A CASE STUDY FOR SULFURIC ACID FLUE GAS CONDITIONING At NOVA SCOTIA POWER, TRENTON UNIT 5

Jerry Lynch
President
FSA, Inc.
A subsidiary of Wahlco Environmental Systems, Inc.
2 Enterprise Drive
Shelton, Connecticut 06484

Jeff Lee
Mechanical Engineer
Generation Engineering Department
Nova Scotia Power, Inc.
Halifax, Nova Scotia B3J2W5

A CASE STUDY FOR SULFURIC ACID FLUE GAS CONDITIONING At NOVA SCOTIA POWER, TRENTON UNIT 5

Abstract

Regulatory concerns and the recent development of economically attractive sources of low sulfur coal have prompted Nova Scotia Power Incorporated (NSPI) to explore ways to reduce sulfur emissions at their Trenton Power Station located in Trenton Nova Scotia. Designed to burn oil and coal, the Trenton Unit No. 5 Steam Generator was scheduled for a low sulfur coal test burn using flue gas conditioning for fly ash resistivity control.

Trenton Unit No. 5 is a 150 MWe unit that was commissioned in 1969 and is equipped with a weighted wire precipitator, with a rigid discharge third field added in 1986. The equipment was originally designed to operate on medium to high sulfur coal, and was expected to have difficulty when operating on low sulfur coal. During an abbreviated low sulfur coal test burn which ran for approximately three weeks, the Trenton Unit No.5 Boiler was able to operate within compliance levels at full load capacity using sulfuric acid flue gas conditioning (FGC).

NSPI selected FSA, Inc., a subsidiary of Wahlco Environmental Systems, Inc. to supply and test its' Lance Vaporizer Sulfuric Acid Vapor Injection System for the flue gas conditioning process. The sulfuric acid system was selected by NSPI based upon projected lower installed equipment costs, and a plant preference for using existing procedures and experience with handling liquid acid rather than using unfamiliar SO_2/SO_3 materials. This paper will present the results of the Trenton Unit No. 5 test burn, discuss the effectiveness of sulfuric acid vapor injection, and review the FGC system commercial design, operating costs, and impact on plant sulfur emissions.

A CASE STUDY FOR SULFURIC ACID FLUE GAS CONDITIONING
At
NOVA SCOTIA POWER, TRENTON NO. 5

Introduction

As part of Nova Scotia Power Inc's continuing program to reduce environmental emissions from its thermal generating stations, the company has undertaken a program to explore further utilization of locally available low sulfur coal at their Trenton Power Station in Trenton, Nova Scotia. The Trenton Unit 5 Steam Generator was commissioned in 1969, and was designed to operate on a high sulfur, medium ash coal. With plans now calling for operation on low sulfur coal , NSPI anticipates difficulty in meeting compliance with particulate emissions and stack opacity.

The Trenton Unit 5 Steam Generator is a B&W pulverized coal fired boiler with an output generating capacity of 150 MWe. Fly ash collection is provided by a UOP two field precipitator designed for 95% collection on high sulfur coal. During the mid 1980's, NSPI added a Rigid Discharge Electrode (RDE) third collecting field to the original two field weighted wire unit. The new precipitator field addition was provided by Joy Manufacturing of Canada and was designed for a combined collection efficiency of 99.1%. A summary of the precipitator design and operating data is listed in *Table 1.*

The fuel source considered for the Trenton upgrade was the Westray Mine located in nearby Pictou County. As shown in *Table 2*, the fuel analysis for the test coal showed slightly higher sulfur contents ranging between 0.95% to 1.10%. The fly ash combined silica, alumina and iron content was over 91%, a border line candidate for effective SO_3 conditioning without ammonia addition (*Wahlco Dual Process*) [4].

As part of their fuel upgrade program, NSPI investigated several technologies for Flue Gas Conditioning. These included Wahlco's sulphur dioxide (SO_2) to sulfur trioxide (SO_3) injection system, Wahlco's anhydrous ammonia (NH_3) injection system, [1] and FSA's sulfuric acid vapor injection system [2]. Both the sulfur trioxide and the anhydrous ammonia conditioning processes had a proven track record in their field of application. NSPI elected not to utilize these technologies however in order not to introduce new chemical processes to the Trenton plant.

FSA's Lance Vaporizer approach was of interest to NSPI in that commercial grade (66° Baume') sulfuric acid was in regular use at the plant and would not require any changes in procedures for handling and storage. On the other hand, the sulfuric acid process did not share the industrial track record offered by the other technologies. The FGC system was being offered in prototype fashion using a newly developed Lance Vaporizer injection design [3]. After considering the advantages of each FGC approach, NSPI decided to proceed with a commercial demonstration of the Lance Vaporizer System. The demonstration program would be carried out during the Summer of 1992, with plans for installation of a commercial system in 1993.

The FSA Lance Vaporizer FGC System

One form of flue gas conditioning used in the past was sulfuric acid vapor injection with approximately fifteen systems installed during the 1970's. Most of these have since been replaced with modern SO_2/SO_3 conditioning systems and sulfur burner systems. High operating costs and corrosion of the hot vapor transport lines were the main reasons for replacing these systems. For utility boilers larger than 150 megawatts, the operating requirements for the electric air heaters alone were over one megawatt. If sulfuric acid was to be used successfully as a utility flue gas conditioning process, a more energy efficient and more reliable system design was needed.

During the period of 1990 to 1992, FSA developed , tested, and patented an improved process for sulfuric acid flue gas conditioning called the Lance Vaporizer Sulfuric Acid Vapor Injection System. The system was developed as a low cost FGC alternative, and was targeting specifically the small to medium size power boiler (50 MWe to 300 MWe) market. The system incorporated features designed to eliminate the short comings found in earlier sulfuric acid systems, namely hot vapor transport problems and high operating energy costs. The Lance Vaporizer System [6] was designed to transport sulfuric acid in concentrated liquid form to the point of vapor injection. This eliminates the need to transport hot vapor through the plant, enhancing plant safety and reducing system heat losses. *Figure 1* shows a simplified process and instrumentation diagram (P&ID) of the Trenton demonstration equipment.

Each Lance Vaporizer assembly is designed to condition 150,000 ACFM of flue gas with a design injection capacity of 30 ppmv of acid, approximately 3.0 gallons per hour (gph) per lance. Turndown on the system is accomplished by regulating the individual Lance Vaporizer metering pumps. Acid flow to each lance is interlocked with air flow and temperature sensors to insure that proper air flow and hot air temperatures are maintained on each lance for complete acid vaporization. Hot air from the boiler air heater passes over the vaporizer coil, flowing towards the injection end of the lance. Hot air temperatures for the NSPI demonstration were running between 500 and 600 °F. An electric booster heater surrounding the coil vaporizer was provided to hold the temperature of the coil constant during low loads and transient conditions. The Lance Vaporizer assembly is shown in *Figure 2*.

A detail of the vaporizer coil is shown in *Figure 3*. Sulfuric acid enters the coil from the left and flows first towards the exit end of the coil, reverses direction, and then flows back towards the entrance end in counter flow fashion. In this manner, maximum exit vapor temperatures are maintained. Hot air flowing over the coil elevates the temperature of the acid as it flows through the coil and eventually boils off at 535 °F. As the sulfuric acid vapor exits the coil, it mixes with hot air in the lance and is diluted to the desired air/vapor ratio to avoid lance dew point. The vapor is then injected into the flue gas stream through a series of equally spaced nozzles located along the probe assembly. Mixing with the passing flue gas, the acid vapor condenses and completes the flue gas conditioning process.

The Trenton Demonstration Program

Lance Vaporizer Demonstration Equipment

The Unit 5 Boiler is equipped with two Lungstrom rotary type air preheaters To provide maximum residence time for acid vapor mixing, the injection lances were located directly down stream of each air heater outlet. Flue gas travels downward through each air heater and is conditioned immediately as it exits. The conditioned flue gas makes a 90° turn, aided by three turning vanes, and enters into the precipitator inlet plenum. The plenum of the precipitator is divided into an A and B side, corresponding to the two air heater outlets. A plan view of the lance locations is shown in *Figure 4*.

Two separate hot air supply systems were installed connecting each secondary hot air duct to its respective lance assemblies. For each hot air supply, a 10 inch diameter round duct was run and insulated with two inch fiberglass insulation. A manual shut off damper was located at the inlet to each hot air supply duct and also at the inlet to each Lance Vaporizer. The dampers were used to secure the system when not in use, and also to balance air flow between the lances. Air flow requirements for each lance are approximately 600-700 acfm. Boiler load and corresponding lance operating pressure drops determined the actual flows through each lance. *Figure 5* illustrates the general arrangement of the secondary air take offs for each Lance Vaporizer assembly.

The System Skid (see *Figures 6* and *7*) was installed in a mobile trailer for transport to the site. The mobility of the unit allowed NSPI to easily position the equipment on site when it arrived. Utilizing armored teflon hose, an acid supply line was established between the plant's acid storage facility and the system skid day tank. A remote transfer pump was positioned near the acid storage facility and used to pump sulfuric acid from the storage tank to the skid day tank. Each transfer of acid to the system day tank allowed for approximately two days of operation. Acid supply to the individual Lance Vaporizers was also supplied by means of armored teflon hoses. Each supply hose was served by one acid metering pump which was controlled by the system PLC. For electrical power, NSPI provided a 600 VAC 3 phase power feed to the trailer disconnect which was the main power source for the FGC system. A 600/480 VAC step down transformer was mounted in the trailer to provide 480VAC to the entire system.

FGC Test Program

The Test Program for the Lance Vaporizer FGC System was originally planned for an eight week test burn over three months. NSPI developed program objectives to determine the effectiveness of the FGC process and its impact on acid emissions. FSA developed program objectives to determine operating costs and final commercial design requirements. Our specific objectives for the program were:

- Establish that the H_2SO_4 FGC can control stack opacity and outlet emissions at full load conditions.
- Identify commercial design requirements for the system.
- Correlate FGC System operation to boiler load and ESP power levels.
- Correlate H_2SO_4 injection rates to expected injection rates and ESP performance .
- Establish total operating costs for the FGC System.
- Measure any impact on emissions, specifically H_2SO_4 slip.

Test Plan

A test plan was developed by NSPI and FSA to achieve the program objectives listed above. The final program consisted of the following four phases:

- Baseline operation of the boiler on low sulfur coal allowing time for degradation of ESP performance. A baseline performance test would be conducted to measure particulate emissions at the degraded condition.

- Start H_2SO_4 injection at 10 ppmv, increasing to 20 ppmv and 30 ppmv. Particulate, SO_3, and flue gas dew point testing would be performed at these injection intervals.

- Maintain boiler operation at 150 MWe around the clock and record boiler operating data, precipitator operating data, and FGC operating data. Coal samples would be taken and analyzed to verify fuel chemistry.

- Stop H_2SO_4 injection and allow the precipitator to seek original baseline conditions. Perform one final particulate test to verify final baseline conditions.

Test Program Results

Prior to the start of the Test Program, the Unit 5 precipitator was inspected and found in good condition. With fairly clean internals, the precipitator initially ran well on the Westray coal, less than 10% opacity. Within twenty four hours however, power levels dropped significantly and opacity levels began to increase. As shown on *Figure 8*, at approximately thirty hours into the Baseline run, the precipitator entered "Back-corona". Although apparent power levels were increasing, stack opacity continued to deteriorate. The unit stack opacity went from 7% at the start of the Baseline test to a high of 80%. Particulate testing for Baseline conditions was performed at about fifty-five hours into the program. The results of the Baseline testing were 71.1 ng/j at an opacity of 74%.

Start-up of the Lance Vaporizer with an initial injection rate of 10 ppmv made an immediate change in stack opacity. The stack opacity decreased to around 40%. At 20 ppmv the opacity was again lowered to around 35% (see *Figure 9*). At this injection level, NSPI had anticipated an opacity level of around 20% . The precipitator and boiler were checked for possible clues to the higher opacity operation. The precipitator automatic voltage controls were not allowing the precipitator to respond completely to the affects of the flue gas conditioning process. Raising the high voltage control limits allowed the power supplies to ramp up, providing the lower opacity levels that were predicted (see *Figure 9*). The unit was operating at 150 MWe, burning coal with 1.16% sulfur, and 16.5% ash, and maintaining a stack opacity below 20%. A particulate test was performed to verify that desired particulate emission levels were being met (see *Figures 10* and *11*).
As the test program progressed, it was necessary to modify the program due to problems with coal supply, FGC acid transfer, and malfunctions in the source test equipment. Major developments during the test program are summarized below:

- The initial Baseline test took a day and a half longer than planned. Detailed precipitator data and opacity data were taken during the baseline process. Precipitator performance deterioration until opacity eventually reached 80%.

- Testing and analysis were done only at the 10 ppmv and 20 ppmv injection levels.

- Part way through the trial program, adjustments were made to the precipitator AVCs to allow each control to respond to the conditioning process. The existing control settings were voltage limiting power input even though no visible signs indicated sparking. Increasing Automatic Voltage Control limits caused the controls to ramp up to higher power levels, lowering the stack opacity from 35% to 15%.

- On the final two days of testing, 2.0% sulfur coal started creeping into the test program. This obviously made it difficult to separate out the affects of the FGC process from what was being generated naturally by the coal.

FGC Affects on Precipitator Operation

The test burn program continued for 400 hours, and confirmed that the Lance Vaporizer process could maintain desired opacity levels. During periods when the FGC System was shut down, the effects on stack opacity were very pronounced. Changes in stack opacity occurred within five to ten minutes.

In an attempt to fine tune all aspects of the precipitator and FGC operation, several observations were made. NSPI personnel noted that the precipitator third field power levels were not sparking or power limited. The newer third field RDE's appear to collect fly ash more readily and lose corona discharge capacity. Adjustments were made to the voltage limits on the RDE field which increased the field voltage from 52 KV to 58 KV average. Also several different rapping sequences were investigated in an effort to reduce the amplitude of rapping spikes. These changes were made around hour 243 into the program. Both changes improved precipitator performance significantly, reducing the stack opacity from 35% down to 15%. The precipitator was operating at a power density of 100 watts/1000 acfm, compared to 150 watts/1000 acfm at the beginning of the test burn(see *Figure 10*).

During the Baseline phase, power levels on the precipitator were as low as 25-30 watts/1000 acfm before encountering back corona conditions. Opacity levels at that point were around 40% . As back corona increased, the precipitator power level appeared to increase to a power density of 100 watts/1000 acfm. The precipitator opacity level however continued to climb to 80%. Start-up of the conditioning process caused power density to drop initially to 75 watts/1000 acfm as the generation of back corona was quenched. The stack opacity was again 35-40%, similar to the level when back corona was first encountered during the Baseline run. Continued conditioning of the precipitator eventually caused the power density to increase again to its final operating level of 100 watts/1000 acfm. Particulate testing at this level indicated the Unit 5 precipitator was meeting its compliance emission level of less than 43.0 ng/j (see *Figure 11)*.

FGC System Operation

The single most important design feature of the Lance Vaporizer System is its' use of boiler process heat for vaporization energy. Using the boiler secondary air as the vaporizing heat source reduces the system energy costs by as much as 50%. Referring to *Figure 12*, the Trenton Unit 5 precipitator operated well at an acid injection rate of 22 ppmv. For all four lances, this was equal to a total injection rate of 8 GPH. The system operating costs for energy alone at this injection level was approximately $4.00 CAN per hour. If all vaporization energy was supplied electrically, the operating energy costs would increase to approximately $6.50 CAN per hour. A significant benefit is derived from using boiler heat energy generated at 88% efficiency as opposed to electric heat generated at 40% to 50% efficiency. Obviously it is desirable to achieve vaporization with 100% boiler heat, however start-up conditions and low load conditions will require electrical booster heat. Projected operating costs will vary from application to application. The primary factor that will affect operating costs will be the availability of hot secondary air for system use. Projected yearly operating costs for the NSPI system assuming an injection rate of 20 ppmv (8 GPH), chemical cost of $12.00/hr CAN, energy costs of $3.00/hr CAN, and an average system utilization factor of .5 is $65,700 CAN per year ($52,560 US, $0.01/MMBTU) (see *Appendix 1)*.

During operation of the NSPI system, full load air volumes being delivered to each lance were about 80% of desired rate. This was due to the design pressure drop of the injection lance. As shown in *Figure 13*, maximum pressure drop across the injection lances at full load was approximately 7 inches W.G. In that there is no air blower in the system to increase operating pressure drop, the lance air flow is dependent entirely upon available pressure differential between the secondary air duct and the precipitator inlet duct. In most applications, this pressure drop will run around 7-10 inch WG. Air volume to the lance is critical in that it delivers the required heat to the vaporizer coil. Equally important is that proper air flow is also needed to maintain air to acid vapor ratios. Acid dew point conditions within the lance are controlled by adhering to proper acid and air vapor mixtures. Options for increasing air flow through the lances included reducing the design pressure drop of each lance, or by adding a hot air blower to the system. A redesign of the injection lance would be the best choice in that it does not introduce additional operating costs to the system. Where available system pressure drops are found to be less than 7 to 8 inches WG, a blower may be necessary. With the limitations of air flow that existed during the program, the lances would encounter dew point if operated at their full capacity of 30 ppmv injection. It was determined that by increasing the air flow capacity of each lance to the desired level of 600-700 scfm (*Figure 14*), the system can operate safely at all injection rates up to 30 ppmv.

Operating temperatures in the coil vaporizer are also critical to the proper operation of the Lance Vaporizer System. During the NSPI test run, the outlet coil temperature was set at 550°F to insure proper vaporization of the sulfuric acid. To help focus the electric heat onto the coil assembly, the original design for the Lance Vaporizer incorporated an electric booster heater and vaporizer coil built into one assembly (see *Figure 2*). The intent was to take advantage of the close proximity of the heater elements for radiant transfer. It was learned later during the test program that the tantalum used in the vaporizing coil had a maximum operating temperature limit of 700°F. Above this temperature, tantalum will undergo hydrogen embrittlement. The vaporizer booster heater elements operated above this temperature, suggesting that the tantalum coil may have experienced temperatures above 900°F. All four vaporizer coils did experience embrittlement during the program. As a result, two or three elements of each heater assembly failed, reducing heat output from 14 kw to 11 to 12 kw each. Embrittlement of the coil assembly was not identified until the vaporizers were removed from their lances two months after the end of the test program. Future design considerations for the vaporizer assembly include separating the coil and booster heater in the hot air system. Combining the coil and heater into one assembly involved custom manufacturing work which increased the cost of the vaporizer unit. A manufacturing cost savings should be realized by making this change. Alternate materials are also being considered to reduce material costs. Preliminary work with silica iron looks promising in reducing overall vaporizer costs and expanding operating temperature ranges.

FGC and its Affect on Sulfur Emissions

How well an electrostatic precipitator will perform in a fuel switch situation with or without flue gas conditioning can be the single most important factor affecting sulfur emissions. A good operating precipitator with FGC will probably use less conditioning agent to begin with. FGC should not be used as a cure for known precipitator hardware problems.

Table 3 has been prepared to illustrate and compare the three conditions that can exist affecting sulfur emissions from a coal fired power plant.

<u>Condition 1:</u>	Burning High Sulfur Coal	>2% S
	SO_2 Emissions	>1500 ppm
	Opacity	<20%
	Particulate Emissions	<0.43 ng/j
	Sulfur Emissions (H_2SO_4 & Ash)	High

Condition 2: **No FGC**	Burning Low Sulfur Coal	~1% S
	SO_2 Emissions	<1000 ppm
	Opacity	>20%
	Particulate Emissions	>0.43 ng/j
	Sulfur Emissions (H_2SO_4 & Ash)	Moderate
Condition 3: ***With FGC***	Burning Low Sulfur Coal	~1% S
	SO_2 Emissions	<1000 ppm
	Opacity	<20%
	Particulate Emissions	<0.43 ng/j
	Sulfur Emissions (H_2SO_4 & Ash)	Low

The NSPI Unit 5 precipitator performance will respond well to *Conditions 1* and *3* in that the precipitator is designed for high sulfur coal. The specific collecting area of the precipitator is very modest and therefore will require sufficient SO_3/H_2SO_4 in the process gas to meet its' design performance. Under *Condition 1* circumstances the sulfur emissions to the stack are the highest owing to the high levels of SO_2, H_2SO_4, and some particulate sulfate. Under *Condition 2*, sulfur emissions have been reduced only partially. Because of poor precipitator performance, increased particulate emissions are now carrying high levels of sulfate out the stack. Total sulfur emissions have been reduced over *Condition 1* circumstances, but particulate emissions are now accounting for a larger portion of the sulfur emissions. Finally, with FGC in place under *Condition 3* circumstances, particulate emissions are again brought under control by the precipitator reducing total sulfur emissions to their lowest levels.

Two tests were carried out to check the effects on gaseous emissions. They consisted of gas testing with a Mel SO_3 monitor and flue gas dewpoint tests using a Land dewpoint meter.

The tests for SO_3 levels in the flue gas measured between 0.6 and 0.7 ppmv with and without H_3SO_4 injection. The SO_3 monitor samples the total of SO_3 and H_2SO_4 vapor in the flue gas and reports it as SO_3 in ppmv. The reading remained at 0.6 - 0.7 ppmv even after the sulphur content of the coal had risen to 2.0%. These results would indicate that effectively all of the H_2SO_4 vapor was absorbed and collected with the fly ash in the precipitator.

The change in the flue gas dewpoint with the level of H_2SO_4 vapor injected was checked in a separate test. The dewpoint was measured at 155°F without conditioning and rose to 260°F to 270°F with conditioning. This appeared to indicate that some additional H_2SO_4 vapor must be in the flue gas at the stack. The measured dewpoint and flue gas moisture were used to estimate the levels of H_2SO_4 vapor in the flue gas, using a Meullen dewpoint graph. The estimates would suggest that up to 4 ppmv H_2SO_4 was present in flue gas. Further review of published information has found that the use of dewpoint to calculate H_2SO_4 vapor concentrations will lead to artificially high levels of H_2SO_4 vapor when working at levels below 10 ppmv H_2SO_4.

After the detailed review of the trial test data and historical test data, it was concluded that the H_2SO_4 vapor is collected on the fly ash at levels of 95% to 100%. The SO_3 level readings from the Mel SO_3 monitor are the best indication available of the actual SO_3 and H_2SO_4 vapor levels in the flue gas.

Conclusions

The flue gas conditioning trial program at Nova Scotia Power's Trenton Station achieved the program objectives as established by NSPI and FSA and was deemed a success. Although an abbreviated program, all performance and commercial objectives were addressed. From the results of our work at Trenton Station, NSPI and FSA can make the following conclusions:

1. Conditioning with sulfuric acid vapor injection can control fly ash resistivity generated from the Westray coal. Full load generating capacity can be maintained on low sulfur coal and still meet particulate and opacity limits.

2. The FGC process had very little impact on total stack sulfate emissions.

3. Chemical injection rates and system operating costs were in line with original system expectations. The Lance Vaporizer FGC concept was able to deliver sulfuric acid vapor to the ESP injection location at energy savings up to 50% over prior art sulfuric acid systems which used only electric heat.

4. Engineering and material modifications are still needed to resolve commercial design issues concerning acid transfer, lance pressure drop, and vaporizer material selection.

Acknowledgement

The authors wish to express their appreciation and to thank their colleagues for assistance in carrying out the test program and in the preparation of this paper.

List of References

1. Krigmont, H.V. and Coe, E.L., Jr., 1990, "Experience in Conditioning Electrostatic Precipitators", Proceedings of the Forth International Conference of Electrostatic Precipitation, Beijing, China.

2. Lynch, J.G., 1991, "A Novel Approach to Sulfuric Acid Vapor Injection for ESP Flue Gas Conditioning", Proceedings of Tenth EPRI Particulate Control Symposium, Williamsburg, Virginia.

3. Frame, R.D. and Dingman, M.R., 1992, "In-Lance Vaporization Enhances Vaporized Sulfuric Acid Conditioning of Fly Ash Resistivity", Proceedings of the 54th American Power Conference, Chicago, Illinois.

4. Cummings, W.E. and Krigmont, H.V., 1992, Flue Gas Conditioning: Demonstrated & Emerging Technology", Proceedings of the International Joint Power Generation Conference, Atlanta, Georgia.

5. White, H., 1977 Electrostatic Precipitation of Fly Ash, Air Pollution Control Association, Pittsburgh, pp. 50-51.

6. Frame, R.D. and Ferrigan, J.J., 1992, "Operating Performance of In-Lance Vaporization for Sulfuric Acid Conditioning on Fly Ash Resistivity", Proceedings of the International Joint Power Generation Conference, Atlanta, Georgia.

APPENDIX 1
FGC OPERATING COSTS*

Operating costs based on boiler load at 150 MW and with 20 ppm H_2SO_4 injection.

Acid Feedstock

1992 Cost of H_2SO_4 Delivered,		$0.095/lb.
20 ppm = 120 lb./hr.		
	H_2SO_4 cost	**$11.40/hr.**

Hot Air for Lances

C_p=0.25BTU/lb/°F	w=0.075lb./ft^3 @ 68°F
Flow= 450 SCFM @ 77°F	Temperature= 580°F
Mass rate= 450 x .075 x 528/537	Mass rate= 33.18 lb./min.
BTU= (580-68) x .025 x 33.18	BTU= 4247 BTU/min. /lance

Additional Boiler Heat Required

Boiler efficiency = 88%	BTU required = 4lances x 4247 BTU/lance/0.88	
BTU = 1,158,435 BTU/hr.	Fuel cost= $70.00/ton or $2.92/MBTU	
	Hot Air Energy Cost	**$3.38/hr.**

Electric Power., from Data Logger

Duct heaters (4)	56.0 kW.h/hr.	
Pump Skid	1.7 kW.h.hr.	
Heater Control Panel	0.86 kW.h/hr.	
Total	58.56 kW.h/hr.	
Electricity cost @ $0.03/kW.h		**$1.76/hr.**

Total Operating Cost for FGC System

H_2SO_4 Feedstock	$11.40 /hr.	
Hot Air Heat Energy	3.38 /hr.	
Electricity	1.76 /hr.	
Total Hourly Cost		**$16.54/hr.**

Cost of FGC Conditioning per Tonne of Coal

Boiler uses 68 tons or 61.7 tonnes at 150 MW

Cost per Tonne = $16.54 / 61.7 **$0.268/tonne**

* Cost figures are in Canadian Dollars

TABLE 1
TRENTON UNIT 5
PRECIPITATOR DESIGN CHARACTERISTICS

Design Operating Conditions

Gas Volume	513,837 ACFM
Temperature	320°F
Gas Pressure	.15 W.G.
Inlet Dust Concentration	3.63 gr/ACF
Outlet Dust Concentration	0.033 gr/ACF
Design Efficiency	99.1%

Collecting Equipment

Number of Fields	3
Chambers per Field	2
Number of Gas Passages:	
Fields 1 & 2	33
Field 3	24
Spacing of Gas Passages:	
Fields 1 & 2	9 in.
Field 3	12 in.
Collector Curtain Size:	
Fields 1 & 2	9 ft. x 30 ft.
Field 3	12 ft. x 32 ft.
Total Collecting Plate Area:	
Fields 1 & 2	69,120 sq. ft.
Field 3	36,864 sq. ft.
TOTAL	105,984 sq. ft.
Collecting Plate Effective Length:	
Fields 1 & 2	9 ft.
Field 3	12 ft.
Gas Velocity:	
Fields 1 & 2	6.0 fps
Field 3	5.58 fps
SCA (sq. ft./Macf):	
Fields 1 & 2	134.3
Field 3	71.7
TOTAL	206

Discharge Electrodes

Type:	
Fields 1 & 2	Weighted Wire
Field 3	Rigid Electrode
Number:	
Fields 1 & 2	396 per field
Field 3	432 per field
Total Effective Length:	
Fields 1 & 2	32,040 ft.
Field 3	13,824 ft.

Transformer-Rectifier Rating

Fields 1 & 2	47.5 kv, 1,500 mA each
Field 3	55 kv, 700 mA (two installed)
Available Specific Power:	
Fields 1 & 2	230 watts/1000 ACFM
Field 3 (each T/R)	220 watts/1000 ACFM

TABLE 2
TRENTON UNIT No 5
FLUE GAS CONDITIONING TRIAL – JULY 1992

DATE	LOAD MW	COAL TONS/HR	SULFUR %	ASH %	H2SO4 PPM	OPACITY %	FLYASH LBS/HR	PARTICULATE NG/J	ESP EFF %	SO2 PPM	SO3 PPM	REMARKS
DESIGN	146	62	0.8	13.5	20	<20	16638	34.8	99.1	--	--	SPEC DESIGN POINT
07-14	155	70	1.04	17.4	0	45	19590	57.5	98.9	656	0.6	1ST BASELINE
07-15	153	69	1.04	17.4	0	74	19337	71.1	98.6	--	--	1ST FULL DAY FGC
07-21	154	68	1	14.8	0	95	16318	>70*	<98.4*	--	--	FGC OUT OF SERVICE
07-23	153	68	1.16	16.5	20	45	18140	89.2	98.5	1040	0.6	1ST 20 PPM TEST
	153	68	1.16	16.5	20	30	18140	N/A	--	--	--	RAPPER PGM CHANGE
	153	68	1.16	16.5	20	15	18140	34*	99.3*	--	--	3RD FIELD IN MANUAL
07-24	153	68	1.9	15.86	20	5	17373	20*	99.6*	--	--	TEST EQUIP FAILED
07-29	150	67	2.19	12.73	20	12	13556	36	99.1	--	--	2ND 20 PPM TEST
07-30	150	66	2.41	11.69	20	15	12271	32	99.1	2130	0.7	24 HRS AT 150MW
07-31	150	68	2.41	12.77	0	5	13925	19.6	99.5	--	--	2ND BASELINE COAL SHIFT EMPTYING BUNKERS

* ESTIMATED FIGURES FROM SIMILAR TEST RESULTS

TABLE 3
TRENTON UNIT 5
THEORETICAL SULFUR BALANCE *

	Condition 1 (2.4% 5)	**Condition 2** (1.16% 5)	**Condition 3** (1.16% S/FGC)
Fly Ash Inlet, lb/hr	18,140	18,140	18,140
Sulfur as Gas, ppm	1948	935	935
Sulfur on Ash, ppm	175	93	93
Sulfur on Ash, lb/hr	272 **	145 ***	145
FGC Injection, ppm	0	0	25
FGC Injection, lb/hr	0	0	40
ESP Collecting Eff. %	99.1	98.5	99.3
Fly Ash Collected, lb/hr	17,977	17,868	18,013
Sulfur Collected, ppm	174	92	93
Sulfur Collected, lb/hr	270	143	184
Fly Ash Emitted, lb/hr	163	272	127
Sulfur Emitted as Gas, ppm	1948	935	935
Sulfur Emitted on Ash, ppm	1.60	1.43	0.60
Sulfur Emitted on Ash, lb/hr	2.45	2.22	0.92

Source: EPA-600/2-77-242, Fly Ash Conditioning with Sulfur Trioxide, prepared by Southern Research Institute, E.B. Dismukes, and J.P. Gooch, December 1977.

* Boiler: 137,425 lb/hr Coal Flow, All Cases
306,667 scfm Flue Gas
18,140 lb/hr Fly Ash at ESP Inlet

** SO_3 on Ash: 2.4% - 1.5% Sulfur Coal

*** SO_3 on Ash: 1.16% - 0.8% Sulfur Coal

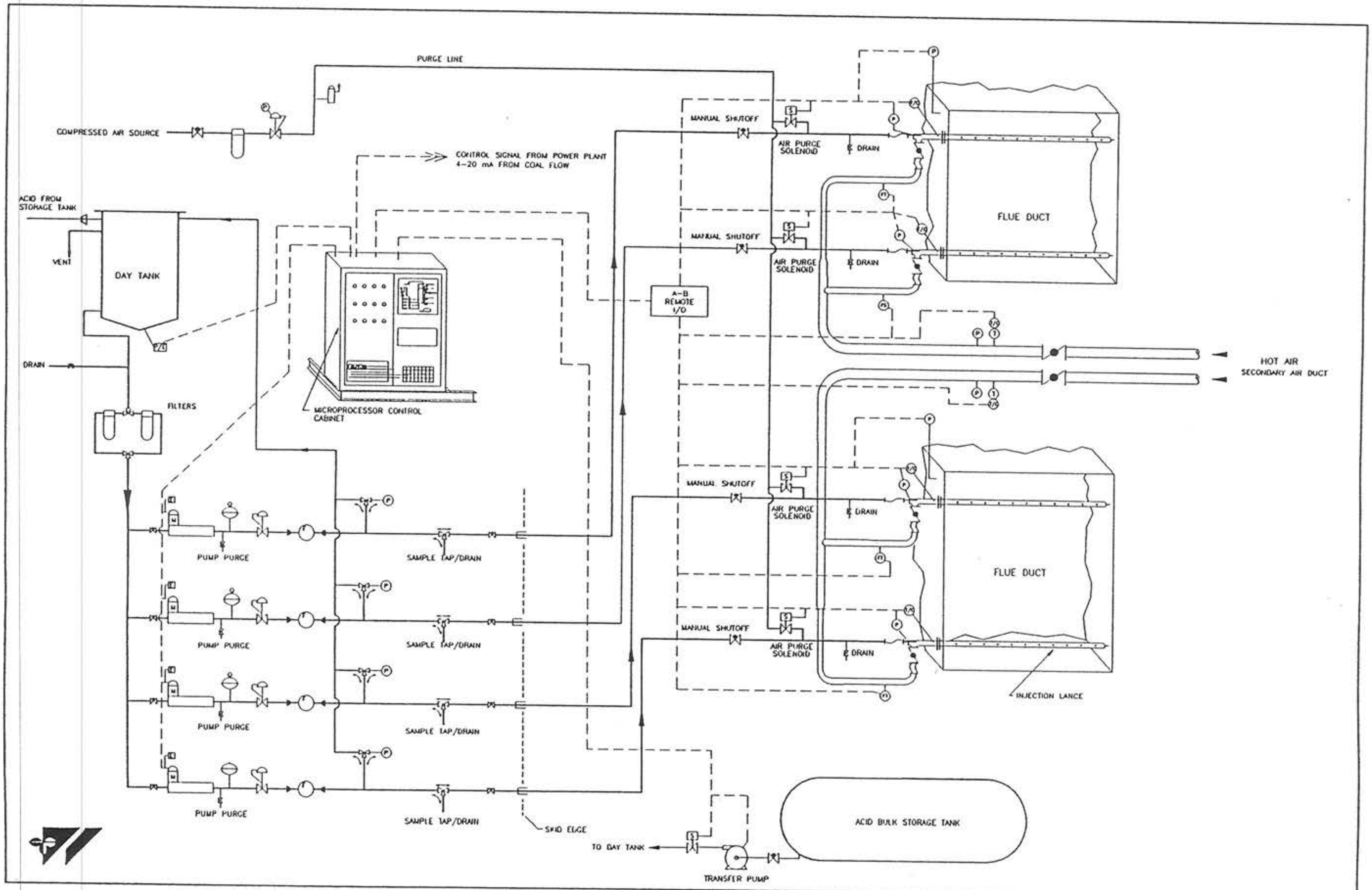

FIGURE 1. SYSTEM P&D

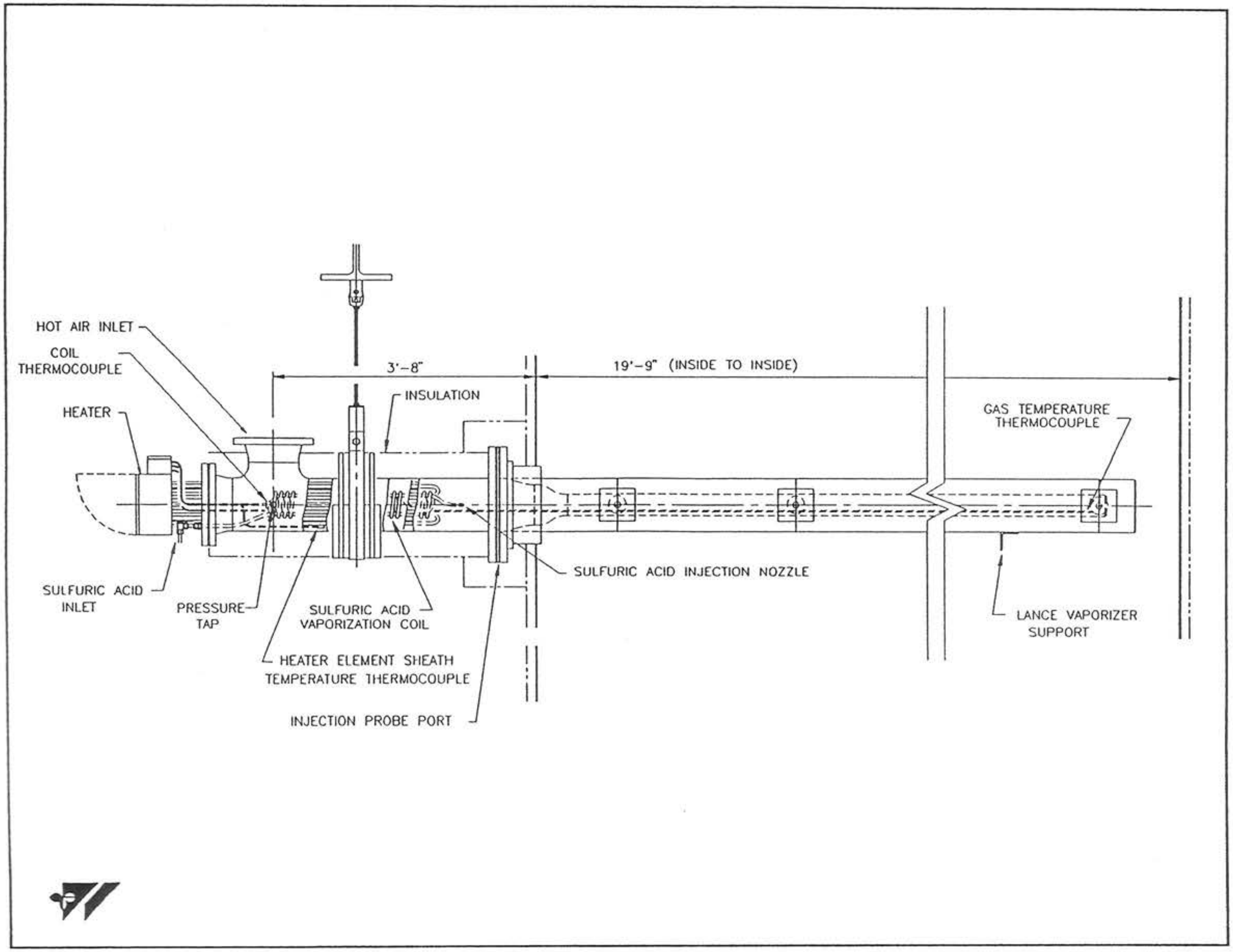

FIGURE 2. LANCE VAPORIZER ASSEMBLY

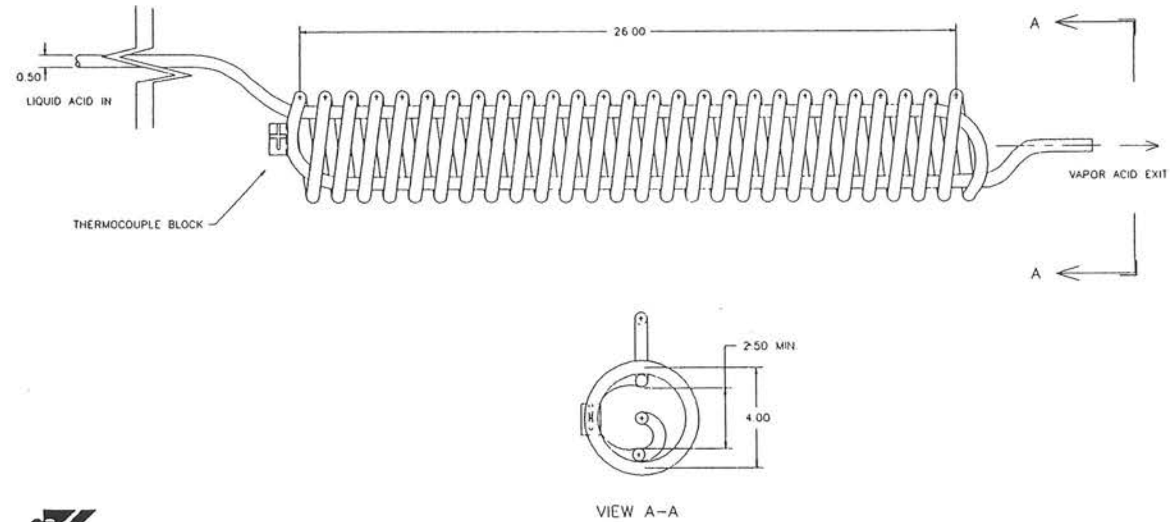

FIGURE 3. LANCE VAPORIZER HEATER COIL

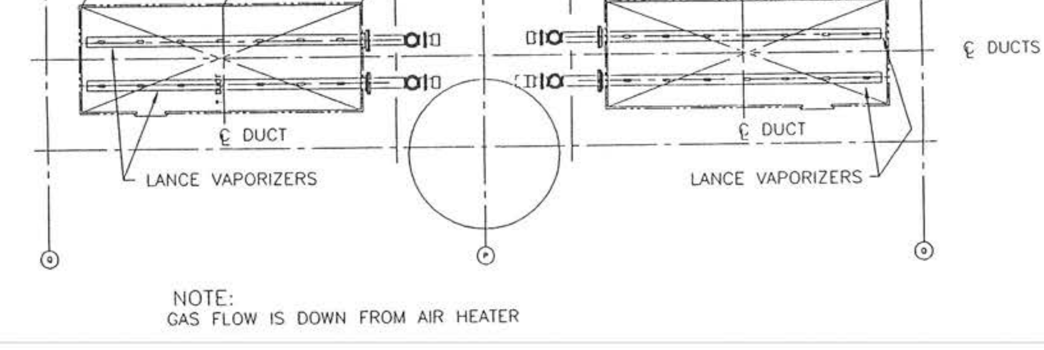

FIGURE 4. LANCE VAPORIZER LOCATIONS – PLAN VIEW

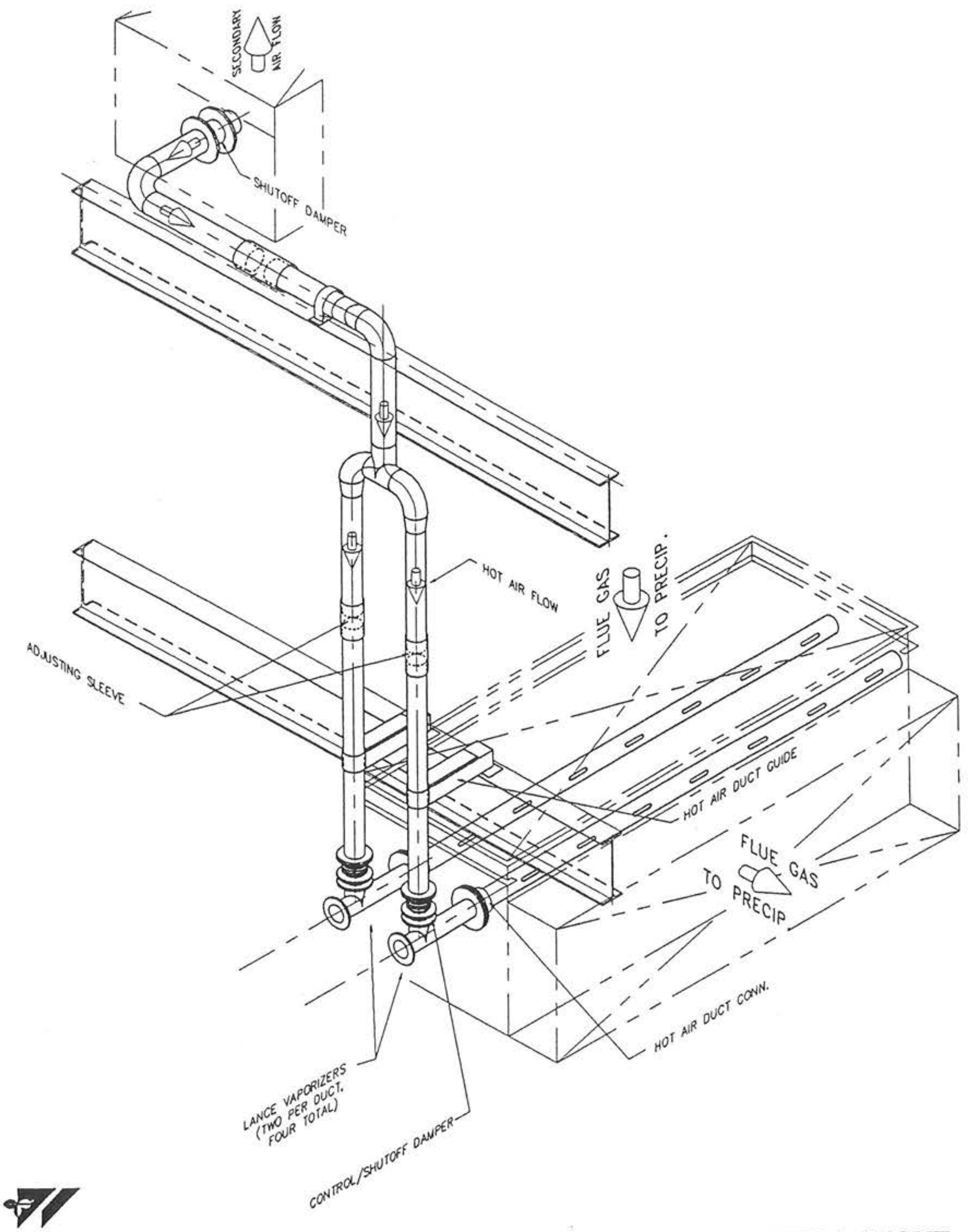

FIGURE 5. HOT AIR SUPPLY DUCT AND LANCE VAPORIZER LAYOUT

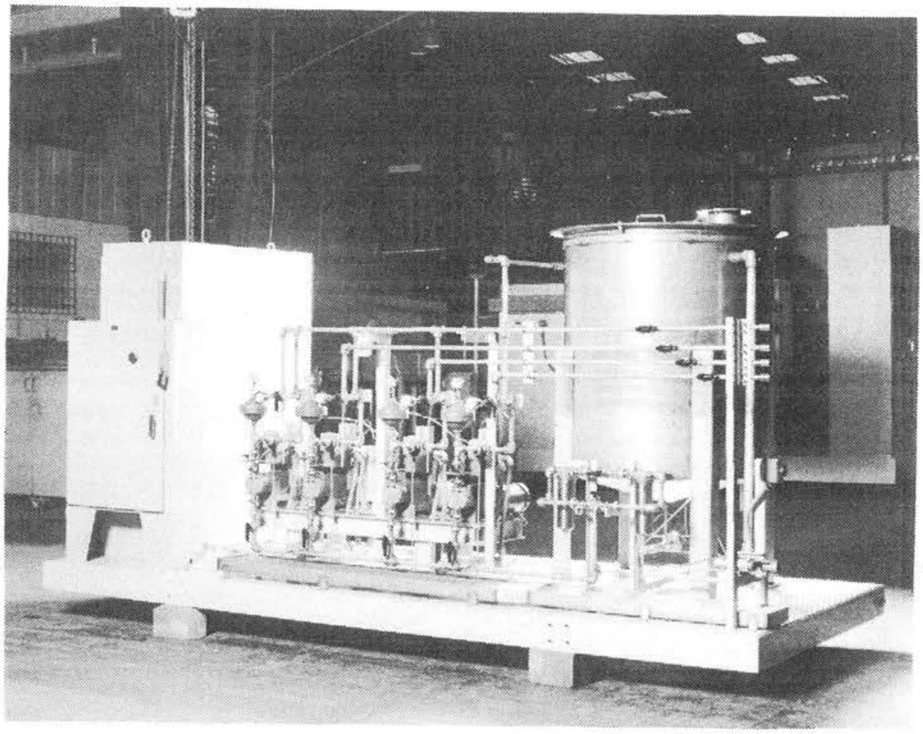

FIGURE 6. CONTROL AND PUMP SKID

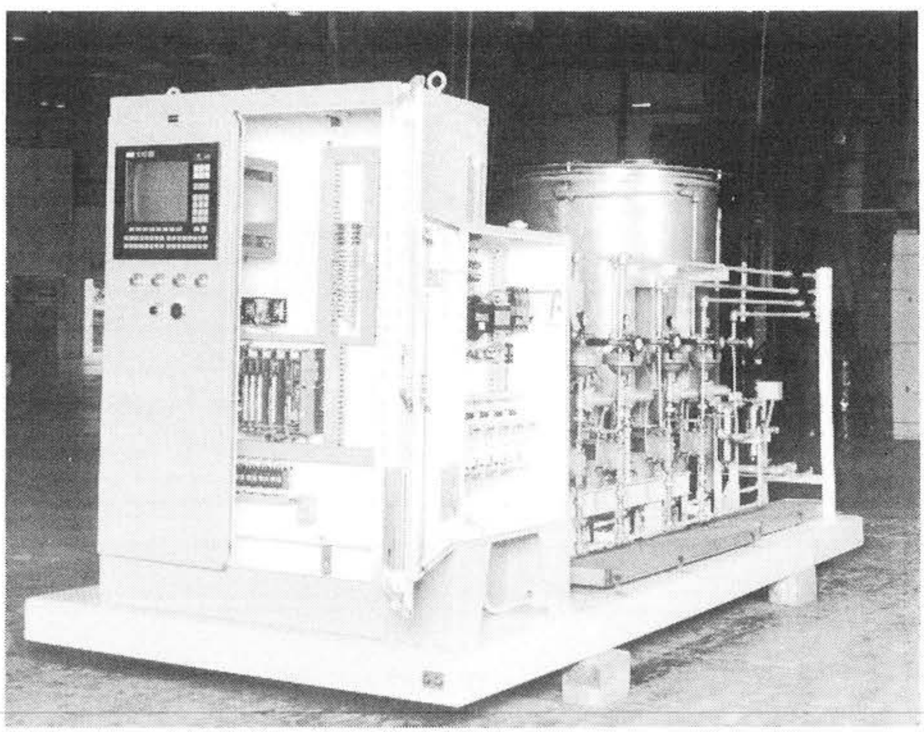

FIGURE 7. CONTROL AND PUMP SKID

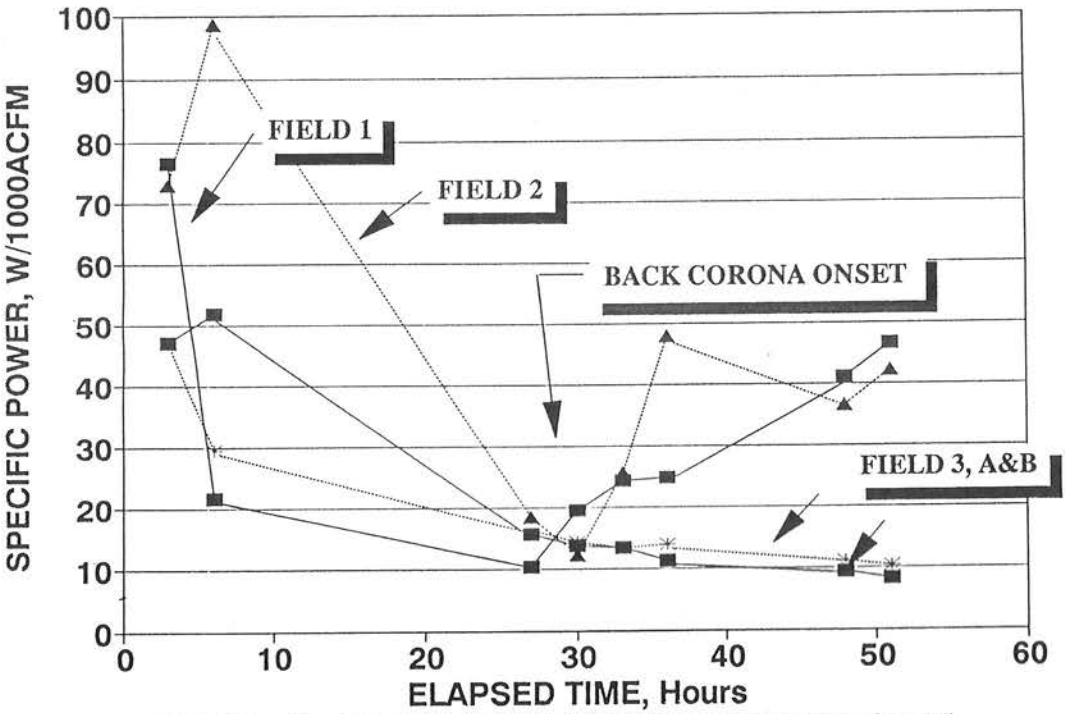

FIGURE 8. FGC DEMONSTRATION, NSP TRENTON #5
TEST COAL BASELINE OPERATION

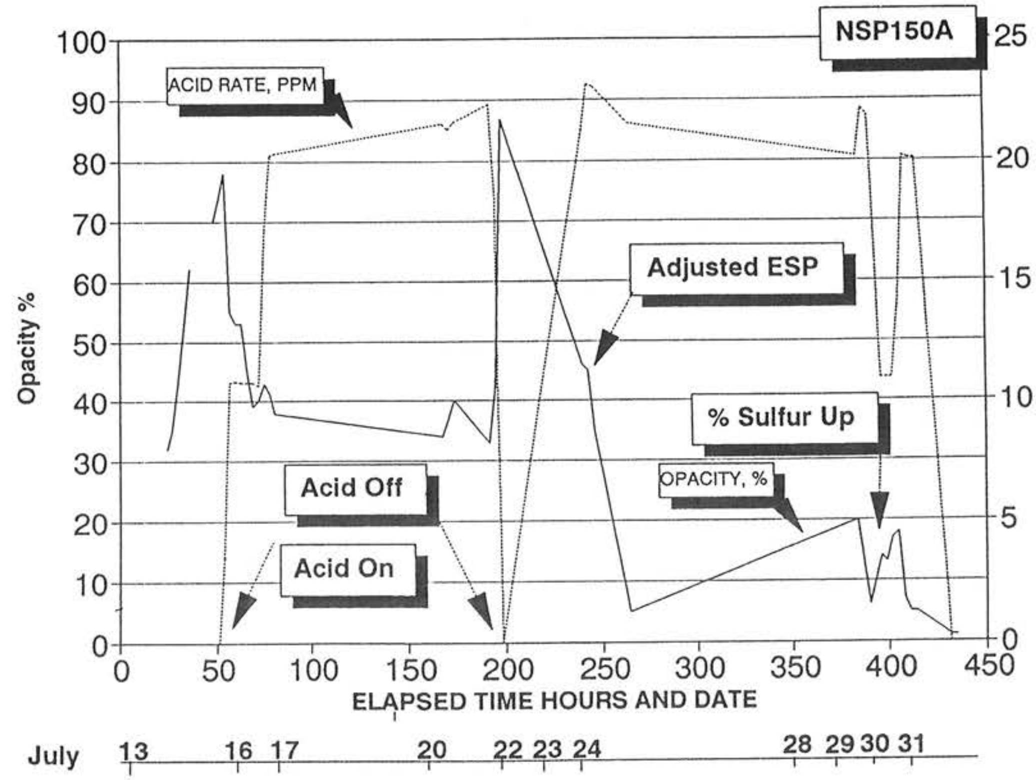

FIGURE 9. LAPSED TIME RESULTS

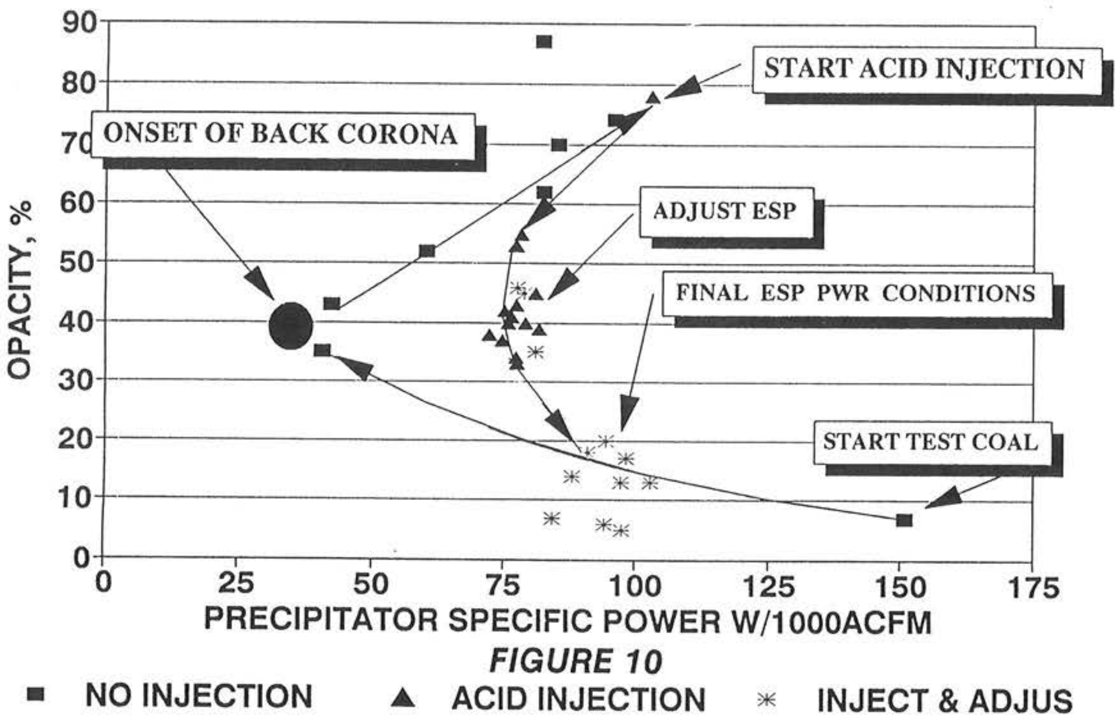

FIGURE 10. FGC DEMONSTRATION, NSP TRENTON #5
FULL LOAD (150MW) RESULTS

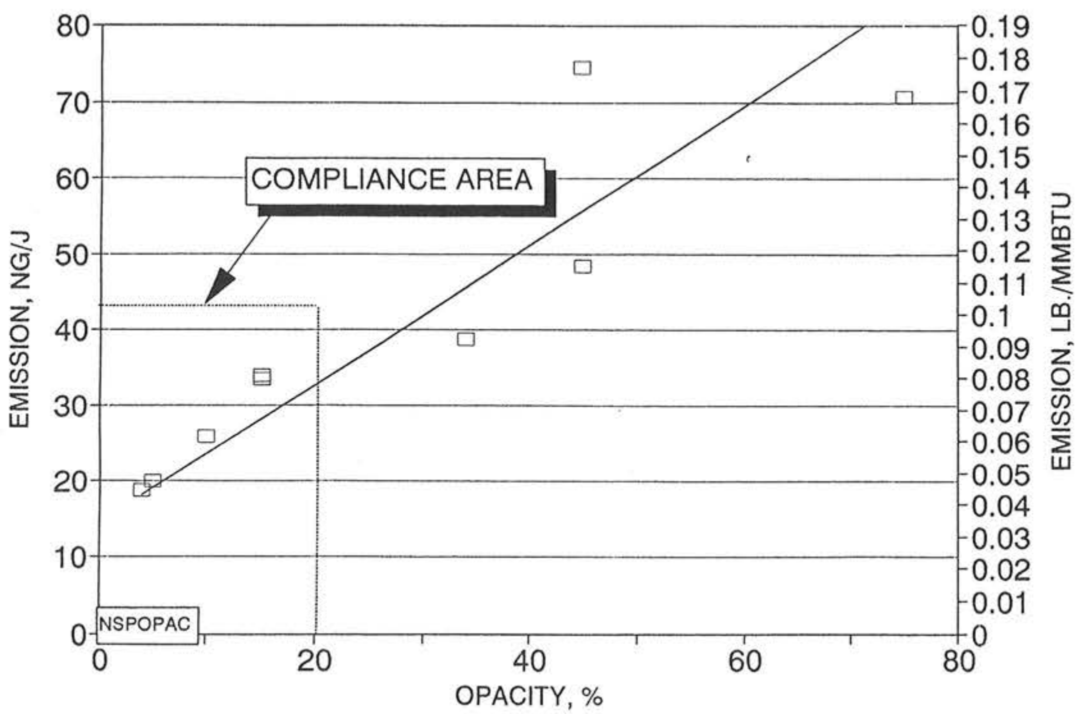

FIGURE 11. FGC DEMONSTRATION, NSP TRENTON #5
EMISSION, OPACITY CORRELATION

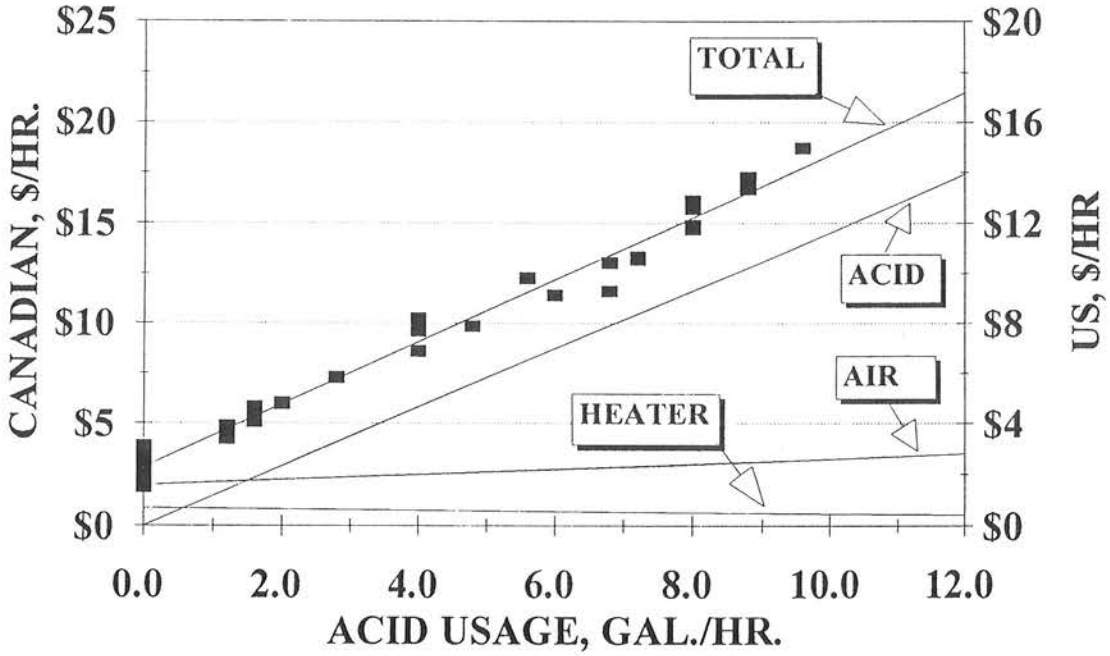

FIGURE 12. FGC DEMONSTRATION, NSP TRENTON #5
SYSTEM OPERATING COSTS

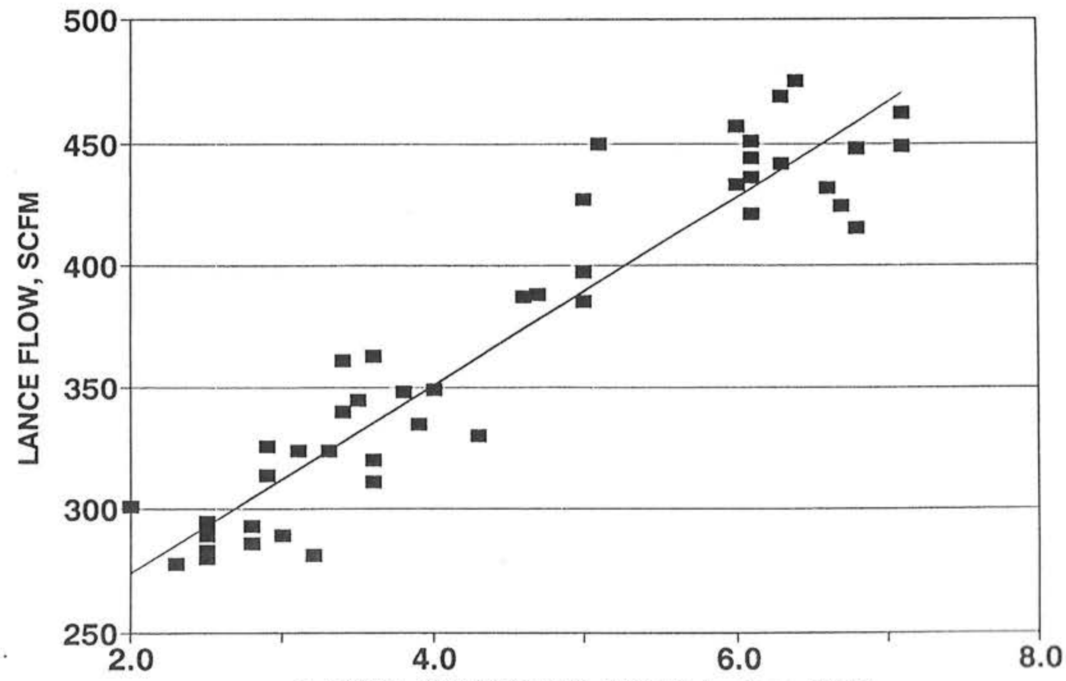

FIGURE 13. FGC DEMONSTRATION, NSP TRENTON #5
LANCE #3 FLOW STUDY

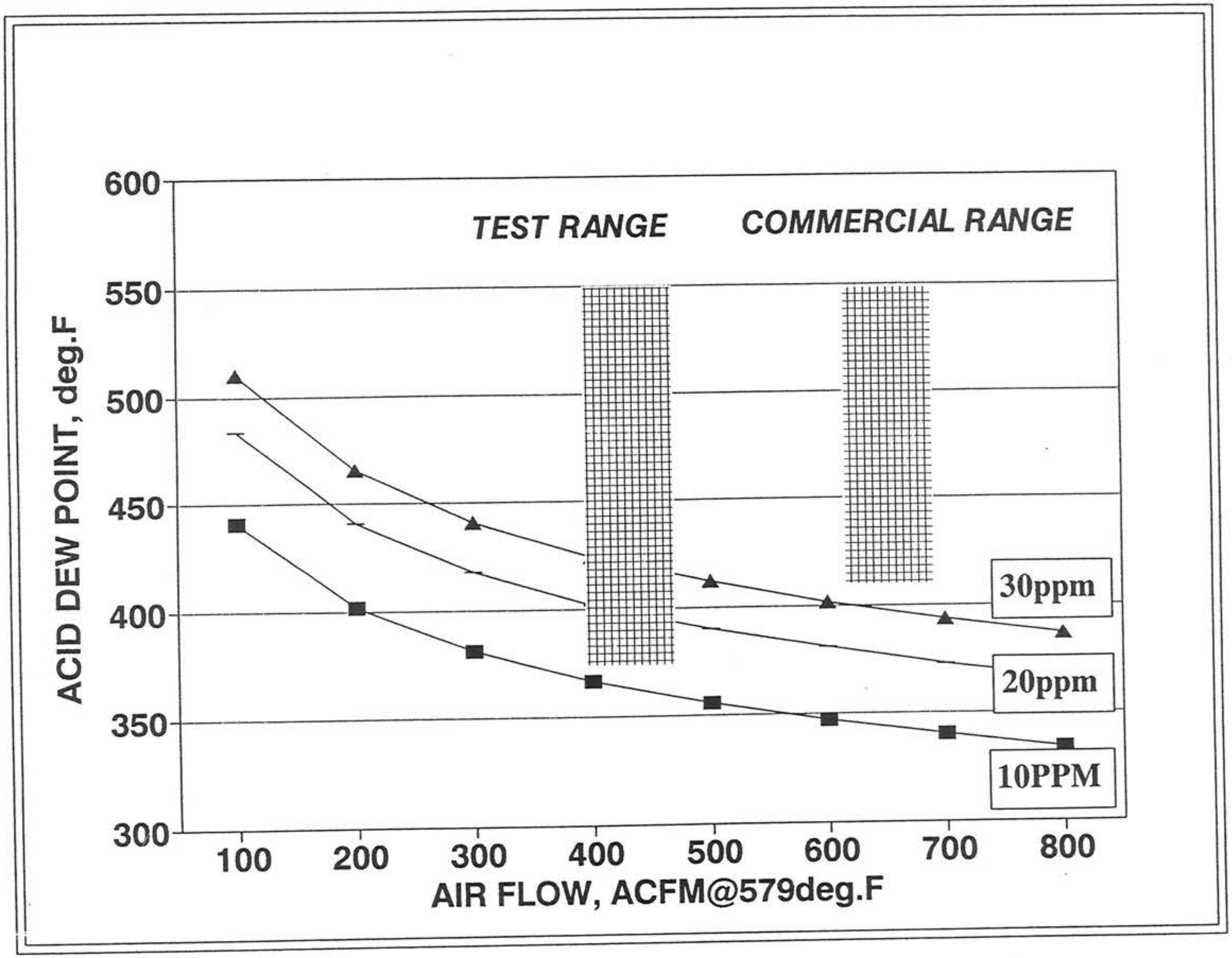

FIGURE 14. LANCE ACID DEW POINT
100% BOILER LOAD

APPENDIX 1
FGC OPERATING COSTS*

Operating costs based on boiler load at 150 MW and with 20 ppm H_2SO_4 injection.

Acid Feedstock

1992 Cost of H_2SO_4 Delivered, $0.095/lb.

20 ppm = 120 lb./hr.

H_2SO_4 cost **$11.40/hr.**

Hot Air for Lances

C_p=0.25BTU/lb/°F — w=0.075lb./ft^3 @ 68°F

Flow= 450 SCFM @ 77°F — Temperature= 580°F

Mass rate= 450 x .075 x 528/537 — Mass rate= 33.18 lb./min.

BTU= (580-68) x .025 x 33.18 — BTU= 4247 BTU/min. /lance

Additional Boiler Heat Required

Boiler efficiency = 88% — BTU required = 4lances x 4247 BTU/lance/0.88

BTU = 1,158,435 BTU/hr. — Fuel cost= $70.00/ton or $2.92/MBTU

Hot Air Energy Cost **$3.38/hr.**

Electric Power., from Data Logger

Duct heaters (4)	56.0 kW.h/hr.
Pump Skid	1.7 kW.h.hr.
Heater Control Panel	0.86 kW.h/hr.
Total	58.56 kW.h/hr.

Electricity cost @ $0.03/kW.h **$1.76/hr.**

Total Operating Cost for FGC System

H_2SO_4 Feedstock	$11.40 /hr.
Hot Air Heat Energy	3.38 /hr.
Electricity	1.76 /hr.

Total Hourly Cost **$16.54/hr.**

Cost of FGC Conditioning per Tonne of Coal

Boiler uses 68 tons or 61.7 tonnes at 150 MW

Cost per Tonne = $16.54 / 61.7 **$0.268/tonne**

* Cost figures are in Canadian Dollars