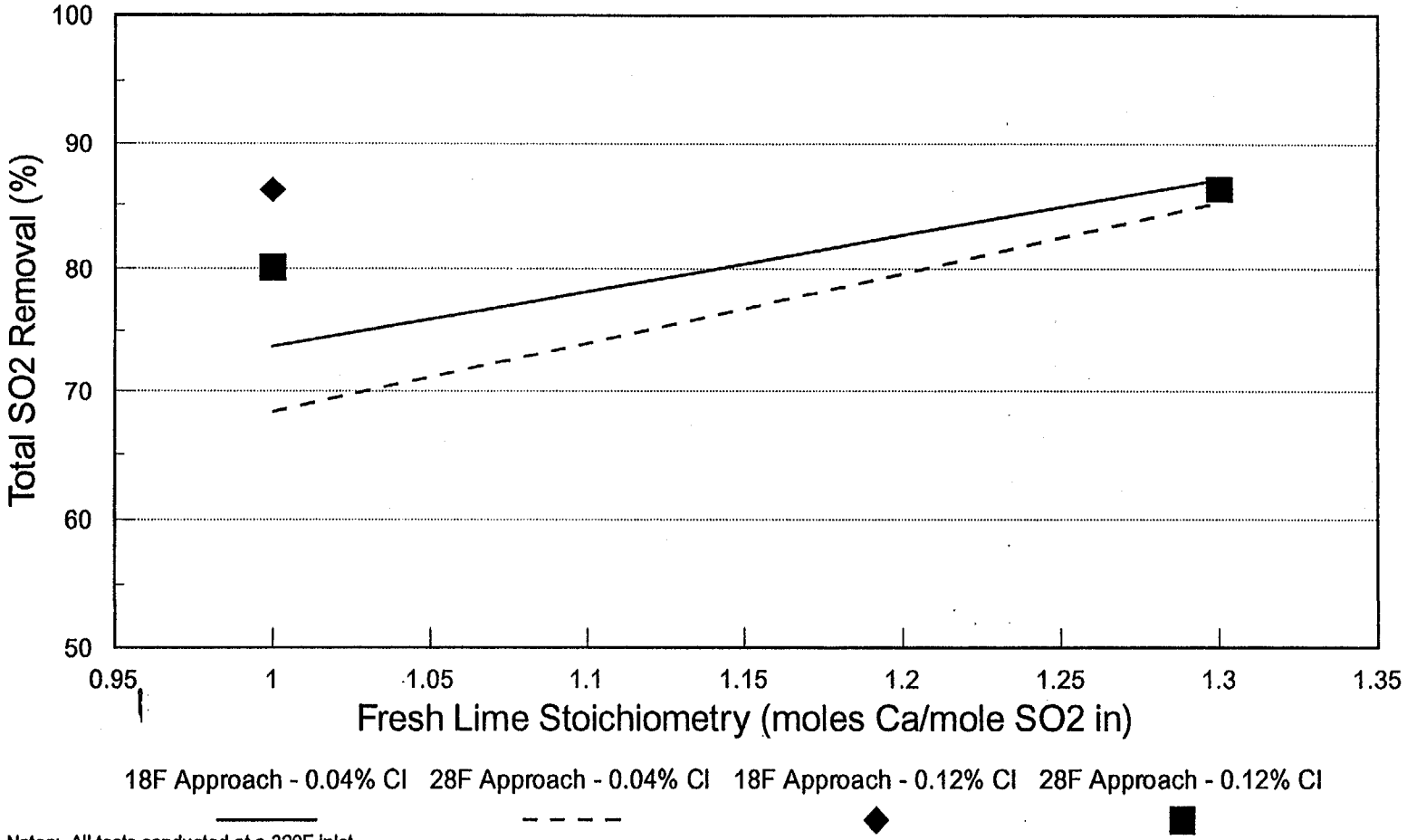
Lime Utilization

The total system (reactor/cyclone/ESP) calculated lime utilizations based on the process data ranged from 50 to 84 percent during the factorial tests. The lime utilization in the GSA system is calculated by dividing the total system SO_2 removal by the fresh lime stoichiometry. The lowest lime utilization rates, as expected, were for tests conducted at the higher approach temperature (28°F) and higher fresh lime stoichiometry (1.30 moles $Ca(OH)_2$/mole inlet SO_2). Decreasing the approach temperature and/or the fresh lime stoichiometry improved the lime utilization in the GSA system. Calcium chloride spiking also improved the lime utilization compared to tests conducted at the same operating conditions at the baseline (0.02-0.04 weight percent) coal chloride levels.

The lime utilization was also determined analytically for three sample locations; the recycle feeder box solid samples, the solids from the first field ESP hopper, and a composite from ESP fields 2 through 4. Typically, the measured calcium utilization for the reactor recycle solids would

AirPol GSA SO2 Removal Results

3-AP Series Baseline/Chloride Spiking Tests



Notes: All tests conducted at a 320F inlet flue gas temperature, 25 wt % solids lime slurry and 14,000 scfm.

FIGURE 4-12

either be lower or fall in between the measured calcium utilization values for the ESP solids. The highest calcium utilization values were typically measured for the solids from ESP hoppers 2 through 4. This result is to be expected due to the additional SO_2 removal that occurs in the ESP.

Comparison with Previous 10-MW SD Results

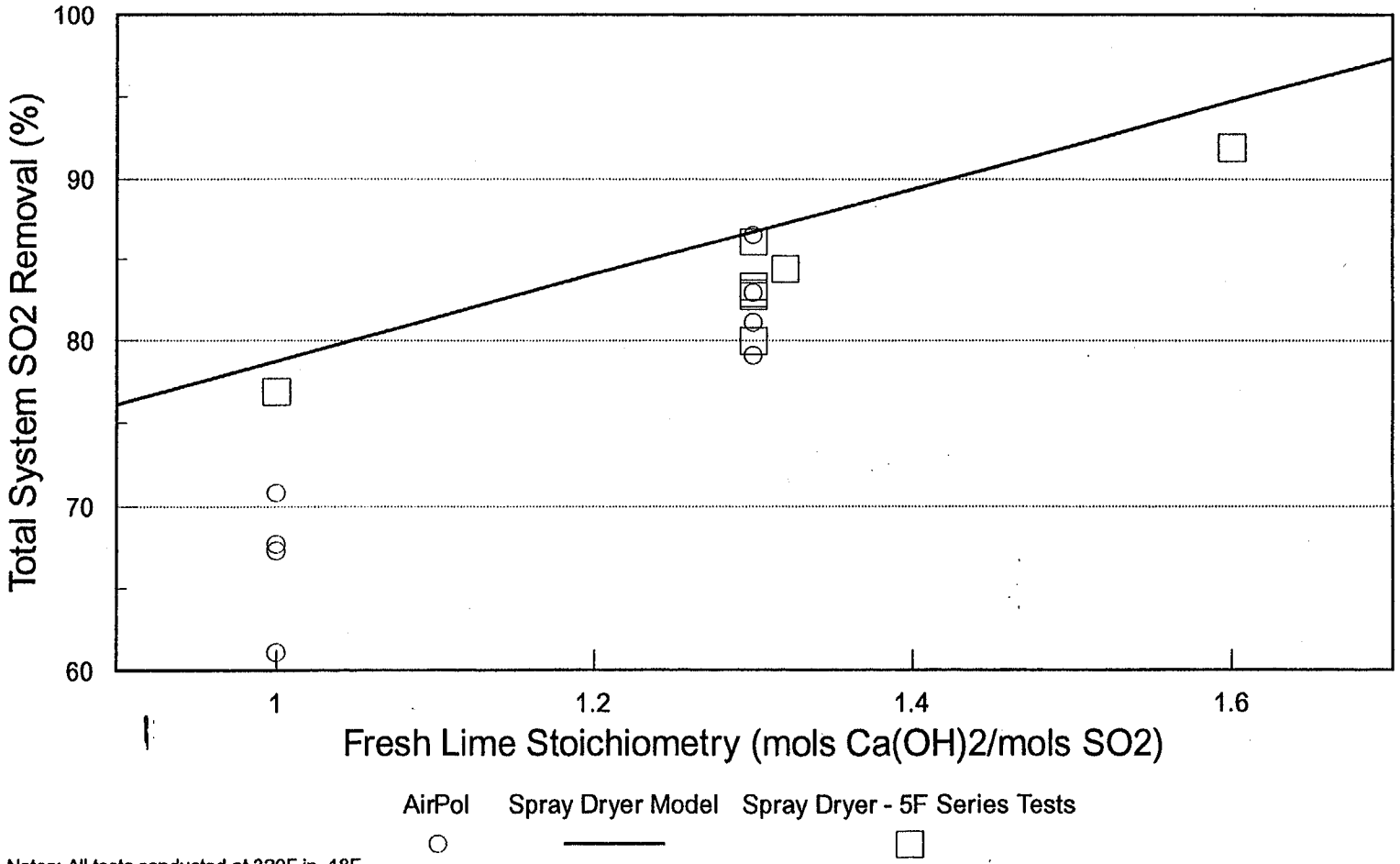
Prior to conducting the AirPol GSA demonstration, approximately five years of research and development were conducted at the CER evaluating a 10-MW SD/ESP system. A comparison of the SD/ESP SO_2 removal results and the AirPol GSA SO_2 removal results at essentially identical test conditions is presented in Figure 4-13. In this figure, the total system SO_2 removal is plotted as a function of fresh lime stoichiometry, which is defined in the same terms for both systems, i.e., moles $Ca(OH)_2$/mole inlet SO_2. The results plotted in this figure are for tests that were conducted at a 320°F inlet flue gas temperature, an 18°F approach temperature, a flue gas flow rate of approximately 20,000 scfm at the inlet venturi, and at a baseline (0.02-0.04 percent) coal chloride level. The SD/ESP results plotted in this figure are from tests 5-F-03, -50, -53, -65, -68, -69, -70, and -71, which were completed near the end of the SD test program when the boiler was burning the same Martwick coal used in the first part of the GSA test program.

Also plotted in this figure is a regression line based on the SD/ESP removal efficiency model developed by TVA from the expanded data base. (This model was reported in an April 18, 1991 internal TVA memorandum entitled, "Preliminary Results of the Remodeling of the Chloride Evaluation Data" and reflects the model projections for a coal chloride level of 0.04 percent.) However, since this model was developed from SD tests with a higher coal chloride level, these model projections are somewhat less accurate than the actual test data from the SD tests. The individual SD test results plotted in Figure 4-13 are slightly lower than the regression model because other data at different test conditions were included when developing the model.

Based on the data in the figure, the GSA system SO_2 removal performance appears to be lower than the SD/ESP results at a fresh lime stoichiometry

Comparison of Spray Dryer and AirPol

SO2 Removal Performance



Notes: All tests conducted at 320F in, 18F approach temperature and 3% S/0.02 to 0.04% Cl coal, and approximately 20,000 scfm in.

FIGURE 4-13

of 1.0 moles $Ca(OH)_2$/mole inlet SO_2. At a fresh lime stoichiometry of 1.3 moles $Ca(OH)_2$/mole inlet SO_2, the GSA test results and the individual SD test results are virtually identical. The limited test results available at the lower lime stoichiometry do not provide an explanation for the apparent "poorer" performance in the GSA system. However, the suspicion is that these lower SO_2 removal efficiencies are an artifact of the half-factorial test plan design, where some of the variable levels were not at their optimum condition.

The comparable total system SO_2 removal achieved in the GSA FGD system means that this technology has a significant advantage over the SD FGD technology. The flue gas residence time in the GSA reactor/cyclone is much lower than in the SD vessel (4 vs. 10-12 sec.). This means that one can achieve comparable SO_2 removal performance in the GSA FGD system with a much smaller (and hence cheaper) absorption vessel. This is a significant advantage for the GSA FGD technology, particularly if additional testing at the lower lime stoichiometry indicates that the apparent differences in SO_2 removal performance at this condition are due to variability in the data and the test plan design.

The fact that the GSA circulating bed absorber is very effective for heat and mass transfer between the lime slurry and the SO_2-laden flue gas is an important factor in achieving this low flue gas residence time. The dry recycle solids making up this churning circulating bed, which distributes the lime slurry throughout the GSA reactor, also means that only a small, single, two-fluid nozzle is needed to inject the fresh lime slurry. The SD technology, in contrast, requires a single, larger rotary atomizer or multiple two-fluid or rotary atomizers to inject and distribute the combined lime/recycle slurry into the SD vessel. Thus, essentially the same SO_2 removal performance can be achieved with a small, single atomizer, which is a significant advantage.

28-Day GSA Demonstration Run

As part of the Clean Coal test program, a 28-day (approximately 690 hours) demonstration run was performed at one set of operating conditions to

determine the reliability of the GSA system. This test began on October 25 and was completed on November 24 with one short (40 hour) outage due to a boiler tube leak. The operating conditions selected for this 28-day demonstration run were a total system (reactor/cyclone/ESP) SO_2 removal efficiency set point of 91 percent, 18°F approach temperature, 20,000 scfm flue gas flow rate at the inlet venturi, 320°F inlet flue gas temperature, 30 rpm recycle screw speed, fly ash injection rate equivalent to 1.5 gr/acf (to bring the inlet fly ash loading up to about 2.0 gr/acf), and calcium chloride spiking to simulate scrubbing flue gas from a boiler firing a 0.12 weight percent chlorine coal.

This 28-day GSA demonstration run was divided into 9 test segments to keep the data files manageable. The length of these test segments varied from 1 to 7 days. With the exception of the last two test segments, 1-DR-07 and 1-DR-08, the fresh lime stoichiometry was allowed to fluctuate to meet the target SO_2 removal efficiency. The fresh lime stoichiometry was fixed at 1.40 and 1.45 moles $Ca(OH)_2$/mole inlet SO_2 for test segments 1-DR-07 and 1-DR-08, respectively.

The 1-MW PJBH pilot plant was down during all of these test segments with the exception of test 3-DR-04. The PJBH was started up and operated for approximately 30 hours during this test segment before being shut down due to the failure of approximately one-third of the bags. The original plan had been to operate the PJBH pilot plant during the last two weeks of the GSA demonstration run, but this plan was abandoned.

A summary of the average operating conditions and the SO_2 removal performance of the GSA system for the DR series test segments is presented in Table 4-6. With the exception of test segments 1-DR-06 and 1-DR-07, which were run at a specific lime stoichiometry, the average total system SO_2 removal set point efficiency for all of the test segments was greater than 90 percent. The average fresh lime stoichiometry required to achieve this SO_2 removal varied from 1.32 to 1.58 moles $Ca(OH)_2$/mole inlet SO_2 depending on the test segment. The lime utilization rates ranged from 58 to 69 percent during the GSA demonstration run.

AirPol GSA/ESP SO2 Removal Results Summary
DR Series - 28-Day Demonstration Run

Test No.	Ca/S Ratio	Reactor Inlet Temperature (F)	Approach Temperature (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Injection Rate (lb/min)	Reactor Product Chloride Content (%)	Reactor/ Cyclone SO2 Removal (%)	ESP SO2 Removal (%)	Total System SO2 Removal (%)
1-DR-01	1.46	320	18	20,000	30	7.4	0.27	89.2	1.7	90.9
1-DR-02	1.47	319	18	20,000	30	7.0	0.34	89.0	1.3	90.3
1-DR-03	1.58	319	18	20,000	30	7.3	0.21	91.1	0.5	91.6
1-DR-04	1.48	319	18	20,000	30	7.1	0.19	88.0	3.7	91.7
3-DR-04	1.32	320	18	20,000	30	7.3	0.32	85.7	4.8	90.5
1-DR-05	1.52	319	18	20,000	30	7.2	0.33	87.2	3.0	90.2
1-DR-06	1.43	320	18	20,000	30	7.3	0.30	87.2	2.7	89.9
1-DR-07	1.40	320	18	20,000	30	7.3	0.30	77.0	6.9	83.9
1-DR-08	1.45	320	18	20,000	30	7.4	0.41	88.3	5.2	93.5

The fluctuation in fresh lime stoichiometry is illustrated more clearly in Figure 4-14, which plots the average daily lime stoichiometry during the GSA demonstration run. As shown in this figure, the average daily lime stoichiometry ranged from 1.4 to 1.6 moles $Ca(OH)_2$/mole inlet SO_2. For the last three days of the GSA demonstration run, the lime stoichiometry was fixed at the values of 1.40 and 1.45 moles $Ca(OH)_2$/mole inlet SO_2, respectively.

The GSA demonstration run test conditions were selected based on the results from the previous factorial test program to achieve greater than 90 percent total system SO_2 removal at a reasonable, 1.3 moles $Ca(OH)_2$/ mole inlet SO_2 lime stoichiometry. These SO_2 performance results were obtained in test 2-AP-06, which was conducted in March, and tests 2-AP-91 and 2-AP-92, which were conducted in June. However, during the GSA demonstration run, fresh lime stoichiometries greater than 1.4 moles $Ca(OH)_2$/mole inlet SO_2 were required to achieve over 90 percent total system SO_2 removal.

There are several possible explanations for this discrepancy between the previous factorial test results and this demonstration run regarding the lime stoichiometry required to achieve greater than 90 percent SO_2 removal. Part of this discrepancy is probably due to Unit 9 firing a higher sulfur coal during some of the GSA demonstration run test segments. Approximately one week into the demonstration run on October 31, the supply of Andalex coal was exhausted and the unit was switched to a higher sulfur Warrior coal. The unit continued to burn this higher sulfur coal until November 9. The unit also briefly burned this same higher sulfur coal again on November 11, 18, and 22. Based on data from prior tests, an increase in the inlet SO_2 concentration resulting from the combustion of this higher sulfur coal would cause a decrease in the SO_2 removal performance (or require a higher lime stoichiometry to achieve the same SO_2 removal performance). Thus, the higher lime stoichiometries during these periods, i.e., 1.5-1.6 moles $Ca(OH)_2$/mole inlet SO_2, were not completely unexpected and these high lime stoichiometries are not a major concern. Also, some of the demonstration test segments were conducted at lower solids chloride levels compared to the factorial tests. Late in

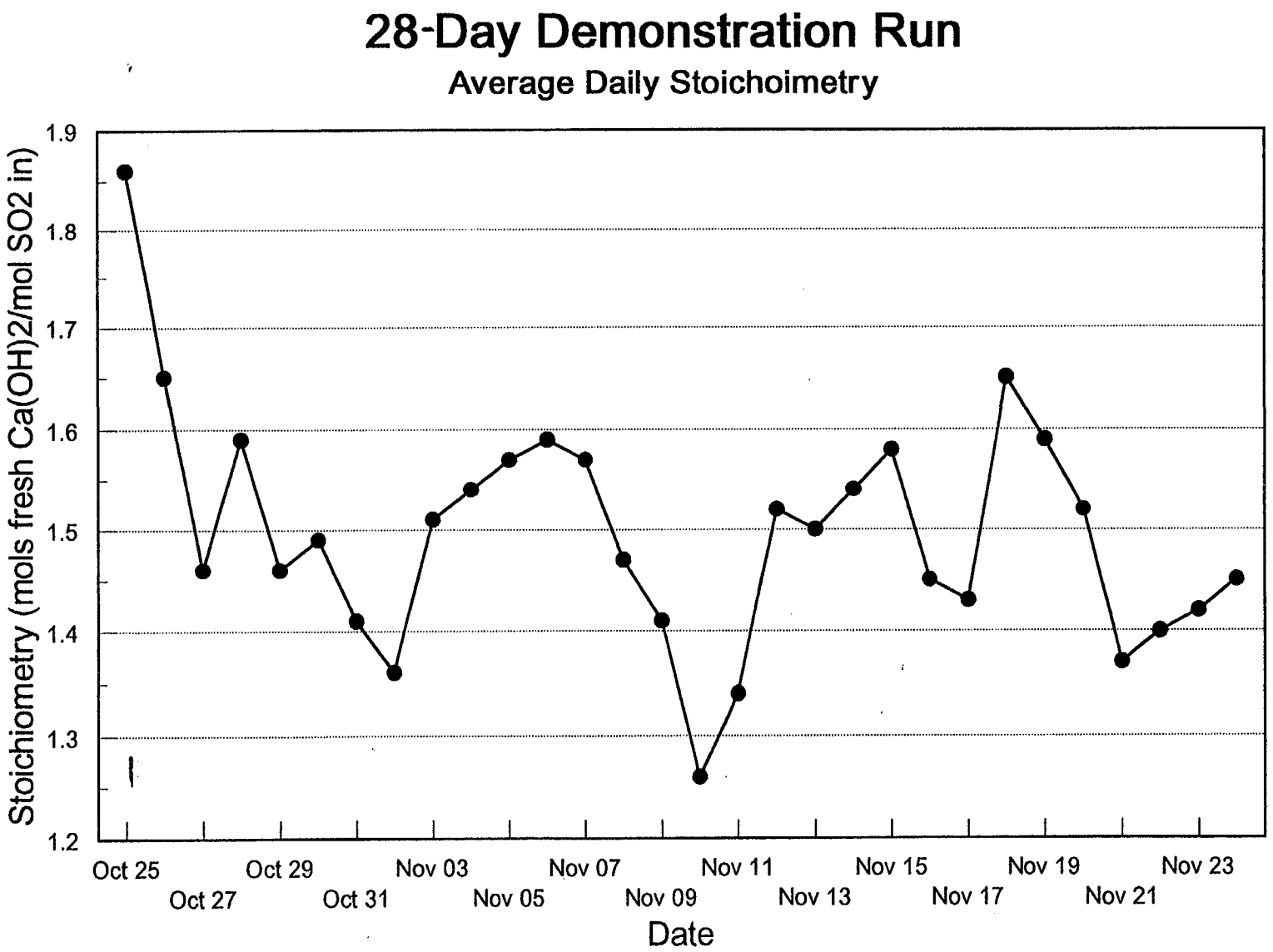

28-Day Demonstration Run
Average Daily Stoichoimetry
Stoichiometry (mols fresh Ca(OH)2/mol SO2 in)
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
Oct 25
Oct 27
Oct 29
Oct 31
Nov 03
Nov 05
Nov 07
Nov 09
Nov 11
Nov 13
Nov 15
Nov 17
Nov 19
Nov 21
Nov 23
Date

FIGURE 4-14

the demonstration run, it was discovered that the fly ash loading in the flue gas entering the GSA reactor may have been higher than originally planned. The source of this excess ash may have been the higher ash levels in the flue gas from the boiler. This higher ash level would dilute both the chloride and the alkalinity levels in the GSA system and therefore lead to a higher lime stoichiometry to achieve the SO_2 removal set point.

14-Day PJBH Demonstration Run

As mentioned in the previous discussion, the original plan was for the 1-MW PJBH pilot plant to be operated for two weeks in parallel with the ESP during the 28-day GSA demonstration run. However, due to the failure of the PJBH bag fabric, the PJBH was not operated during this time period. Therefore, the original GSA demonstration run conditions were repeated, beginning in February, with the PJBH in operation to evaluate PJBH performance over a longer period of time at one set of operating conditions.

The operating conditions for the 14-day PJBH demonstration run were a total system (reactor/cyclone/ESP) SO_2 removal efficiency set point of 91 percent, 18°F approach temperature, 20,000 scfm flue gas flow rate at the inlet venturi, 320°F inlet flue gas temperature, 30 rpm recycle screw speed, and calcium chloride spiking to simulate scrubbing flue gas from a boiler firing a 0.12 weight percent chlorine coal. One difference in the operating conditions for the PJBH demonstration run compared to the prior, 28-day GSA demonstration run, was a lower fly ash injection rate. During the 28-day GSA demonstration run, the fly ash injection rate was set to achieve an increase of 1.5 gr/acf in the inlet particulate concentration to the GSA reactor. This injection rate in combination with the fly ash already present in the flue gas was designed to achieve the desired total particulate concentration of 2.0 gr/acf. Since the particulate concentration from Unit 9 is higher while firing the Andalex coal (approximately 1.0 gr/acf vs. 0.5 gr/acf with the previous coals), the fly ash injection rate set point was reduced to 1.0 gr/acf for the PJBH demonstration run.

All of the PJBH demonstration run test segments were conducted while Unit 9 fired the low-chloride (0.04% Cl) Andalex coal. Mississippi pebble lime was used for all the tests and the lime slurry solids concentration set point was 25 percent. The ESP was operated with all four fields in service and the baffle was in place in the fourth field ESP hopper during all test segments.

The PJBH demonstration run was divided into 4 test segments to keep the data files manageable. The length of these test segments varied from 4 to 5 days. One segment of the demonstration run was completed in February and three test segments were completed during the month of March. A summary of the average operating conditions and SO_2 removal performance is presented in Table 4-7 for all of the PJBH demonstration run test segments.

A plot of the average daily fresh lime stoichiometry during the PJBH demonstration run is presented in Figure 4-15. As shown in the figure, there were two periods when the average lime stoichiometry was significantly higher than the overall demonstration run average of 1.40 moles $Ca(OH)_2$/mole inlet SO_2. The first period was from February 28 through March 1. The high lime stoichiometry during this period was due to a lime slurry flow meter calibration problem. Based on a flow meter calibration on March 1, the lime slurry flow meter was indicating 4 percent higher than the actual lime slurry flow rate. Therefore, the reported lime stoichiometry was 4 percent higher than the actual lime stoichiometry for some period prior to the March 1 calibration. Based on the data, the reported lime stoichiometry for February 28 may have also been influenced by the lime slurry flow meter calibration.

The second period in which the fresh lime stoichiometry was significantly higher than the overall test average was after the pilot plant outage from March 8 to March 10. When the PJBH demonstration run resumed on March 12, the fresh lime stoichiometry was very high, averaging over 1.7 moles $Ca(OH)_2$/mole inlet SO_2. The high lime stoichiometry required to achieve the 91 percent SO_2 removal set point is probably due to the low chloride concentration in the recycle and ESP solids during the first part

AirPol GSA/ESP SO2 Removal Results Summary

PJ Series - 14-Day Demonstration Run

Test No.	Ca/S Ratio	Reactor Inlet Temperature (F)	Approach Temperature (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Injection Rate (lb/min)	Reactor Product Chloride Content (%)	Reactor/ Cyclone SO2 Removal (%)	ESP SO2 Removal (%)	Total System SO2 Removal (%)
1-PJ-01	1.37	319	18	20,000	30	4.9	0.32	88.9	2.5	91.4
1-PJ-02	1.41	319	18	20,000	30	4.9	0.32	88.2	2.7	90.9
1-PJ-03	1.34	320	18	20,000	30	4.9	0.29	88.2	3.1	91.3
1-PJ-04	1.43	319	18	20,000	30	4.9	0.30	90.8	0.5	91.3

TABLE 4-7

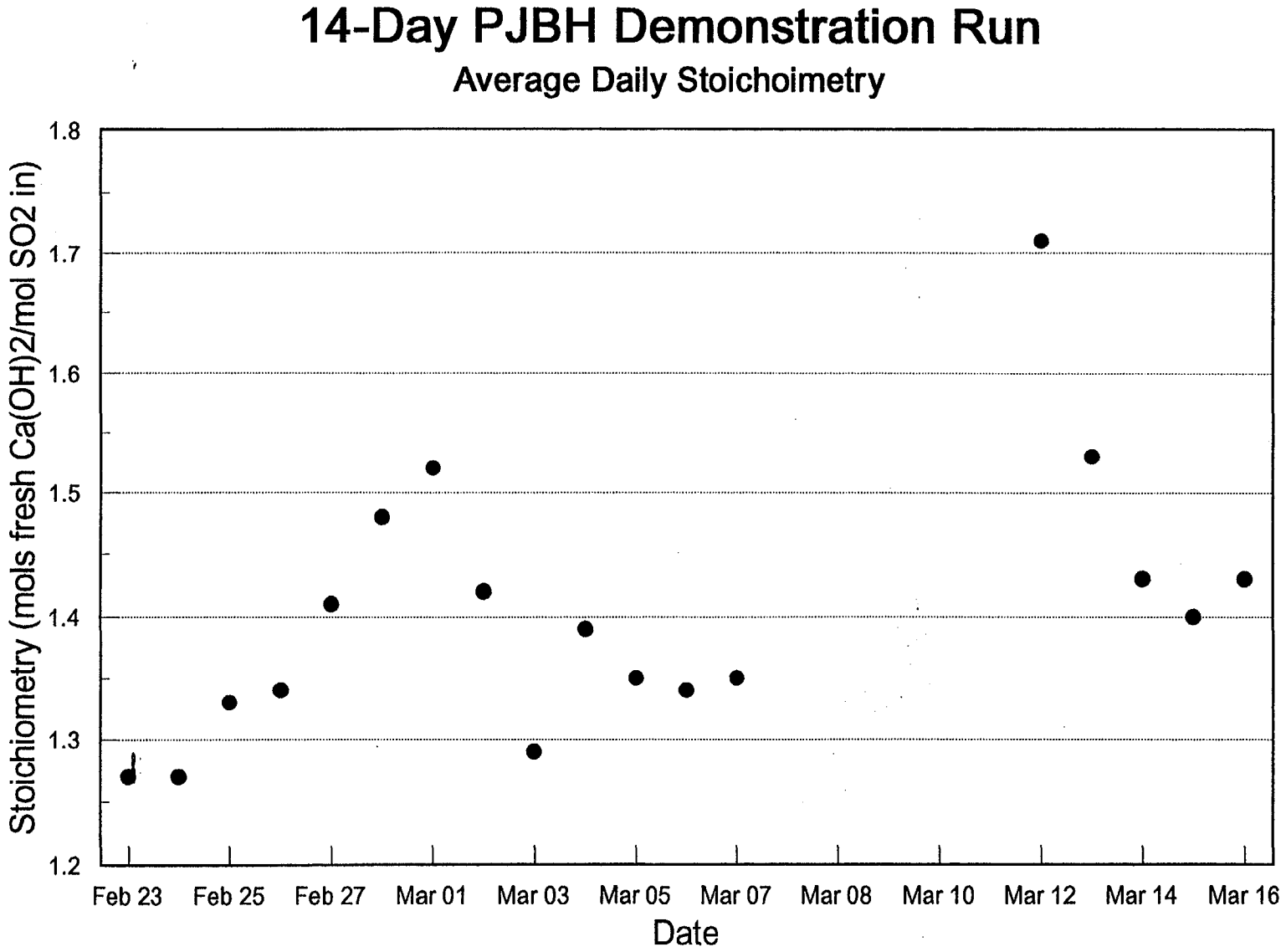

14-Day PJBH Demonstration Run
Average Daily Stoichoimetry
Stoichiometry (mols fresh Ca(OH)2/mol SO2 in)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
Feb 23
Feb 25
Feb 27
Mar 01
Mar 03
Mar 05
Mar 07
Mar 08
Mar 10
Mar 12
Mar 14
Mar 16
Date

FIGURE 15

of this test segment. Several of the recycle and ESP solid samples on March 12 had shown very low levels of chloride. The reactor and ESP solids chloride levels did not reach steady state until approximately mid-day on March 13. Therefore, the data from March 12 was not used in developing the test segment averages.

Also influencing the fresh lime stoichiometry was the wet-bulb temperature used during the PJBH demonstration run. There were several periods during the demonstration run when the approach temperature control was switched between the manual wet-bulb measurements and the continuous wet-bulb monitor (CWBM). This switching was due to problems with the CWBM in which the two measurements deviated by more than $3^{o}F$. Test data in which an inaccurate wet-bulb temperature was used for approach temperature control was removed prior to developing the reported test results.

Figure 4-16 provides a plot of the average total system SO_2 removal for each PJBH demonstration run test segment. The total system SO_2 removal for both the GSA/ESP and the GSA/PJBH configurations are plotted in the figure. The GSA/ESP total system SO_2 removal efficiency averaged 91.2 percent during the PJBH demonstration run. The GSA/PJBH total system SO_2 removal efficiency, which is also presented in Table 4-8, was significantly higher and averaged 97.7 percent. Since the GSA/PJBH configuration provides much higher SO_2 removal efficiency performance compared to the GSA/ESP, the lime stoichiometry required to achieve 91 percent overall SO_2 removal efficiency would be lower than the average of 1.40 moles $Ca(OH)_2$/mole inlet SO_2 for the GSA/ESP configuration.

The average total system lime utilization data for both the GSA/ESP and GSA/PJBH configurations are presented in Figure 4-17. The GSA/ESP total system lime utilization averaged 66.1 percent during the 14-day PJBH demonstration run. The GSA/PJBH total system lime utilization was 4.4 percentage points higher, due to the higher SO_2 removal across the PJBH, and averaged 70.5 percent. Therefore, the GSA/PJBH configuration would be more cost effective in terms of reagent utilization in comparison to the GSA/ESP configuration.

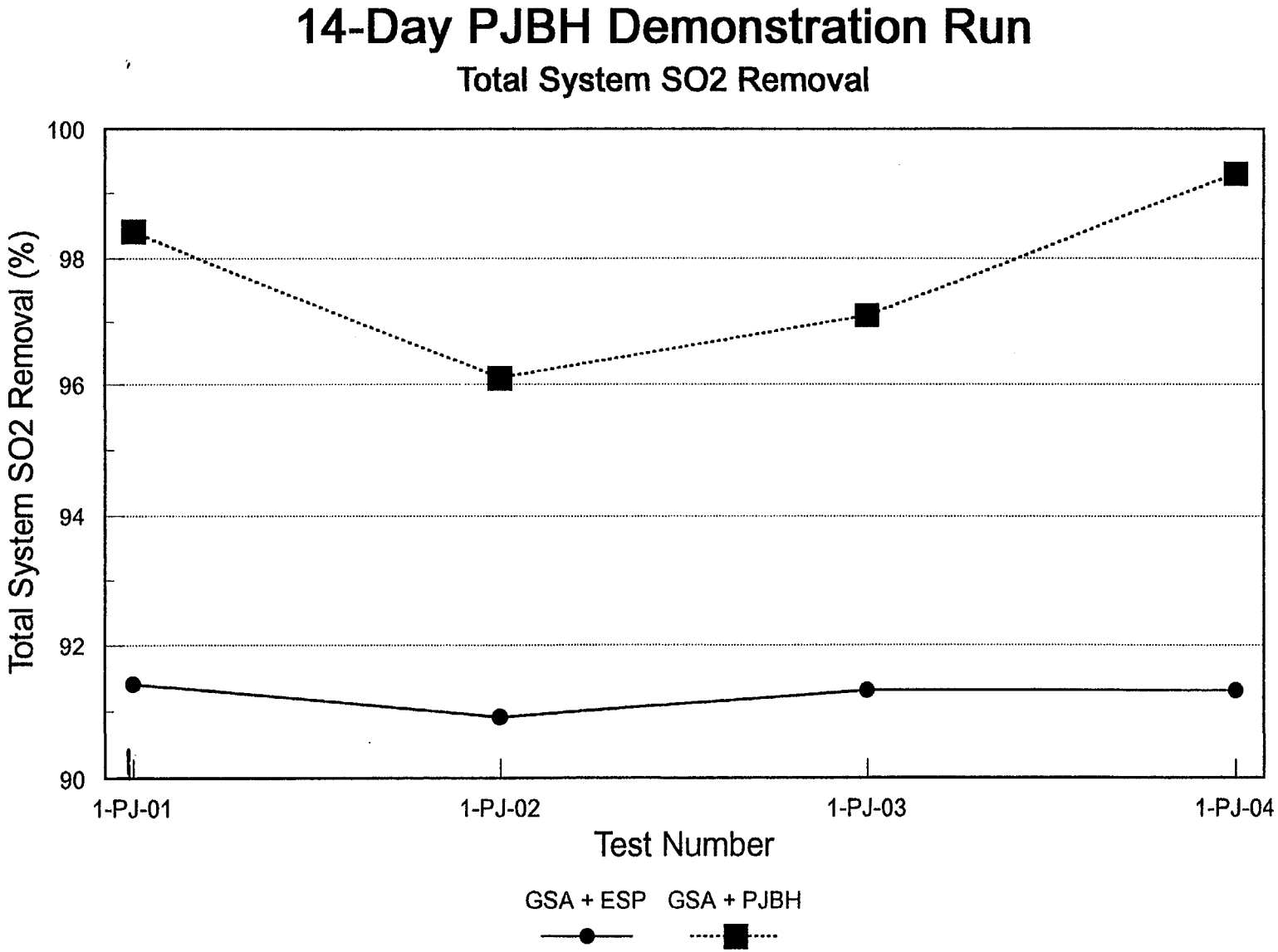

14-Day PJBH Demonstration Run
Total System SO2 Removal
Total System SO2 Removal (%)
100
98
96
94
92
90
1-PJ-01
1-PJ-02
1-PJ-03
1-PJ-04
Test Number
GSA + ESP
GSA + PJBH

FIGURE 16

AirPol GSA/PJBH SO2 Removal Results Summary

PJ Series - 14-Day Demonstration Run

Test No.	Ca/S Ratio	Reactor Inlet Temperature (F)	Approach Temperature (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Injection Rate (lb/min)	Reactor Product Chloride Content (%)	Reactor/ Cyclone SO2 Removal (%)	PJBH SO2 Removal (%)	Total System SO2 Removal (%)
1-PJ-01	1.37	319	18	20,000	30	4.9	0.32	88.9	9.5	98.4
1-PJ-02	1.41	319	18	20,000	30	4.9	0.32	88.2	7.9	96.1
1-PJ-03	1.34	320	18	20,000	30	4.9	0.29	88.2	8.9	97.1
1-PJ-04	1.43	319	18	20,000	30	4.9	0.30	90.8	8.5	99.3

TABLE 4-8

14-Day PJBH Demonstration Run

Total System Lime Utilization

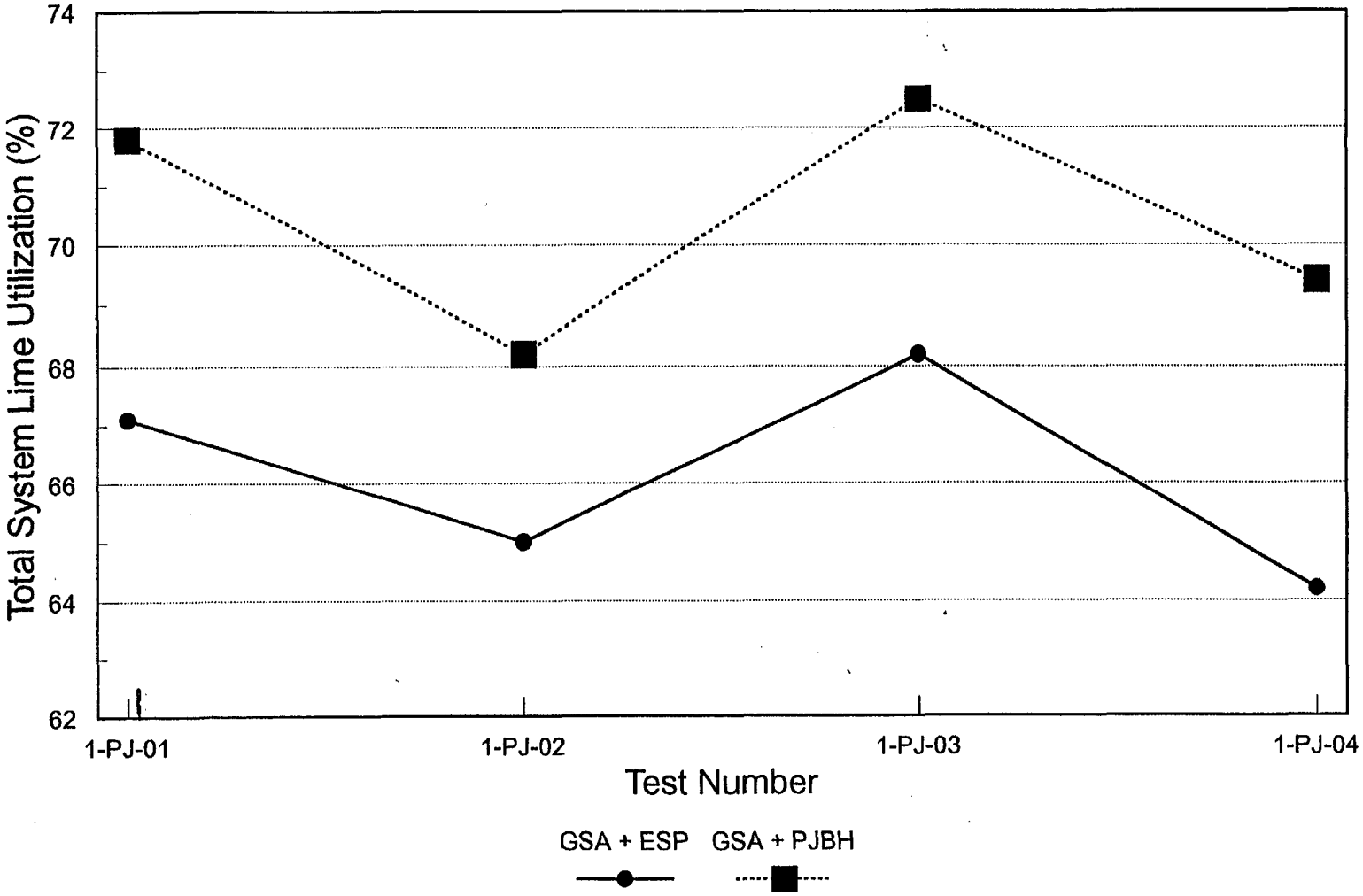


FIGURE 4-17

Figure 4-18 presents the calculated reactor lime utilization and the measured reactor recycle solids calcium utilization for each PJBH demonstration run test segment. As shown in the figure, the calculated and measured utilizations are almost identical for all four test segments. This very good agreement helps to validate the reported SO_2 removal results for these test segments.

ESP PARTICULATE CONTROL PERFORMANCE

Factorial Tests

The ESP particulate control results for the tests conducted at baseline chloride levels are presented in Table 4-9 for the 2-AP series tests and in Table 4-10 for the 3-AP series tests. Similarly, the particulate control results are presented in Tables 4-11 and 4-12 for the chloride spiking tests for the 2-AP and 3-AP series, respectively.

The ESP particulate removal results for all of the 2-AP and 3-AP series tests are plotted in Figure 4-19. In the figure, the ESP emissions in lb/MBtu are plotted as a function of ESP specific collection area (SCA). The baseline chloride and calcium chloride spiking test data are separated in this figure. In addition, linear regression lines for each data set are plotted in the figure. The outlet emissions typically range from 0.005 to 0.015 lb/MBtu and they do not appear to decrease with increasing SCA for the baseline tests, as would normally be expected. This result could be explained if the ESP emissions were dominated by non-ideal effects, such as sneakage, rapping reentrainment, low-resistivity reentrainment, etc., that were limiting the ESP performance. However, for the chloride spiking tests, there does appear to be a slight decrease in emissions with increasing SCA. If the emissions from baseline test conditions are limited by non-ideal effects, chloride spiking may help to overcome this limitation by making the collected solids more cohesive and improving their ability to stick to the collection plates and other particles and thus, not be reentrained.

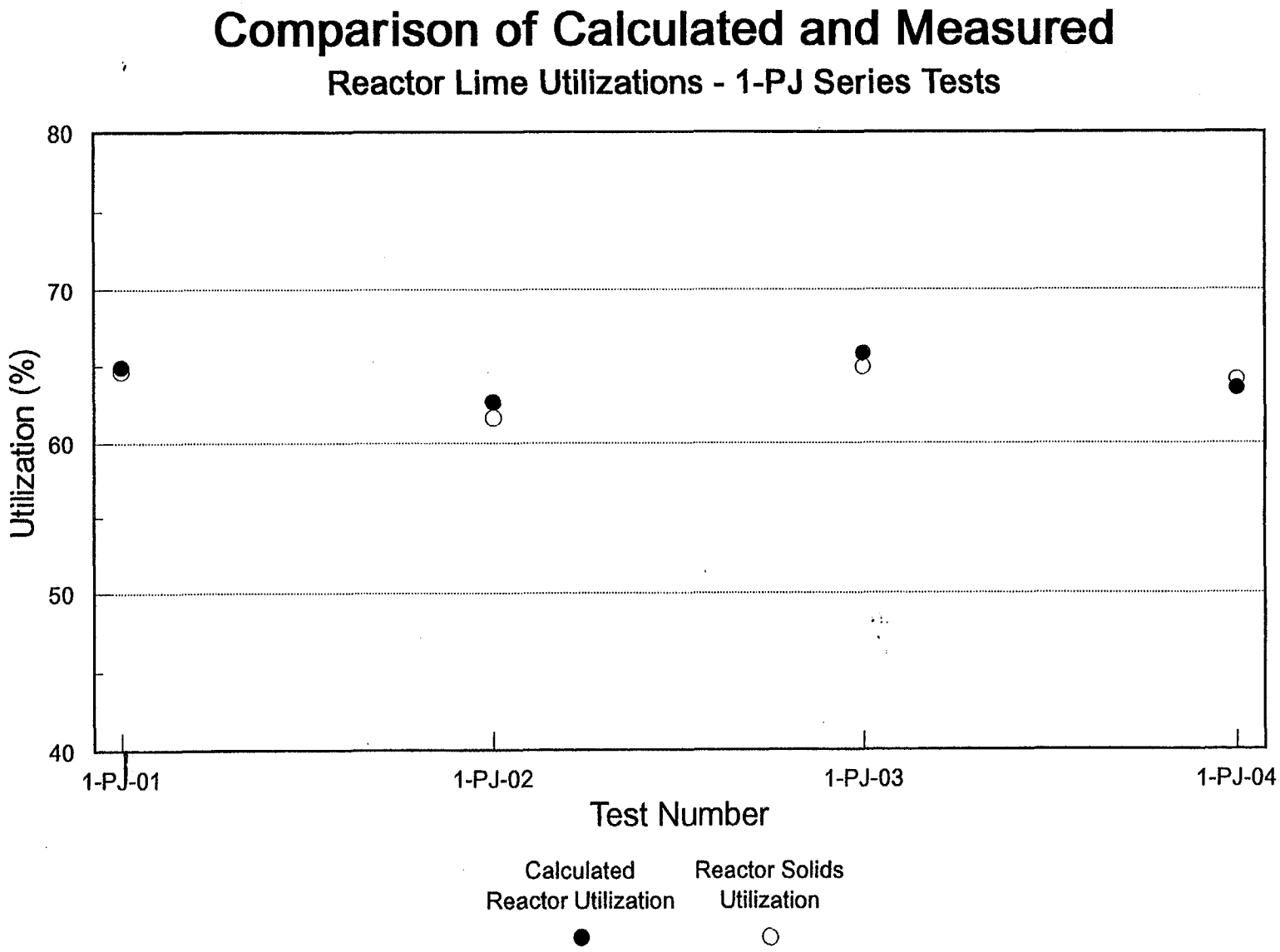

Comparison of Calculated and Measured
Reactor Lime Utilizations - 1-PJ Series Tests
80
70
60
50
40
Utilization (%)
1-PJ-01
1-PJ-02
1-PJ-03
1-PJ-04
Test Number
Calculated Reactor Utilization
Reactor Solids Utilization

FIGURE 4.8

AirPol GSA/ESP Particulate Control Performance Results Summary

2-AP Series - Baseline Tests

Test No.	Ca/S Ratio	Reactor Inlet Temp (F)	Approach Temp (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Injection Rate (lb/min)	Reactor Product Chloride Content (%)	ESP Fields	ESP SCA (ft2/ kacfm)	ESP Inlet Mass Loading (gr/acf)	ESP Outlet Mass Loading (gr/acf)	ESP Eff Mass Basis (%)	ESP Eff Conc Basis (%)	ESP Emissions (lb/MMBtu)
2-AP-09	1.0	320	8	14,000	30	0	0	4	673	2.598	0.0059	99.77	99.75	0.021
2-AP-79	1.0	320	8	14,000	30	0	0	4	651	2.380	0.0004	99.99	99.98	0.001
2-AP-72	1.0	320	8	20,000	45	7.3	0	4	453	3.938	0.0018	99.96	99.95	0.006
2-AP-16	1.0	320	8	20,000	45	7.8	0.04	4	463	4.455	0.0012	99.97	99.97	0.004
2-AP-11	1.3	320	8	14,000	30	5.0	0	4	664	4.823	0.0019	99.96	99.96	0.007
2-AP-81	1.3	320	8	14,000	30	5.2	0	4	643	3.584	0.0012	99.97	99.96	0.004
2-AP-10	1.3	320	8	20,000	45	0	0	4	460	3.404	0.0027	99.92	99.92	0.009
2-AP-80	1.3	320	8	20,000	45	0	0.09	4	453	3.242	0.0006	99.99	99.98	0.001
2-AP-01	1.0	319	18	14,000	30	0	0	4	652	2.785	0.0017	99.94	99.94	0.006
2-AP-71	1.0	320	18	14,000	30	0	0.02	4	641	2.806	0.0024	99.93	99.91	0.008
2-AP-78	1.0	320	18	20,000	30	7.2	0	4	458	3.266	0.0015	99.96	99.95	0.005
2-AP-04	1.0	320	18	19,000	45	0	0	4	486	2.870	0.0028	99.91	99.90	0.009
2-AP-74	1.0	320	18	20,000	45	0	0	4	445	2.553	0.0022	99.93	99.91	0.007
2-AP-03	1.3	319	18	14,000	45	0	0	4	638	3.810	0.0041	99.90	99.88	0.014
2-AP-73	1.3	320	18	14,000	45	5.1	0	4	641	4.566	0.0046	99.91	99.89	0.017
2-AP-95	1.3	320	18	20,000	45	0	0.05	4	448	2.447	0.0014	99.95	99.94	0.005
2-AP-96	1.3	322	18	20,000	45	0	0.21	4	448	2.477	0.0026	99.91	99.89	0.009
2-AP-14	1.3	320	18	18,000	45	6.7	0.12	4	491	5.644	0.0030	99.95	99.94	0.010
2-AP-63	1.3	320	18	20,000	45	7.2	0.04	4	456	4.681	0.0026	99.95	99.94	0.009
2-AP-63	1.3	320	18	20,000	45	7.2	0.03	4	447	5.069	0.0039	99.93	99.92	0.013
2-AP-88	1.0	320	28	14,000	30	0	0.04	4	642	2.283	0.0047	99.80	99.78	0.015
2-AP-87	1.0	320	28	20,000	45	7.3	0	4	446	2.995	0.0017	99.95	99.94	0.006
2-AP-86	1.3	320	28	14,000	45	0	0.03	4	629	3.065	0.0022	99.94	99.93	0.007
2-AP-97	1.3	320	28	20,000	30	0	0	4	442	2.042	0.0089	99.45	99.37	0.029
2-AP-19	1.3	320	28	20,000	30	7.1	0	4	463	4.443	0.0028	99.95	99.93	0.010
2-AP-57	1.3	319	28	19,500	30	7.1	0	4	463	4.665	0.0030	99.94	99.93	0.010

TABLE 4-9

AirPol GSA/ESP Particulate Control Performance Results Summary

3-AP Series - Baseline Tests

Test No.	Ca/S Ratio	Reactor Inlet Temp (F)	Approach Temp (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Injection Rate (lb/min)	Reactor Product Chloride Content (%)	ESP Fields	ESP SCA (ft2/ kacfm)	ESP Inlet Mass Loading (gr/acf)	ESP Outlet Mass Loading (gr/acf)	ESP Eff Mass Basis (%)	ESP Eff Conc Basis (%)	ESP Emissions (lb/MMBtu)
3-AP-12	1.0	320	8	14,000	30	0	0	4	857	3.352	0.0091	99.78	99.70	0.030
3-AP-58	1.0	320	8	14,000	30	0	0	4	835	3.022	0.0016	99.96	99.94	0.005
3-AP-42	1.3	320	8	14,000	30	0	0	4	864	3.645	0.0038	99.92	99.89	0.012
3-AP-11	1.3	319	8	14,000	30	5.2	0	4	840	-	-	-	-	-
3-AP-62	1.0	319	18	14,000	30	0	0.13	4	850	-	-	-	-	-
3-AP-08	1.0	320	18	20,000	30	7.0	0	4	543	3.797	0.0024	99.95	99.93	0.009
3-AP-44	1.3	319	18	14,000	45	0	0.02	4	829	0.606	0.0022	99.71	99.59	0.008
3-AP-03	1.3	319	18	14,000	45	5.0	0	4	861	4.896	0.0026	99.96	99.95	0.010
3-AP-26	1.3	260	18	14,000	12	4.7	0	4	911	3.561	0.0045	99.91	99.87	0.016
3-AP-27	1.3	260	18	14,000	30	4.7	0	4	893	-	-	-	-	-
3-AP-02	1.3	319	18	14,000	45	5.1	0	4	823	5.303	0.0024	99.97	99.95	0.008
3-AP-18	1.0	319	28	14,000	30	0	0	4	844	2.932	0.0020	99.95	99.94	0.007
3-AP-59	1.0	320	28	14,000	30	5.2	0	4	844	-	-	-	-	-
3-AP-21	1.0	319	28	20,000	45	7.3	0	4	457	4.412	0.0026	99.95	99.94	0.010
3-AP-56	1.3	320	28	14,000	30	0	0	4	855	-	-	-	-	-
3-AP-20	1.3	320	28	14,000	45	0	0	4	815	4.765	0.0040	99.92	99.90	0.014
3-AP-20	1.3	320	28	14,000	45	0	0.03	4	826	3.535	0.0042	99.91	99.88	0.014
3-AP-13	1.3	319	28	14,000	45	0	0	4	839	3.323	0.0025	99.94	99.92	0.009
3-AP-45	1.3	320	28	14,000	45	5.2	0	4	805	5.600	0.0018	99.97	99.97	0.006
3-AP-19	1.3	320	28	20,000	30	7.4	0	4	525	3.024	0.0027	99.93	99.91	0.009

TABLE [illegible]0

AirPol GSA/ESP Particulate Control Performance Results Summary
2-AP Series - Chloride Spiking Tests

Test No.	Ca/S Ratio	Reactor Inlet Temp (F)	Approach Temp (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Injection Rate (lb/min)	Reactor Product Chloride Content (%)	ESP Fields	ESP SCA (ft2/ kacfm)	ESP Inlet Mass Loading (gr/acf)	ESP Outlet Mass Loading (gr/acf)	ESP Eff Mass Basis (%)	ESP Eff Conc Basis (%)	ESP Emissions (lb/MMBtu)
2-AP-28	1.0	320	18	14,000	40	5.0	0.39	4	646	4.972	0.0027	99.95	99.94	0.009
2-AP-75	1.0	320	18	14,000	45	4.7	0.45	4	635	4.516	0.0028	99.95	99.94	0.010
2-AP-17	1.0	320	18	20,000	30	0	0.75	4	452	2.461	0.0033	99.89	99.86	0.011
2-AP-82	1.0	320	18	20,000	30	0	0.87	4	448	2.585	0.0015	99.95	99.94	0.004
2-AP-07	1.3	320	18	14,000	30	5.4	0.29	4	642	5.089	0.0025	99.95	99.95	0.008
2-AP-77	1.3	320	18	14,000	30	5.0	0.30	4	626	3.471	0.0118	99.96	99.95	0.005
2-AP-98	1.3	320	18	14,000	30	5.2	0.30	4	641	4.544	0.0029	99.95	99.95	0.007
2-AP-06	1.3	320	18	20,000	45	0	0.47	4	444	3.853	0.0037	99.91	99.90	0.012
2-AP-92	1.3	320	18	20,000	45	0	0.72	4	445	3.313	0.0008	99.98	99.98	0.003
2-AP-91	1.3	320	18	20,000	45	7.2	0.32	4	452	4.532	0.0018	99.97	99.96	0.006
2-AP-22	1.0	320	28	14,000	45	0	0.57	4	626	-	-	-	-	-
2-AP-90	1.0	320	28	14,000	45	0	0.86	4	628	2.431	0.0020	99.93	99.91	0.007
2-AP-25	1.0	320	28	18,600	30	6.8	0.28	4	472	4.763	0.0041	99.92	99.91	0.014
2-AP-94	1.0	320	28	20,000	30	0	0.81	4	443	2.400	0.0039	99.86	99.83	0.013
2-AP-85	1.0	320	28	20,000	30	7.4	0.31	4	441	3.147	0.0025	99.93	99.92	0.008
2-AP-84	1.3	320	28	14,000	30	0	0.60	4	623	2.630	0.0012	99.96	99.95	0.004
2-AP-24	1.3	320	28	14,000	30	0	0.41	4	631	3.471	0.0033	99.91	99.90	0.011
2-AP-83	1.3	320	28	20,000	30	7.3	0.26	4	431	3.359	0.0026	99.93	99.92	0.009

TABLE 4-11

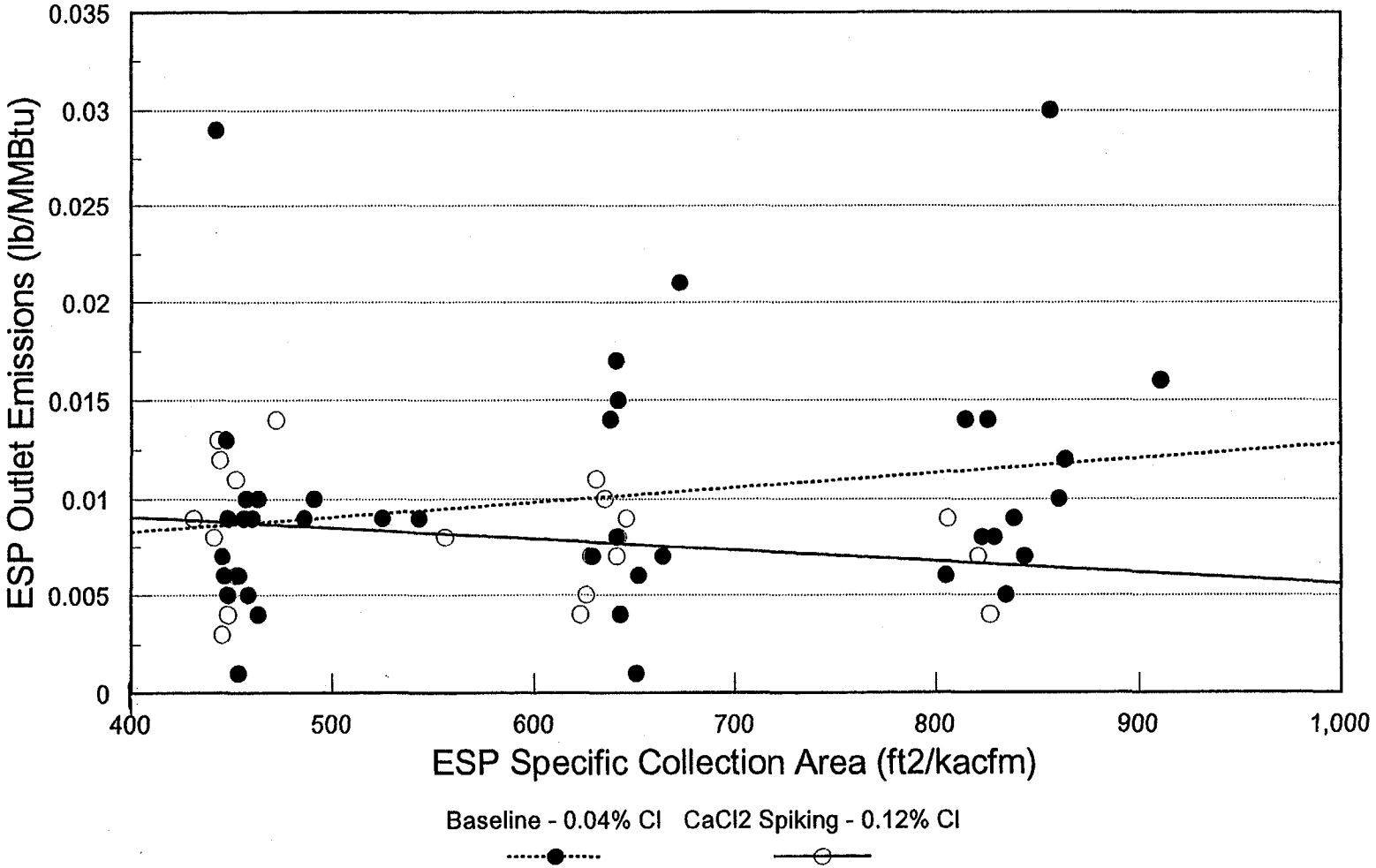
AirPol GSA/ESP Particulate Control Performance Results Summary
3-AP Series - Chloride Spiking Tests

Test No.	Ca/S Ratio	Reactor Inlet Temp (F)	Approach Temp (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Injection Rate (lb/min)	Reactor Product Chloride Content (%)	ESP Fields	ESP SCA (ft2/ kacfm)	ESP Inlet Mass Loading (gr/acf)	ESP Outlet Mass Loading (gr/acf)	ESP Eff Mass Basis (%)	ESP Eff Conc Basis (%)	ESP Emissions (lb/MMBtu)
3-AP-29	1.0	320	18	14,000	45	5.2	0.31	4	806	5.357	0.0024	99.96	99.95	0.009
3-AP-22	1.0	320	28	14,000	45	0	0.57	4	827	3.201	0.0013	99.97	99.96	0.004
3-AP-24	1.3	320	28	14,000	30	0	0.46	4	821	3.321	0.0020	99.95	99.94	0.007
3-AP-23	1.3	320	28	19,200	45	7.2	0.26	4	556	5.091	0.0025	99.96	99.95	0.008

TABLE 4

AirPol GSA ESP Performance Results

ESP Particulate Emissions versus SCA



Notes: Data from 2-AP and 3-AP series tests.

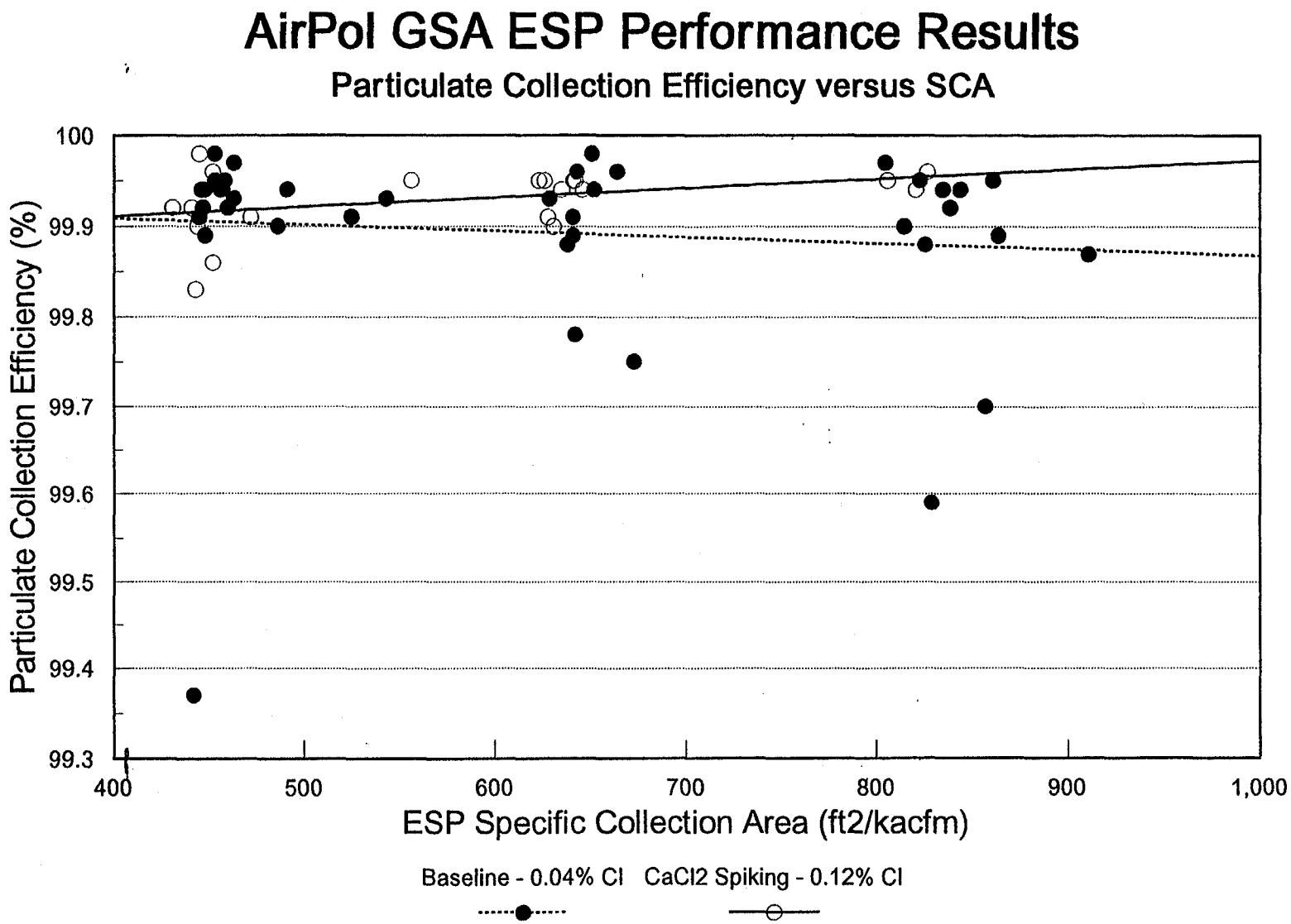
FIGURE 4-19

Similar to Figure 4-19, Figure 4-20 plots the ESP particulate collection efficiency as a function of ESP SCA for all of the 2-AP and 3-AP series tests. The particulate collection efficiency is typically above 99.9 percent. Also, similar to the particulate emissions, the ESP efficiency does not improve with increasing SCA at baseline conditions but does appear to improve slightly with calcium chloride spiking.

Comparison with Previous 10-MW SD Results

Figures 4-21 and 4-22 compare the ESP particulate control performance of the AirPol GSA FGD system with that achieved in the prior SD FGD system testing. Figure 4-21 plots the ESP particulate emissions as a function of SCA for both baseline and chloride spiking tests. Similar particulate emissions are observed for both FGD systems at SCAs ranging from 400 to 500 ft^2/kacfm. Figure 4-22, which plots the ESP particulate removal as a function of SCA, also shows that the ESP particulate removal for both FGD systems is approximately the same at SCAs of 400 to 500 ft^2/kacfm. These figures show the deterioration in particulate control performance at SCAs below 400 ft^2/kacfm for the SD FGD system. However, no low SCA tests were completed with the GSA system for comparison. It may be important to determine whether a similar deterioration will be observed with the GSA FGD system, since most FGD retrofit applications involving ESPs would be in the 200 to 400 ft^2/kacfm SCA size range. There were, however, indications during the GSA demonstration run, which is discussed later, that the ESP performance may deteriorate at lower SCA levels.

The major difference between these two technologies is that the GSA system has a cyclone installed immediately downstream of the GSA reactor to reduce the inlet grain loading entering the ESP. The inlet grain loadings entering the ESP during the GSA testing ranged from 3-5 gr/acf vs. the 6-10 gr/acf that were typical during the SD testing. These lower inlet grain loadings in the GSA system mean that the ESP can achieve the required emission regulations with a lower particulate removal efficiency than would be required with the SD system, which is another advantage for the GSA FGD technology.



Notes: Data from 2-AP and 3-AP series tests.

FIGURE 4-20

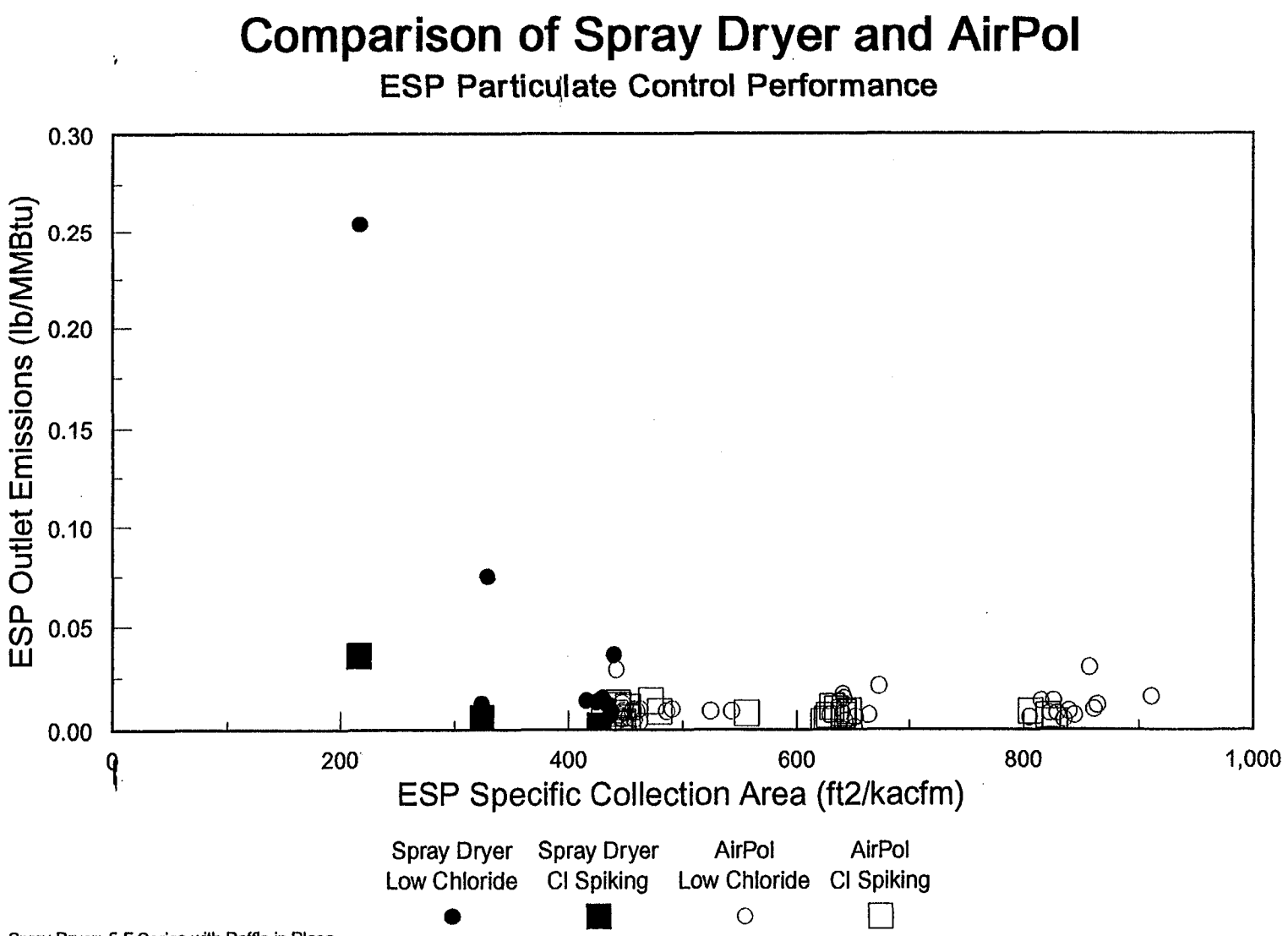

Comparison of Spray Dryer and AirPol
ESP Particulate Control Performance
ESP Outlet Emissions (lb/MMBtu)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
200
400
600
800
1,000
ESP Specific Collection Area (ft2/kacfm)
Spray Dryer Low Chloride
Spray Dryer Cl Spiking
AirPol Low Chloride
AirPol Cl Spiking
Spray Dryer: 5-F Series with Baffle in Place

FIGURE 4-21

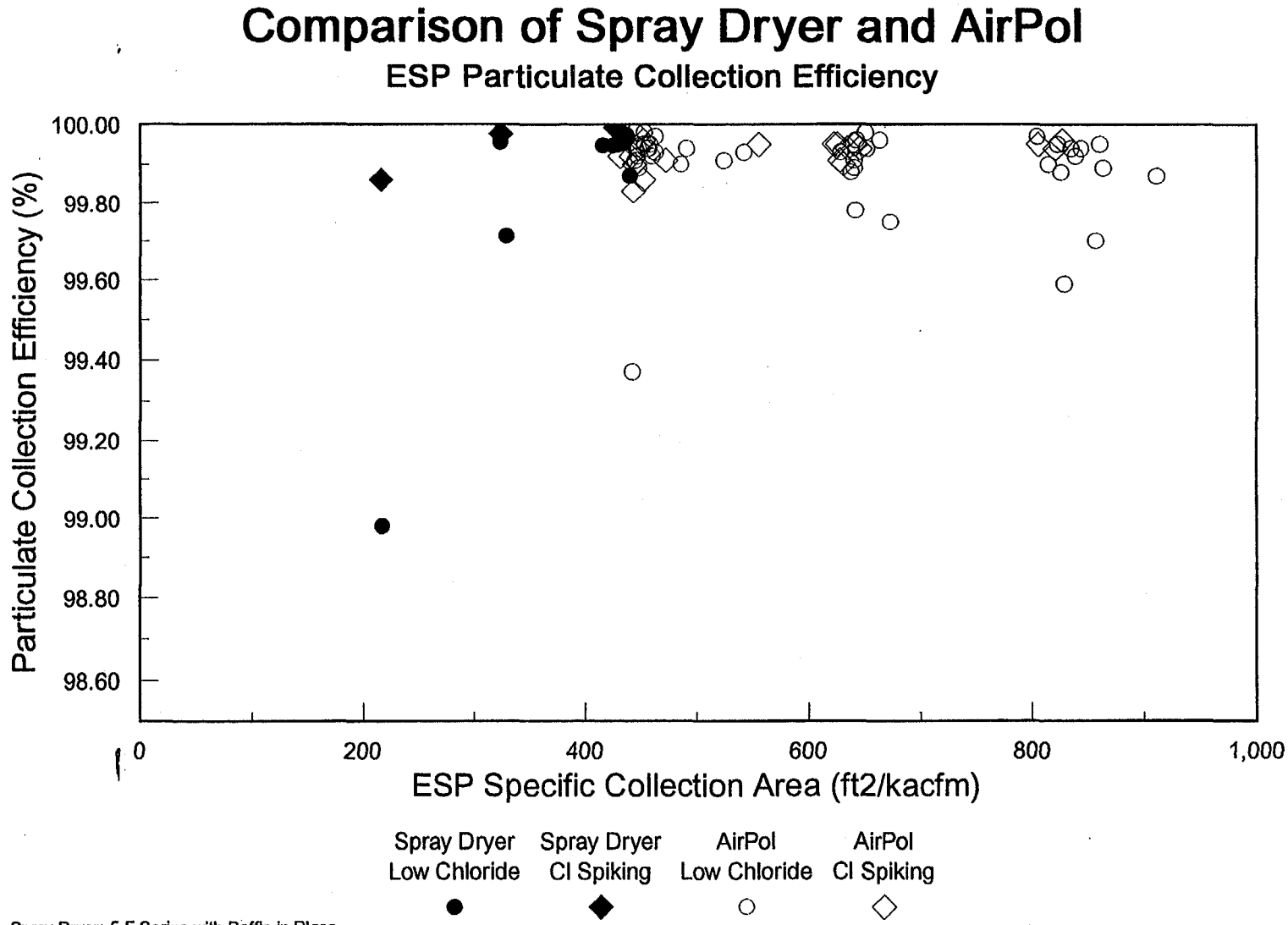

Comparison of Spray Dryer and AirPol
ESP Particulate Collection Efficiency
Particulate Collection Efficiency (%)
100.00
99.80
99.60
99.40
99.20
99.00
98.80
98.60
0
200
400
600
800
1,000
ESP Specific Collection Area (ft2/kacfm)
Spray Dryer Low Chloride
Spray Dryer Cl Spiking
AirPol Low Chloride
AirPol Cl Spiking
Spray Dryer: 5-F Series with Baffle in Place

FIGURE 4-22

However, the cyclone in the GSA system removes the larger particles; thus, a higher proportion of the particles entering the ESP are the smaller, more difficult to remove particles. This larger proportion of smaller particles may contribute to the lower secondary current levels in the first field of the ESP (i.e., current suppression) that were noted in the GSA testing. There were lower secondary currents in the first field of the ESP noted during the SD testing, but not to the low levels seen in the GSA testing. This higher proportion of smaller particles in the GSA FGD system may also have contributed to the relative insensitivity of the particulate emissions to significant increases in the ESP SCA above 400 ft^2/kacfm, since these smaller particles are more prone to reentrainment and other non-ideal effects.

28-Day GSA Demonstration Run

A summary of the ESP particulate control results for the 28-day GSA demonstration run is presented in Table 4-13. Based on these results, there was a significant decrease in the ESP particulate control performance during this 28-day demonstration run. This decrease in performance is more clearly illustrated in Figures 4-23 and 4-24. In Figure 4-23, the ESP particulate collection efficiency is plotted for each test segment. Included in this figure are both the test averages and the individual mass loading test results. The average ESP particulate collection efficiency was greater than 99.95 percent through the first five test segments (1-DR-01 through 3-DR-04). The last three test segments, 1-DR-05 through 1-DR-07, exhibited poorer performance with the particulate collection efficiency averaging approximately 99.90 percent. Effectively, the particulate penetration doubled (0.05 versus 0.10 percent penetration) during these last three test segments.

Figure 4-24 presents the ESP particulate emissions for each test segment. Similar to Figure 4-23, both the test averages and individual test data are presented. Concurrent with the poorer ESP particulate removal efficiency, an increase in ESP particulate emissions was also observed for the last three test segments as the ESP emission increased from about 0.006 to 0.015 lb/MBtu. However, even the higher emission rates (0.015 lb/MBtu) are about one-half the NSPS for particulates.

AirPol GSA/ESP Particulate Control Performance Results Summary

DR Series - 28-Day Demonstration Run

Test No.	Ca/S Ratio	Reactor Inlet Temp (F)	Approach Temp (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Injection Rate (lb/min)	Reactor Product Chloride Content (%)	ESP Fields	ESP SCA (ft2/ kacfm)	ESP Inlet Mass Loading (gr/acf)	ESP Outlet Mass Loading (gr/acf)	ESP Eff Mass Basis (%)	ESP Eff Conc Basis (%)	ESP Emissions (lb/MMBtu)
1-DR-01	1.46	320	18	20,000	30	7.4	0.27	4	440	4.608	0.0021	99.96	99.95	0.007
1-DR-02	1.47	319	18	20,000	30	7.0	0.34	4	449	4.612	0.0015	99.97	99.97	0.005
1-DR-03	1.58	319	18	20,000	30	7.3	0.21	4	439	4.563	0.0013	99.97	99.97	0.004
1-DR-04	1.48	319	18	20,000	30	7.1	0.19	4	450	4.253	0.0017	99.96	99.96	0.006
3-DR-04	1.32	320	18	20,000	30	7.3	0.32	4	465	4.226	0.0019	99.96	99.95	0.006
1-DR-05	1.52	319	18	20,000	30	7.2	0.33	4	434	4.858	0.0042	99.91	99.91	0.014
1-DR-06	1.43	320	18	20,000	30	7.3	0.30	4	436	4.387	0.0050	99.89	99.89	0.016
1-DR-07	1.40	320	18	20,000	30	7.3	0.30	4	425	-	-	-	-	-
1-DR-08	1.45	320	18	20,000	30	7.4	0.41	4	441	-	-	-	-	-

TABLE 4-13

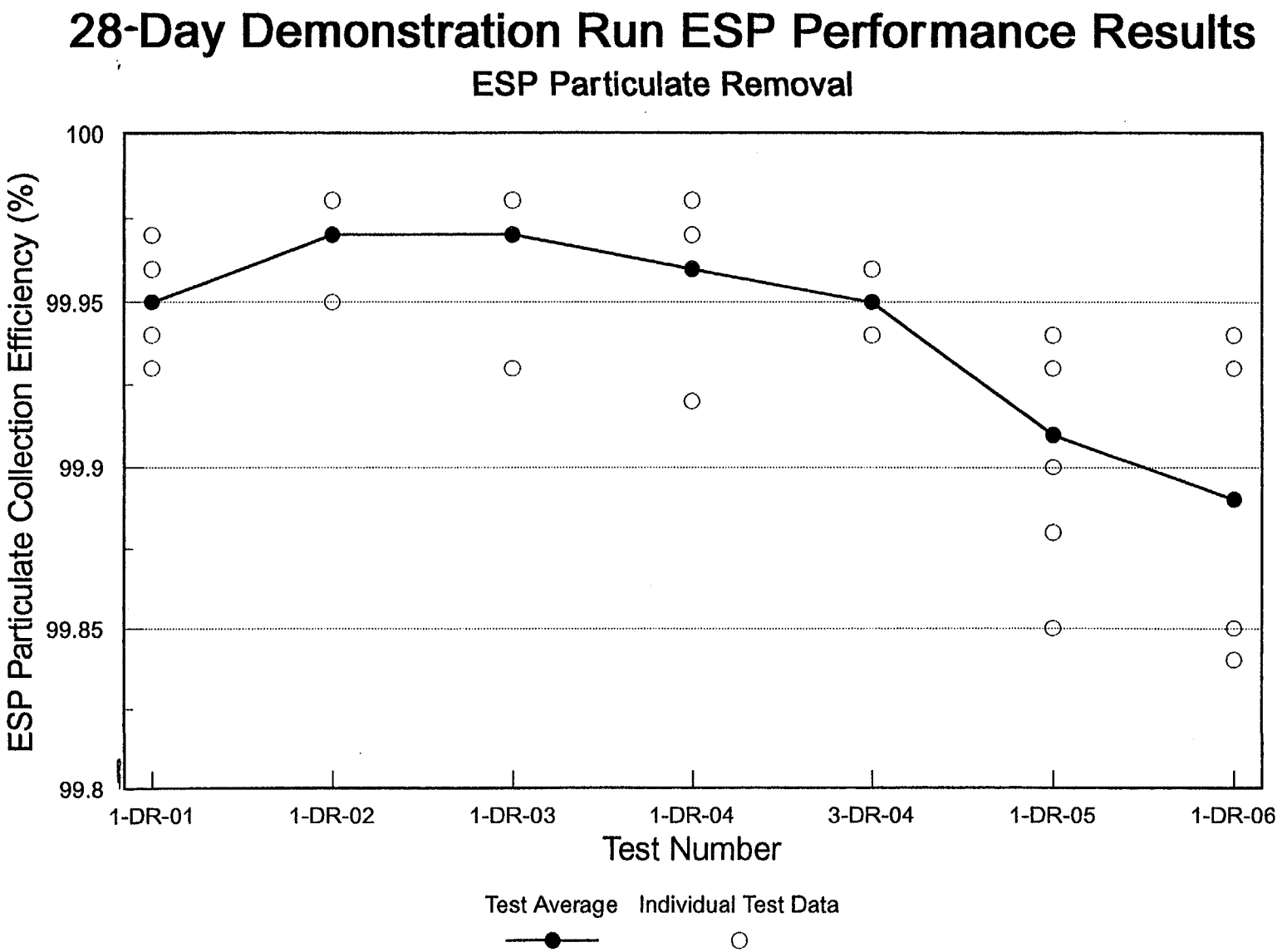

28-Day Demonstration Run ESP Performance Results
ESP Particulate Removal
ESP Particulate Collection Efficiency (%)
100
99.95
99.9
99.85
99.8
1-DR-01
1-DR-02
1-DR-03
1-DR-04
3-DR-04
1-DR-05
1-DR-06
Test Number
Test Average
Individual Test Data

FIGURE 4-23

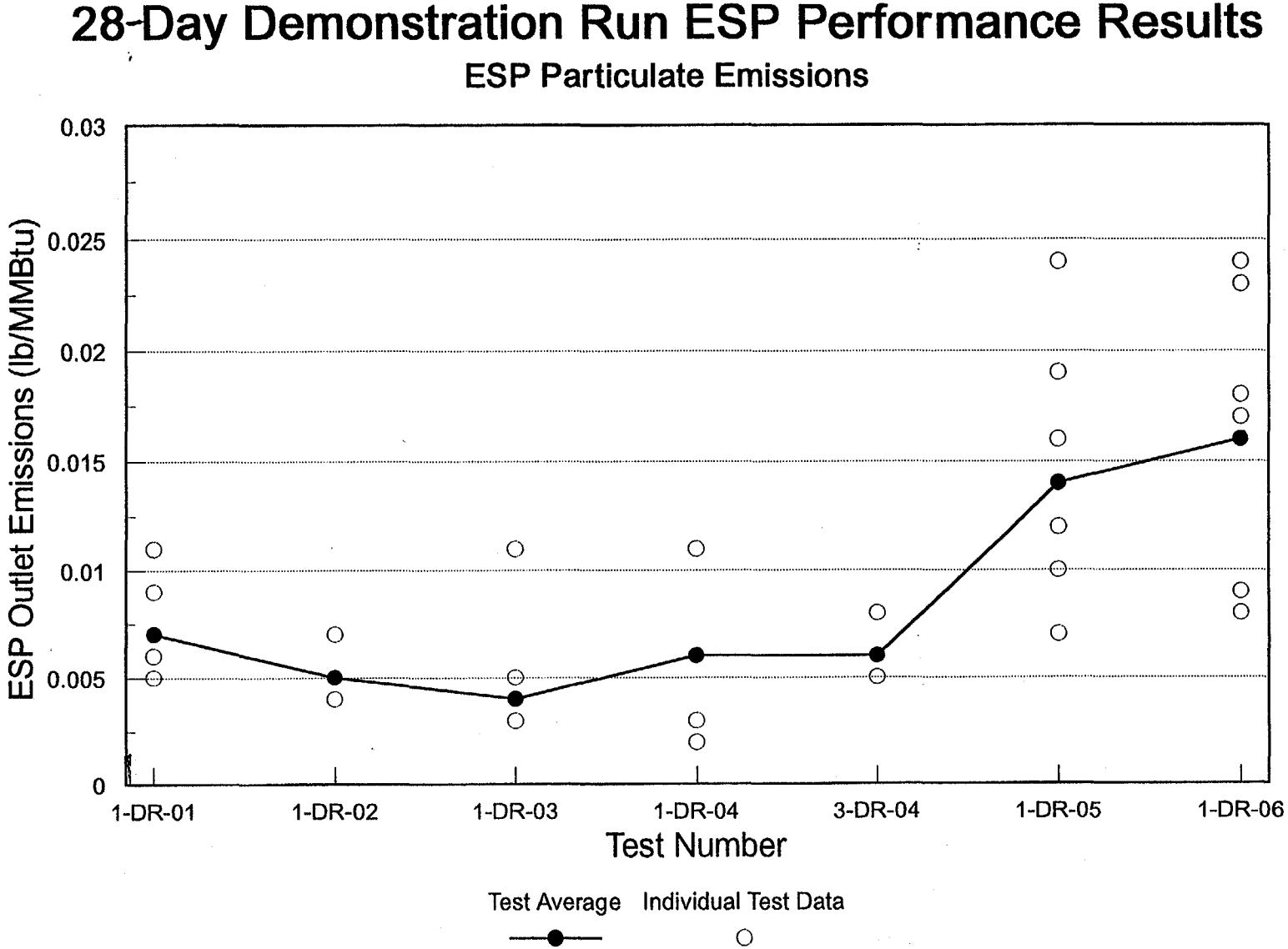

28-Day Demonstration Run ESP Performance Results
ESP Particulate Emissions
ESP Outlet Emissions (lb/MMBtu)
0.03
0.025
0.02
0.015
0.01
0.005
0
1-DR-01
1-DR-02
1-DR-03
1-DR-04
3-DR-04
1-DR-05
1-DR-06
Test Number
Test Average
Individual Test Data

FIGURE 4-24

The poorer ESP particulate control performance during the last three test segments appears to be due to a decrease in the power levels in all 4 ESP fields. The reduction in power levels in the first two fields was due to solids build-ups on the hopper ridges between fields 1 and 2 and between fields 2 and 3. The reduction in power levels in fields 3 and 4 were due to the increased particulate loading entering these fields. A more complete discussion of the ESP operation during the GSA demonstration run is presented later in this section.

14-Day PJBH Demonstration Run

Similar to the 28-day GSA demonstration run, the ESP particulate collection efficiency deteriorated over time during the 14-day PJBH demonstration run. A summary of the ESP particulate control results for the 14-day PJBH demonstration run is presented in Table 4-14. This deterioration in the ESP performance is shown in Figures 4-25 and 4-26. In Figure 4-25, the ESP particulate removal is plotted for each test segment. Both the test segment averages and the individual removal efficiencies from each mass loading run are plotted in the figure. The average ESP particulate removal efficiency decreased from 99.96 percent in the first test segment (1-PJ-01) to 99.89 percent in the last test segment (1-PJ-04). As would be expected with this decrease in the particulate removal efficiency, the ESP particulate emissions also increased over time during the PJBH demonstration run as shown in Figure 4-26. The average particulate emissions increased steadily from 0.006 to 0.017 lb/MBtu during the demonstration run. Both of these figures indicate that the ESP particulate control performance was still deteriorating at the conclusion of the PJBH demonstration run.

The reason for the deterioration in ESP particulate control performance over time during this demonstration run is not clear. In the previous 28-day GSA demonstration run, the deterioration in particulate control performance was attributed to solids build-ups on the hopper ridges between fields 1 and 2 and fields 2 and 3, which electrically shorted out fields 1 and 2. However, significant solids buildups on the hopper ridges did not occur during the PJBH demonstration run. The ESP was inspected on

AirPol GSA/ESP Particulate Control Performance Results Summary
PJ Series - 14 Day Demonstration Run

Test No.	Ca/S Ratio	Reactor Inlet Temp (F)	Approach Temp (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Injection Rate (lb/min)	Reactor Product Chloride Content (%)	ESP Fields	ESP SCA (ft2/ kacfm)	ESP Inlet Mass Loading (gr/acf)	ESP Outlet Mass Loading (gr/acf)	ESP Eff Mass Basis (%)	ESP Eff Conc Basis (%)	ESP Emissions (lb/MMBtu)
1-PJ-01	1.37	319	18	20,000	30	4.9	0.32	4	531	4.533	0.0017	99.97	99.96	0.006
1-PJ-02	1.41	319	18	20,000	30	4.9	0.32	4	534	4.188	0.0027	99.94	99.93	0.010
1-PJ-03	1.34	320	18	20,000	30	4.9	0.29	4	536	4.543	0.0042	99.92	99.90	0.014
1-PJ-04	1.43	319	18	20,000	30	4.9	0.30	4	520	4.439	0.0049	99.91	99.89	0.017

TABLE 4-14

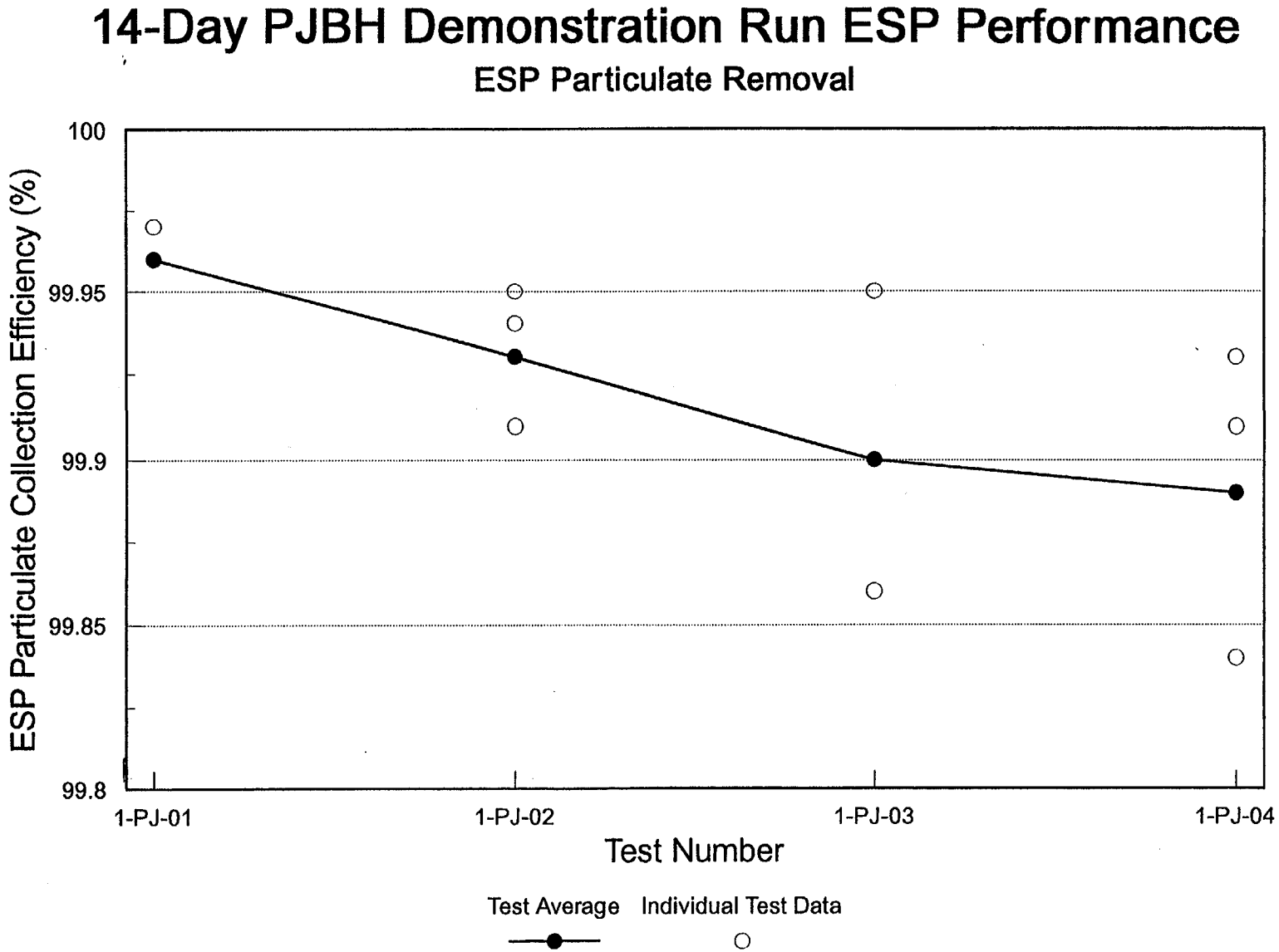

14-Day PJBH Demonstration Run ESP Performance
ESP Particulate Removal
ESP Particulate Collection Efficiency (%)
100
99.95
99.9
99.85
99.8
1-PJ-01
1-PJ-02
1-PJ-03
1-PJ-04
Test Number
Test Average
Individual Test Data

FIGURE 4-25

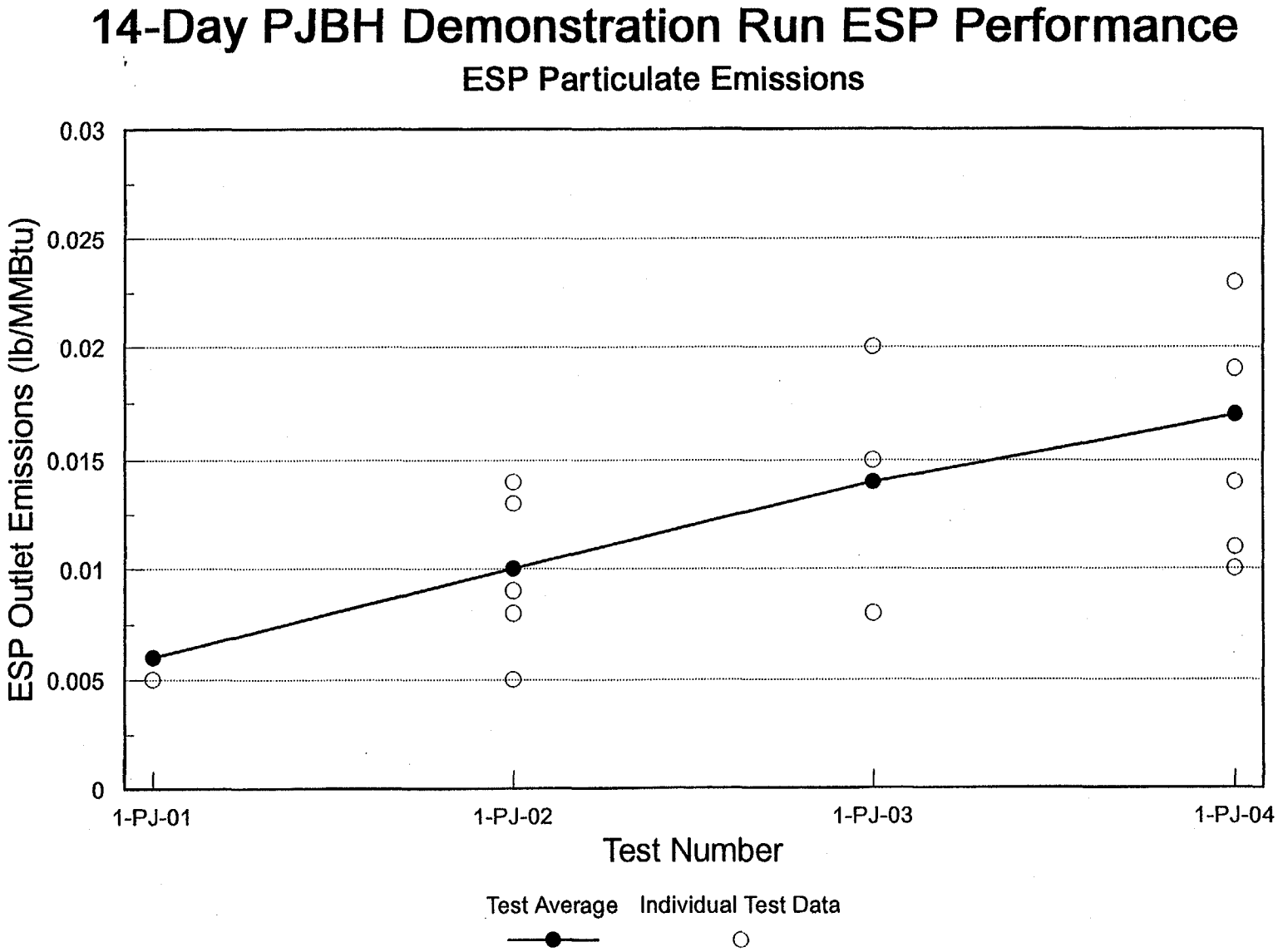

14-Day PJBH Demonstration Run ESP Performance
ESP Particulate Emissions
ESP Outlet Emissions (lb/MMBtu)
0.03
0.025
0.02
0.015
0.01
0.005
0
1-PJ-01
1-PJ-02
1-PJ-03
1-PJ-04
Test Number
Test Average
Individual Test Data

FIGURE 4-26

March 9, between test segments 1-PJ-03 and 1-PJ-04, and again on March 25. Although some solids build-up was observed on the hopper ridges during these inspections, it did not extend up into the plates and wires where the field would be shorted out.

During the March 9 ESP inspection, however, the emitter wires in the first field were found to be heavily coated with solids. Some of the wires had solids build-ups that were 3/4 in. thick. The cause of these build-ups was that the wires were not being rapped in the first field due to the failure of the coupling between the rapper drive motor and the rappers. Apparently the first field wires had not been rapped since February 1, when the rapper drive motor had failed and was subsequently replaced. However, even after the first field rappers were repaired, the ESP particulate control performance continued to deteriorate. Therefore, it does not appear that the build-up on the first field wires was influencing the ESP particulate control performance.

Contrary to the ESP particulate control performance, the PJBH, which was operating in the in-parallel mode, did not exhibit a decrease in performance during the PJBH demonstration run. Based on the data in Table 4-15, the particulate removal efficiency and outlet emissions averaged 99.99 percent and 0.0017 lb/MBtu, respectively. This particulate emission rate is more than an order of magnitude below the NSPS for particulates.

Figures 4-27 and 4-28 compare the ESP and PJBH particulate control performance during the PJBH demonstration run. In Figure 4-27, the average ESP and PJBH particulate removal efficiencies for each test segment are plotted. Figure 4-28 shows the average ESP and PJBH outlet particulate emissions for each test segment. As shown in each figure, the PJBH particulate control performance was superior to that of the ESP. In addition, the PJBH particulate control performance did not deteriorate over time during the 14-day PJBH demonstration run.

AirPol GSA/PJBH Particulate Control Performance Results Summary
PJ Series - 14-Day Demonstration Run

Test No.	Ca/S Ratio	Reactor Inlet Temp (F)	Approach Temp (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Injection Rate (lb/min)	Reactor Product Chloride Content (%)	PJBH Inlet Mass Loading (gr/acf)	PJBH Outlet Mass Loading (gr/acf)	PJBH Eff Basis (%)	PJBH Emissions (lb/MMBtu)
1-PJ-01	1.37	319	18	20,000	30	4.9	0.32	3.009	0.0003	99.99	0.001
1-PJ-02	1.41	319	18	20,000	30	4.9	0.32	3.369	0.0007	99.98	0.002
1-PJ-03	1.34	320	18	20,000	30	4.9	0.29	3.383	0.0008	99.98	0.002
1-PJ-04	1.43	319	18	20,000	30	4.9	0.30	3.442	0.0003	99.99	0.001

TABLE 4-15

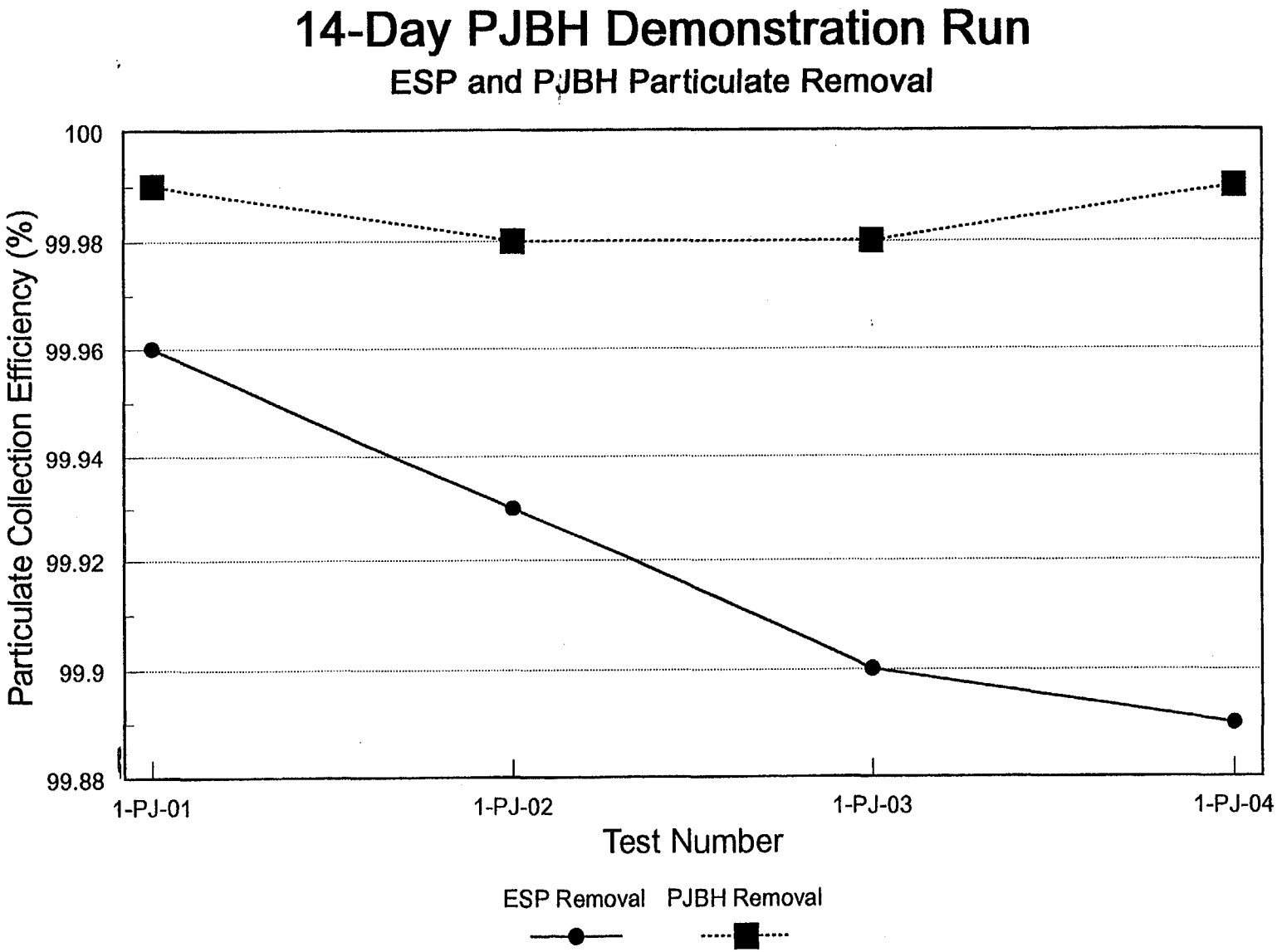

14-Day PJBH Demonstration Run
ESP and PJBH Particulate Removal
Particulate Collection Efficiency (%)
100
99.98
99.96
99.94
99.92
99.9
99.88
1-PJ-01
1-PJ-02
1-PJ-03
1-PJ-04
Test Number
ESP Removal
PJBH Removal

FIGURE 4-27

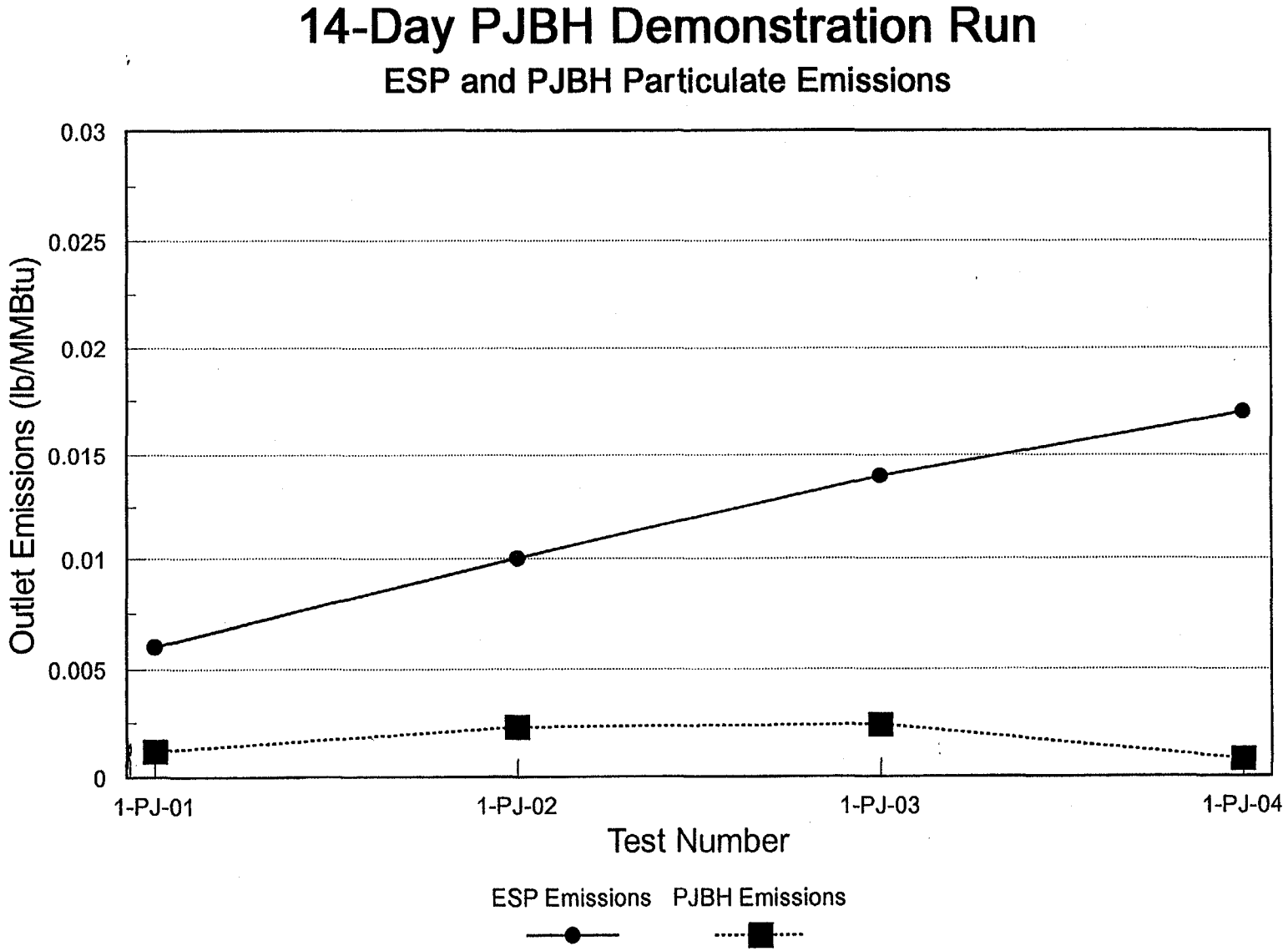

14-Day PJBH Demonstration Run
ESP and PJBH Particulate Emissions
Outlet Emissions (lb/MMBtu)
0.03
0.025
0.02
0.015
0.01
0.005
0
1-PJ-01
1-PJ-02
1-PJ-03
1-PJ-04
Test Number
ESP Emissions
PJBH Emissions

FIGURE 4-28

ESP OPERATION

Factorial Tests

The average secondary voltage and current levels for the tests conducted at the baseline chloride level (0.04 weight percent coal chloride) are presented in Table 4-16 for the 2-AP series tests and in Table 4-17 for the 3-AP series tests. Similarly, the average secondary voltage and current are presented in Tables 4-18 and 4-19 for the chloride spiking tests (0.12 weight percent coal chloride equivalent) for the 2-AP and 3-AP series, respectively.

The changes in some of the variable levels during the factorial tests resulted in changes in the ESP operation. Specifically, the secondary current levels in field 1 and sometimes in fields 2 and 3 would be suppressed depending on the test conditions. The current suppression in the ESP was greater during the tests conducted at the 20,000 scfm flue gas flow rate and at the 28^{o}F approach temperature compared to similar tests conducted at the 14,000 scfm flow rate and a lower approach temperature. The current suppression is thought to be due to changes in both particle size distribution and particle resistivity due to the higher approach temperature. These changes were then aggravated at the higher gas velocity at the higher flue gas flow rate. The changes in the levels for the other variable did not have as significant effect on the secondary current suppression. In addition, the degree of secondary current suppression in the first field did not appear to influence either the ESP particulate removal efficiency or emission rate.

28-Day GSA Demonstration Run

As mentioned previously, the ESP particulate removal performance seemed to deteriorate over time during the 28-day GSA demonstration run. The reason for the poorer performance is thought to be due to a decrease in power levels in all four ESP fields. The most significant decrease in the power levels was noted in the first two ESP fields. Table 4-20 summarizes the average secondary current and voltage levels for each field for each

Average AirPol ESP Second[illegible] Currents and Voltages

2-AP Series - Baseline Tests

Test No.	Ca/S Ratio	Reactor Inlet Temp (F)	App. Temp (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Inj. Rate (lb/min)	Coal Chloride Content (%)	First Field Current (mA)	Second Field Current (mA)	Third Field Current (mA)	Fourth Field Current (mA)	First Field Voltage (kV)	Second Field Voltage (kV)	Third Field Voltage (kV)	Fourth Field Voltage (kV)
2-AP-09	1.0	320	8	14,000	30	0	0.03	175	195	196	193	52	48	48	43
2-AP-79	1.0	320	8	14,000	30	0	0.04	43	196	197	194	41	45	46	40
2-AP-72	1.0	320	8	20,000	45	7.3	0.04	97	196	195	194	49	46	47	41
2-AP-16	1.0	320	8	20,000	45	7.8	0.04	143	195	196	196	52	46	47	43
2-AP-11	1.3	320	8	14,000	30	5.0	0.03	185	197	197	194	51	45	45	42
2-AP-81	1.3	320	8	14,000	30	5.2	0.04	182	196	197	194	51	43	45	40
2-AP-10	1.3	320	8	20,000	45	0	0.03	55	192	196	194	46	49	46	41
2-AP-80	1.3	320	8	20,000	45	0	0.04	68	195	197	195	49	46	45	40
2-AP-01	1.0	319	18	14,000	30	0	0.03	59	196	196	*	46	48	48	44
2-AP-71	1.0	320	18	14,000	30	0	0.04	179	196	179	196	54	45	46	43
2-AP-78	1.0	320	18	20,000	30	7.2	0.04	155	196	196	196	54	45	48	42
2-AP-04	1.0	320	18	19,000	45	0	0.03	12	196	196	195	42	52	47	44
2-AP-74	1.0	320	18	20,000	45	0	0.04	95	195	196	195	51	48	48	42
2-AP-03	1.3	319	18	14,000	45	0	0.03	79	196	198	*	50	46	46	43
2-AP-73	1.3	320	18	14,000	45	5.1	0.04	190	196	197	195	53	43	46	40
2-AP-95	1.3	320	18	20,000	45	0	0.04	122	196	197	195	54	45	45	39
2-AP-96	1.3	322	18	20,000	45	0	0.04	83	196	198	194	51	45	45	39
2-AP-14	1.3	320	18	18,000	45	6.7	0.04	67	197	197	194	51	47	45	40
2-AP-63	1.3	320	18	20,000	45	7.2	0.04	56	193	196	196	49	49	47	42
2-AP-63	1.3	320	18	20,000	45	7.2	0.04	136	196	196	196	56	47	47	43
2-AP-88	1.0	320	28	14,000	30	0	0.04	166	196	196	196	54	47	47	42
2-AP-87	1.0	320	28	20,000	45	7.3	0.04	42	195	196	196	51	49	48	41
2-AP-86	1.3	320	28	14,000	45	0	0.04	40	196	196	195	48	45	46	40
2-AP-97	1.3	320	28	20,000	30	0	0.04	9	149	196	194	45	50	48	40
2-AP-19	1.3	320	28	20,000	30	7.1	0.03	11	187	196	193	46	54	48	42
2-AP-57	1.3	319	28	19,500	30	7.1	0.04	32	190	196	196	51	51	48	43

* Faulty current meter.

TABLE 4-16

Average AirPol ESP Secondary Currents and Voltages
3-AP Series - Baseline Tests

Test No.	Ca/S Ratio	Reactor Inlet Temp (F)	App. Temp (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Inj. Rate (lb/min)	Coal Chloride Content (%)	First Field Current (mA)	Second Field Current (mA)	Third Field Current (mA)	Fourth Field Current (mA)	First Field Voltage (kV)	Second Field Voltage (kV)	Third Field Voltage (kV)	Fourth Field Voltage (kV)
3-AP-12	1.0	320	8	14,000	30	0	0.04	133	196	195	198	48	47	47	42
3-AP-58	1.0	320	8	14,000	30	0	0.04	125	191	195	195	46	38	45	40
3-AP-42	1.3	320	8	14,000	30	0	0.04	129	191	196	196	47	42	43	41
3-AP-11	1.3	319	8	14,000	30	5.2	0.04	158	195	197	195	48	43	44	41
3-AP-62	1.0	319	18	14,000	30	0	0.04	191	196	197	195	51	45	46	42
3-AP-08	1.0	320	18	20,000	30	7.0	0.03	174	196	196	196	55	48	49	43
3-AP-44	1.3	319	18	14,000	45	0	0.04	144	182	196	193	49	43	45	42
3-AP-03	1.3	319	18	14,000	45	5.0	0.03	195	197	196	196	51	45	47	42
3-AP-26	1.3	260	18	14,000	12	4.7	0.03	199	196	196	195	51	46	47	43
3-AP-27	1.3	260	18	14,000	30	4.7	0.03	198	197	196	195	51	45	47	42
3-AP-02	1.3	319	18	14,000	45	5.1	0.03	140	196	197	197	51	45	46	41
3-AP-18	1.0	319	28	14,000	30	0	0.03	73	196	197	198	49	48	48	43
3-AP-59	1.0	320	28	14,000	30	5.2	0.04	104	197	196	195	49	46	47	42
3-AP-21	1.0	319	28	20,000	45	7.3	0.03	21	193	196	196	46	52	48	42
3-AP-56	1.3	320	28	14,000	30	0	0.04	99	197	198	195	49	44	45	40
3-AP-20	1.3	320	28	14,000	45	0	0.03	27	194	198	197	45	47	45	41
3-AP-20	1.3	320	28	14,000	45	0	0.04	51	196	197	194	47	45	45	42
3-AP-13	1.3	319	28	14,000	45	0	0.03	30	193	196	197	47	48	47	42
3-AP-45	1.3	320	28	14,000	45	5.2	0.04	121	196	198	196	50	45	45	42
3-AP-19	1.3	320	28	20,000	30	7.4	0.03	9	179	196	197	45	52	48	42

TABLE 4-

Average AirPol ESP Secondary Currents and Voltages
2-AP Series - Chloride Spiking Tests

Test No.	Ca/S Ratio	Reactor Inlet Temp (F)	App. Temp (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Inj. Rate (lb/min)	Coal Chloride Content (%)	First Field Current (mA)	Second Field Current (mA)	Third Field Current (mA)	Fourth Field Current (mA)	First Field Voltage (kV)	Second Field Voltage (kV)	Third Field Voltage (kV)	Fourth Field Voltage (kV)
2-AP-28	1.0	320	18	14,000	40	5.0	0.12	33	193	196	195	37	46	47	43
2-AP-75	1.0	320	18	14,000	45	4.7	0.12	44	195	195	194	40	46	47	41
2-AP-17	1.0	320	18	20,000	30	0	0.12	25	143	189	193	37	46	47	42
2-AP-82	1.0	320	18	20,000	30	0	0.12	20	144	187	195	38	46	47	43
2-AP-07	1.3	320	18	14,000	30	5.4	0.12	20	195	197	195	36	46	46	42
2-AP-77	1.3	320	18	14,000	30	5.0	0.12	33	195	197	196	37	44	45	40
2-AP-98	1.3	320	18	14,000	30	5.2	0.12	158	196	196	195	50	43	44	41
2-AP-06	1.3	320	18	20,000	45	0	0.12	17	110	186	195	34	48	47	43
2-AP-92	1.3	320	18	20,000	45	0	0.12	50	160	194	195	46	46	45	43
2-AP-91	1.3	320	18	20,000	45	7.2	0.12	12	158	192	195	35	48	45	43
2-AP-22	1.0	320	28	14,000	45	0	0.12	15	177	197	194	37	49	45	41
2-AP-90	1.0	320	28	14,000	45	0	0.12	160	197	196	196	52	46	47	43
2-AP-25	1.0	320	28	18,600	30	6.8	0.12	18	195	196	194	46	52	49	44
2-AP-94	1.0	320	28	20,000	30	0	0.12	86	195	196	195	55	48	48	43
2-AP-85	1.0	320	28	20,000	30	7.4	0.12	103	195	196	195	53	48	49	43
2-AP-84	1.3	320	28	14,000	30	0	0.12	183	196	196	195	53	44	46	42
2-AP-24	1.3	320	28	14,000	30	0	0.12	33	196	197	194	47	47	46	42
2-AP-83	1.3	320	28	20,000	30	7.3	0.12	49	195	196	196	52	48	47	40

TABLE 4-18

Average AirPol ESP Secondary Currents and Voltages
3-AP Series - Chloride Spiking Tests

Test No.	Ca/S Ratio	Reactor Inlet Temp (F)	App. Temp (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Inj. Rate (lb/min)	Coal Chloride Content (%)	First Field Current (mA)	Second Field Current (mA)	Third Field Current (mA)	Fourth Field Current (mA)	First Field Voltage (kV)	Second Field Voltage (kV)	Third Field Voltage (kV)	Fourth Field Voltage (kV)
3-AP-29	1.0	320	18	14,000	45	5.2	0.12	124	196	197	193	43	44	46	42
3-AP-22	1.0	320	28	14,000	45	0	0.12	14	194	197	195	38	48	45	41
3-AP-24	1.3	320	28	14,000	30	0	0.12	95	197	197	195	49	45	46	42
3-AP-23	1.3	320	28	19,200	45	7.2	0.12	9	189	196	196	41	53	47	43

TABLE 4

Average AirPol ESP Secondary Currents and Voltages
1-DR Series

Test No.	Ca/S Ratio	Reactor Inlet Temp (F)	App. Temp (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Inj. Rate (lb/min)	Coal Chloride Content (%)	First Field Current (mA)	Second Field Current (mA)	Third Field Current (mA)	Fourth Field Current (mA)	First Field Voltage (kV)	Second Field Voltage (kV)	Third Field Voltage (kV)	Fourth Field Voltage (kV)
1-DR-01	1.46	320	18	20,000	30	7.4	0.27	71	193	196	197	52	47	46	41
1-DR-02	1.47	319	18	20,000	30	7.0	0.34	46	180	195	198	45	49	47	41
1-DR-03	1.58	319	18	20,000	30	7.3	0.21	75	170	196	198	52	46	46	41
1-DR-04	1.48	319	18	20,000	30	7.1	0.19	8	171	196	197	38	53	47	42
3-DR-04	1.32	320	18	20,000	30	7.3	0.32	9	38	179	195	35	40	49	41
1-DR-05	1.52	319	18	20,000	30	7.2	0.33	13	24	178	195	33	40	50	41
1-DR-06	1.43	320	18	20,000	30	7.3	0.30	13	20	177	194	34	37	49	40
1-DR-07	1.40	320	18	20,000	30	7.3	0.30	11	27	189	196	36	41	51	41
1-DR-08	1.45	320	18	20,000	30	7.4	0.41	12	15	169	192	34	38	49	40

TABLE 4-20

demonstration run test segment. Figures 4-29 and 4-30 illustrate the decrease in power levels. In Figure 4-29, the average secondary current level for each ESP field is plotted for each test segment. Similarly, the average secondary voltage level for each ESP field for each test segment is presented in Figure 4-30. In both figures, the power levels seem to decline in the first field over the first week of the test and then "reset" to a higher level. The hypothesis to explain the higher power levels noted in the first field after test segment 1-DR-02 is that this increase was due to the cleaning of the first field and the hopper ridges during the short November 1-3 outage for the boiler tube leak.

The power levels then resumed the deterioration until there was a significant drop in power levels in field 1 during test segment 1-DR-04 and in field 2 during test segment 3-DR-04. Although the power levels decreased during test segment 3-DR-04, the ESP particulate control performance for this test segment was equivalent to the prior four test segments. This is because the mass loading tests, which were used to determine the performance levels were conducted on November 9, while the secondary current and voltage were decreasing in the second field. This is illustrated in Figure 4-31, which shows a daily plot of the secondary current for each field. As shown in this figure, the secondary current in field 2 was dropping during the day on November 9. There was also a slight drop in the secondary current level observed in field 3 on November 9. However, a more significant drop in secondary current levels was observed in field 3 on November 10. Also shown in the figure is a slight drop in average secondary current for field 4 on November 10. The secondary current in fields 3 and 4 were lower after November 10 and remained at the lower levels for the remainder of the demonstration run.

The reason for the drop in power levels in the ESP fields appears to be due to a solids build-up shorting out the first two fields. Solids build-ups were observed on the ridge beams between the first and second field and the second and third field hoppers. These build-ups, which were observed during an ESP inspection on November 29, extended up into the

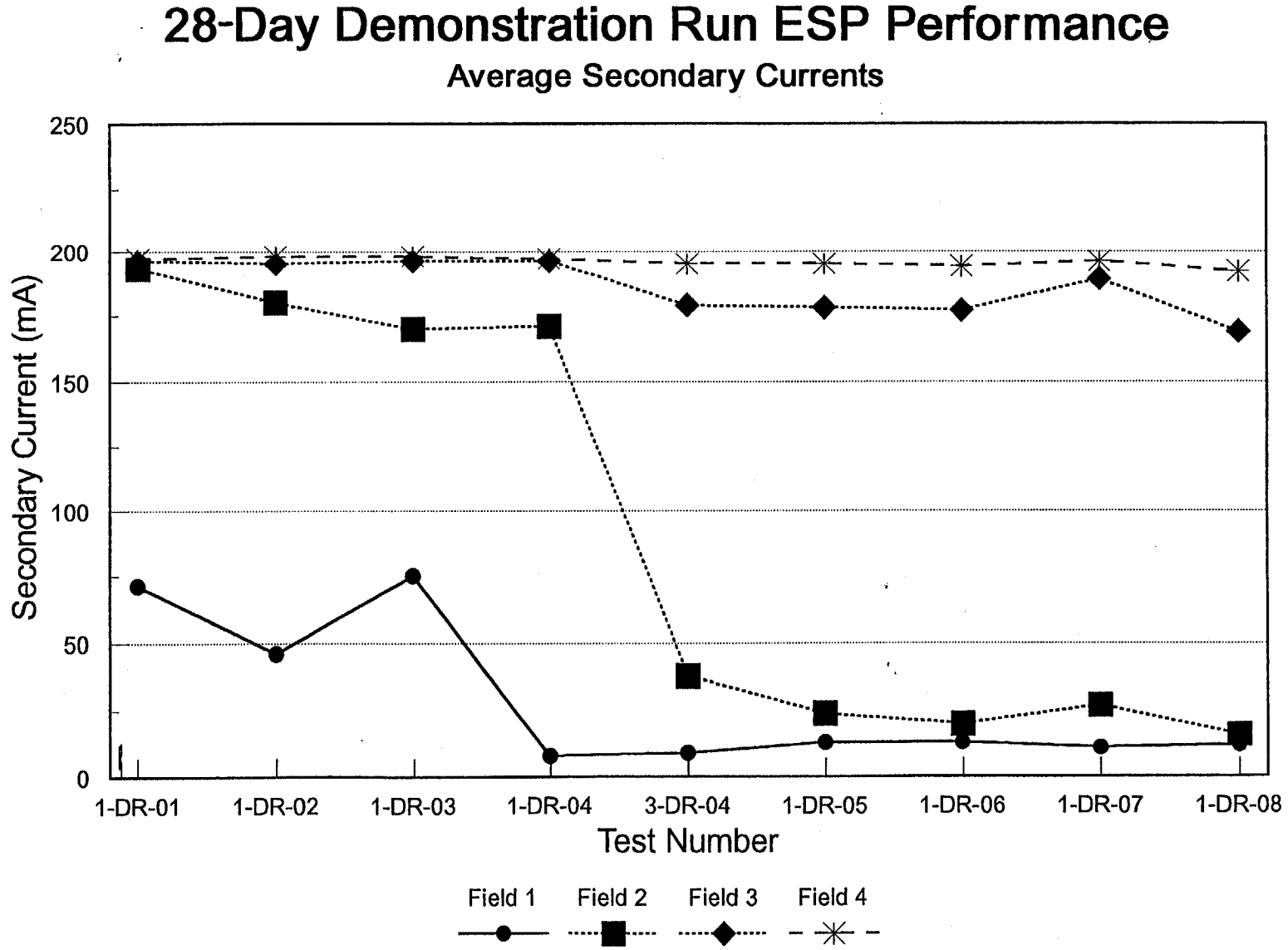

28-Day Demonstration Run ESP Performance
Average Secondary Currents
Secondary Current (mA)
250
200
150
100
50
0
1-DR-01
1-DR-02
1-DR-03
1-DR-04
3-DR-04
1-DR-05
1-DR-06
1-DR-07
1-DR-08
Test Number
Field 1
Field 2
Field 3
Field 4

FIGURE 4-29

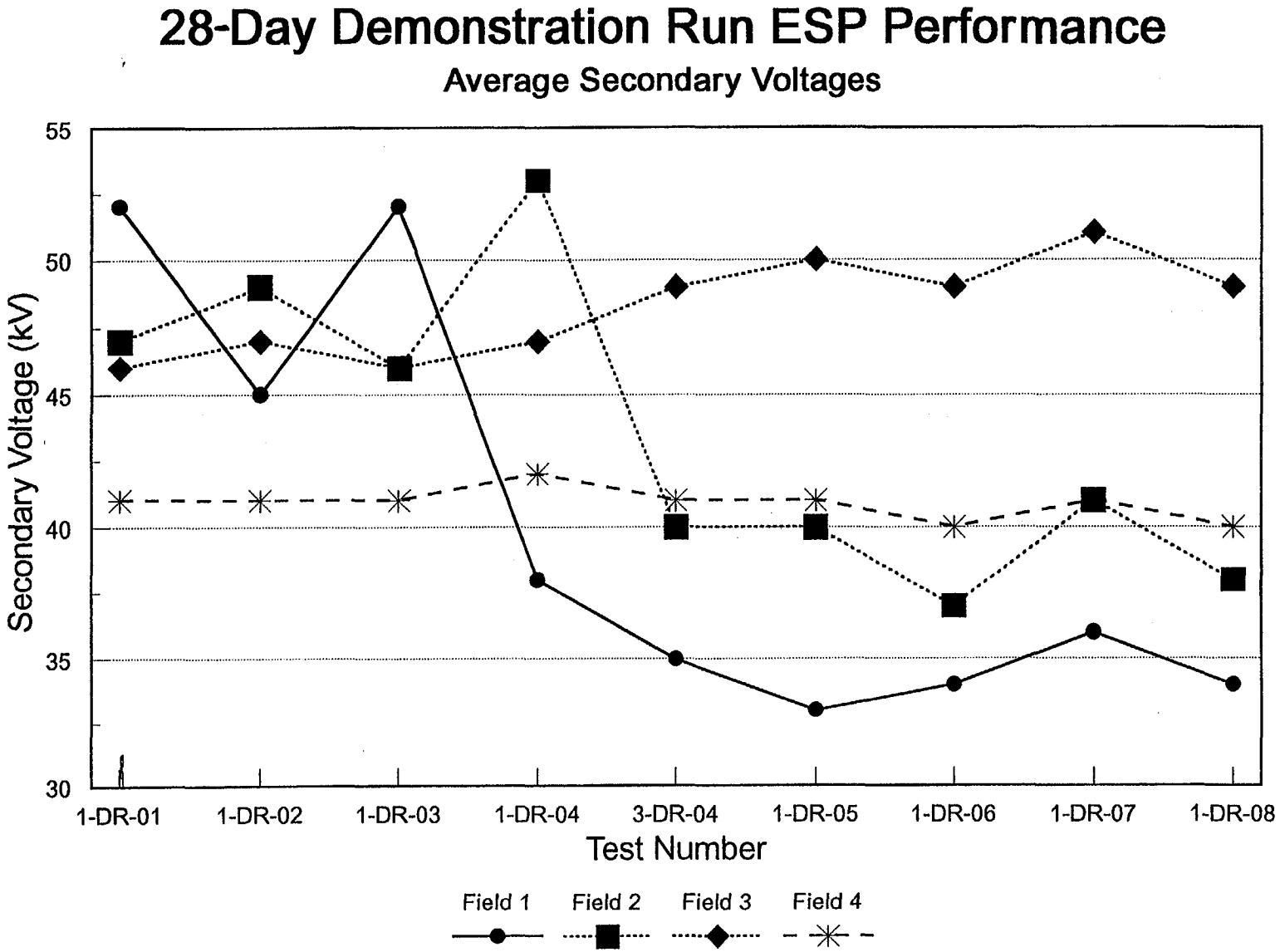

28-Day Demonstration Run ESP Performance
Average Secondary Voltages
Secondary Voltage (kV)
55
50
45
40
35
30
1-DR-01
1-DR-02
1-DR-03
1-DR-04
3-DR-04
1-DR-05
1-DR-06
1-DR-07
1-DR-08
Test Number
Field 1
Field 2
Field 3
Field 4

FIGURE 30

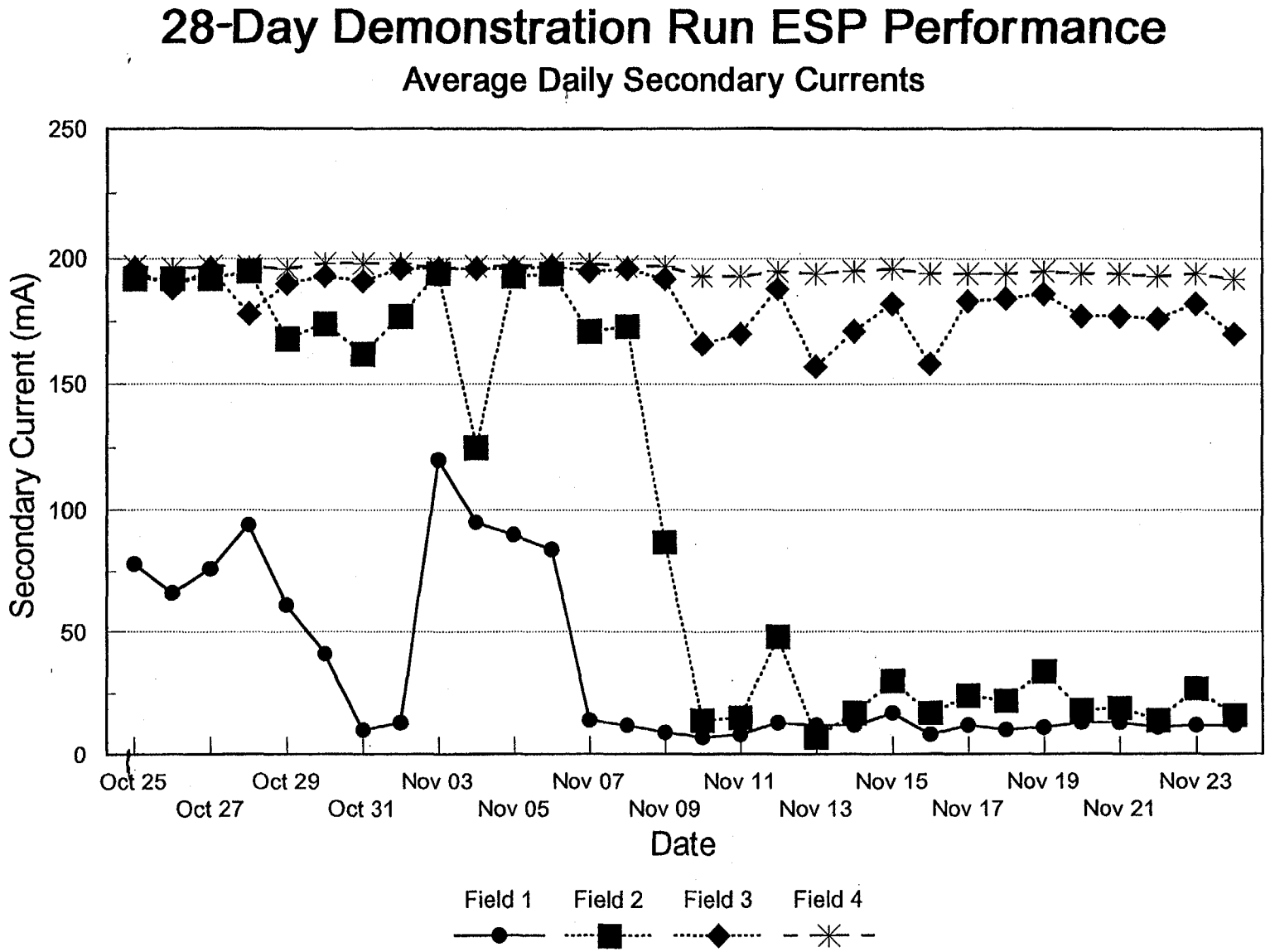

28-Day Demonstration Run ESP Performance
Average Daily Secondary Currents
Secondary Current (mA)
250
200
150
100
50
0
Oct 25
Oct 27
Oct 29
Oct 31
Nov 03
Nov 05
Nov 07
Nov 09
Nov 11
Nov 13
Nov 15
Nov 17
Nov 19
Nov 21
Nov 23
Date
Field 1
Field 2
Field 3
Field 4

FIGURE 4-31

plates and wires approximately 6 to 8 inches. The reduction in power levels in fields 3 and 4 was probably due to the increase in particulate loading resulting from the poorer particulate collection performance in fields 1 and 2.

14-Day PJBH Demonstration Run

The average secondary currents and voltages for each test segment during the PJBH demonstration run are presented in Table 4-21. As previously noted, the solids build-up on the first field wires due to failure of the rapper drive may have affected the first field secondary current during the first three test segments. Figures 4-32 and 4-33 present the average secondary current levels for each field during the PJBH demonstration run. In Figure 4-32, the average secondary current levels are plotted for each test segment. The figure shows a significant increase in the average first field secondary current during the last test segment (1-PJ-04), compared to the prior test segments when the first field wires were not being rapped. Figure 4-33, which plots the average daily secondary currents during the PJBH demonstration run, also shows a significant increase in the first field current for the last test segment, 1-PJ-04. However, there was a sharp decrease in the first field secondary current on the last day of the PJBH demonstration run, for an as yet unexplained reason. Also observed during the PJBH demonstration run was a decrease in the second field secondary current level from February 27 to March 3. No explanation was found for this decrease in secondary current in the second field.

Average AirPol ESP Secondary Currents and Voltages
1-PJ Series

Test No.	Ca/S Ratio	Reactor Inlet Temp (F)	App. Temp (F)	Flue Gas Flow Rate (scfm)	Recycle Screw Speed (rpm)	Reactor Inlet Fly Ash Inj. Rate (lb/min)	Coal Chloride Content (%)	First Field Current (mA)	Second Field Current (mA)	Third Field Current (mA)	Fourth Field Current (mA)	First Field Voltage (kV)	Second Field Voltage (kV)	Third Field Voltage (kV)	Fourth Field Voltage (kV)
1-PJ-01	1.37	319	18	20,000	30	4.9	0.12	21	155	197	198	45	46	45	41
1-PJ-02	1.41	319	18	20,000	30	4.9	0.12	25	112	198	196	45	43	45	41
1-PJ-03	1.34	320	18	20,000	30	4.9	0.12	31	183	197	196	45	47	44	42
1-PJ-04	1.43	319	18	20,000	30	4.9	0.12	130	199	198	195	50	43	44	41

TABLE 4-21

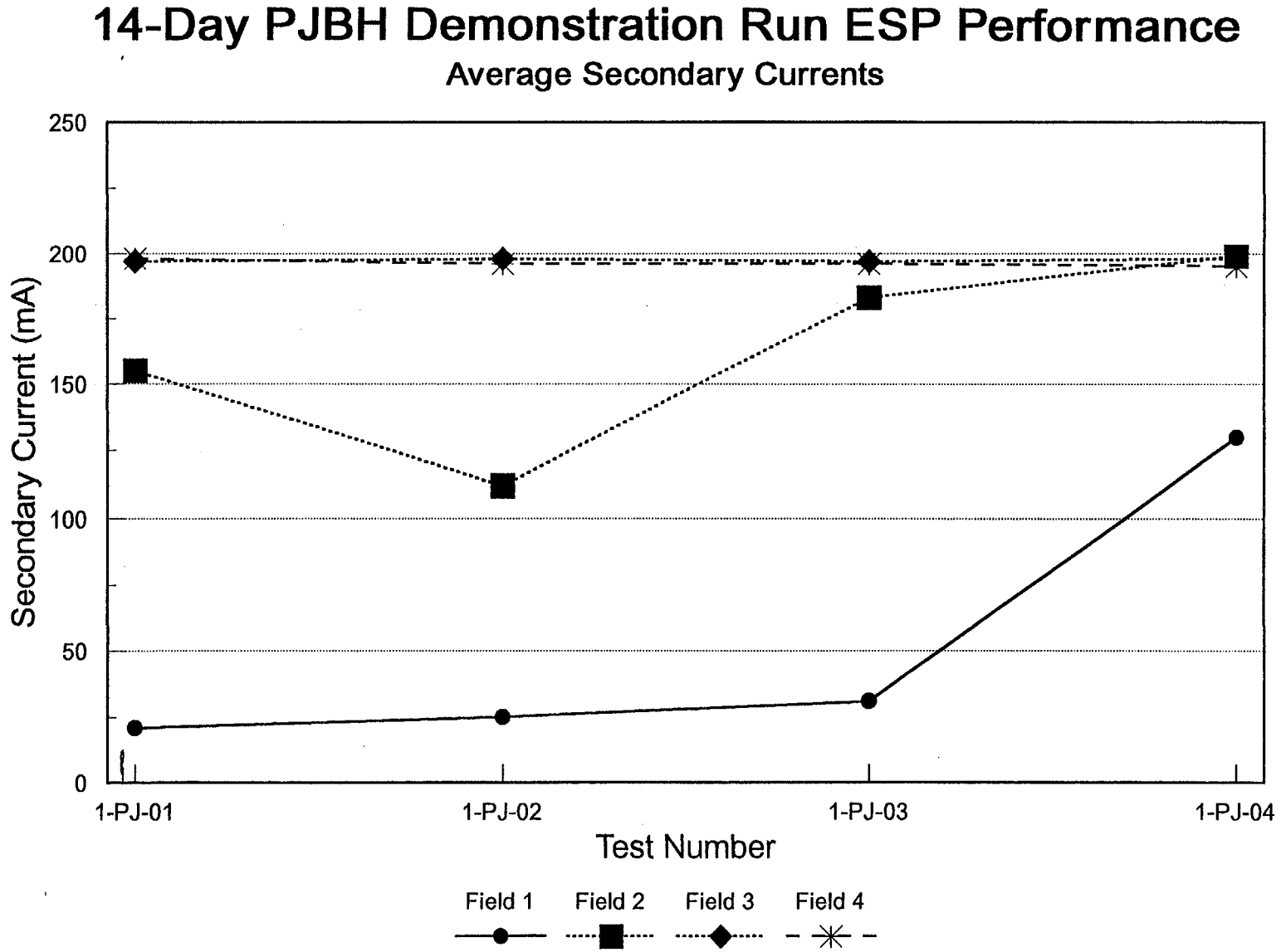

14-Day PJBH Demonstration Run ESP Performance
Average Secondary Currents
Secondary Current (mA)
250
200
150
100
50
0
1-PJ-01
1-PJ-02
1-PJ-03
1-PJ-04
Test Number
Field 1
Field 2
Field 3
Field 4

FIGURE 32

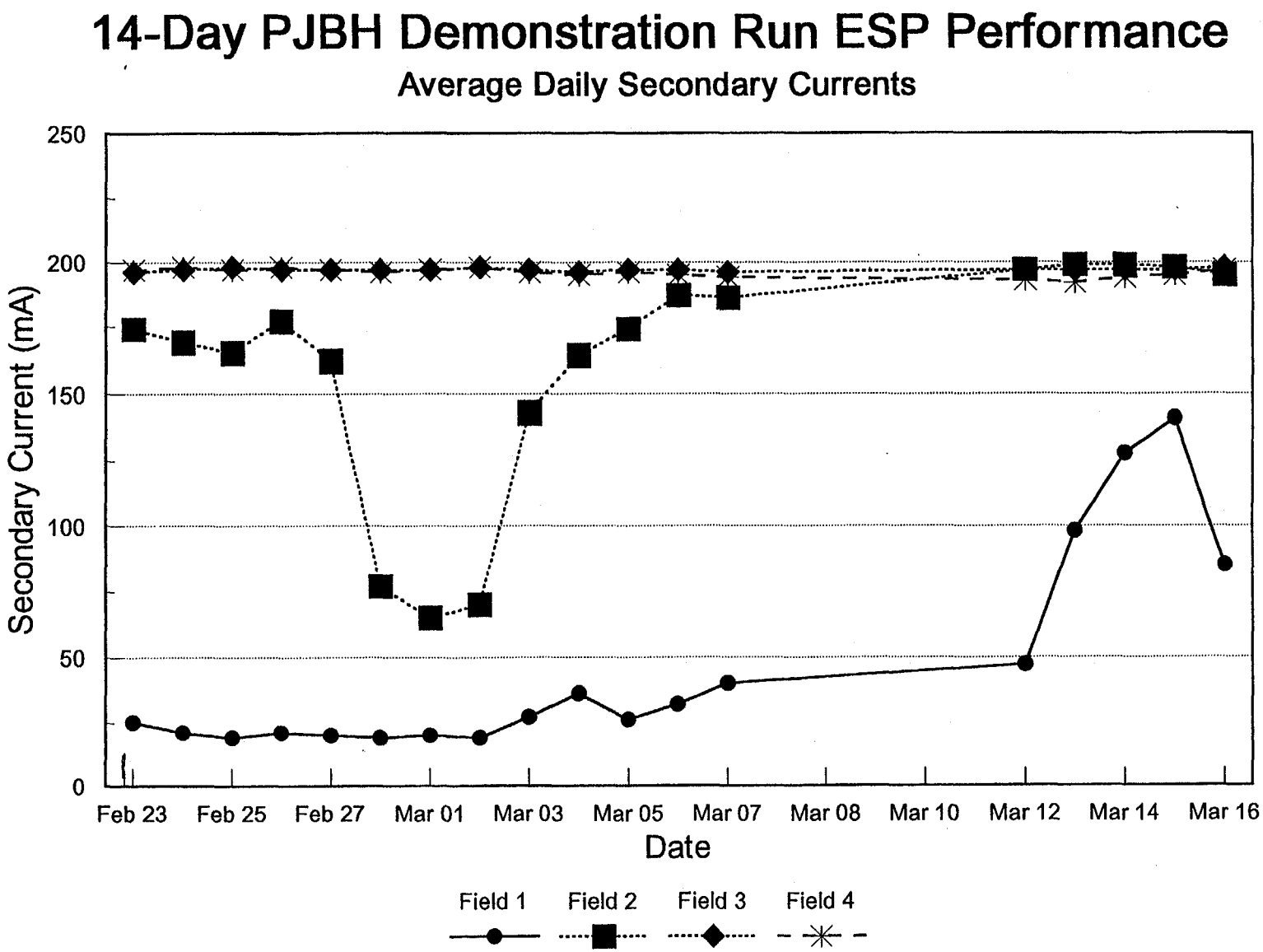

14-Day PJBH Demonstration Run ESP Performance
Average Daily Secondary Currents
Secondary Current (mA)
250
200
150
100
50
0
Feb 23
Feb 25
Feb 27
Mar 01
Mar 03
Mar 05
Mar 07
Mar 08
Mar 10
Mar 12
Mar 14
Mar 16
Date
Field 1
Field 2
Field 3
Field 4

FIGURE 4-33

Section 5

MAJOR OPERATING AND MAINTENANCE EXPERIENCES

The operating and maintenance experiences were limited to a few minor problems. The GSA system as installed at the CER was remarkably trouble-free and there were no major problems encountered during the testing. Therefore, attention was focused on a number of minor problems, which are discussed in more detail below. These minor problems are addressed by the test phase in which they were first noted.

FACTORIAL TESTING

Each of the factorial tests was typically run at a specified set of test conditions for only two days. A number of minor problems were noted during these short-term tests as discussed below.

Recycle Feeder Box

One of the more important of these minor problems involved the recycle feeder box. The recycle feeder box, which provided in-process storage of the dry solids collected by the cyclone, periodically emptied rapidly during a test, causing a sudden increase in the pressure drop in the GSA system. In the early part of the factorial test plan, this pressure drop spike typically tripped the ID fan. (This ID fan trip was a safety feature to protect the ESP and other equipment from high-negative static pressure transients.)

A specific set of test conditions was typically associated with this recycle feeder box problem. The specific test conditions included: high flue gas flow rate (20,000 scfm), high fly ash loading (2.0 gr/acf), high coal chloride level (0.12 percent), and high recycle screw speed (45 rpm). All four of these specific conditions had to be present in the test for the problem to occur. Thus, this problem could be avoided by not running a test at these specific variable levels.

A materials handling consultant was brought in to inspect the system and determine the cause of this problem. The cause was found to be the relatively long pipe from the recycle feeder box to the reactor, which allowed a syphon to form under these specific test conditions. The syphon was surprisingly powerful with a negative pressure exceeding -50 in H_2O developing in this long pipe prior to the rapid emptying of the recycle feeder box.

The consultant suggested that the permanent solution to this syphon problem would be to install a taller recycle feeder box or relocate the feeder box. This design change would be relatively simple to include in a new installation, but expensive to implement at the CER. This design change would have two positive effects. First, the taller recycle feeder box would shorten the length of the pipe carrying the dry solids back to the reactor. According to the consultant, the length of the return line to the reactor influences the magnitude of the syphon effect, i.e., the shorter the length of the return line, the smaller the syphon effect. Second, the taller recycle feeder box would increase the residence time in the recycle feeder box for the solids from the cyclone to deaerate.

When the solids in the recycle feeder box contained substantial amounts of the spherical fly ash particles and also calcium chloride, which added a surface layer of moisture on the particles, the recycle solids tended to flow easily out of the recycle feeder box under the negative pressure in the reactor. If the recycle feeder box residence time was increased to three minutes by making the box taller, the recycle solids would have more time to settle and deaerate. Without this air entrained in the recycle solids, the particles would be less likely to be pulled out of the recycle feeder box.

The recycle feeder box installed at the CER originally had a three-minute residence time based on the design recycle screw speed of 10-22 rpm. However, after the startup testing demonstrated that increasing the recycle screw speed from 10 to 22 rpm increased the overall system SO_2 removal efficiency, the decision was made to double the maximum speed of these screws to 45 rpm and to test the recycle screw speed at two levels: 30 and

45 rpm. At the 45 rpm recycle screw speed, the solids residence time in the feeder box was only about one minute and the solids did not have sufficient time to deaerate.

A more cost-effective solution for the CER installation was to install vent lines from the recycle feeder box to the cyclone to break this syphon before it could cause the recycle feeder box to empty. Also, a small observation port above the recycle screws in the feeder box was left open to help equalize the pressure in the system. These vent lines were installed using 1 in. rubber hose that connected the cyclone, the top of the recycle feeder box, and the discharge end of the recycle feeder box. Unfortunately, these vent lines tended to plug on occasion. This plugging of the vent lines was thought to occur when the recycle feeder box was filled completely. The solids then backed up into the cyclone and entered the top of the vent line connecting the recycle feeder box with the cyclone, plugging the line. This plugged vent line went undetected until the test conditions that generated the "syphon effect" were run and the recycle feeder box emptied rapidly, causing a pressure drop spike that tripped the ID fan.

A change in the operating procedures was also initiated to reduce the chance of the syphon effect causing an ID fan trip. The computer control system was reprogrammed to decrease the flue gas flow rate by 500 scfm whenever the static pressure at the ESP outlet approached the ID fan trip point. (A lower flue gas flow rate reduced the pressure drop in the system.) There were several factorial tests completed at the lower-than-planned flue gas flow rate because the computer control system had reduced the flue gas flow rate to prevent an ID fan trip. Even after this modification was made, however, the ID fan tripped on a high negative pressure on occasion.

Fly Ash Injection System

The fly ash loading in the flue gas entering the reactor was somewhat higher than planned during essentially all of the factorial testing. During an inspection of the fly ash injection system in late June, the rotary valve below the fly ash silo was found to be badly worn and fly ash

was apparently slipping past the valve, even when the valve was not operating. After this inspection, a new abrasion-resistant rotary valve was ordered, but could not be delivered and installed until after most of the factorial tests had been completed. Material balance calculations for some of the previously completed factorial tests indicated that the acid insoluble levels in the recycle solids product were consistent with a fly ash injection rate that was nearly double the planned rate. This uncertainty in the actual fly ash level for these factorial tests may have contributed to the variability in the test data.

These significantly higher-than-planned fly ash injection rates may have also contributed to the "syphon effect" problem encountered in the factorial testing by increasing the concentration of the spherical fly ash particles in the recycle solids. After the new abrasion-resistant, rotary valve was installed below the fly ash silo, no tests were completed at the appropriate conditions to determine if the resulting lower fly ash injection rate "solved" the syphon problem.

Several calibration checks for the new, abrasion-resistant rotary valve in November and December 1993 indicated that this rotary valve was metering the correct amount of fly ash into the flue gas. Thus, both the GSA and PJBH demonstration runs, which were completed after the installation of the new rotary valve, are thought to have been run at the planned fly ash injection rate.

ESP Deposits

There were solids buildups in the ESP during the GSA factorial testing. These solids deposits seemed to be correlated with tests, which had both the high coal chloride (0.12 percent) and the close approach-to-saturation temperature ($18^{o}F$) levels. The GSA solids produced under these test conditions seemed to have a high angle of repose. An inspection of the ESP following the completion of a test at these conditions typically showed solids deposits on nearly all of the horizontal surfaces in the ESP. Even the grating in the walkways between the first and second fields of the ESP had a significant buildup of solids. These deposits also occurred on the

hopper ridges below and slightly behind the first and second fields of the ESP. These solids deposits on the hopper ridges reduced the clearance between the plates and wires and these solids deposits and affected the electrical characteristics of these two fields.

There were also solid buildups on the walls in the ESP hoppers, particularly in the first field. These buildups were thickest in the corners of the hopper. On some occassions these deposits in the first field hopper corners "grew" into the collector plate area, effectively shorting out the field. This hopper was thought to be heated and well-insulated, but did not have rappers to dislodge these solids deposits. Later, after the completion of the GSA test program, the first field hopper heaters were found to have been disconnected. The insulation on the first field hopper was also found to be inadequate. (These deficiencies were thought to be the result of the modifications that were made to the first field hopper in early 1992.)

The major problem with these solids deposits in the hopper and on the hopper ridges was that these deposits appeared to be "growing" toward the collector plates and wires in the first field. These solids deposits, which may have contributed to the extremely low secondary current levels in the first field, were typically seen after completing high-chloride factorial tests at a close approach-to-saturation temperature. (See the discussion of the low secondary current levels below.) Normally these deposits were removed during the ESP inspections, but "grew" back during the next chloride-spiking test that was run at the close approach-to-saturation temperature condition. These solids deposits in the first field were not a significant problem in the factorial tests since there was no apparent correlation between the first field secondary current level and the emission rate from the ESP. Furthermore, these deposits could be periodically removed during outages before they reached significant levels.

ESP Secondary Current Levels

The average secondary current level in the first field of the ESP ranged from extremely low to the full-current level of 195 mA. These low average secondary current levels seemed to be correlated with a high flue gas flow

rate (20,000 scfm) and either the high approach-to-saturation temperature (28°F) or the high coal chloride level (0.12 percent).

These low secondary current levels in the first field could be due to either space-charge effects or a low-resistivity problem (or both). The apparent correlation between the coal chloride level and the current level would be indicative of a low-resistivity effect. The high angle of repose for the GSA solids during the chloride-spiking tests completed at a close approach-to-saturation temperature is indicative of the deliquescent nature of calcium chloride and the production of "sticky" particles that are likely to clump into larger particles. Thus, this result implies that the low secondary current levels for these tests may not be due to space-charge effects, which are caused by small particles.

The high approach-to-saturation temperature tests could result in either a resistivity problem or the production of small particles and thus, a space-charge problem. The high approach-to-saturation temperature would reduce the surface moisture level on the particles, lowering the cohesivity of these solids, and thereby preventing the agglomeration of the small particles.

Reactor Deposits

There were solids deposits on the reactor walls on occasion, particularly on the south wall of the reactor above the nozzle elevation. These solids deposits were typically not removed after the inspection of the reactor since these deposits were relatively minor and were thought to reach a steady-state level. This steady-state level occurred when the deposits built up and then fell off when sufficiently large, only to gradually rebuild with continued operation. These solids deposits did not seem to cause any operating problems.

On infrequent occasions, however, larger solids deposits were noted on the reactor wall. For the most part, these deposits did not cause operating problems. These larger solids deposits on the reactor wall occasionally broke free and fell through the venturi section at the bottom of the

reactor. These larger solids would deposit on the turning vanes at the inlet elbow. These turning vanes were located above the double-dump valve and if the solids were sufficiently large, the turning vanes could be blocked. This resulting bridge over the top of the double-dump valve would prevent the removal of the solids from the system. This bridging had been more of a problem early in the factorial testing when the original, small (6 in. dia.) rotary valve had been installed at this location. Because of this problem, a larger double-dump valve was installed and the frequency of these bridging problems declined substantially. However, these incidents still occurred periodically.

One possible remedy for this problem would be to install a delumper above this double-dump valve to reduce the size of any solids entering the valve. The inclusion of this delumper would be a prudent decision for a commercial installation to ensure the reliability of the GSA system. These delumpers are frequently used in the cone bottoms of SD FGD systems to prevent the oversize material from plugging the discharge in the cone bottom of the SD.

On several occasions the solids deposits on the reactor walls were more substantial. In nearly all of these incidents, a problem with either the two-fluid nozzle or its alignment was found to be the cause of these deposits. These deposits were typically not the direct cause for the system to shut down, but rather these solids deposits were found during a later inspection of the reactor. (The most extensive deposits were found during the reactor inspection after the completion of the 28-day GSA demonstration run, which had been successfully completed with no major apparent operating problems.) However, a severe nozzle or alignment problem, which happened infrequently, eventually resulted in a high pressure drop in the system that brought the system off-line.

Two-Fluid Nozzle

There were also deposits found on both the outside and inside of the two-fluid nozzle. These deposits became more extensive as the length of time between nozzle changeouts increased. The deposits on the outside of the nozzle appeared to be an inverted cone-like extension of the nozzle,

growing upward and outward into the reactor. However, no major operating problems were associated with these deposits. These deposits were probably due to a gradual buildup of material over time due to the interaction of the hot flue gas and lime slurry at the outside edge of the nozzle cone.

The deposits on the inside of the nozzle were located on the perforated plate separating the lower chamber where the atomizing air entered the nozzle and the upper chamber where the fresh lime slurry and trim water were introduced into the nozzle. On occasion some of the holes in the plate were plugged by these deposits. These solids appeared to be calcium carbonate deposits resulting from the pH change in the trim water when it was mixed with the lime slurry. The trim water was filtered river water and probably contained dissolved calcium carbonate, which then precipitated in the nozzle with the pH increase due to the lime slurry.

The nozzle and lance were typically changed out every two weeks during the factorial testing at the CER. (The lance is the piping internal to the reactor through which the feed slurry flows to reach the nozzle.) The slurry and trim water lines to the lance had quick-disconnect-type connections to facilitate the nozzle/lance changeout. The replacement nozzle and lance assembly was inserted as soon as the original assembly was removed to minimize the length of time without slurry being injected into the reactor. The total time for this changeout was typically about five minutes and was accomplished without shutting the GSA system down. The assembly that was removed from the reactor was then cleaned and inspected in preparation for its next use. The nozzles were cleaned with a weak acid solution and the average cleaning time was about 4 hours. The deposits inside and outside the nozzle were not difficult to remove.

Initially, the two-fluid nozzle was changed out relatively frequently, on a daily basis during the startup tests and then weekly during the initial factorial tests. Later, the time interval between changeouts was gradually stretched until it was being changed out every two weeks. There were attempts to increase the time interval between changeouts to four weeks, but the deposition of solids in and on the nozzle made this too long of a time period, and the changeout frequency reverted back to every two weeks. The basis for trying to decrease the frequency of the nozzle changeout was

that no SO_2 removal occurs during the short period of time that the nozzle was being changed out. Without the lime slurry injection, the approach-to-saturation temperature in the reactor quickly increased to 150-200°F and the SO_2 removal efficiency in the GSA system decreased to near zero.

Although the changeout time was estimated at only five minutes, if a high SO_2 removal efficiency is required, possibly because the unit is burning a high-sulfur coal, the SO_2 emissions during frequent changeouts of the nozzle assembly could be a significant contributor to the total SO_2 emissions during the averaging period, particularly for those units having short averaging periods.

The other reason for reducing the frequency of the nozzle assembly changeout was to reduce the operating and maintenance requirements for the process. One of the major factors that utilities use in evaluating alternative SO_2 control technologies is the operating and maintenance labor required. Thus, longer intervals between nozzle assembly changeouts might be a substantial advantage for the GSA process.

The stainless steel washers used in the two-fluid nozzle have shown relatively good service life. Only one of these washers had been worn to the point that it failed. The one washer that failed had an elongated orifice (about 11/16 in. dia. vs. a normal 7/16 in. dia) that is thought to have resulted in "poor" atomization and led to the deposition of solids in the reactor, which led to the shutdown of the system. Normally these washers are replaced every 500-600 hours. However, it should also be noted that these washers are not exposed to an erosive environment since the washers were only used to atomize the de-gritted, dilute lime slurry.

Recycle Screw Deposits

Solids buildups have been noted on the recycle screws in the recycle feeder box on a relatively infrequent basis. This material had to be chipped off the recycle screws and also the troughs that the screws turned through. Both the recycle feeder box and the troughs for the recycle screws were heated so that condensation was not thought to be the cause of these

deposits. Instead, these deposits were thought to be a gradual buildup over time, which could be removed during regularly scheduled maintenance outages. (The opening of the observation port to minimize the potential syphon effect may have aggrevated this problem by allowing ambient air to enter the recycle feeder box above these recycle screws.)

Level Indication in Recycle Feeder Box

The design of the GSA system at the CER included weigh cells to determine the solids levels in the recycle feeder box. These weigh cells were not satisfactory for determining the solids level in the recycle feeder box. Even though the CER was a research and development facility and had instrument mechanics readily available to regularly calibrate these weigh cells, the weigh cells were unreliable for process control purposes. The weigh cell readings, if used at all, were used primarily for trend-following rather than as an absolute value. A reliable level indicator for the recycle feeder box would be needed for a commercial GSA installation. A nuclear-type level indicator would probably be the most reliable and would "shoot" downward through the height of the recycle feeder box.

GSA DEMONSTRATION RUN

Several operating and maintenance problems occurred during the 28-day GSA demonstration run. Since this run was significantly longer than any of the previous factorial tests, one would expect some problems to occur that were not apparent in the shorter tests. Each of these problems is discussed in more detail below.

High Ca/S Level

During the 28-day GSA demonstration run, a higher-than-expected Ca/S level was required to achieve the average 91 percent overall system SO_2 removal efficiency. For the initial week of the demonstration run while the boiler was burning the design coal, the average Ca/S level required to achieve the 91 percent overall system SO_2 removal efficiency setpoint ranged from 1.40-1.45 moles $Ca(OH)_2$/mole inlet SO_2. Based on the previous factorial

tests, the expectation had been that the Ca/S level would be in the range of 1.30-1.35 moles $Ca(OH)_2$/mole inlet SO_2. When the results showed that a higher Ca/S level was needed, TVA checked a long list of possible causes for the higher-than-expected Ca/S level, but no problems with the system were found.

When no equipment problems were found, various other reasons for the higher-than-expected Ca/S were evaluated. Because this "problem" occurred at the end of the test program, no definitive explanation for this result was determined. However, four possible reasons, acting alone or in concert, were thought to be the reason for this "problem". First, in the previous factorial testing, the Ca/S level was controlled at a setpoint. In this demonstration run, the control system was focused on the overall system SO_2 removal efficiency setpoint. The SO_2 removal efficiency tended to fluctuate because of a number of factors (e.g., changes in the inlet flue gas SO_2 concentration) and in the SO_2 control mode, the Ca/S level was continually changing to maintain the setpoint. This tended to cause the Ca/S level to overcompensate on average and be above that level found to be needed in the previous factorial testing. This "over-shoot" is more pronounced in a higher sulfur coal application where a high SO_2 removal efficiency is required because of the flattening of the Ca/S effect on SO_2 removal, i.e., at already high Ca/S levels, a larger increase in the Ca/S level is required to generate an incremental increase in the overall system SO_2 removal.

Second, the recycle screw speed was reduced from 45 to 30 rpm in the demonstration run to eliminate any potential for operating problems, i.e., the "syphon effect" (see earlier discussion). The other test conditions for the 28-day GSA demonstration run included the high flue gas flow rate (20,000 scfm), high fly ash loading (2.0 gr/acf), and high coal chloride (0.12 percent) level. If the recycle screw speed had been set at 45 rpm, the GSA system might have achieved a slightly higher overall system SO_2 removal efficiency, but would have been susceptible to the syphon effect. Since the primary emphasis in this run was to keep the GSA system on-line continuously for the full 28-day period, the decision was made to be conservative and use the lower recycle screw speed. (The preliminary

analysis of the factorial test results had indicated that the recycle screw speed had a very minor effect, if any, on the overall system SO_2 removal efficiency.)

Third, the fly ash loading at the system inlet was somewhat higher in this GSA demonstration run with the Andalex coal. During the previous testing with the other coals, the fly ash loading at the system inlet had been about 0.5 gr/acf. This level (0.5 gr/acf) was the basis for the addition of 1.5 gr/acf of fly ash during this run. However, with the Andalex coal, the fly ash loading at the system inlet was later determined to be somewhat higher at about 1.0 gr/acf. When the additional fly ash was injected at the rate of 1.5 gr/acf, the total fly ash loading in the flue gas at the reactor inlet was higher than planned. These higher fly ash loadings would displace some of the recycle material and thereby reduce the overall system SO_2 removal efficiency. (However, this reduction in SO_2 removal was expected to be relatively minor, based on the preliminary analysis of the factorial test results.)

Fourth, the high overall system SO_2 removal efficiencies that were achieved at a somewhat lower Ca/S level in the factorial testing were not absolute. These results were subject to the normal variability in the test data. This meant that even though one was repeating a test condition, the overall system SO_2 removal efficiency could vary around a median value. If the factorial test results had been at the high end of this variability range, some of the apparent increase in the Ca/S level to achieve the overall system SO_2 removal efficiency during the demonstration run could be due to this variability.

Boiler-Related Problems

During the first week of this 28-day GSA demonstration run, there was an interruption in the supply of the Unit 9 coal. The planned deliveries of the high-sulfur (2.7 percent) Andalex coal were delayed because of problems at the mine. On October 31, the boiler was switched to the higher sulfur (3.5 percent) Warrior coal that is normally burned in Unit 10 at Shawnee. However, this "problem" allowed the system to demonstrate its flexibility by treating the flue gas resulting from the combustion of the higher sulfur

coal and still maintain the 90+ percent SO_2 removal efficiency setpoint (although at a higher Ca/S level). The boiler continued burning the higher sulfur Warrior coal for about one week. Thus, several test segments were completed while the boiler was burning this Warrior coal.

Shortly after the higher sulfur Warrior coal was loaded into Unit 9, the unit was shut down to repair a tubeleak. The unit and the GSA system were shut down on November 1. Since this forced outage was due to a boiler problem and was unrelated to the GSA system, the lost test time was added to the end of the run. The boiler and the GSA system were both back on-line on November 3. This boiler outage caused a two-day delay in the completion of the 28-day demonstration run.

ESP Solids Deposits

The presence of solids deposits on the hopper ridges in both the first and second ESP fields did appear to result in a degradation of the ESP performance during the 28-day GSA demonstration run. In this longer-term run, the ESP performance seemed to decline slightly over time in the first week and then improved when the boiler came off-line and the hopper ridges were cleaned. Once back on-line, the ESP performance resumed its gradual decline. About two weeks into the run, a mechanical problem prevented the removal of solids from the first field hopper and forced the temporary shutdown of the first field. This shutdown resulted in a high inlet grain loading to the second field. Shortly after this mechanical problem, the average secondary current in the second field plummeted to an extremely low level. (The first field secondary current was already at a low level.) The emission rate doubled from about 0.007 to 0.015 lb/MBtu at about the same time that the average secondary current level in the ESP second field declined.

Although the average secondary current levels in the first and second fields dropped to extremely low levels, the third and fourth field continued to operate at or near the full-current level. One potential explanation for this apparently inconsistent result is the site-specific design of the ESP that is installed at the CER. The ridge between the first and second field hoppers is located below and slightly behind the plates in the first field. Similarly, the ridge between the second and third field hoppers is located

below and slightly behind the plates in the second field. The relatively close clearance between these hopper ridges and the plates and wires in these two fields make them particularly susceptible to the effect of the solids deposits. The more "typical" design for the third and fourth field hoppers and fields, i.e., with the hopper ridges below and further behind the plates and wires, provided more clearance. This larger clearance in these fields apparently resulted in essentially no impact on these fields from solids deposits on the hopper ridges, even after both the first and second fields had "shorted out" and were operating at extremely low secondary current levels.

The emission rates from the ESP seemed to correlate with the daily average secondary current level in the second field of the ESP. The average daily secondary current in the second field of the ESP, which is shown in Figure 5-1, remained at relatively high levels through the first two weeks of the demonstration run and the emission rates remained at very low levels (0.004-0.009 lb/MBtu) during this time period. However, once the average secondary current level in the second field dropped precipitously and remained at very low levels, the emission rate ramped up to the range of 0.015 lb/MBtu and remained at this level for the remainder of the run, as shown in Figure 5-2.

The dramatic decline in the average secondary current level occurred during the period from November 10-14 and the first mass loading run on November 13 showed a large step change in the emission rate over the previous data from November 9. (No mass loading data are available for the period of November 10-12.) During the last two weeks of the run the emission rate appeared to reach a steady-state level of about 0.015 lb/MBtu. Although these average emission rates show some fluctuation, given the much wider range of the individual data points, all of these average values are essentially the same.

The lower secondary current in the second field of the ESP may have appeared sooner, except that the boiler went down to repair a tubeleak late on November 1 and the hopper ridges were cleaned on November 2. This cleaning was initially thought to have delayed the onset of the decrease in the secondary current in the second field of the ESP and the "poor" ESP performance.

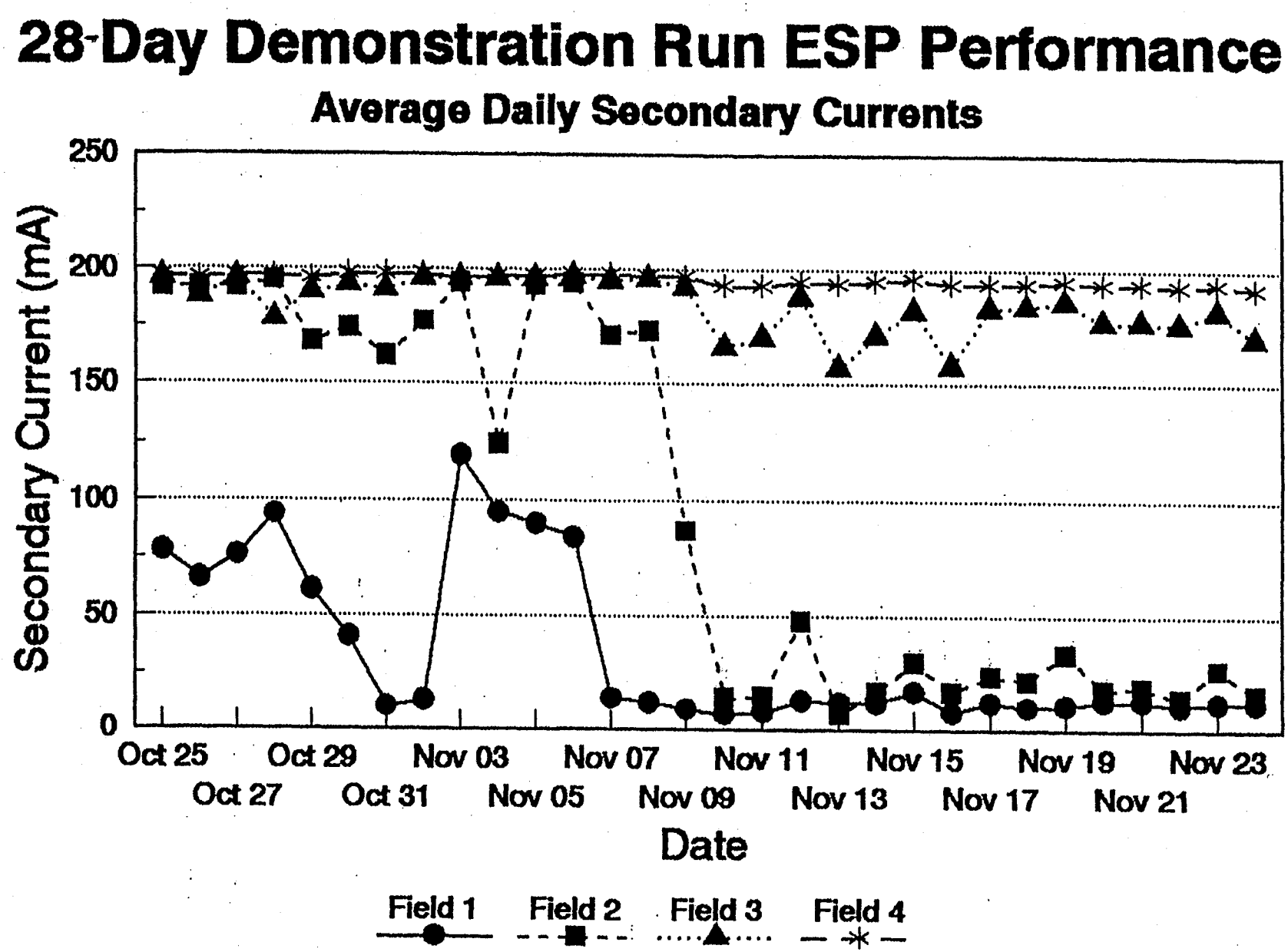

28-Day Demonstration Run ESP Performance
Average Daily Secondary Currents
Secondary Current (mA)
250
200
150
100
50
0
Oct 25
Oct 27
Oct 29
Oct 31
Nov 03
Nov 05
Nov 07
Nov 09
Nov 11
Nov 13
Nov 15
Nov 17
Nov 19
Nov 21
Nov 23
Date
Field 1
Field 2
Field 3
Field 4

FIGURE 5-1

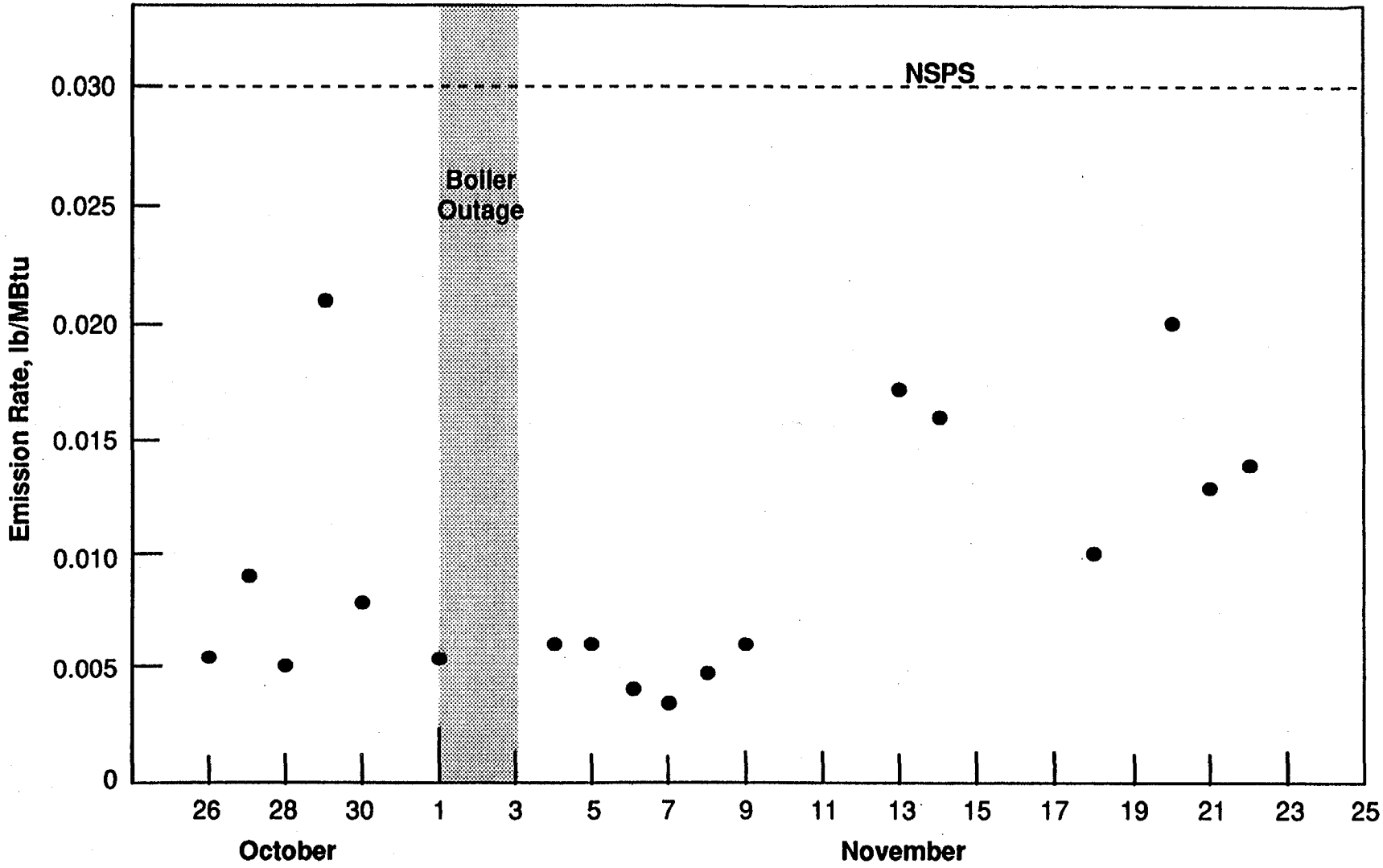


Figure 5-2. Daily Average ESP Emission Rate

Double-Dump Valve

The solids deposits on the hopper ridges in the back of the first and second fields of the ESP may have been partially due to problems with the first field double-dump valve. The first problem with this valve occurred on October 29 when the rubber liner tore and a portion of this liner fell into the valve throat, blocking the flow of solids from the hopper. The blockage was removed without bringing the system down. Although no effect was noted on the secondary voltage and current in the first field, the solids in the hopper could have built up and contributed to the deposits on the hopper ridge. Fortunately, the boiler came down with a tubeleak on November 1 and this outage provided an opportunity to clean out the solids deposits on the hopper ridges.

The screw conveyor that removes the solids from the first field hopper failed and could not be reset on November 12. Since solids could not be removed from the first field hopper during this period, the first field was deenergized while the screw conveyor was repaired. A backing plate from the first field double-dump valve was found to have fallen into the screw conveyor and bound up the screw. This backing plate was removed and the screw conveyor was returned to service.

However, with the first field deenergized, the inlet grain loading entering the second field would have increased dramatically. This higher inlet grain loading could have filled the second field hopper and led to solids deposits on the hopper ridge below and behind the second field of the ESP.

The fact that this incident occurred in the same time frame that the secondary current in the second field of the ESP dropped precipitously may not be coincidental. No mass loading runs were completed around the ESP on this day because of these problems and there is no data to confirm that these problems were a contributor to the increased ESP emissions. However, after the repairs had been made, the emission rate data from the following day, November 13, indicated that a "large" step change had occurred with the emission rates substantially higher than the emission rates reported immediately prior to the double-dump valve and screw conveyor problems. The emission rates seemed to improve somewhat over the next 5 days.

PJBH Operation

The original plan was to start up the PJBH on Monday, November 7, and keep it on-line during the final two weeks of the 28-day GSA demonstration run. The PJBH, which would be operating in the "in-parallel" mode, started up and began operating as scheduled. However, after about 30 hours of operation, the opacity in the CER stack suddenly increased to unacceptable levels and the tubesheet pressure dop in the PJBH dropped to a very low level (less than 2 in. of water). The PJBH was taken off-line and remained down for the remainder of the GSA demonstration run.

There was also a failure of the damper control motor at this time, which confused the resolution of the PJBH problem. This motor failure turned out to be unrelated to the cause of the high opacity, but had to be resolved before the cause of the bag leaks could be discovered.

Eventually, the PJBH was opened up and inspected. The cause of the opacity problem was readily apparent once the PJBH was opened up. The hopper was full of solids, but more importantly the ends of a number of the acrylic bags were missing. The inspection of these bags indicated that there was scorch damage on those bags above where the fabric was missing. Thus, flue gas from the ESP inlet containing 3-4 gr/acf of particulates was passing through the PJBH into the CER stack. Since no spare bags were available, a new set of acrylic bags was ordered and the PJBH demonstration run had to be postponed until March 1994.

Several of the damaged bags were sent to a consultant for failure analysis and the operating data from the PJBH was analyzed in detail. Based on the PJBH data and bag analyses, the tentative conclusion was that the bags had been damaged by a small, smoldering-type fire in the PJBH hopper. There were several observations that supported this unlikely conclusion. First, several large, "football-size" lumps of solids were found in the PJBH hopper, possibly indicating the presence of a fire. Second, a thermocouple installed in the PJBH hopper had recorded a brief, high-temperature spike (>1,000^{o}F), which is indicative of a smoldering-type fire moving past the thermocouple. Third, the scorch damage on the bags was consistent with the presence of a fire. Fourth, the flue gas temperature in the PJBH outlet

duct, which is normally below that of the inlet flue gas (because of heat losses in the PJBH and air inleakage), increased above the inlet flue gas temperature at essentially the same time that the opacity in the CER stack increased and the tubesheet pressure drop decreased.

This smoldering-type fire in the PJBH hopper was thought to be due to a unique set of circumstances that were unlikely to be repeated. The "fuel" for this smoldering fire was presumed to be the unburned carbon in the fly ash that was present in the hopper. (The fly ash from Unit 9 contains high levels of unburned carbon.) The PJBH had previously been operated in the fly-ash-only, "in-parallel" mode during the air toxics testing in mid-to-late October and then had been taken off-line. Apparently these carbon-laden fly ash particles had formed a bridge over the rotary valve in PJBH hopper and remained in the hopper "drying out" during the two-week outage prior to the restart of the PJBH on November 7.

With the heating up of the PJBH and the presence of oxygen from air inleakage through the rotary valve in the bottom of the hopper, the dry carbon on the flyash was assumed to undergo spontaneous combustion near the bottom of the hopper. This "fire" gradually moved up through the material in the hopper, forming the "football-size" lumps of solids and passing by the thermocouple. Once the fire reached the top of the solids in the hopper, the concentration of unburned carbon decreased rapidly since these top layers were laid down during the GSA demonstration run. However, before the fire had exhausted all of the fuel, the ends of about one-third of the bags were burned. This would appear to indicate that the ends of some of the bags had been buried in the solids in the PJBH hopper or were very close to the surface, if not actually buried.

GSA System Inspection

After the 28-day GSA demonstration run was successfully completed, the system was shut down and inspected. The inspection of the GSA reactor revealed solids buildup in the bottom section of the GSA reactor. The buildup was located on the reactor walls approximately 6 ft above the nozzle and extended upward for about 7 ft. The buildup consisted of "fingers" of material that pointed downward and inward toward the nozzle.

Some of these fingers extended about one foot inward from the reactor wall. The buildup was heaviest on the south and west walls of the reactor. In addition to this heavier buildup, there was a light scaling on the bottom 10-15 ft of the reactor wall that was about 1/4 to 1/2 in. thick.

Some of the buildup had obviously fallen off the wall and was lying on the turning vanes in the reactor inlet elbow. This material was very hard and was removed after the inspection. Apparently some of these "fingers" had broken off and then built back up during the run.

The ESP inspection revealed that in addition to the solids buildups on the hopper ridges, which extended up into the space occupied by the first and second field plates and wires, there were buildups on all of the horizontal surfaces. Even the catwalks between some of the fields had up to one ft of material built up. All of the discharge wires and collector plates in the first two fields had a light scale of material. The collector plates in the third and fourth fields had a heavier coating of solids. This was probably due to the higher particulate loading entering these fields with the very low secondary current levels in the first two fields during the last two weeks of the demonstration run.

PJBH DEMONSTRATION RUN

Several operating and maintenance problems were encountered during the 14-day PJBH demonstration run, which had not been encountered previously. The only problem of signficance was a lower-than-planned A/C level in the PJBH during the last week of the run.

Low A/C Level

The PJBH demonstration run was interrupted during the second week because of a coal supply problem. When additional supplies of the Andalex coal became available, the GSA/PJBH system was restarted. The A/C in the PJBH after the restart began at the design level of 4.0 acfm/ft^2, but gradually began to decline. After several days, the A/C had declined about 10 percent to a level of 3.6 acfm/ft^2.

The lower-than-planned A/C level was found to be due to a high pressure drop in the PJBH pilot plant system. Even with the louver-type damper upstream of PJBH ID fan in the fully-open position, the flue gas flow rate decreased below the design level for the run. The suspicion was that there were deposits in the flue gas ductwork either in the inlet or the outlet ductwork that caused this higher pressure drop in the PJBH system.

To overcome this problem, the setpoint to initiate the cleaning of the PJBH was decreased from 5 in. to 4 in. of water. The cut-off for the cleaning cycle was decreased from 4 in. to 3 in. of water. This reduction in the tubesheet pressure drop allowed a return to the higher design flue gas flow rate for the final day of the PJBH run.

Two-Fluid Nozzle

The suspected plugging in the PJBH ductwork was thought to be due to the upset condition that occurred after the boiler was switched to the low-sulfur compliance coal. The GSA system initially remained on-line after the coal switch. However, at the low-sulfur coal conditions, the ratio of fly-ash-to-lime increased dramatically and operating problems were encountered, which resulted in an upset condition in the reactor, and the GSA system was shut down. This upset condition may have resulted in damp solids being deposited in the PJBH ductwork where they remained unnoticed until the restart of the PJBH.

One other minor problem that was noted during the PJBH demonstration run was that the alignment of the two-fluid nozzle in the reactor must be checked periodically and adjusted, as necessary. During this PJBH run, a problem was noted with both the clamps holding the lance and a worn gasket. Fortunately, these problems were discovered and corrected during the low-sulfur coal outage in the middle of this run.

First-Field Rappers

During the low-sulfur coal outage, the system was inspected and relatively thick deposits were noted on the wires in the first field. The rapper system for these emitter wires had apparently failed in early February because of a sheared pin. This pin was replaced and the rappers were reengaged to clean these wires. This repair led to a significant increase in the average secondary current level in the first field.

Section 6

CONCLUSIONS AND RECOMMENDATIONS

The 10-MW GSA system at the CER successfully achieved all of the major objectives of the planned test program including:

1. The GSA/ESP process demonstrated high SO_2 removal efficiencies (80-90 percent) at modest Ca/S levels (1.30 moles $Ca(OH)_2$/mole inlet SO_2) and a close approach-to-saturation temperature (8^oF) when treating flue gas resulting from the combustion of a 2.7 percent sulfur, low-chloride (0.02-0.04 percent) coal during the factorial tests;

2. The GSA/ESP process demonstrated high SO_2 removal efficiencies (90+ percent) at a modest Ca/S level (1.30 moles $Ca(OH)_2$/mole inlet SO_2) and a higher approach-to-saturation temperature (18^oF) with slightly higher levels of chlorine in the coal (0.12 percent) during the factorial tests;

3. The GSA/ESP process had very low particulate emission rates, i.e., well below the NSPS for particulates, when a four-field ESP with an SCA > 440 ft^2/kacfm was used for particulate control;

4. The GSA/PJBH had a very low particulate emission rate, i.e., well below the NSPS when operating at an A/C level of 4.0 acfm/ft^2.

5. A 28-day, continuous, GSA demonstration run was successfully completed. During this run the GSA/ESP system averaged 90+ percent SO_2 removal efficiency, even when the boiler was switched to a higher sulfur coal. The ESP emission rate remained below the NSPS for particulates (0.03 lb/MBtu) throughout the run, although the particulate emissions increased somewhat after about two weeks of operation, but then steadied out at about 0.015 lb/MBtu, i.e., one-half the NSPS level. The GSA/ESP system also demonstrated its

reliability by remaining on-line, achieving both the SO_2 and particulate removal requirements during the entire 28-day period that the boiler was operating.

6. A 14-day, continuous, PJBH demonstration run was successfully completed. During this run the GSA/PJBH system average 96+ percent SO_2 removal efficiency. (The SO_2 removal efficiency in the GSA/ESP system averaged 91 percent during this run.) The PJBH emission rate was about one order of magnitude below the NSPS for particulate during this run. The GSA/PJBH demonstrated its reliability by remaining on-line, achieving both the SO_2 and particulate removal requirements during the entire 14-day period that the boiler was burning the design coal.

In addition to these conclusions related to the major objectives of the GSA program, several other conclusions were apparent during the GSA testing at the CER.

1. Most of the SO_2 removal efficiency occurs in the reactor/cyclone with relatively low SO_2 removals (2-8 percentage points) in the particulate control device. The SO_2 removal efficiency was lower in the ESP than in the PJBH, as was expected.

2. The enhanced mass and heat transfer characteristics of the reactor allow these high SO_2 removal efficiencies to be achieved at a very low flue gas residence time without incurring operating problems. The reactor also operates at a high flue gas velocity (20-25 ft/sec).

3. The expected enhancing effect of chlorine on the SO_2 removal efficiency in the GSA/ESP process was documented. Even modest coal chloride levels (0.12 percent), which are typical of many coals, can provide this effect;

4. The SO_2 removal efficiency in the GSA/PJBH system was typically about 3-5 percentage points higher than that achieved in the GSA/ESP system at the same test conditions;

5. The GSA system produces a by-product material containing very low moisture levels. This material contains both fly ash and unreacted lime and thus, with the addition of water, undergoes a pozzolanic reaction and can be disposed of in a landfill.

6. The GSA system has no wet/dry interface and the entire system is fabricated from carbon steel rather than high-cost alloy material; and

SECTION 7

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