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CLEAN COAL TECHNOLOGY III

10 MW DEMONSTRATION OF GAS SUSPENSION ABSORPTION

FINAL PUBLIC DESIGN REPORT

PARTICIPANT

AirPol Inc.

Teterboro, N.J.

Frank E. Hsu
Project Manager

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LEGAL NOTICE

ABSTRACT

The Public Design report provides the nonproprietary design information for the "10 MW Demonstration of Gas Suspension Absorption (GSA)" Demonstration Project at Tennessee Valley Authority's (TVA) Shawnee Power Station, Center for Emission Research (CER).

The 10 MW Demonstration of Gas Suspension Absorption (GSA) program is designed to demonstrate the performance of the GSA system in treating the flue gas from a boiler burning high sulfur coal. This project involves design, manufacturing, construction and testing of a retrofitted GSA system.

This report presents a nonproprietary description of the technology and overall process performance requirements, plant location and plant facilities.

The process, mechanical, structural and electrical design of the GSA system as well as project cost information are included. It also includes a description of the modification or alterations made during the course of construction and start-up.

Plant start-up provisions, environmental considerations and control, monitoring and safety considerations are also addressed for the process.

This report, initially drafted in 1993, covers design information available prior to startup of the demonstration project. It does not reflect the results obtained in that project, which is now complete.

POINT OF CONTACT

Frank E. Hsu
Project Manager
AirPol Inc.
32 Henry Street
Teterboro, New Jersey 07608
Tel. (201)-288-7070

Sharon K. Marchant
Project Manager
Pittsburgh Energy Technology Center
United States Department of Energy
Pittsburgh, Pennsylvania 15236
Tel. (412)-892-6008

Thomas A. Burnett
Project Specialist
Tennessee Valley Authority
Chattanooga, Tennessee 37402
Tel. (615)-751-3938

TABLE OF CONTENT

LEGAL NOTICE....................i
ABSTRACT....................ii
POINT OF CONTACT....................iii
TABLE OF CONTENT....................iv
LIST OF TABLES....................vi
LIST OF FIGURES....................viii
LIST OF ABBREVIATIONS....................ix
EXECUTIVE SUMMARY....................x

1.0 INTRODUCTION....................1

1.1 SIGNIFICANCE OF THE PROJECT....................1
1.2 PURPOSE OF THE PUBLIC DESIGN REPORT....................3
1.3 THE ROLE OF DOE IN THE PROJECT....................4
1.3.1 Innovative Clean Coal Technology Program....................4
1.3.2 Management Plan and Organization Chart....................4

2.0 OVERVIEW OF THE PROJECT....................7

2.1 INTRODUCTION....................7
2.2 LOCATION....................10
2.3 LAND REQUIREMENT....................10
2.4 DEMONSTRATION SYSTEM....................10
2.4.1 Process Description....................10
2.4.2 Plot Plan/Layout....................15
2.4.3 Proprietary Information....................20
2.5 MAJOR TEST FACILITY EMISSION....................21
2.5.1 Major Emission....................21
2.5.2 Discussion....................21
2.6 BYPRODUCTS....................22
2.6.1 Description....................22
2.6.2 Quantity and Quality....................22

3.0 PROJECT PROCESS DATA....................23

3.1 PROCESS DESIGN BASIS....................23
3.2 PROCESS DESCRIPTION....................25
3.3 MASS AND ENERGY BALANCE....................29
3.4 UTILITY AND REAGENT REQUIREMENTS....................74
3.5 DESIGN CONSIDERATIONS....................75
3.6 NORMAL OPERATION....................77
3.7 START-UP/SHUT DOWN CONDITIONS....................79

3.8 ENVIRONMENTAL CONSIDERATIONS 79

4.0 EHSS CONSIDERATIONS 80

5.0 PROJECT SCHEDULE 82

6.0 EQUIPMENT 83

6.1 EQUIPMENT SPECIFICATION 83
6.2 EQUIPMENT COST 83

7.0 COSTS 94

7.1 PROJECT COSTS 94
7.2 CAPITAL COSTS 96
7.3 START-UP COSTS 96
7.4 OPERATING AND MAINTENANCE COSTS 96

8.0 PROJECTED PERFORMANCE 99

8.1 PROJECTED TECHNICAL PERFORMANCE 99
8.2 PROJECTED ENVIRONMENTAL PERFORMANCE 99
8.2.1 Projected Environmental Performance in Air Quality 99
8.2.2 Projected Environmental Performance in Water Quality 99
8.2.3 Projected Environmental Performance in Solid Waste Quality 99
8.3 PROJECTED ECONOMICS 100

9.0 COMMERCIAL APPLICATIONS 101

10.0 CONCLUSIONS 103

11.0 REFERENCES 104

LIST OF TABLES

Table 2.1	PROJECT WORK BREAKDOWN STRUCTURE	9
Table 3.1	PROCESS DESIGN DATA	23
Table 3.2-1	TYPICAL COAL COMPOSITIONS FOR THE HIGH-SULFUR COALS (PROXIMATE ANALYSIS)	26
Table 3.2-2	TYPICAL COAL COMPOSITIONS FOR THE HIGH-SULFUR COALS (ULTIMATE ANALYSIS)	26
Table 3.2-3	PEBBLE LIME COMPOSITION	27
Table 3.3-1	SUMMARY TABLE FOR GSA SYSTEM PROCESS DESIGN	30
Table 3.3-2	PROCESS CALCULATION, MASS AND ENERGY BALANCE FOR DESIGN CASE	32
Table 3.3-3	PROCESS CALCULATION, MASS AND ENERGY BALANCE FOR MINIMUM CASE	39
Table 3.3-4	PROCESS CALCULATION, MASS AND ENERGY BALANCE FOR MAXIMUM CASE	46
Table 3.3-5	PROCESS CALCULATION, MASS AND ENERGY BALANCE FOR DESIGN CASE WITH BAGHOUSE IN SERIES WITH ESP	53
Table 3.3-6	PROCESS CALCULATION, MASS AND ENERGY BALANCE FOR MINIMUM CASE WITH BAGHOUSE IN SERIES WITH ESP	60
Table 3.3-7	PROCESS CALCULATION, MASS AND ENERGY BALANCE FOR MAXIMUM CASE WITH BAGHOUSE IN SERIES WITH ESP	67
Table 6.1-1	EQUIPMENT DESIGN SPECIFICATION	85
Table 6.1-2	INSTRUMENT SPECIFICATION 10 MW DEMONSTRATION OF GSA	89

Table 6.2 MAJOR EQUIPMENT COSTS
10 MW DEMONSTRATION OF GSA....91

Table 7.1 PROJECT COST BREAKDOWN BY TASK
10 MW DEMONSTRATION OF GSA....95

Table 7.3 START-UP COSTS
10 MW DEMONSTRATION OF GSA....97

Table 7.4 OPERATING AND MAINTENANCE COSTS
10 MW DEMONSTRATION OF GSA....98

LIST OF FIGURES

Figure 1.3.2	AIRPOL PROJECT ORGANIZATION 10 MW DEMONSTRATION OF GSA	5
Figure 2.4.1-1	PROCESS FLOW BLOCK DIAGRAM GAS SUSPENSION ABSORPTION SYSTEM	11
Figure 2.4.1-2	PROCESS FLOW DIAGRAM GAS SUSPENSION ABSORPTION SYSTEM	12
Figure 2.4.1-3	PROCESS CONTROL SCHEMATIC DIAGRAM GAS SUSPENSION ABSORPTION SYSTEM	14
Figure 2.4.2-1	PLOT PLAN GAS SUSPENSION ABSORPTION SYSTEM AT TVA SHAWNEE POWER STATION	16
Figure 2.4.2-2	GENERAL ARRANGEMENT 10 MW DEMONSTRATION OF GSA	17
Figure 2.4.2-3	GENERAL ARRANGEMENT --- ELEVATION-I 10 MW DEMONSTRATION OF GSA	18
Figure 2.4.2-4	GENERAL ARRANGEMENT --- ELEVATION-II 10 MW DEMONSTRATION OF GSA	19
Figure 3.3	PROCESS DIAGRAM FOR MASS BALANCE 10 MW DEMONSTRATION OF GSA	31
Figure 3.6	PROCESS FLOW DIAGRAM 10 MW DEMONSTRATION OF GSA	78
Figure 6.1	PROCESS FLOW DIAGRAM FOR EQUIPMENT LIST 10 MW DEMONSTRATION OF GSA	84

LIST OF ABBREVIATIONS

ACFM	-	actual cubic feet per minute
ASTM	-	American Society of Testing and Materials
AST	-	approach to saturation temperature
Btu	-	British thermal unit
CCT	-	Clean Coal Technology
CER	-	Center for Emissions Research, Shawnee Fossil Plant
CS	-	carbon steel
CSRL	-	carbon steel rubber lined
DOE	-	Department of Energy
EHSS	-	Environmental Health Safety Standards
EPA	-	Environmental Protection Agency
ESP	-	Electrostatic Precipitator
FGD	-	flue gas desulfurization
ft	-	feet
GSA	-	Gas Suspension Absorption
HCl	-	hydrochloric acid
hr	-	hour
KDAQ	-	Kentucky Division for Air Quality
KDWQ	-	Kentucky Division for Water Quality
lb	-	pound
I.D.	-	induced draft
MBtu	-	million British thermal units
MW	-	megawatt
NEPA	-	National Environmental Policy Act
O_2	-	oxygen
%	-	percent
ppm	-	parts per million by volume
SCFM	-	standard cubic feet per minute
SD	-	spray dryer
SO_2	-	sulfur dioxide
SS	-	stainless steel
TVA	-	Tennessee Valley Authority
WG	-	water gauge

EXECUTIVE SUMMARY

AirPol, with the assistance of the Tennessee Valley Authority (TVA), will demonstrate the Gas Suspension Absorption (GSA) technology entitled "10 MW Demonstration of Gas Suspension Absorption". AirPol is performing this demonstration under a Cooperative Agreement awarded by the United States (U.S.) Department of Energy (DOE) in October 1990. This project was selected in Round III of the Clean Coal Technology Program (CCT Program). The goal of the program is to furnish the U.S. energy marketplace with a number of advanced, more efficient, and environmentally responsive coal-using technologies. These technologies will reduce and/or eliminate the economic and environmental impediments that limit the full consideration of coal as a viable future energy resource.

This project is the first North American demonstration of the GSA system for flue gas desulfurization (FGD) for a coal-fired utility boiler. This low-cost retrofit project seeks to demonstrate the GSA system, which is expected to remove more than 90% of the sulfur dioxide (SO_2) from the flue gas, while achieving a high utilization of reagent lime. TVA has provided its Center for Emissions Research (CER) as the host site and is providing operation, maintenance, and technical support during the operations and testing phase of this project. The CER is located at the TVA's Shawnee Fossil Plant near Paducah, Kentucky.

The experience gained by AirPol in designing, fabricating, and constructing the GSA equipment through the execution of this project will be used for future commercialization of the GSA technology. The results of the operation and testing phase will be used to further improve the GSA system design and operation. Subsequent to optimization of GSA system, air toxic testing will be performed to determine GSA's capability in removing hazardous air pollutants.

Along with the operation and testing of the GSA, a 1 MW pulsed jet fabric filter will be tested to evaluate its long-term reliability and pollutant (both SO_2 and air toxics) removal performance. The filter will be connected to the ESP to allow testing of the GSA system in one of three alternative arrangements: GSA with ESP only, GSA with fabric filter only, and GSA with ESP followed by fabric filter.

Raw flue gas will be provided to the GSA from Shawnee's unit 9 which has been configured to divert 10% its total flue gas output to the GSA system. The diverted flue gas enters the bottom of the reactor where it is mixed with suspended solids and lime slurry which are being fed into the reactor by way of a spray nozzle. The slurry is suspended in the reactor by the flue gas stream during which the slurry and flue gas undergo a chemical reaction in which SO_2 reacts with the lime. The major products of this reaction are calcium sulfite and calcium sulfate. The partially cleaned flue gases leave the reactor and enter a cyclone where the solids containing the calcium salts, ash and unreacted lime are separated from the gas stream. About 99 % of the solids collected from the cyclone are recycled back to the reactor so that any unused lime can further react with acid gases in the flue gas. This lowers the overall consumption of lime. The remaining 1 % of the solids from the cyclone leave the system at this point as by-product. The flue gases leave the separating cyclone and enter an existing electrostatic precipitator (ESP) for particulate collection. Cleaned flue gases are released to the atmosphere from the ESP through a separate pilot plant stack. The GSA system is designed to remove more than 90 % SO_2 using high sulfur U.S. coal. Coal sulfur content during the demonstration will range from 4 to 5 pounds of SO_2 per million Btu (lbs SO_2/MBtu), about 2.7 - 3.0 % sulfur by weight. The process chemistry is shown as follows:

The following primary reactions take place in suspended solids containing lime:

$$Ca(OH)_2\ (aq) + SO_2\ (aq) \rightarrow CaSO_3 \cdot 1/2\ H_2O\ (s) + 1/2\ H_2O\ (l)$$

$$Ca(OH)_2\ (aq) + SO_3\ (aq) + H_2O\ (1) \rightarrow CaSO_4 \cdot 2\ H_2O\ (s)$$

In addition to the primary reactions the following secondary reactions also take place:

$$Ca(OH)_2\ (aq) + 2\ HCl\ (aq) + 4\ H_2O\ (1) \rightarrow CaCl_2 \cdot 6\ H_2O\ (s)$$

$$Ca(OH)_2\ (aq) + CO_2\ (aq) \rightarrow CaCO_3\ (s) + H_2O\ (1)$$

$$CaSO_3\ (aq) \cdot 1/2\ H_2\ O + 1/2\ O_2\ (aq) + 1/2\ H_2O\ (1) \rightarrow CaSO_4 \cdot H_2O\ (s)$$

The GSA is distinguished from the average semi-dry scrubbing processes by its modest space requirement, simple means of introducing reagent to the reactor, direct means of recirculating unused lime, and low reagent consumption. The GSA system consists of the following major equipment:

- A circulating fluidized reactor.
- A separating cyclone incorporating a system for recycling separated material to the reactor.
- A slurry preparation system which proportions the slurry to the reactor via a nozzle.
- A dust collector which removes fly ash and reacted lime from the gas stream.

In laying out the general arrangement of the GSA system, design consideration was given to the following factors:

1. Minimizing material and construction cost by making the connecting duct system as compact as possible, while providing adequate gas flow pattern throughout the system.

2. Providing an enclosure to enclose the most frequently serviced area of the GSA system. The enclosure will provide personnel protection in the injection lance area and the feeder

box area, and shields the air sluice, slurry and water pipes from inclement weather.

3. Designing the access system to provide direct access to the lower operating area (injection nozzle level) and to save costs by utilizing the existing stair tower.

Existing equipment that is suitable for the new GSA system use is reused to minimize interface work and save equipment cost. The equipment being reused includes the following:

- Air compressor
- Lime preparation system
- Slurry pump
- ESP and ash handling system
- Motor control panel is modified to add additional circuit breakers for the added motors.

In view of the fact that the GSA outlet gas temperature is close to the saturation temperature of the flue gas, special design consideration was given in heating and insulation for the vessels and gas duct to prevent condensation. Basically, all of the main equipment such as reactor, cyclone, baghouse and feeder box as well as ductwork are designed for external insulation with flat sheet aluminum lagging.

During normal operation, the GSA system is under the control of an automatic process control system which consists of three control loops. Recycled Solid Control Loop continuously controls the flow of recycled solids to the reactor, based on the amount of flue gas entering the system. Feed Water Rate Control ensures that the flue gas is sufficiently cooled to optimize the chemical processes. Lime Feed Rate Control Loop controls the lime addition. This control loop enables direct proportioning of lime feed according to monitored results and further contributes to maintaining a low level of lime consumption. The setting of all the control parameters are adjusted during initial start-up and can be changed during normal operation if required by a significant change in the operating condition.

The financing of the 10 MW Demonstration of GSA project is provided by TVA and AirPol Inc. with financial assistance from DOE under Cooperative Agreement. The budgeted cost of the project is $7,717,189.

During the design and construction phase, the effort has been aimed at the proper development of the GSA technology for the successful installation of the demonstration unit. Having accomplished the design and construction of the demonstration unit, effort is now made on optimizing the GSA for maximum operating efficiency and economics.

As presented in the this report, the GSA process has been designed with proper considerations for existing site condition, cost economization, environmental impact and operation concerns. The demonstration unit is expected to achieve all the projected performance and be commercialized in time for the intended market.

It is expected that this demonstration project will truly fulfill the goal of the Clean Coal Technology Program.

1.0 INTRODUCTION

1.1 SIGNIFICANCE OF THE PROJECT

This "10 MW Demonstration of Gas Suspension Absorption (GSA)" Demonstration Project will demonstrate the GSA system which is expected to remove more than 90% of the SO_2 from coal-fired flue gas, while achieving a high utilization of reagent lime.

The host site facility will be TVA's Center for Emissions Research (CER) located at the Shawnee Fossil Plant in West Paducah, Kentucky. Over the past 15 years, the CER has served as a testground for flue gas desulfurization (FGD) systems. The GSA system will be tested for a period of twelve (12) months.

The GSA is distinguished from average semi-dry scrubbing processes by its modest space requirement, simple means of introducing reagent to the reactor, direct means of recirculating unused lime, and low reagent consumption.

It is expected that the results from this demonstration project will prove GSA to be an effective, economic and space efficient answer to the SO_2 removal need of the U.S. utility industry. The importance and significance of this project is demonstrated by the following facts:

- That the GSA system is retrofitted into an existing system with extremely tight available space helps demonstrate the GSA advantage in being retrofitted into existing boiler systems.

- The GSA technology will be demonstrated at a coal-fired boiler plant with operating conditions that are typical of the average U.S. utility plants. Upon commercialization, this technology will have wide application to the utility industry.

- Commercialization of the GSA technology, as part of the objective of this project, will be carried out in time to meet the demand for FGD equipment generated by the new Clean Air Act Amendments.

- The fact that there is an existing spray dryer system that has gone through similar type of tests provides good comparison of the GSA with competing technologies.

- As part of the demonstration program, a comparison of a GSA system with electrostatic precipitator and a GSA system with fabric filter will be made. This comparison will demonstrate GSA's flexibility in operating in conjunction with different types of existing dust collectors, and provide valuable information of GSA performance with either type of dust collector.

- As part of the demonstration program, air toxics test will be conducted to determine GSA's ability in removing air toxics. If such capability is confirmed as expected, the GSA will prove to be a viable solution to the pollution problem faced by the U.S. utility industry.

Based on comparison of capital and operating cost of GSA and other FGD processes, it was found that the GSA is especially suited for utility plants with sizes ranging from 50 to 250 MW. The simplicity in GSA design and operation plus the modest space requirement makes the GSA ideal for retrofitting to existing plants. One major advantage of the GSA as compared to other semi-dry scrubbing process is the fact that operation of the GSA will not result in excessive additional dust loading to the gas stream, thus reducing the cost for upgrading the existing dust collector. The potential market for the GSA system is estimated at $300 million within the next 20 years.

1.2 PURPOSE OF THE PUBLIC DESIGN REPORT

The purpose of the Public Design Report for "10 MW Demonstration of Gas Suspension Absorption" is to consolidate for public use all available non-proprietary design information on the project. This report is based on detailed design information with the incorporation of the design changes made during construction and initial start-up. The report contains sufficient background information to provide an overview of the project and pertinent cost data.

The scope of the report is limited to non-proprietary information. Its content is not sufficient to provide a complete tool in designing a replicate plant. However, this report will serve as a reference for the design considerations involved in a commercial-scale facility.

1.3 THE ROLE OF DOE IN THE PROJECT

1.3.1 Innovative Clean Coal Technology Program

The Clean Coal Technology Demonstration Program (CCT Program) is a government and industry co-funded technology development effort to demonstrate a new generation of innovative coal utilization processes in a series of full-scale, "showcase" facilities built across the country. These demonstrations will be on a scale large enough to generate all the data required for design, construction, and operation, for technical/economic evaluation and future commercialization of the process.

The goal of the program is to furnish the U.S. energy marketplace with a number of advanced, more efficient, and environmentally responsive coal-using technologies. These technologies will reduce and/or eliminate the economic and environmental impediments that limit the full consideration of coal as a viable future energy resource.

To achieve this goal, a multi-phased effort consisting of five separate solicitations is administered by the Department of Energy. Projects selected through these solicitations will demonstrate technology options with the potential to meet the needs of energy markets and respond to relevant environmental considerations.

The third solicitation (CCT-III), issued in 1989, targeted those technologies capable of achieving significant reductions in the emission of SO_2 and/or NO_x from existing facilities to minimize environmental impacts, such as transboundary and interstate pollution, and/or provide for future energy needs in an environmentally acceptable manner.

In response to the third solicitation, AirPol Inc. submitted a proposal for the design, installation and testing of the Gas Suspension Absorption (GSA) system at Tennessee Valley Authority's (TVA) Center for Emission Research (CER). AirPol's proposal was selected as the result of DOE's evaluation in terms of technical advantage, cost effectiveness, technical readiness, EHSS, and business and management performance potential. On July 25, 1990, a Cooperative Agreement was signed by AirPol for the project entitled "10 MW Demonstration of Gas Suspension Absorption". The project was approved by Congress in October of 1990, and the Cooperative Agreement for the project was awarded by DOE on October 11, 1990.

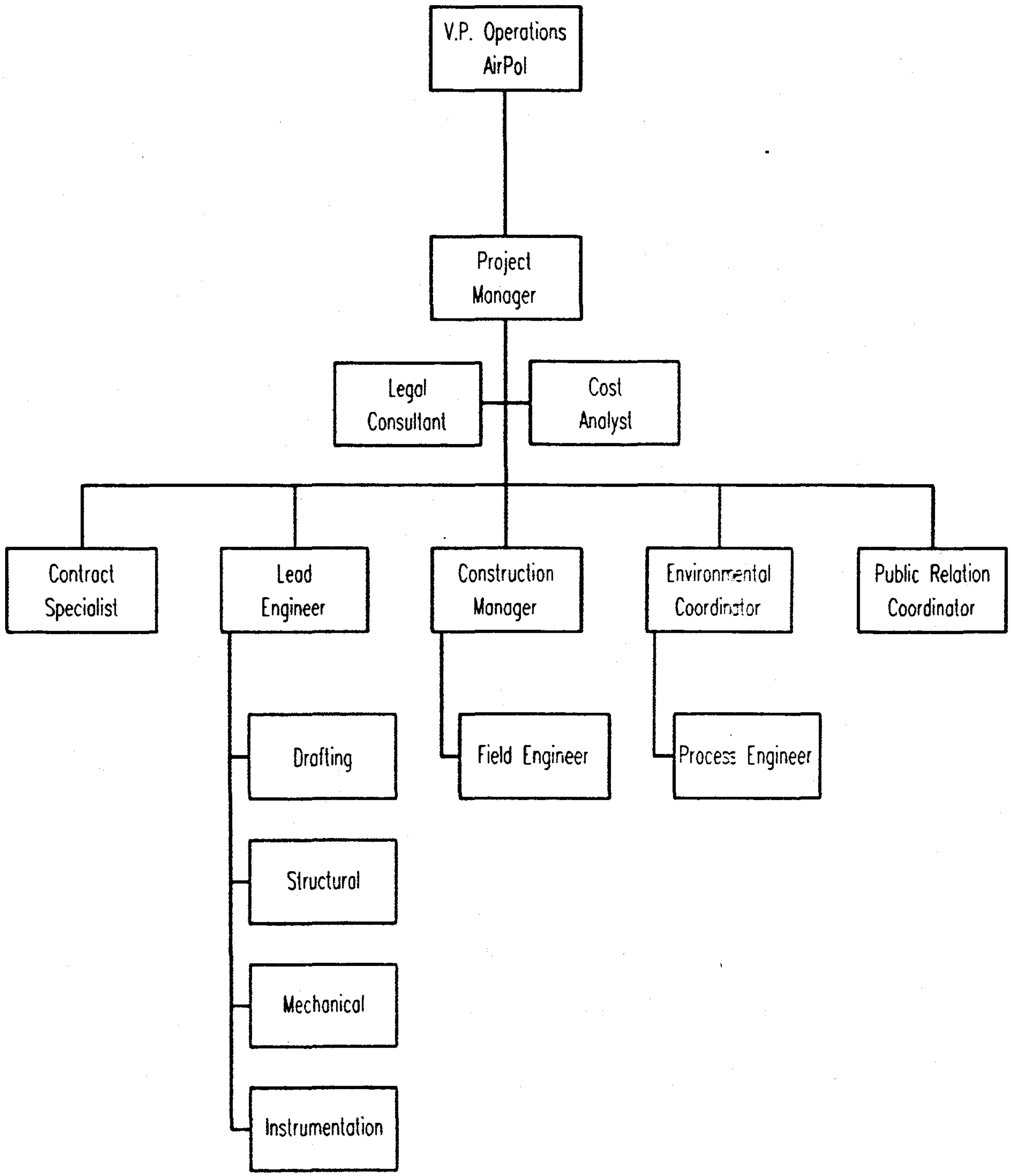
1.3.2 Management Plan and Organization Chart

The DOE entered into a Cooperative Agreement with AirPol Inc. to conduct this project. The DOE will monitor the project through the Contracting Officer and the Project Manager.

The major participants in the execution of this project are AirPol, TVA, and FLS miljo. AirPol takes the lead in executing this project, whereas TVA acts as a subcontractor to AirPol providing the host site and testing/operation service, and FLS miljo as the technology owner providing

Figure 1.3.2

AIRPOL PROJECT ORGANIZATION
10 MW DEMONSTRATION OF GSA



technology transfer and technical assistance to AirPol.

AirPol's project execution team, as shown in Figure 1.3.2, consists of the following members:

Vice President of Operations - Chief in charge of the overall project, and the prime decision maker in all phases of the project.

Project Manager - Responsible for the timely completion of all tasks required for the project. Acts as the focal point in steering the progress of the project, and in coordinating with DOE and TVA. Maintains overall cost and schedule control of the project. Provides supervision and guidance to the project execution team. Coordinates with Purchasing Manager on all procurement tasks. Interfaces with the Process Specialist on all technological and environmental matters.

Legal Consultant - Provides legal advice to the Project Manager.

Contract Specialist - Responsible for all procurement tasks for the project. Compiles and disseminates project cost data to the President and the Project Manager for their review and analysis.

Environmental Coordinator - Responsible for the preparation of all environmental information required for DOE to fulfill its obligation under National Environmental Policy Act (NEPA).

Construction Manager - Responsible for the management and coordination of all construction and start-up related activities.

Throughout the course of this project, reports dealing with technical, cost and environmental aspects of the project will be prepared by AirPol and provided to DOE. AirPol and TVA will also prepare and publish technical papers on the demonstrated technology, operating results, and its commercial advantages.

2.0 OVERVIEW OF THE PROJECT

2.1 INTRODUCTION

This low-cost retrofit project will demonstrate the GSA system which is expected to remove more than 90% of the SO_2 from coal-fired flue gas, while achieving a high utilization of reagent lime.

The GSA process is a novel concept for FGD that was developed by AirPol's parent company, F.L. Smidth miljo a/s in Copenhagen, Denmark. The process was initially developed as a cyclone preheater system for cement kiln raw meal (limestone and clay). This innovative system provided both capital and energy savings by reducing the required length of the rotary kiln and lowering fuel consumption. The GSA system also showed superior heat and mass transfer characteristics and was subsequently used for the calcination of limestone, alumina, and dolomite. The GSA system for FGD applications was developed later by injecting lime slurry and the recycled solids into the bottom of the reactor to function as an acid gas absorber.

In 1985, a GSA pilot plant was built in Denmark to establish design parameters for SO_2 and hydrogen chloride (HCl) absorption for waste incineration applications. The first commercial GSA unit was installed at the KARA Waste-to-Energy Plant at Roskilde, Denmark, in 1988.

With the increased emphasis on SO_2 emissions reduction by electric utility and industrial plants as required by the Clean Air Act Amendments of 1990, there is a need for a simple and economic FGD process, such as GSA, by the small to mid-size plants where a wet FGD system may not be feasible. The GSA FGD process, with commercial and technical advantages expected to be confirmed in this demonstration project, will be a viable alternative to meet the needs of the U.S. utility industry and the industrial boilers.

The GSA system brings coal combustion gases into contact with a suspended mixture of solids, including sulfur-absorbing lime. After the lime absorbs the sulfur pollutants, the solids are separated from the gases in a cyclone device and recirculated back into the system where they capture additional sulfur pollutant. The cleaned flue gases are sent through a dust collector before being released into the atmosphere. The key to the system's superior economic performance with high sulfur coals is the recirculation of solids. Typically, a solid particle will pass through the system about one hundred times before leaving the system. Another advantage of the GSA system is that a single spray nozzle is used to inject fresh lime slurry.

A 10 MW GSA demonstration system shall be installed and tested at the Tennessee Valley Authority (TVA) Shawnee Fossil Plant at West Paducah, Kentucky. The new GSA system will replace the existing spray dryer that was installed previously as a test unit. The experience gained in designing, manufacturing and constructing the GSA equipment through executing this project will be used for future commercialization of the GSA system. Results of the operation and experimental testing will be used to further improve the GSA design and operation.

Subsequent to optimization of GSA system, air toxic testing will be performed to determine

GSA's capability in removing hazardous air pollutants.

Along with the operation and testing of the GSA, a 1 MW pulsed jet fabric filter will be tested to evaluate its long-term reliability and pollutant (both SO_2 and air toxics) removal performance. The filter will be connected to the ESP to allow testing of the GSA system in one of three alternative arrangements: GSA with ESP only, GSA with fabric filter only, and GSA with ESP followed by fabric filter.

The specific technical objectives of the GSA demonstration project are to:

- Effectively demonstrate SO_2 removal in excess of 90% using high sulfur U.S. coal.

- Optimize recycle and design parameters to increase efficiencies of lime reagent utilization and SO_2 removal.

- Compare removal efficiency and cost with existing Spray Dryer/Electrostatic Precipitator technology.

- To obtain data regarding the GSA's ability to remove air toxics from the waste gas stream (1) with ESP, (2) with fabric filter, and (3) with fabric filter following ESP.

- To compare the air toxics removal between a GSA with ESP and a GSA with fabric filter.

- To compare the SO_2 removal between a GSA with ESP and a GSA with fabric filter.

- To evaluate the merits of a fabric filter following an ESP as a polishing unit in both SO_2 and air toxic removal.

- To evaluate the performance and long-term reliability of the fabric filter in GSA applications.

In order to accomplish these objectives, the demonstration project is divided into phases and tasks as shown in the Table 2.1, Project Work Breakdown Structure.

The design phase was completed on schedule in December 1991. The construction phase was completed at the end of September 1992. The testing phase started in October 1992 and will end in October 1993.

Table 2.1

PROJECT WORK BREAKDOWN STRUCTURE

PHASE	TASK	DESCRIPTIONS
Phase I		Engineering and Design
	Task I	Project and Contract Management
	Task II	Process and Technology Design
	Task III	Environmental Analysis
	Task IV	Engineering Design
Phase II		Procurement and Construction
	Task I	Project and Contract Management
	Task II	Procurement and Furnish Material
	Task III	Construction and Commissioning
Phase III		Operation and Testing
	Task I	Project Management
	Task II	Start-up and Training
	Task III	Experimental Testing and Reporting

2.2 LOCATION

The project will be conducted at the TVA Shawnee Fossil Plant in McCracken County, Kentucky, located approximately 10 miles northwest of Paducah, Kentucky. The plant is located on the south bank of the Ohio River at river mile 945 on several hundred acres of river floodplain and a low upland terrace developed in thick deposits of unconsolidated clays, silts, and gravel. The active plant area is situated on this terrace, which lies above the 500-year floodplain.

The Shawnee Fossil Plant currently operates 10 coal-fired boiler units with a total nameplate capacity of 1735 MW. Units 1-8 are fired with low-sulfur coal while units 9 and 10 are able to utilize a high-sulfur coal. Unit 9 currently supplies 7 % of its total flue gas to an experimental flue gas desulfurization (FGD) system, which is to be replaced by the new GSA demonstration system. Units 1 through 9 are identical wall-fired Babcock and Wilcox boilers, each having a nameplate generating capacity of 175 MW, while unit 10 is a 160-MW Atmospheric Fluidized Bed Combustion boiler that was retrofitted in the 1980s.

2.3 LAND REQUIREMENT

Due to the fact that demonstration system is retrofitted into the existing test facility the space requirement is only for the installation of the GSA reactor and cyclone. A space of 20 feet by 12 feet is used for the installation. Existing facilities such as the lime preparation system, stair tower, ESP, I.D. fan, and associated ductwork are reused.

2.4 DEMONSTRATION SYSTEM

2.4.1 Process Description

As shown in Figure 2.4.1-1 and 2.4.1-2, the GSA system consists of:

- A circulating fluidized reactor.
- A separating cyclone incorporating a system for recycling separated material to the reactor.
- A slurry preparation system which proportions the slurry to the reactor via a nozzle.
- A dust collector which removes fly ash and reacted lime from the gas stream.

The flue gas from the boiler is fed into the bottom of the reactor where it is mixed with the suspended solids wetted with lime slurry. The solids consist of reaction products, residual lime and fly ash.

Figure 2.4.1-1

PROCESS FLOW BLOCK DIAGRAM
GAS SUSPENSION ABSORPTION SYSTEM

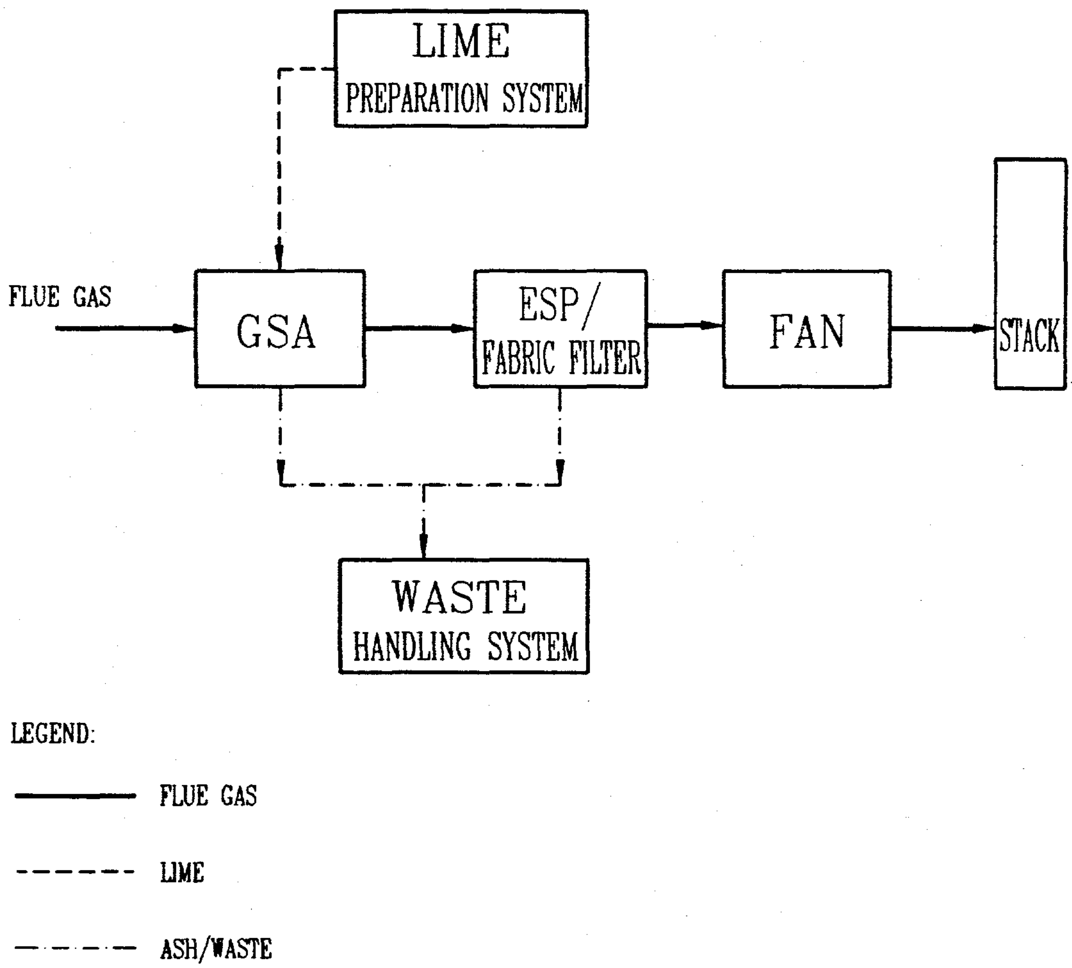
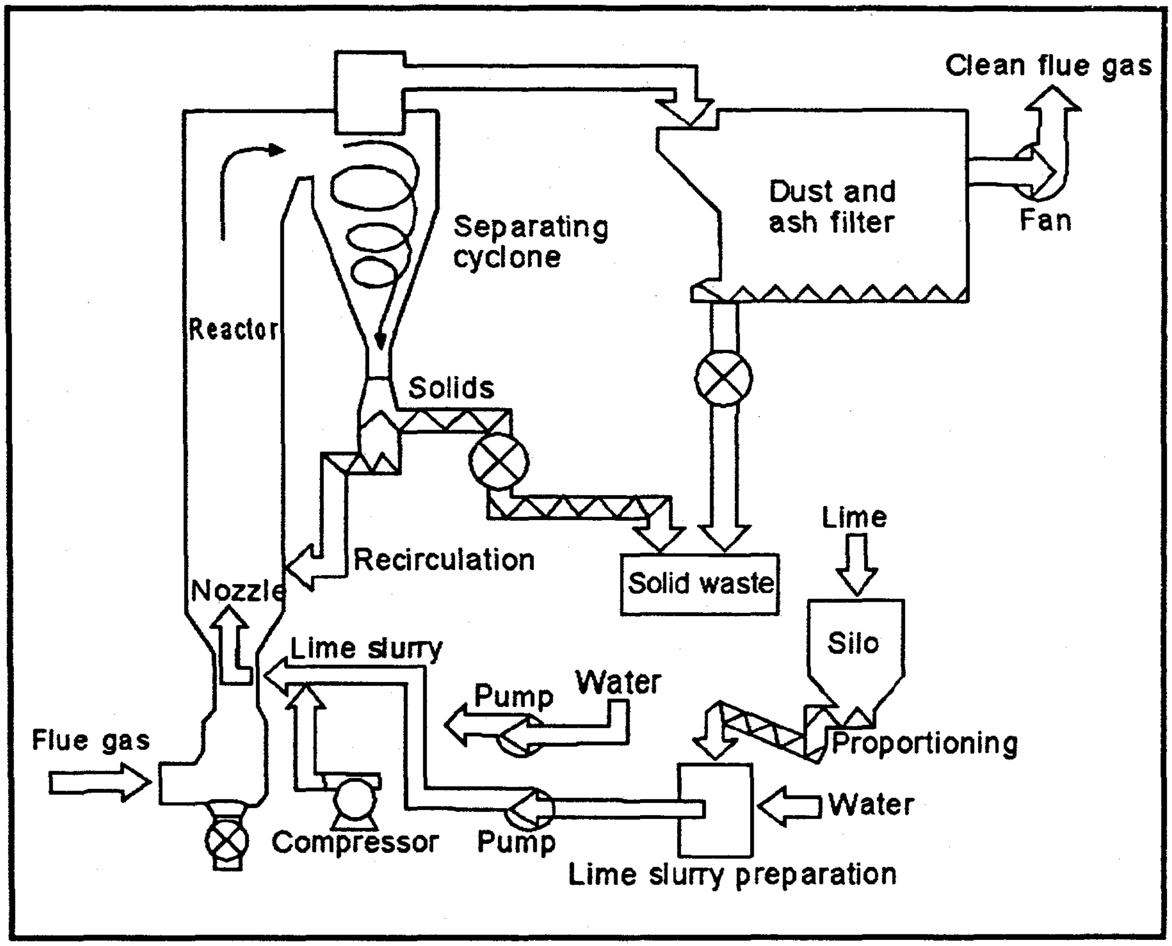


Figure 2.4.1-2

PROCESS FLOW DIAGRAM
GAS SUSPENSION ABSORPTION SYSTEM



During the drying process in the reactor, the lime slurry undergoes a chemical reaction with the acid components, SO_2 and HCl of the flue gas, capturing and neutralizing them.

The partially cleaned flue gas flows through the separating cyclone to an electrostatic precipitator, or a fabric filter, which removes the dust and ash particles. The flue gas, which has now been cleaned, is then released into the atmosphere through the stack.

The solids are separated from the gas stream in the cyclone. Approximately 95% to 99% of the solids is fed back to the reactor via a screw conveyor, while the remaining solids leave the system as a waste product. The 95% to 99% which is recirculated to the reactor is still reactive. This means that the recirculated lime is still able to react with and neutralize the acid gas in the flue gas. In addition, the fly ash in the flue gas makes a positive contribution in the neutralization process to a much higher degree than in conventional semi-dry flue gas cleaning plants.

Owing to the recirculation of solids the GSA process provides an efficient utilization of the lime slurry and fly ash, thus minimizing the need for the introduction of fresh lime.

One of the reasons for the high efficiency of the GSA process is that the absorber is based on gas suspension technology. This means that a very high concentration of fly ash, dust particles, and lime is fluidized inside the reactor. This concentration will normally be as high as 200-800 grains/scf.

This GSA control system, as shown in Figure 2.4.1-3, incorporates three control loops:

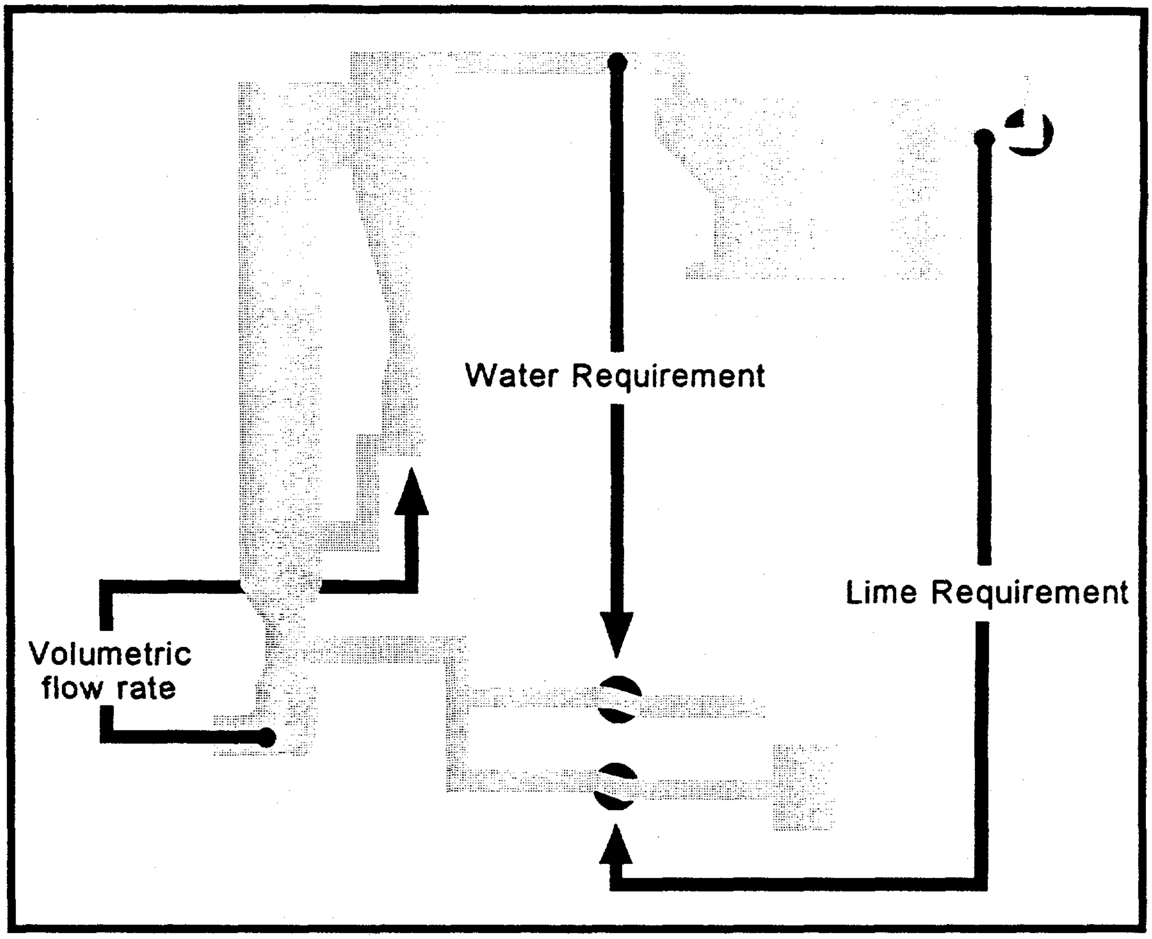
1. The first loop continuously controls the flow of recycled solids to the reactor, based on the amount of flue gas entering the system. The large reaction area and even distribution in the reactor of the absorbent provides for efficient mixing of the lime with the flue gas. At the same time, the large volume of dry material prevents the slurry from adhering to the sides of the reactor.

2. The second control loop ensures that the flue gas is sufficiently cooled to optimize the chemical processes. This is achieved by the addition of extra water along with the lime slurry. The amount of water added into the system is governed by the temperature of the flue gas exiting the reactor to avoid any risk of acid condensation.

3. The third control loop controls lime addition. This is accomplished by continuously monitoring the acid content in the outlet flue gas and comparing it with the required emission level. This control loop enables direct proportioning of lime feed according to monitored results and further contributes to maintaining a low level of lime consumption.

Figure 2.4.1-3

PROCESS CONTROL SCHEMATIC DIAGRAM
GAS SUSPENSION ABSORPTION SYSTEM



2.4.2 Plot Plan/Layout

Figure 2.4.2-1 represents the plot plan for the facility and Figures 2.4.2-2, 2.4.2-3 and 2.4.2-4 represent general arrangement of the GSA system.

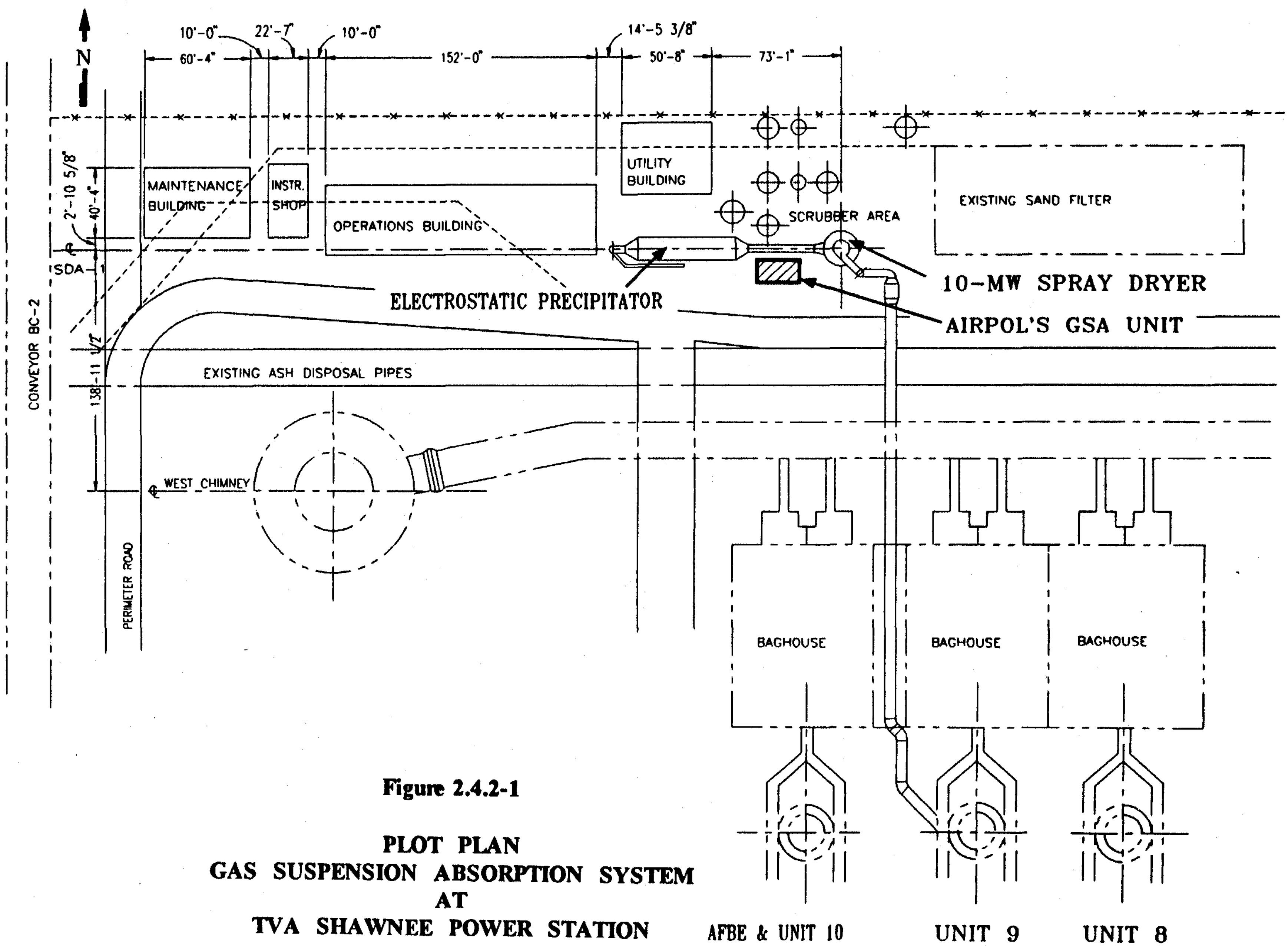


Figure 2.4.2-1

PLOT PLAN
GAS SUSPENSION ABSORPTION SYSTEM
AT
TVA SHAWNEE POWER STATION

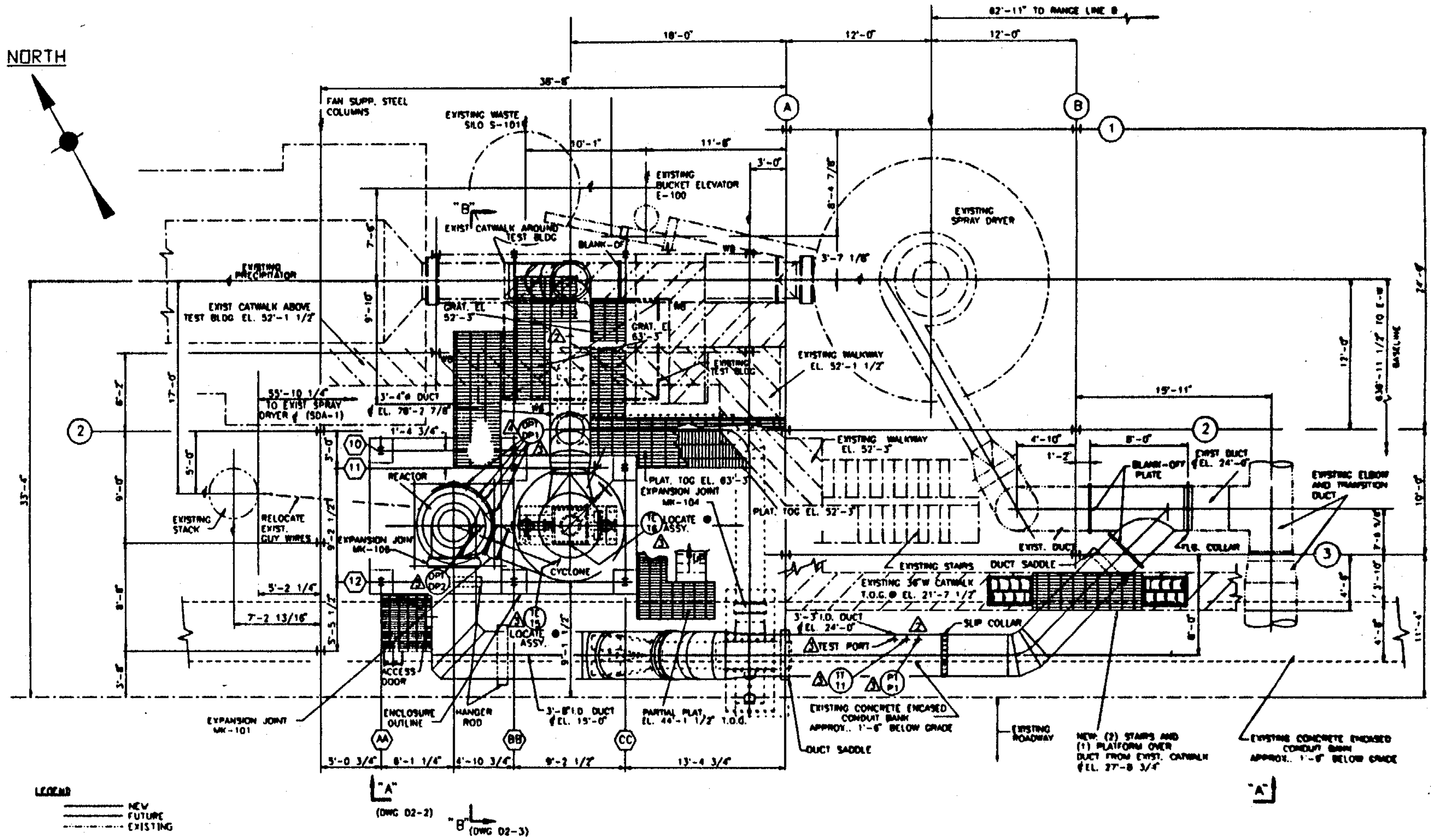


Figure 2.4.2-2

GENERAL ARRANGEMENT
10 MW DEMONSTRATION OF GSA

Figure 2.4.2-3

GENERAL ARRANGEMENT --- ELEVATION-I
10 MW DEMONSTRATION OF GSA

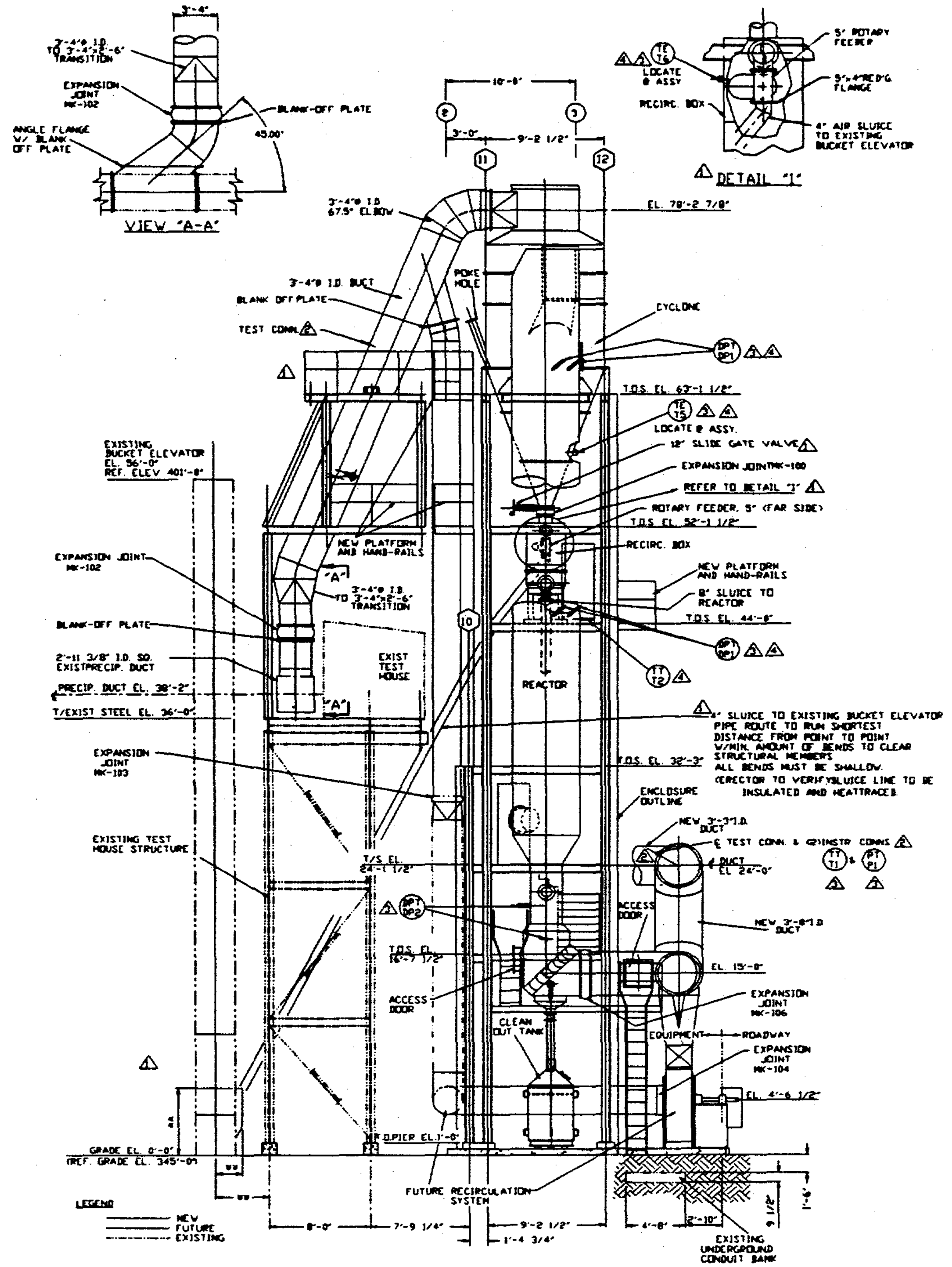
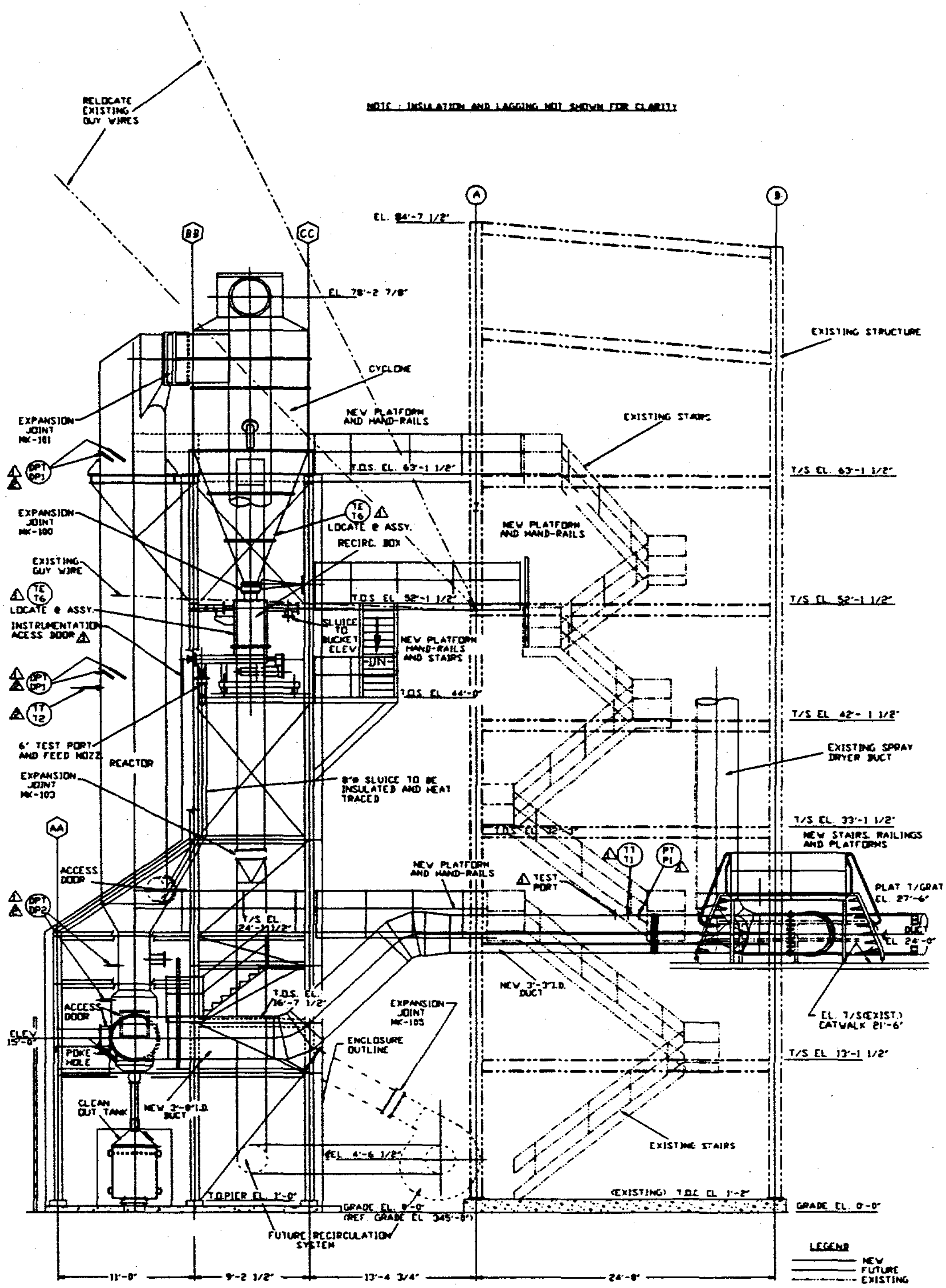


Figure 2.4.2-4

GENERAL ARRANGEMENT --- ELEVATION-II
10 MW DEMONSTRATION OF GSA



2.4.3 Proprietary Information

Listed as followings are the proprietary items for reader's references.

- Dimensions of the fluidized reactor, cyclone, feeder box, ESP and fabric filter.
- Detailed inner structure/configuration of the equipment.
- Critical process and equipment design parameters.
- Critical operating control data.
- Piping and instrument diagrams.
- Other pertinent information of the system, which are not be addressed in this paper.

2.5 MAJOR TEST FACILITY EMISSION

2.5.1 Major Emission

Since the demonstrated GSA process is a semi-dry process, there is no effluent from the process. The major emission from the operation is the gaseous discharge from the stack into the atmosphere.

2.5.2 Discussion

Air emissions from the Shawnee Fossil Plant are subject to the Clean Air Act, EPA regulations, and Kentucky Division for Air Quality (KDAQ) regulations. KDAQ requires TVA to continuously measure opacity and SO_2 emissions from unit 9 and to issue quarterly reports. Although opacity and SO_2 concentrations of the 10-MW slipstream are continuously measured, TVA is not required to submit these results to KDAQ. Since the GSA is expected to perform at a higher SO_2 removal efficiency than the existing Spray Dryer system, SO_2 emission will be reduced as a result of the GSA installation.

The Ohio River from the Shawnee Fossil Plant to its mouth is currently classified by the Kentucky Division for Water Quality (KDWQ) for primary and secondary contact, recreation, and domestic water supply. Approximately 1.5 billion gallons of water are discharged to the Ohio River daily from the Shawnee Fossil Plant. The GSA demonstration will result in no additional water discharge over the amount discharged from the plant during normal operations.

The solid streams resulting from the operation of the GSA unit are expected to have the same composition as the existing spray dryer wastes and by-products. In keeping with existing practices, these non-recyclable solids will be mixed with pilot plant ESP ash, diluted with water to generate a slurry containing approximately 10 % solids and pumped to an existing ash pond for dewatering and ultimate disposal with other ash. Changes in ash pond effluent quality or quantity as a result of the operation of the GSA are not expected.

2.6 BYPRODUCTS

2.6.1 Description

The byproduct from the demonstration system are cleaned gas exiting the stack and waste material discharged from the reactor and cyclone. The cleaned gas will be discharged into the atmosphere. The solid byproduct will be mixed with the ESP ash, diluted with water to generate a slurry containing approximately 10% solids and pumped to an existing ash pond for dewatering and ultimate disposal with other ash. Changes in ash pond effluent quality or quantity as a result of the operation of the GSA are not expected.

2.6.2 Quantity and Quality

The GSA system is designed to treat a slip stream from Boiler No. 9 of 20,000 SCFM of boiler flue gas. The average composition of the byproduct from the GSA system is as follows:

$Ca(OH)_2$	1.4 %
$CaCO_3$	9.0 %
$CaSO_3$	44.0 %
$CaSO_4$	19.4 %
Acid Insoluble	26.2 %

The quantity of waste is approximately 1,060 lb/hr being sluiced with 17,000 gallons of water per day. The once-through cooling water used by the entire plant and returned to the Ohio River is 1.5 billion gallons of water per day. Since the waste from the GSA unit is the same as that currently discharged to the ash ponds and is only 0.001 % of the total water discharge to the Ohio River, the demonstration project is not expected to have any environmental impact or impact on current operational practices.

The SO_2 loading is 389 lbs/hr in the inlet gas stream and 31 lbs/hr in the outlet. The dust loading is 501 lbs/hr in the inlet gas stream and 2.18 lbs/hr in the outlet gas stream. This level of particulate discharge into the atmosphere is below the EPA maximum limit of 0.03 lb/MBtu.

3.0 <u>PROJECT PROCESS DATA</u>

3.1 PROCESS DESIGN BASIS

The following information has been used as the basis for designing the GSA system. The design basis is based upon actual plant operating condition.

Table 3.1

PROCESS DESIGN DATA

ITEM	DESIGN BASIS	RANGE
GSA		
Gas Volume to System	35,300 ACFM @ 320°F	21,180 ~ 38,830 ACFM
Inlet Dust Loading	2.81 GR/DSCF	0.5 ~ 2.9
Inlet HCL	18.74 PPM (by volume)	-
Inlet SO_2	1,873.33 PPM (by volume)	1,400 ~ 2,200
Ca/S Molar Rate	2.13	-
Outlet HCl	0 PPM (by volume)	-
Outlet SO_2	134.89 PPM (by volume)	-
SO_2 Removal Rate	> 90 %	-
Pressure Drop	8.5" WG	-
ESP		
Gas Volume	30,909 ACFM @161°F	18,460 ~ 33,850 ACFM
Dust Loading to ESP	2.03 GR/DSCF	2 ~ 5
Dust Loading from ESP	0.01 GR/DSCF	-
Pressure Drop	1.5" WG	-
Particulate Removal Rate	NSPS	< NSPS

Table 3.1 (Continued)

PROCESS DESIGN DATA

ITEM	DESIGN BASIS	RANGE
FABRIC FILTER		
Gas Volume	5,000 ACFM @ 158°F	-
Inlet Dust Loading	2.03 GR/DSCF	0.5 ~ 2.9
Pressure Drop	6" WG	-
REAGENT FEED		
Pebble-Lime Silo Storage Time	10 Days	-
Lime Slurry Tank Storage Time	14 Hours	-
Lime Slurry Feed Tank Storage Time	9 Hours	-
OTHERS		
Plant Elevation	345 FT	-
Barometric Pressure	29.92" WG	-
Ambient Temperature	25 - 88°F	-

3.2 PROCESS DESCRIPTION

The primary objective for the installation of the GSA system at the TVA's CER is to demonstrate its ability to effectively remove sulfur dioxide (SO_2) from unconditioned flue gas. Raw flue gas will be provided to the GSA from Shawnee's unit 9 which has been configured to divert 10% its total flue gas output to the GSA for the purpose of testing experimental scrubber technologies.

The diverted flue gas enters the bottom of the reactor where it is mixed with suspended solids and lime slurry which are being fed into the reactor by way of a spray nozzle. The slurry is suspended in the reactor by the flue gas stream during which the slurry and flue gas undergo a chemical reaction in which SO_2 reacts with the lime. The major products of this reaction are calcium sulfite and calcium sulfate. The partially cleaned flue gases leave the reactor and enter a cyclone where the solids containing the calcium salts, ash and unreacted lime are separated from the gas stream. About 99 % of the solids collected from the cyclone are recycled back to the reactor so that any unused lime can further react with acid gases in the flue gas. This lowers the overall consumption of lime. The remaining 1 % of the solids from the cyclone leave the system at this point as by-product. The flue gases leave the separating cyclone and enter an existing electrostatic precipitator (ESP) for particulate collection. Cleaned flue gases are released to the atmosphere from the ESP through a separate pilot plant stack. The GSA system is designed to remove more than 90 % SO_2 using high sulfur U.S. coal. Coal sulfur content during the demonstration will range from 4 to 5 pounds of SO_2 per million Btu (lbs SO_2/MBtu), about 2.7 - 3.0 % sulfur by weight. The typical coal compositions for the high-sulfur coals and the sorbent (pebble lime) characteristics are shown in Table 3.2-1 and 3.2-2, respectively.

Along with the operation and testing of the GSA, a 1-MW pulsed jet fabric filter will be tested to evaluate its long-term reliability and pollutant removal performance. The fabric filter will be connected to the ESP to allow testing of the GSA system in one of three alternative arrangements: GSA with ESP only, GSA with fabric filter only, and GSA with ESP followed by fabric filter.

Table 3.2-1
TYPICAL COAL COMPOSITIONS
FOR THE HIGH-SULFUR COALS (PROXIMATE ANALYSIS)

Unit: Wt. Percent, Dry-Basis

ITEM	PEABODY	EMERALD ENERGY	ANDALEX
Carbon	49.94	50.13	49.66
Sulfur	3.1	3.3	2.8
Moisture	11.3	10.1	8.9
Volatiles	40.36	41.25	38.71
Ash	9.7	8.5	11.6
Higher Heating Value (Btu/lb)	13117.3	13240.5	12870.8

Table 3.2-2
TYPICAL COAL COMPOSITIONS
FOR THE HIGH-SULFUR COALS (ULTIMATE ANALYSIS)

Unit: Percent, Dry-Basis

ITEM	PEABODY	EMERALD ENERGY	ANDALEX
Carbon	72.98	76.26	69.45
Hydrogen	4.92	5.72	5.03
Oxygen	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	11.16

Table 3.2-3
PEBBLE LIME COMPOSITION

ITEM	QUANTITY (%)
Ca^{++} (by wt.)	70
Mg^{++} (by wt.)	0.5
CO_3 (by wt.)	1.0
Acid Insolubles	0.4
Loss-On-Ignition	0.3
Available Alkalinity	93 ~ 94
Bulk Density (lb/cu. ft.)	57
Surface Area (sq. ft./grain)	5.38 ~ 32.28

Process Chemistry

No sooner the acids in the flue gas intimately contact with suspended solids containing lime than several reactions take place. The primary reactions, which characterize process operation, can be expressed as:

$$Ca(OH)_2\ (aq) + SO_2\ (aq) \rightarrow CaSO_3 \cdot 1/2\ H_2O\ (s) + 1/2\ H_2O\ (l)$$

$$Ca(OH)_2\ (aq) + SO_3\ (aq) + H_2O\ (1) \rightarrow CaSO_4 \cdot 2\ H_2O\ (s)$$

The calcium hydroxide reacts with sulfur dioxide and sulfur trioxide to form calcium sulfite and calcium sulfate, respectively. In addition to the primary reactions the following secondary reactions also take place. They remove hydrogen chloride and convert carbon dioxide into calcium carbonate and water. Also hydrated calcium salt, $CaSO_4 \cdot H_2O$, is produced among these reactions.

$$Ca(OH)_2\ (aq) + 2\ HC1\ (aq) + 4\ H_2O\ (1) \rightarrow CaC1_2 \cdot 6\ H_2O\ (s)$$

$$Ca(OH)_2\ (aq) + CO_2\ (aq) \rightarrow CaCO_3\ (s) + H_2O\ (1)$$

$$CaSO_3\ (aq) \cdot 1/2\ H_2\ O + 1/2\ O_2\ (aq) + 1/2\ H_2O\ (1) \rightarrow CaSO_4 \cdot H_2O\ (s)$$

Process Characteristics

The main advantage of the GSA process over other competing technologies is in the means of the reagent is introduced and used for SO_2 absorption. A spray dryer

- requires a costly and sensitive high speed rotary atomizer for fine atomization,
- absorbs SO_2 in an "umbrella" of finely atomized slurry with a droplet size of about 50 microns, and
- requires high air pressure and multiple nozzle heads to ensure fine atomization and full coverage of the reactor cross section.

The GSA, on the other hand,

- uses a low pressure dual fluid nozzle,
- absorbs SO_2 on the wetted surface of suspended solids with superior mass and heat transfer characteristics, and
- uses only one spray nozzle for the purpose of introducing slurry and water to the reactor.

As a result, the GSA process is more economical and efficient than the spray dryer.

3.3 MASS AND ENERGY BALANCE

The mass and energy balance of the GSA system was calculated for three different operating conditions, i.e. design, minimum and maximum cases. The detailed calculation data for these three different operating conditions are listed in Figure 3.3 and Table 3.3-2 through Table 3.3-7. The stoichiometric ratio was defined as the moles of calcium hydroxide ($Ca(OH)_2$) over the moles of total acid gas in, and set to be 2.13. While the approach to saturation temperature (AST) of 35 deg F was used in all of the calculations. It was later found that values of the stoichiometric ratio and AST temperature, 1.3 and 18 deg F, respectively, from the demonstration testing were lower than that of used in design phase which were based upon the applications of municipal incinerators. Table 3.3-1 is a summary table for the three cases. It is to be noted that the flue gas inlet volume for minimum case is 60 % of the design case while the maximum case is defined as 10 % greater than the design case. For the demonstration project, the flue gas flow rate through the baghouse was controlled at 5000 ACFM. The case for baghouse in series with ESP is also summarized in Table 3.3-1. The SO_2 removal rate for this case was slightly higher than that achieved without the baghouse, since the residue lime coated on the particles, which were caked on the bag surfaces, further reacted with the SO_2 in the flue gas. The same higher particulate removal rate occurred for the configuration of the baghouse in series with ESP. The total amount of lime and water consumption for minimum, design and maximum cases had the same proportion as the gas flow volume among these three cases.

Table 3.3-1

SUMMARY TABLE FOR GSA SYSTEM PROCESS DESIGN

ITEM	MINIMUM CASE	DESIGN CASE	MAXIMUM CASE
Gas Volume to System	12,600 SCFM	21,000 SCFM	23,100 SCFM
AST Temp.	35 °F	35 °F	35 °F
SO_2 Removal Rate (%)	91.98	91.98	91.98
Particulate Removal Rate (%)	99.58	99.58	99.58
Lime Consumption	6 Ton/Day	10 Ton/Day	11 Ton/Day
Water Demand	5.5 GPM	9 GPM	10 GPM
Waste Rate	14 Ton/Day	23 Ton/Day	25 Ton/Day
Baghouse in Series with ESP			
Gas Volume to System	12,600 SCFM	21,000 SCFM	23,100 SCFM
AST Temp.	35 °F	35 °F	35 °F
SO_2 Removal Rate (%)	93.96	93.96	93.96
Particulate Removal Rate (%)	99.68	99.68	99.68
Lime Consumption	6 Ton/Day	10 Ton/Day	11 Ton/Day
Water Demand	5.5 GPM	9 GPM	10 GPM
Waste Rate	14 Ton/Day	23 Ton/Day	25 Ton/Day

Figure 3.3

PROCESS DIAGRAM FOR MASS BALANCE
10 MW DEMONSTRATION OF GSA

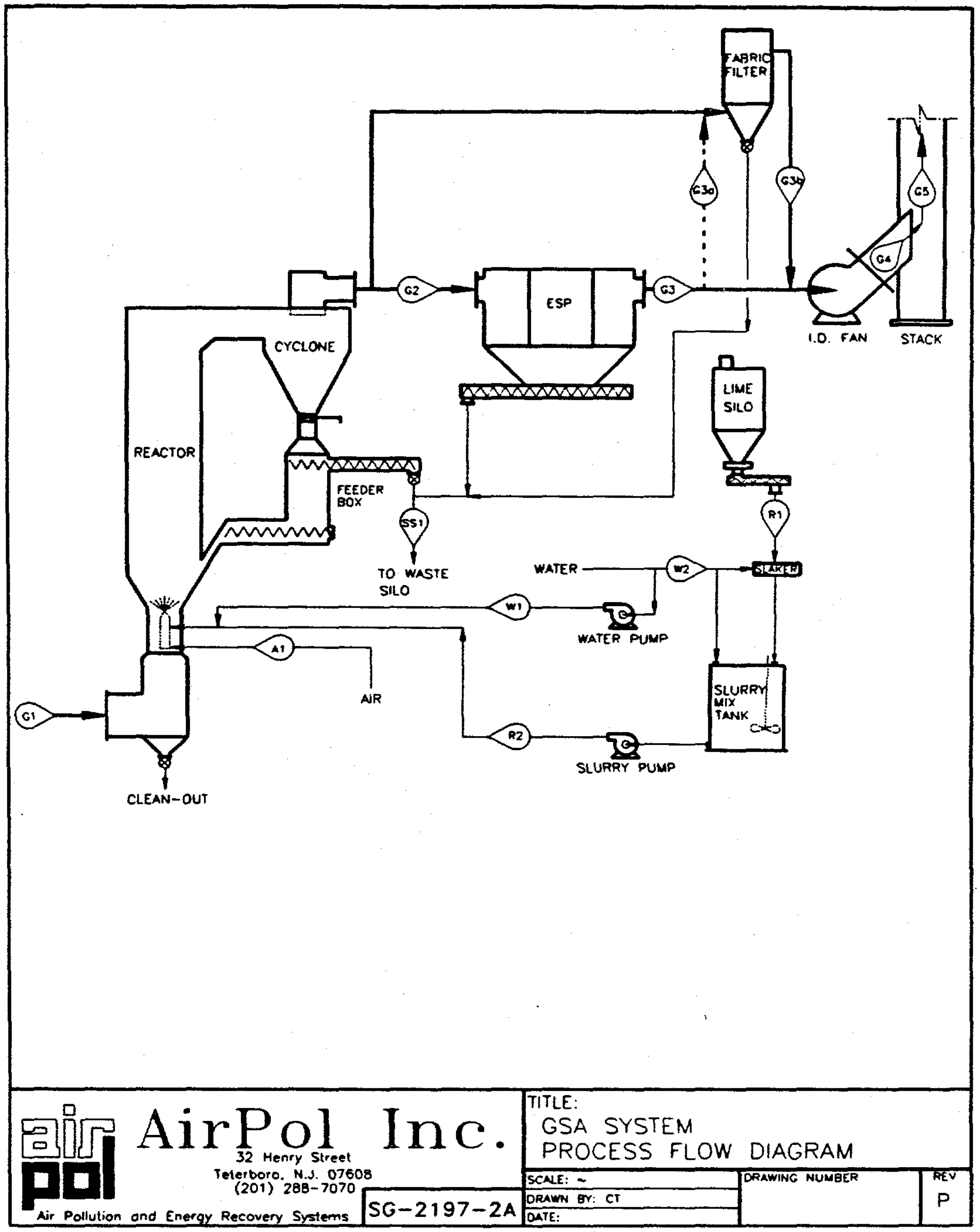


Table 3.3-2

Process Calculation, Mass and Energy Balance for Design Case

AirPol ref	:RD 43	06-Apr-94
Customer	:D.O.E. Clean Coal Technology	09:43 AM
Jobsite	:NCER, TVA, Paducah, Kentucky	Pg 1 of 2
Application	:Coal-Fired Boiler	
Condition	:Design case	

OPERATING CONDITIONS

SITE DATA

Elevation	345.0 ft ASL	105.2 m ASL
Ambient Pressure	14.514 psia	750.6 mm Hg
Ambient Temperature	80.0 deg F avg	26.7 deg C avg
Relative Humidity	60 %	

REFERENCE DATA

Standard Temperature	68 deg F	20 deg C
Standard Pressure	14.696 psia	760 mm Hg

APC SYSTEM INLET GAS CONDITION

Gas composition	lb/hr	kg/hr	vol % wet
O2	7,385	3,350	6.576
N2	73,130	33171	74.385
CO2	17,227	7,814	11.154
HCl	2	1	0.002
HF	0	0	0.000
SO2	389	176	0.173
SO3	5	2	0.002
Ar	0	0	0.000
CO	0	0	0.000
NO	51	23	0.049
NO2	0	0	0.000
H2O	4,843	2,197	7.660
Total	103,032	46735	100.000

Dust load	501 lb/hr	227 kg/hr
actual dust load	2.806 grs/scfd	6,422 mg/Nm^3 dry
@ 7% O2	2.831 grs/scfd	6,478 mg/Nm^3 dry
Inlet Temperature	320 deg F	160 deg C
Inlet Pressure	(18.00)in wg	(457.20)mm wg
Inlet Flow	35,299 acfm	
	22,539 scfm	35681 Nm3/h wet

POLLUTANT CONCENTRATION

Inlet @ 7% O2	SO2	HCl	HF	NOx	DUST
ppmd	1,890	19	0	0	-
mg/dNm3	5,401	31	0	0	6,952
gr/dscf	-	-	-	-	2.831

Outlet @ 7% O2					
ppmd	152	-	-	-	-
mg/dNm3	435	-	-	-	29
gr/dscf	-	-	-	-	0.012
lb/hr	31.19	-	-	-	2.11
% Removal Eff.	91.98	-	-	-	99.58

AirPol ref	:RD 43	06-Apr-94
Customer	:D.O.E. Clean Coal Technology	09:43 AM
Jobsite	:NCER, TVA, Paducah, Kentucky	Pg 2 of 2
Application	:Coal-Fired Boiler	
Condition	:Design case	

OPERATING CONDITIONS

1) GSA		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	320.0	161.2	deg C	160.0	71.8
PRESSURE	in wg	(18.0)	(26.5)	mm wg	(457.2)	(673.1)
FLOW	acfm	35,299	30,770	m3/hr	59,973	52,279
	scfmw	21,001	22,481	Nm3/hr	35,681	38,195
	lb/hr	103,533	107,646	kg/hr	46,962	48,827

2) ESP		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	161.2	157.9	deg C	71.8	69.9
PRESSURE	in wg	(26.5)	(27.9)	mm wg	(673.1)	(708.7)
FLOW	acfm	30,770	30,716	m3/hr	52,279	52,187
	scfmw	22,481	22,479	Nm3/hr	38,195	38,193
	lb/hr	107,646	107,258	kg/hr	48,827	48,652

3) ID FAN		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	157.9	170.4	deg C	69.9	76.9
PRESSURE	in wg	(27.9)	0.5	mm wg	(708.7)	12.7
FLOW	acfm	30,716	29,133	m3/hr	52,187	49,497
	scfmw	22,479	22,479	Nm3/hr	38,193	38,193
	lb/hr	107,258	107,258	kg/hr	48,652	48,652
DENSITY	lb/ft3	0.058	0.061	kg/m3	0.932	0.983

TOTAL SYSTEM REQUIREMENTS

SYSTEM WATER DEMAND	9 US gpm	35 lpm
Cooling Water Rate	0 US gpm	1 lpm
Lime Slurry Rate @ 20% by wt	9 US gpm	35 lpm
SYSTEM COMP. AIR @ 0 PSIG	281 lb/hr	128 kg/hr
	63 scfm-68	106 m3/hr
CaO REQ'D @ 90.00 % PURITY	813 lb/hr	369 kg/hr
	9.8 TON/DAY	8.9 mTON/DAY
TOTAL WASTE RATE	1,930 lb/hr	875 kg/hr
	23 TON/DAY	21.0 mTON/DAY
GAS SATURATION TEMP.	126 deg F	52 deg C
APPROACH TO SATURATION TEMP	35 deg F	19 deg C
GSA STOICHIOMETRIC RATIO	2.13 MOL Ca(OH)2/MOL ACID GAS IN	
APPROX.CaCl2 @ 35 deg F AST	42 lb/hr	
	4 % of Lime Rate	

AirPol ref	:RD 43	06-Apr-94
Customer	:D.O.E. Clean Coal Technology	09:43 AM
Jobsite	:NCER, TVA, Paducah, Kentucky	
Application	:Coal-Fired Boiler	Page No. 3
Condition	:Design case	

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		G1	G2	G3	G4	G5
		GSA Gas Inlet lbs/hr	ESP Gas Inlet lbs/hr	ID Fan Gas Inlet lbs/hr	Stack Gas Inlet lbs/hr	Stack Gas Outlet lbs/hr
FLOW RATE	-lb/hr	103,533	107,646	107,258	107,258	107,258
	-acfm	35,299	30,770	30,716	29,133	29,136
	-scfm-32	21,001	22,481	22,479	22,479	22,479
	-gpm	....	....	....	....	....
PR	-in wg	(18.00)	(26.50)	(27.90)	0.50	0.00
	-psig	....	....	....	....	....
TEMP	-deg F	320	161	158	170	170
DENSITY	-lb/cf	0.049	0.058	0.058	0.061	0.061
O2	-vol % dry	7.12	7.18	7.18	7.18	7.18
H2O	-vol %	7.66	13.69	13.70	13.70	13.70
SO2	-ppmd	1,873	297	150	150	150
@ 7% O2	-ppmd	1,890	301	152	152	152
	-lb/mmBtu	....	....	....	....	....
HCl	-ppmd	19	0	0	0	0
@ 7% O2	-ppmd	19	0	0	0	0
	-lb/mmBtu	....	....	....	....	....
Dust	-gr/dscf	2.806	2.035	0.012	0.012	0.012
	-mg/dNm3	6,892	4,999	30	30	30
	-lb/mmBtu	0.802	0.582	0.003	0.003	0.003
@ 7% O2	-gr/dscf	2.831	2.062	0.012	0.012	0.012
@ 7% O2	-mg/dNm3	6,952	5,063	30	30	30
Cl-	-ppm	....	....	....	....	....

AirPol ref	:RD 43	06-Apr-94
Customer	:D.O.E. Clean Coal Technology	09:43 AM
Jobsite	:NCER, TVA, Paducah, Kentucky	
Application	:Coal-Fired Boiler	Page No. 4
Condition	:Design case	

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		A1	R1	R2
		GSA Atomz Air lbs/hr	Pebble lime lbs/hr	Lime Slury to GSA lbs/hr
FLOW RATE	-lb/hr	281.2	813.2	5,241.4
	-acfm	8.2	....	....
	-scfm-32	58.3	....	....
	-gpm	....	....	9.23
PR	-in wg	....	....	....
	-psig	100	....	100
TEMP	-deg F	80	....	78
DENSITY	-lb/cf	0.572	56.000	70.910
O2	-vol % dry	....	....	....
H2O	-vol %	....	....	....
SO2	-ppmd	....	....	....
@ 7% O2	-ppmd	....	....	....
HCl	-ppmd	....	....	....
@ 7% O2	-ppmd	....	....	....
Dust	-gr/dscf	....	....	....
0	-mg/dNm3	....	....	....
@ 7% O2	-gr/dscf	....	....	....
@ 7% O2	-mg/dNm3	....	....	....
Cl-	-ppm	....	....	....

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		SS1	W1	W2
		GSA/Filter Solid Wast lbs/hr	Cooling H2O to GSA lbs/hr	Lime Slury Water lbs/hr
FLOW RATE	-lb/hr	1,929.7	132.6	4,193.2
	-acfm	....	....	....
	-scfm-32	....	....	....
	-gpm	....	0.27	8.39
PR	-in wg	....	....	....
	-psig	....	100	....
TEMP	-deg F	....	68	68
DENSITY	-lb/cf	....	62.40	62.40
O2	-vol % dry	....	....	....
H2O	-vol %	....	....	....
SO2	-ppmd	....	....	....
@ 7% O2	-ppmd	....	....	....
HCl	-ppmd	....	....	....
@ 7% O2	-ppmd	....	....	....
Dust	-gr/dscf	....	....	....
0	-mg/dNm3	....	....	....
@ 7% O2	-gr/dscf	....	....	....
@ 7% O2	-mg/dNm3	....	....	....
Cl-	-ppm	....	....	....

AirPol ref	RD 43	06-Apr-94
Customer	D.O.E. Clean Coal Technology	09:43 AM
Jobsite	NCER, TVA, Paducah, Kentucky	
Application	Coal-Fired Boiler	Page No. 1
Condition	Design case	

MASS BALANCE

ITEM		IN	OUT
1) GSA/ESP			
TEMP	-DEG F	320	161
PRESSURE	-IN WG	(18.00)	(26.50)
FLUE GAS	-LBS/HR	103,533	---
WATER	-LBS/HR	133	---
SLAKED LI	-LBS/HR	5,241	---
COMP. AIR	-LBS/HR	281	---
CaCl2 ADD	-LBS/HR	42	---
DUST RECY	-LBS/HR	46,102	46,102
ESP			
TEMP	-DEG F	161	158
PRESSURE	-IN WG	(26.50)	(27.90)
FLUE GAS	-LBS/HR	---	107,258
WASTE PRO	-LBS/HR	---	1,972
COMP. AIR	-LBS/HR	0	---
LEAK. AIR	-LBS/HR	0	---
TOTAL	-LBS/HR	109,230	109,230
2) EXHAUST FAN			
TEMP	-DEG F	158	170
PRESSURE	-IN WG	(27.90)	0.50
FLUE GAS	-LBS/HR	107,258	107,258
3) HYDRATED LIME			
HYD'D LIM	-LBS/HR	1,048	---
WATER	-LBS/HR	4,193	---
LIME SLUR	-LBS/HR	---	5,241 @ 20 % by wt solution
TOTAL	-LBS/HR	5,241	5,241

ITEM	IN LBS/HR	OUT LBS/HR
SO2	389	31.2
HCl	2	0.0
DUST	501	2.2

ENERGY BALANCE

		IN	OUT
GSA	mmBTU/HR	15.56	15.56
ESP	mmBTU/HR	13.44	13.44

Table 3.3-3

Process Calculation, Mass and Energy Balance for Minimum Case

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:04 PM
Jobsite	:CER, TVA, Paducah, Kentucky	Pg 1 of 2
Application	:Coal-Fired Boiler	
Condition	:Minimum case - 60% of Design	

OPERATING CONDITIONS

SITE DATA		
Elevation	345.0 ft ASL	105.2 m ASL
Ambient Pressure	14.514 psia	750.6 mm Hg
Ambient Temperature	80.0 deg F avg	26.7 deg C avg
Relative Humidity	60 %	

REFERENCE DATA		
Standard Temperature	68 deg F	20 deg C
Standard Pressure	14.696 psia	760 mm Hg

APC SYSTEM INLET GAS CONDITION

Gas composition	lb/hr	kg/hr	vol % wet
O2	4,431	2,010	6.576
N2	43,878	19,903	74.385
CO2	10,336	4,689	11.154
HCl	1	1	0.002
HF	0	0	0.000
SO2	233	106	0.173
SO3	3	1	0.002
Ar	0	0	0.000
CO	0	0	0.000
NO	31	14	0.049
NO2	0	0	0.000
H2O	2,906	1,318	7.660
Total	61,819	28,041	100.000

Dust load	300 lb/hr	136 kg/hr
actual dust load	2.806 grs/scfd	6,422 mg/Nm^3 dry
@ 7% O2	2.831 grs/scfd	6,478 mg/Nm^3 dry
Inlet Temperature	320 deg F	160 deg C
Inlet Pressure	(18.00)in wg	(457.20)mm wg
Inlet Flow	21,179 acfm	
	13,523 scfm-68	21409 Nm3/h wet

POLLUTANT CONCENTRATION

Inlet @ 7% O2	SO2	HCl	HF	NOx	DUST
ppmd	1,890	19	0	0	-
mg/dNm3	5,401	31	0	0	6,952
gr/dscf	-	-	-	-	2.831

Outlet @ 7% O2	SO2	HCl	HF	NOx	DUST
ppmd	152	-	-	-	-
mg/dNm3	435	0	-	-	29
gr/dscf	-	-	-	-	0.012
lb/hr	18.72	0.00	-	-	1.27
% Removal Eff.	91.98	100.00	-	-	99.58

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:04 PM
Jobsite	:CER, TVA, Paducah, Kentucky	Pg 2 of 2
Application	:Coal-Fired Boiler	
Condition	:Minimum case - 60% of Design	

OPERATING CONDITIONS

			INLET	OUTLET		INLET	OUTLET
1) GSA							
	TEMP	deg F	320.0	161.2	deg C	160.0	71.8
	PRESSURE	in wg	(18.0)	(26.5)	mm wg	(457.2)	(673.1)
	FLOW	acfm	21,179	18,460	m3/hr	35,984	31,364
		scfmw	12,601	13,488	Nm3/hr	21,409	22,915
		lb/hr	62,120	64,584	kg/hr	28,177	29,295
2) ESP			INLET	OUTLET		INLET	OUTLET
	TEMP	deg F	161.2	155.4	deg C	71.8	68.6
	PRESSURE	in wg	(26.5)	(27.9)	mm wg	(673.1)	(708.7)
	FLOW	acfm	18,460	18,356	m3/hr	31,364	31,187
		scfmw	13,488	13,487	Nm3/hr	22,915	22,914
		lb/hr	64,584	64,352	kg/hr	29,295	29,190
3) ID FAN			INLET	OUTLET		INLET	OUTLET
	TEMP	deg F	155.4	167.9	deg C	68.6	75.5
	PRESSURE	in wg	(27.9)	0.5	mm wg	(708.7)	12.7
	FLOW	acfm	18,356	17,410	m3/hr	31,187	29,579
		scfmw	13,487	13,487	Nm3/hr	22,914	22,914
		lb/hr	64,352	64,352	kg/hr	29,190	29,190
	DENSITY	lb/ft3	0.058	0.062	kg/m3	0.936	0.987

TOTAL SYSTEM REQUIREMENTS

SYSTEM WATER DEMAND	5.5 US gpm	21 lpm
Cooling Water Rate	0.2 US gpm	1 lpm
Lime Slurry Rate @ 20% by wt	5.5 US gpm	21 lpm
SYSTEM COMP. AIR @ 0 PSIG	169 lb/hr	76 kg/hr
	37 scfm-68	64 m3/hr
CaO REQ'D @ 90.00 % PURITY	488 lb/hr	221 kg/hr
	5.9 TON/DAY	5.3 mTON/DAY
TOTAL WASTE RATE	1,158 lb/hr	525 kg/hr
	14 TON/DAY	12.6 mTON/DAY
GAS SATURATION TEMP.	126 deg F	52 deg C
APPROACH TO SATURATION TEMP	35 deg F	19 deg C
GSA STOICHIOMETRIC RATIO	2.13 MOL Ca(OH)2/MOL ACID GAS IN	
APPROX.CaCl2 @ 35 deg F AST	25 lb/hr	
	4 % of Lime Rate	

AirPol ref :RD 43 14-Jul-94
Customer :D.O.E. Clean Coal Technology 02:04 PM
Jobsite :CER, TVA, Paducah, Kentucky
Application :Coal-Fired Boiler Page No. 3
Condition :Minimum case - 60% of Design

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		G1	G2	G3	G4	G5
		GSA Gas Inlet lbs/hr	ESP Gas Inlet lbs/hr	ID Fan Gas Inlet lbs/hr	Stack Gas Inlet lbs/hr	Stack Gas Outlet lbs/hr
FLOW RATE	-lb/hr	62,120	64,584	64,352	64,352	64,352
	-acfm	21,179	18,460	18,356	17,410	17,399
	-scfm-32	12,601	13,488	13,487	13,487	13,487
	-gpm	....	....	....	....	....
PR	-in wg	(18.00)	(26.50)	(27.90)	0.50	0.00
	-psig	....	....	....	....	....
TEMP	-deg F	320	161	155	168	167
DENSITY	-lb/cf	0.049	0.058	0.058	0.062	0.062
O2	-vol % dry	7.12	7.18	7.18	7.18	7.18
H2O	-vol %	7.66	13.69	13.69	13.69	13.69
SO2	-ppmd	1,873	297	150	150	150
@ 7% O2	-ppmd	1,890	301	152	152	152
	-lb/mmBtu	....	....	....	....	....
HCl	-ppmd	19	0	0	0	0
@ 7% O2	-ppmd	19	0	0	0	0
	-lb/mmBtu	....	....	....	....	....
Dust	-gr/dscf	2.806	2.035	0.012	0.012	0.012
	-mg/dNm3	6,892	4,998	30	30	30
	-lb/mmBtu	0.481	0.349	0.002	0.002	0.002
@ 7% O2	-gr/dscf	2.831	2.061	0.012	0.012	0.012
@ 7% O2	-mg/dNm3	6,952	5,063	30	30	30
Cl-	-ppm	....	....	....	....	....

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:04 PM
Jobsite	:CER, TVA, Paducah, Kentucky	
Application	:Coal-Fired Boiler	Page No. 4
Condition	:Minimum case - 60% of Design	

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		A1	R1	R2
		GSA Atomz Air lbs/hr	Pebble lime lbs/hr	Lime Slury to GSA lbs/hr
FLOW RATE	-lb/hr	168.5	487.9	3,144.9
	-acfm	4.9	....	....
	-scfm-32	34.9	....	....
	-gpm	....	....	5.54
PR	-in wg	....	....	....
	-psig	100	....	100
TEMP	-deg F	80	....	78
DENSITY	-lb/cf	0.572	56.000	70.910
O2	-vol % dry	....	....	....
H2O	-vol %	....	....	....
SO2	-ppmd	....	....	....
@ 7% O2	-ppmd	....	....	....
HCl	-ppmd	....	....	....
@ 7% O2	-ppmd	....	....	....
Dust	-gr/dscf	....	....	....
0	-mg/dNm3	....	....	....
@ 7% O2	-gr/dscf	....	....	....
@ 7% O2	-mg/dNm3	....	....	....
Cl-	-ppm	....	....	....

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:04 PM
Jobsite	:CER, TVA, Paducah, Kentucky	
Application	:Coal-Fired Boiler	Page No. 5
Condition	:Minimum case - 60% of Design	

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		SS1	W1	W2
		GSA/Filter Solid Wast lbs/hr	Cooling H2O to GSA lbs/hr	Lime Slury Water lbs/hr
FLOW RATE	-lb/hr	1,157.8	76.8	2,515.9
	-acfm	....	....	....
	-scfm-32	....	....	....
	-gpm	....	0.15	5.03
PR	-in wg	....	....	....
	-psig	....	100	....
TEMP	-deg F	....	68	68
DENSITY	-lb/cf	....	62.40	62.40
O2	-vol % dry	....	....	....
H2O	-vol %	....	....	....
SO2	-ppmd	....	....	....
@ 7% O2	-ppmd	....	....	....
HCl	-ppmd	....	....	....
@ 7% O2	-ppmd	....	....	....
Dust	-gr/dscf	....	....	....
0	-mg/dNm3	....	....	....
@ 7% O2	-gr/dscf	....	....	....
@ 7% O2	-mg/dNm3	....	....	....
Cl-	-ppm	....	....	....

AirPol ref	RD 43	14-Jul-94
Customer	D.O.E. Clean Coal Technology	02:04 PM
Jobsite	CER, TVA, Paducah, Kentucky	
Application	Coal-Fired Boiler	Page No. 1
Condition	Minimum case - 60% of Design	

MASS BALANCE

ITEM		IN	OUT
1) GSA/ESP			
TEMP	-DEG F	320	161
PRESSURE	-IN WG	(18.00)	(26.50)
FLUE GAS	-LBS/HR	62,120	---
WATER	-LBS/HR	77	---
SLAKED LI	-LBS/HR	3,145	---
COMP. AIR	-LBS/HR	169	---
CaCl2 ADD	-LBS/HR	25	---
DUST RECY	-LBS/HR	27,659	27,659
ESP			
TEMP	-DEG F	161	155
PRESSURE	-IN WG	(26.50)	(27.90)
FLUE GAS	-LBS/HR	---	64,352
WASTE PRO	-LBS/HR	---	1,183
COMP. AIR	-LBS/HR	0	---
LEAK. AIR	-LBS/HR	0	---
TOTAL	-LBS/HR	65,535	65,535
2) EXHAUST FAN			
TEMP	-DEG F	155	168
PRESSURE	-IN WG	(27.90)	0.50
FLUE GAS	-LBS/HR	64,352	64,352
3) HYDRATED LIME			
HYD'D LIM	-LBS/HR	629	---
WATER	-LBS/HR	2,516	---
LIME SLUR	-LBS/HR	---	3,145 @ 20 % by wt solution
TOTAL	-LBS/HR	3,145	3,145

ITEM	IN LBS/HR	OUT LBS/HR
SO2	233	18.7
HCl	1	0.0
DUST	300	1.3

ENERGY BALANCE

		IN	OUT
GSA	mmBTU/HR	9.33	9.33
ESP	mmBTU/HR	8.02	8.02

Table 3.3-4

Process Calculation, Mass and Energy Balance for Maximum Case

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:12 PM
Jobsite	:CER, TVA, Paducah, Kentucky	Pg 1 of 2
Application	:Coal-Fired Boiler	
Condition	:Maximum case - 10% Above Design	

OPERATING CONDITIONS

SITE DATA

Elevation	345.0 ft ASL	105.2 m ASL
Ambient Pressure	14.514 psia	750.6 mm Hg
Ambient Temperature	80.0 deg F avg	26.7 deg C avg
Relative Humidity	60 %	

REFERENCE DATA

Standard Temperature	68 deg F	20 deg C
Standard Pressure	14.696 psia	760 mm Hg

APC SYSTEM INLET GAS CONDITION

Gas composition	lb/hr	kg/hr	vol % wet
O2	8,123	3,685	6.576
N2	80,443	36,488	74.385
CO2	18,950	8,596	11.154
HCl	2	1	0.002
HF	0	0	0.000
SO2	428	194	0.173
SO3	5	2	0.002
Ar	0	0	0.000
CO	0	0	0.000
NO	56	26	0.049
NO2	0	0	0.000
H2O	5,327	2,416	7.660
Total	113,335	51,408	100.000

Dust load	551 lb/hr	250 kg/hr
actual dust load	2.806 grs/scfd	6,422 mg/Nm^3 dry
@ 7% O2	2.831 grs/scfd	6,478 mg/Nm^3 dry
Inlet Temperature	320 deg F	160 deg C
Inlet Pressure	(18.00)in wg	(457.20)mm wg
Inlet Flow	38,828 acfm	
	24,793 scfm-68	39249 Nm3/h wet

POLLUTANT CONCENTRATION

Inlet @ 7% O2	SO2	HCl	HF	NOx	DUST
ppmd	1,890	19	0	0	-
mg/dNm3	5,401	31	0	0	6,952
gr/dscf	-	-	-	-	2.831

Outlet @ 7% O2	SO2	HCl	HF	NOx	DUST
ppmd	152	-	-	-	-
mg/dNm3	435	0	-	-	29
gr/dscf	-	-	-	-	0.012
lb/hr	34.31	0.00	-	-	2.33
% Removal Eff.	91.98	100.00	-	-	99.58

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:12 PM
Jobsite	:CER, TVA, Paducah, Kentucky	Pg 2 of 2
Application	:Coal-Fired Boiler	
Condition	:Maximum case - 10% Above Design	

OPERATING CONDITIONS

1) GSA		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	320.0	161.2	deg C	160.0	71.8
PRESSURE	in wg	(18.0)	(26.5)	mm wg	(457.2)	(673.1)
FLOW	acfm	38,828	33,848	m3/hr	65,970	57,508
	scfmw	23,101	24,729	Nm3/hr	39,249	42,015
	lb/hr	113,886	118,412	kg/hr	51,658	53,711

2) ESP		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	161.2	158.2	deg C	71.8	70.1
PRESSURE	in wg	(26.5)	(27.9)	mm wg	(673.1)	(708.7)
FLOW	acfm	33,848	33,806	m3/hr	57,508	57,436
	scfmw	24,729	24,728	Nm3/hr	42,015	42,013
	lb/hr	118,412	117,985	kg/hr	53,711	53,517

3) ID FAN		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	158.2	170.7	deg C	70.1	77.1
PRESSURE	in wg	(27.9)	0.5	mm wg	(708.7)	12.7
FLOW	acfm	33,806	32,063	m3/hr	57,436	54,475
	scfmw	24,728	24,728	Nm3/hr	42,013	42,013
	lb/hr	117,985	117,985	kg/hr	53,517	53,517
DENSITY	lb/ft3	0.058	0.061	kg/m3	0.932	0.982

TOTAL SYSTEM REQUIREMENTS

SYSTEM WATER DEMAND	10 US gpm	38 lpm
Cooling Water Rate	0 US gpm	1 lpm
Lime Slurry Rate @ 20% by wt	10 US gpm	38 lpm
SYSTEM COMP. AIR @ 0 PSIG	309 lb/hr	140 kg/hr
	69 scfm-68	117 m3/hr
CaO REQ'D @ 90.00 % PURITY	894 lb/hr	406 kg/hr
	10.7 TON/DAY	9.7 mTON/DAY
TOTAL WASTE RATE	2,123 lb/hr	963 kg/hr
	25 TON/DAY	23.1 mTON/DAY
GAS SATURATION TEMP.	126 deg F	52 deg C
APPROACH TO SATURATION TEMP	35 deg F	19 deg C
GSA STOICHIOMETRIC RATIO	2.13 MOL Ca(OH)2/MOL ACID GAS IN	
APPROX.CaCl2 @ 35 deg F AST	46 lb/hr	
	4 % of Lime Rate	

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:12 PM
Jobsite	:CER, TVA, Paducah, Kentucky	
Application	:Coal-Fired Boiler	Page No. 3
Condition	:Maximum case - 10% Above Design	

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		G1	G2	G3	G4	G5
		GSA Gas Inlet lbs/hr	ESP Gas Inlet lbs/hr	ID Fan Gas Inlet lbs/hr	Stack Gas Inlet lbs/hr	Stack Gas Outlet lbs/hr
FLOW RATE	-lb/hr	113,886	118,412	117,985	117,985	117,985
	-acfm	38,828	33,848	33,806	32,063	32,070
	-scfm-32	23,101	24,729	24,728	24,728	24,728
	-gpm	....	....	....	....	....
PR	-in wg	(18.00)	(26.50)	(27.90)	0.50	0.00
	-psig	....	....	....	....	....
TEMP	-deg F	320	161	158	171	170
DENSITY	-lb/cf	0.049	0.058	0.058	0.061	0.061
O2	-vol % dry	7.12	7.18	7.18	7.18	7.18
H2O	-vol %	7.66	13.69	13.70	13.70	13.70
SO2	-ppmd	1,873	297	150	150	150
@ 7% O2	-ppmd	1,890	301	152	152	152
	-lb/mmBtu	....	....	....	....	....
HCl	-ppmd	19	0	0	0	0
@ 7% O2	-ppmd	19	0	0	0	0
	-lb/mmBtu	....	....	....	....	....
Dust	-gr/dscf	2.806	2.035	0.012	0.012	0.012
	-mg/dNm3	6,892	4,999	30	30	30
	-lb/mmBtu	0.882	0.640	0.004	0.004	0.004
@ 7% O2	-gr/dscf	2.831	2.062	0.012	0.012	0.012
@ 7% O2	-mg/dNm3	6,952	5,063	30	30	30
Cl-	-ppm	....	....	....	....	....

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		A1	R1	R2
		GSA Atomz Air lbs/hr	Pebble lime lbs/hr	Lime Slury to GSA lbs/hr
FLOW RATE	-lb/hr	309.4	894.5	5,765.6
	-acfm	9.0	....	....
	-scfm-32	64.1	....	....
	-gpm	....	....	10.15
PR	-in wg	....	....	....
	-psig	100	....	100
TEMP	-deg F	80	....	78
DENSITY	-lb/cf	0.572	56.000	70.910
O2	-vol % dry	....	....	....
H2O	-vol %	....	....	....
SO2	-ppmd	....	....	....
@ 7% O2	-ppmd	....	....	....
HCl	-ppmd	....	....	....
@ 7% O2	-ppmd	....	....	....
Dust	-gr/dscf	....	....	....
0	-mg/dNm3	....	....	....
@ 7% O2	-gr/dscf	....	....	....
@ 7% O2	-mg/dNm3	....	....	....
Cl-	-ppm	....	....	....

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		SS1	W1	W2
		GSA/Filter Solid Wast lbs/hr	Cooling H2O to GSA lbs/hr	Lime Slury Water lbs/hr
FLOW RATE	-lb/hr	2,122.7	147.1	4,612.5
	-acfm	....	....	....
	-scfm-32	....	....	....
	-gpm	....	0.29	9.23
PR	-in wg	....	....	....
	-psig	....	100	....
TEMP	-deg F	....	68	68
DENSITY	-lb/cf	....	62.40	62.40
O2	-vol % dry	....	....	....
H2O	-vol %	....	....	....
SO2	-ppmd	....	....	....
@ 7% O2	-ppmd	....	....	....
HCl	-ppmd	....	....	....
@ 7% O2	-ppmd	....	....	....
Dust	-gr/dscf	....	....	....
0	-mg/dNm3	....	....	....
@ 7% O2	-gr/dscf	....	....	....
@ 7% O2	-mg/dNm3	....	....	....
Cl-	-ppm	....	....	....

AirPol ref	RD 43	14-Jul-94
Customer	D.O.E. Clean Coal Technology	02:12 PM
Jobsite	CER, TVA, Paducah, Kentucky	
Application	Coal-Fired Boiler	Page No. 1
Condition	Maximum case - 10% Above Design	

MASS BALANCE

ITEM		IN	OUT
1) GSA/ESP			
TEMP	-DEG F	320	161
PRESSURE	-IN WG	(18.00)	(26.50)
FLUE GAS	-LBS/HR	113,886	---
WATER	-LBS/HR	147	---
SLAKED LI	-LBS/HR	5,766	---
COMP. AIR	-LBS/HR	309	---
CaCl2 ADD	-LBS/HR	46	---
DUST RECY	-LBS/HR	50,713	50,713
ESP			
TEMP	-DEG F	161	158
PRESSURE	-IN WG	(26.50)	(27.90)
FLUE GAS	-LBS/HR	---	117,985
WASTE PRO	-LBS/HR	---	2,169
COMP. AIR	-LBS/HR	0	---
LEAK. AIR	-LBS/HR	0	---
TOTAL	-LBS/HR	120,154	120,154
2) EXHAUST FAN			
TEMP	-DEG F	158	171
PRESSURE	-IN WG	(27.90)	0.50
FLUE GAS	-LBS/HR	117,985	117,985
3) HYDRATED LIME			
HYD'D LIM	-LBS/HR	1,153	---
WATER	-LBS/HR	4,612	---
LIME SLUR	-LBS/HR	---	5,766 @ 20 % by wt solution
TOTAL	-LBS/HR	5,766	5,766

ITEM	IN LBS/HR	OUT LBS/HR
SO2	428	34.4
HCl	2	0.0
DUST	551	2.4

ENERGY BALANCE

		IN	OUT
GSA	mmBTU/HR	17.11	17.11
ESP	mmBTU/HR	14.80	14.80

Table 3.3-5

Process Calculation, Mass and Energy Balance for Design Case with Baghouse in Series with ESP

AirPol ref	:RD 43	07-Apr-94
Customer	:D.O.E. Clean Coal Technology	10:54 AM
Jobsite	:NCER, TVA, Paducah, Kentucky	Pg 1 of 2
Application	:Coal-Fired Boiler	
Condition	:Design case with Baghouse in Series with ESP	

OPERATING CONDITIONS

SITE DATA		
Elevation	345.0 ft ASL	105.2 m ASL
Ambient Pressure	14.514 psia	750.6 mm Hg
Ambient Temperature	80.0 deg F avg	26.7 deg C avg
Relative Humidity	60 %	

REFERENCE DATA		
Standard Temperature	68 deg F	20 deg C
Standard Pressure	14.696 psia	760 mm Hg

APC SYSTEM INLET GAS CONDITION

Gas composition	lb/hr	kg/hr	vol % wet
O2	7,385	3,350	6.576
N2	73,130	33171	74.385
CO2	17,227	7,814	11.154
HCl	2	1	0.002
HF	0	0	0.000
SO2	389	176	0.173
SO3	5	2	0.002
Ar	0	0	0.000
CO	0	0	0.000
NO	51	23	0.049
NO2	0	0	0.000
H2O	4,843	2,197	7.660
Total	103,032	46735	100.000

Dust load	501 lb/hr	227 kg/hr
actual dust load	2.806 grs/scfd	6,422 mg/Nm^3 dry
@ 7% O2	2.831 grs/scfd	6,478 mg/Nm^3 dry
Inlet Temperature	320 deg F	160 deg C
Inlet Pressure	(18.00)in wg	(457.20)mm wg
Inlet Flow	35,299 acfm	
	22,539 scfm	35681 Nm3/h wet

POLLUTANT CONCENTRATION

Inlet @ 7% O2	SO2	HCl	HF	NOx	DUST
ppmd	1,890	19	0	0	-
mg/dNm3	5,401	31	0	0	6,952
gr/dscf	-	-	-	-	2.831

Outlet @ 7% O2	SO2	HCl	HF	NOx	DUST
ppmd	152	-	-	-	-
mg/dNm3	435	-	-	-	29
gr/dscf	-	-	-	-	0.012
lb/hr	31.20	-	-	-	2.11
% Removal Eff.	91.98	-	-	-	99.58

AirPol ref	:RD 43	07-Apr-94
Customer	:D.O.E. Clean Coal Technology	10:54 AM
Jobsite	:NCER, TVA, Paducah, Kentucky	Pg 2 of 2
Application	:Coal-Fired Boiler	
Condition	:Design case with Baghouse in Series with ESP	

OPERATING CONDITIONS

1) GSA		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	320.0	161.2	deg C	160.0	71.8
PRESSURE	in wg	(18.0)	(26.5)	mm wg	(457.2)	(673.1)
FLOW	acfm	35,299	30,770	m3/hr	59,973	52,279
	scfmw	21,001	22,481	Nm3/hr	35,681	38,195
	lb/hr	103,533	107,646	kg/hr	46,962	48,827

2) ESP		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	161.2	157.9	deg C	71.8	69.9
PRESSURE	in wg	(26.5)	(27.9)	mm wg	(673.1)	(708.7)
FLOW	acfm	30,770	30,716	m3/hr	52,279	52,187
	scfmw	22,481	22,479	Nm3/hr	38,195	38,193
	lb/hr	107,646	107,258	kg/hr	48,827	48,652

3) PJBH		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	157.9	151.9	deg C	69.9	66.6
PRESSURE	in wg	(27.9)	(33.9)	mm wg	(708.7)	(861.1)
FLOW	acfm	5,000	5,282	m3/hr	8,495	8,974
	scfmw	3,659	3,841	Nm3/hr	6,217	6,525
	lb/hr	17,460	18,330	kg/hr	7,920	8,314

4) ID FAN		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	157.3	172.6	deg C	69.6	78.1
PRESSURE	in wg	(27.9)	0.5	mm wg	(708.7)	12.7
FLOW	acfm	31,437	29,470	m3/hr	53,412	50,070
	scfmw	22,660	22,660	Nm3/hr	38,500	38,500
	lb/hr	108,129	108,129	kg/hr	49,046	49,046
DENSITY	lb/ft3	0.058	0.061	kg/m3	0.932	0.980

TOTAL SYSTEM REQUIREMENTS

SYSTEM WATER DEMAND	9	US gpm	35	lpm
Cooling Water Rate	0	US gpm	1	lpm
Lime Slurry Rate @ 20% by wt	9	US gpm	35	lpm
SYSTEM COMP. AIR @ 0 PSIG	281	lb/hr	128	kg/hr
	63	scfm-68	107	m3/hr
CaO REQ'D @ 90.00 % PURITY	813	lb/hr	369	kg/hr
	9.8	TON/DAY	8.9	mTON/DAY
TOTAL WASTE RATE	1,930	lb/hr	875	kg/hr
	23	TON/DAY	21.0	mTON/DAY
GAS SATURATION TEMP.	126	deg F	52	deg C
APPROACH TO SATURATION TEMP	35	deg F	19	deg C
GSA STOICHIOMETRIC RATIO	2.13	MOL Ca(OH)2/MOL ACID GAS IN		
APPROX.CaCl2 @ 35 deg F AST	42	lb/hr		
	4	% of Lime Rate		

AirPol ref	:RD 43	07-Apr-94
Customer	:D.O.E. Clean Coal Technology	10:54 AM
Jobsite	:NCER, TVA, Paducah, Kentucky	
Application	:Coal-Fired Boiler	Page No. 3
Condition	:Design case with Baghouse in Series with ESP	

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		G1	G2	G3	G3a	G3b
		GSA Gas Inlet lbs/hr	ESP Gas Inlet lbs/hr	ESP Gas Outlet lbs/hr	PJBH Gas Inlet lbs/hr	PJBH Gas Outlet lbs/hr
FLOW RATE	-lb/hr	103,533	107,646	107,258	17,460	18,330
	-acfm	35,299	30,770	30,716	5,000	5,282
	-scfm-32	21,001	22,481	22,479	3,659	3,841
	-gpm	....	....	....	....	....
PR	-in wg	(18.00)	(26.50)	(27.90)	(27.90)	(33.90)
	-psig	....	....	....	....	....
TEMP	-deg F	320	161	158	158	152
DENSITY	-lb/cf	0.049	0.058	0.058	0.058	0.058
O2	-vol % dry	7.12	7.18	7.18	7.18	7.92
H2O	-vol %	7.66	13.69	13.70	13.70	13.07
SO2	-ppmd	1,873	297	150	150	14
@ 7% O2	-ppmd	1,890	301	152	152	15
	-lb/mmBtu	....	....	....	....	....
HCl	-ppmd	19	0	0	0	0
@ 7% O2	-ppmd	19	0	0	0	0
	-lb/mmBtu	....	....	....	....	....
Dust	-gr/dscf	2.806	2.035	0.012	0.012	0.000
	-mg/dNm3	6,892	4,999	30	30	0
	-lb/mmBtu	0.802	0.582	0.003	0.001	0.000
@ 7% O2	-gr/dscf	2.831	2.062	0.012	0.012	0.000
@ 7% O2	-mg/dNm3	6,952	5,063	30	30	0
Cl-	-ppm	....	....	....	....	....

AirPol ref	:RD 43	07-Apr-94
Customer	:D.O.E. Clean Coal Technology	10:54 AM
Jobsite	:NCER, TVA, Paducah, Kentucky	
Application	:Coal-Fired Boiler	Page No. 4
Condition	:Design case with Baghouse in Series with ESP	

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		G4	G5	A1	A2
		Stack Gas Inlet lbs/hr	Stack Gas Outlet lbs/hr	GSA Atomz Air lbs/hr	PJBH Leak.air lbs/hr
FLOW RATE	-lb/hr	108,129	108,129	281.2	875.4
	-acfm	29,470	29,474	8.2	202.2
	-scfm-32	22,660	22,660	58.5	184.2
	-gpm	....	....	....	....
PR	-in wg	0.50	0.00	....	....
	-psig	....	....	100	0
TEMP	-deg F	173	172	80	80
DENSITY	-lb/cf	0.061	0.061	0.569	0.072
O2	-vol % dry	7.30	7.30	....	....
H2O	-vol %	13.59	13.59	....	....
SO2	-ppmd	127	127	....	....
@ 7% O2	-ppmd	130	130	....	....
	-lb/mmBtu	....	....	....	....
HCl	-ppmd	0	0	....	....
@ 7% O2	-ppmd	0	0	....	....
	-lb/mmBtu	....	....	....	....
Dust	-gr/dscf	0.010	0.010	....	....
	-mg/dNm3	25	25	....	....
	-lb/mmBtu	0.003	0.003	....	....
@ 7% O2	-gr/dscf	0.010	0.010	....	....
@ 7% O2	-mg/dNm3	25	25	....	....
Cl-	-ppm	....	....	....	....

AirPol ref :RD 43 07-Apr-94
Customer :D.O.E. Clean Coal Technology 10:54 AM
Jobsite :NCER, TVA, Paducah, Kentucky
Application :Coal-Fired Boiler
Condition :Design case with Baghouse in Series with ESP

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		R1	R2	SS1	W1	W2
		Pebble lime lbs/hr	Lime Slury to GSA lbs/hr	GSA/Filter Solid Wast lbs/hr	Cooling H2O to GSA lbs/hr	Lime Slury Water lbs/hr
FLOW RATE	-lb/hr	813.2	5,241.4	1,929.7	132.6	4,193.2
	-acfm	....	....	....	....	....
	-scfm-32	....	....	....	....	....
	-gpm	....	9.23	....	0.27	8.39
PR	-in wg	....	....	....	....	....
	-psig	....	100	....	100	....
TEMP	-deg F	....	78	....	68	68
DENSITY	-lb/cf	56.000	70.910	....	62.40	62.40
O2	-vol % dry	....	....	....	....	....
H2O	-vol %	....	....	....	....	....
SO2	-ppmd	....	....	....	....	....
@ 7% O2	-ppmd	....	....	....	....	....
HCl	-ppmd	....	....	....	....	....
@ 7% O2	-ppmd	....	....	....	....	....
Dust	-gr/dscf	....	....	....	....	....
0	-mg/dNm3	....	....	....	....	....
@ 7% O2	-gr/dscf	....	....	....	....	....
@ 7% O2	-mg/dNm3	....	....	....	....	....
Cl-	-ppm	....	....	....	....	....

AirPol ref RD 43 — 07-Apr-94, 10:54 AM

Customer: D.O.E. Clean Coal Technology

Jobsite: NCER, TVA, Paducah, Kentucky

Application: Coal-Fired Boiler

Condition: Design case with Baghouse in Series with ESP

MASS BALANCE

ITEM		IN	OUT
1) GSA/ESP			
TEMP	-DEG F	320	161
PRESSURE	-IN WG	(18.00)	(26.50)
FLUE GAS	-LBS/HR	103,533	---
WATER	-LBS/HR	133	---
SLAKED LI	-LBS/HR	5,241	---
COMP. AIR	-LBS/HR	281	---
CaCl2 ADD	-LBS/HR	42	---
DUST RECY	-LBS/HR	46,102	46,102
ESP			
TEMP	-DEG F	161	158
PRESSURE	-IN WG	(26.50)	(27.90)
FLUE GAS	-LBS/HR	---	107,258
WASTE PRO	-LBS/HR	---	1,972
COMP. AIR	-LBS/HR	0	---
LEAK. AIR	-LBS/HR	0	---
TOTAL	-LBS/HR	109,230	109,230
2) PJBH			
TEMP	-DEG F	158	152
PRESSURE	-IN WG	(27.90)	(33.90)
FLUE GAS	-LBS/HR	17,460	18,330
LEAK. AIR	-LBS/HR	875	---
WASTE PRO	-LBS/HR	---	5
TOTAL	-LBS/HR	18,335	18,335
3) EXHAUST FAN			
TEMP	-DEG F	157	173
PRESSURE	-IN WG	(27.90)	0.50
FLUE GAS	-LBS/HR	108,129	108,129
4) HYDRATED LIME			
HYD'D LIM	-LBS/HR	1,048	---
WATER	-LBS/HR	4,193	---
LIME SLUR	-LBS/HR	---	5,241 @ 20 % by wt solution
TOTAL	-LBS/HR	5,241	5,241

ITEM	IN LBS/HR	OUT LBS/HR
SO2	389	31.2
HCl	2	0.0
DUST	501	2.2

ENERGY BALANCE

		IN	OUT
GSA	mmBTU/HR	15.56	15.56
ESP	mmBTU/HR	13.44	13.44
PJBH	mmBTU/HR	2.20	2.20

Table 3.3-6

**Process Calculation, Mass and Energy Balance
for Minimum Case
with Baghouse in Series with ESP**

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:23 PM
Jobsite	:CER, TVA, Paducah, Kentucky	Pg 1 of 2
Application	:Coal-Fired Boiler	
Condition	:Minimum case with Baghouse in Series with ESP	

OPERATING CONDITIONS

SITE DATA

Elevation	345.0 ft ASL	105.2 m ASL
Ambient Pressure	14.514 psia	750.6 mm Hg
Ambient Temperature	80.0 deg F avg	26.7 deg C avg
Relative Humidity	60 %	

REFERENCE DATA

Standard Temperature	68 deg F	20 deg C
Standard Pressure	14.696 psia	760 mm Hg

APC SYSTEM INLET GAS CONDITION

Gas composition	lb/hr	kg/hr	vol % wet
O2	4,431	2,010	6.576
N2	43,878	19903	74.385
CO2	10,336	4,689	11.154
HCl	1	1	0.002
HF	0	0	0.000
SO2	233	106	0.173
SO3	3	1	0.002
Ar	0	0	0.000
CO	0	0	0.000
NO	31	14	0.049
NO2	0	0	0.000
H2O	2,906	1,318	7.660
Total	61,819	28041	100.000

Dust load	300 lb/hr	136 kg/hr
actual dust load	2.806 grs/scfd	6,422 mg/Nm^3 dry
@ 7% O2	2.831 grs/scfd	6,478 mg/Nm^3 dry
Inlet Temperature	320 deg F	160 deg C
Inlet Pressure	(18.00)in wg	(457.20)mm wg
Inlet Flow	21,179 acfm	
	13,523 scfm	21409 Nm3/h wet

POLLUTANT CONCENTRATION

Inlet @ 7% O2	SO2	HCl	HF	NOx	DUST
ppmd	1,890	19	0	0	-
mg/dNm3	5,401	31	0	0	6,952
gr/dscf	-	-	-	-	2.831

Outlet @ 7% O2	SO2	HCl	HF	NOx	DUST
ppmd	152	-	-	-	-
mg/dNm3	435	0	-	-	29
gr/dscf	-	-	-	-	0.012
lb/hr	18.72	0.00	-	-	1.27
% Removal Eff.	91.98	100.00	-	-	99.58

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:23 PM
Jobsite	:CER, TVA, Paducah, Kentucky	Pg 2 of 2
Application	:Coal-Fired Boiler	
Condition	:Minimum case with Baghouse in Series with ESP	

OPERATING CONDITIONS

		INLET	OUTLET		INLET	OUTLET
1) GSA						
TEMP	deg F	320.0	161.2	deg C	160.0	71.8
PRESSURE	in wg	(18.0)	(26.5)	mm wg	(457.2)	(673.1)
FLOW	acfm	21,179	18,460	m3/hr	35,984	31,364
	scfmw	12,601	13,488	Nm3/hr	21,409	22,915
	lb/hr	62,120	64,584	kg/hr	28,177	29,295
2) ESP		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	161.2	155.4	deg C	71.8	68.6
PRESSURE	in wg	(26.5)	(27.9)	mm wg	(673.1)	(708.7)
FLOW	acfm	18,460	18,356	m3/hr	31,364	31,187
	scfmw	13,488	13,487	Nm3/hr	22,915	22,914
	lb/hr	64,584	64,352	kg/hr	29,295	29,190
3) PJBH		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	155.4	149.6	deg C	68.6	65.3
PRESSURE	in wg	(27.9)	(33.9)	mm wg	(708.7)	(861.1)
FLOW	acfm	5,000	5,283	m3/hr	8,495	8,976
	scfmw	3,674	3,856	Nm3/hr	6,242	6,551
	lb/hr	17,529	18,403	kg/hr	7,951	8,347
3) ID FAN		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	155.4	169.7	deg C	68.6	76.5
PRESSURE	in wg	(27.9)	0.5	mm wg	(708.7)	12.7
FLOW	acfm	18,877	17,696	m3/hr	32,072	30,065
	scfmw	13,669	13,669	Nm3/hr	23,223	23,223
	lb/hr	65,226	65,226	kg/hr	29,586	29,586
DENSITY	lb/ft3	0.058	0.061	kg/m3	0.922	0.984

TOTAL SYSTEM REQUIREMENTS

SYSTEM WATER DEMAND	5.5	US gpm	21	lpm
Cooling Water Rate	0.2	US gpm	1	lpm
Lime Slurry Rate @ 20% by wt	5.5	US gpm	21	lpm
SYSTEM COMP. AIR @ 0 PSIG	169	lb/hr	76	kg/hr
	38	scfm-68	64	m3/hr
CaO REQ'D @ 90.00 % PURITY	488	lb/hr	221	kg/hr
	5.9	TON/DAY	5.3	mTON/DAY
TOTAL WASTE RATE	1,158	lb/hr	525	kg/hr
	14	TON/DAY	12.6	mTON/DAY
GAS SATURATION TEMP.	126	deg F	52	deg C
APPROACH TO SATURATION TEMP	35	deg F	19	deg C
GSA STOICHIOMETRIC RATIO	2.13	MOL Ca(OH)2/MOL ACID GAS IN		
APPROX.CaCl2 @ 35 deg F AST	25	lb/hr		
	4	% of Lime Rate		

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:23 PM
Jobsite	:CER, TVA, Paducah, Kentucky	
Application	:Coal-Fired Boiler	Page No. 3
Condition	:Minimum case with Baghouse in Series with ESP	

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		G1	G2	G3	G3a	G3b
		GSA Gas Inlet lbs/hr	ESP Gas Inlet lbs/hr	ESP Gas Outlet lbs/hr	PJBH Gas Inlet lbs/hr	PJBH Gas Outlet lbs/hr
FLOW RATE	-lb/hr	62,120	64,584	64,352	17,529	18,403
	-acfm	21,179	18,460	18,356	5,000	5,283
	-scfm-32	12,601	13,488	13,487	3,674	3,856
	-gpm	....	....	....	....	....
PR	-in wg	(18.00)	(26.50)	(27.90)	(27.90)	(33.90)
	-psig	....	....	....	....	....
TEMP	-deg F	320	161	155	155	150
DENSITY	-lb/cf	0.049	0.058	0.058	0.058	0.058
O2	-vol % dry	7.12	7.18	7.18	7.18	7.92
H2O	-vol %	7.66	13.69	13.69	13.69	13.07
SO2	-ppmd	1,873	297	150	150	14
@ 7% O2	-ppmd	1,890	301	152	152	15
	-lb/mmBtu	....	....	....	....	....
HCl	-ppmd	19	0	0	0	0
@ 7% O2	-ppmd	19	0	0	0	0
	-lb/mmBtu	....	....	....	....	....
Dust	-gr/dscf	2.806	2.035	0.012	0.012	0.000
	-mg/dNm3	6,892	4,998	30	30	0
	-lb/mmBtu	0.481	0.349	0.002	0.001	0.000
@ 7% O2	-gr/dscf	2.831	2.061	0.012	0.012	0.000
@ 7% O2	-mg/dNm3	6,952	5,063	30	30	0
Cl-	-ppm	....	....	....	....	....

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:23 PM
Jobsite	:CER, TVA, Paducah, Kentucky	
Application	:Coal-Fired Boiler	Page No. 4
Condition	:Minimum case with Baghouse in Series with ESP	

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		G4	G5	A1	A2
		Stack Gas Inlet lbs/hr	Stack Gas Outlet lbs/hr	GSA Atomz Air lbs/hr	PJBH Leak.air lbs/hr
FLOW RATE	-lb/hr	65,226	65,226	168.5	878.9
	-acfm	17,696	17,685	4.9	203.0
	-scfm-32	13,669	13,669	35.1	184.9
	-gpm	....	....	....	....
PR	-in wg	0.50	0.00	....	....
	-psig	....	....	100	0
TEMP	-deg F	170	169	80	80
DENSITY	-lb/cf	0.061	0.061	0.569	0.072
O2	-vol % dry	7.39	7.39	....	....
H2O	-vol %	13.51	13.51	....	....
SO2	-ppmd	112	112	....	....
@ 7% O2	-ppmd	115	115	....	....
	-lb/mmBtu	....	....	....	....
HCl	-ppmd	0	0	....	....
@ 7% O2	-ppmd	0	0	....	....
	-lb/mmBtu	....	....	....	....
Dust	-gr/dscf	0.009	0.009	....	....
	-mg/dNm3	22	22	....	....
	-lb/mmBtu	0.002	0.002	....	....
@ 7% O2	-gr/dscf	0.009	0.009	....	....
@ 7% O2	-mg/dNm3	22	22	....	....
Cl-	-ppm	....	....	....	....

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:23 PM
Jobsite	:CER, TVA, Paducah, Kentucky	
Application	:Coal-Fired Boiler	Page No. 5
Condition	:Minimum case with Baghouse in Series with ESP	

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		R1	R2	SS1	W1	W2
		Pebble lime lbs/hr	Lime Slury to GSA lbs/hr	GSA/Filter Solid Wast lbs/hr	Cooling H2O to GSA lbs/hr	Lime Slury Water lbs/hr
FLOW RATE	-lb/hr	487.9	3,144.9	1,157.8	76.8	2,515.9
	-acfm	....	....	....	....	....
	-scfm-32	....	....	....	....	....
	-gpm	....	5.54	....	0.15	5.03
PR	-in wg	....	....	....	....	....
	-psig	....	100	....	100	....
TEMP	-deg F	....	78	....	68	68
DENSITY	-lb/cf	56.000	70.910	....	62.40	62.40
O2	-vol % dry	....	....	....	....	....
H2O	-vol %	....	....	....	....	....
SO2	-ppmd	....	....	....	....	....
@ 7% O2	-ppmd	....	....	....	....	....
HCl	-ppmd	....	....	....	....	....
@ 7% O2	-ppmd	....	....	....	....	....
Dust	-gr/dscf	....	....	....	....	....
0	-mg/dNm3	....	....	....	....	....
@ 7% O2	-gr/dscf	....	....	....	....	....
@ 7% O2	-mg/dNm3	....	....	....	....	....
Cl-	-ppm	....	....	....	....	....

AirPol ref	RD 43	14-Jul-94
Customer	D.O.E. Clean Coal Technology	02:23 PM
Jobsite	CER, TVA, Paducah, Kentucky	
Application	Coal-Fired Boiler	
Condition	Minimum case with Baghouse in Series with ESP	

MASS BALANCE

ITEM		IN	OUT
1) GSA/ESP			
TEMP	-DEG F	320	161
PRESSURE	-IN WG	(18.00)	(26.50)
FLUE GAS	-LBS/HR	62,120	---
WATER	-LBS/HR	77	---
SLAKED LI	-LBS/HR	3,145	---
COMP. AIR	-LBS/HR	169	---
CaCl2 ADD	-LBS/HR	25	---
DUST RECY	-LBS/HR	27,659	27,659
ESP			
TEMP	-DEG F	161	155
PRESSURE	-IN WG	(26.50)	(27.90)
FLUE GAS	-LBS/HR	---	64,352
WASTE PRO	-LBS/HR	---	1,183
COMP. AIR	-LBS/HR	0	---
LEAK. AIR	-LBS/HR	0	---
TOTAL	-LBS/HR	65,535	65,535
2) PJBH			
TEMP	-DEG F	155	150
PRESSURE	-IN WG	(27.90)	(33.90)
FLUE GAS	-LBS/HR	17,529	18,403
LEAK. AIR	-LBS/HR	879	---
WASTE PRO	-LBS/HR	---	5
TOTAL	-LBS/HR	18,408	18,408
3) EXHAUST FAN			
TEMP	-DEG F	155	170
PRESSURE	-IN WG	(27.90)	0.50
FLUE GAS	-LBS/HR	65,226	65,226
4) HYDRATED LIME			
HYD'D LIM	-LBS/HR	629	---
WATER	-LBS/HR	2,516	---
LIME SLUR	-LBS/HR	---	3,145 @ 20 % by wt solution
TOTAL	-LBS/HR	3,145	3,145

ITEM	IN LBS/HR	OUT LBS/HR
SO2	233	18.7
HCl	1	0.0
DUST	300	1.0

ENERGY BALANCE

		IN	OUT
GSA	mmBTU/HR	9.33	9.33
ESP	mmBTU/HR	8.02	8.02
PJBH	mmBTU/HR	2.20	2.20

Table 3.3-7

Process Calculation, Mass and Energy Balance for Maximum Case with Baghouse in Series with ESP

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:28 PM
Jobsite	:CER, TVA, Paducah, Kentucky	Pg 1 of 2
Application	:Coal-Fired Boiler	
Condition	:Maximum case with Baghouse in Series with ESP	

OPERATING CONDITIONS

SITE DATA

Elevation	345.0 ft ASL	105.2 m ASL
Ambient Pressure	14.514 psia	750.6 mm Hg
Ambient Temperature	80.0 deg F avg	26.7 deg C avg
Relative Humidity	60 %	

REFERENCE DATA

Standard Temperature	68 deg F	20 deg C
Standard Pressure	14.696 psia	760 mm Hg

APC SYSTEM INLET GAS CONDITION

Gas composition	lb/hr	kg/hr	vol % wet
O2	8,123	3,685	6.576
N2	80,443	36488	74.385
CO2	18,950	8,596	11.154
HCl	2	1	0.002
HF	0	0	0.000
SO2	428	194	0.173
SO3	5	2	0.002
Ar	0	0	0.000
CO	0	0	0.000
NO	56	26	0.049
NO2	0	0	0.000
H2O	5,327	2,416	7.660
Total	113,335	51408	100.000

Dust load	551 lb/hr	250 kg/hr
actual dust load	2.806 grs/scfd	6,422 mg/Nm^3 dry
@ 7% O2	2.831 grs/scfd	6,478 mg/Nm^3 dry

Inlet Temperature	320 deg F	160 deg C
Inlet Pressure	(18.00)in wg	(457.20)mm wg
Inlet Flow	38,828 acfm	
	24,793 scfm	39249 Nm3/h wet

POLLUTANT CONCENTRATION

Inlet @ 7% O2	SO2	HCl	HF	NOx	DUST
ppmd	1,890	19	0	0	-
mg/dNm3	5,401	31	0	0	6,952
gr/dscf	-	-	-	-	2.831

Outlet @ 7% O2	SO2	HCl	HF	NOx	DUST
ppmd	152	-	-	-	-
mg/dNm3	435	0	-	-	29
gr/dscf	-	-	-	-	0.012
lb/hr	34.32	0.00	-	-	2.33
% Removal Eff.	91.98	100.00	-	-	99.58

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:28 PM
Jobsite	:CER, TVA, Paducah, Kentucky	Pg 2 of 2
Application	:Coal-Fired Boiler	
Condition	:Maximum case with Baghouse in Series with ESP	

OPERATING CONDITIONS

1) GSA		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	320.0	161.2	deg C	160.0	71.8
PRESSURE	in wg	(18.0)	(26.5)	mm wg	(457.2)	(673.1)
FLOW	acfm	38,828	33,848	m3/hr	65,970	57,508
	scfmw	23,101	24,729	Nm3/hr	39,249	42,015
	lb/hr	113,886	118,412	kg/hr	51,658	53,711

2) ESP		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	161.2	158.2	deg C	71.8	70.1
PRESSURE	in wg	(26.5)	(27.9)	mm wg	(673.1)	(708.7)
FLOW	acfm	33,848	33,806	m3/hr	57,508	57,436
	scfmw	24,729	24,728	Nm3/hr	42,015	42,013
	lb/hr	118,412	117,985	kg/hr	53,711	53,517

3) PJBH		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	158.2	152.2	deg C	70.1	66.8
PRESSURE	in wg	(27.9)	(33.9)	mm wg	(708.7)	(861.1)
FLOW	acfm	5,000	5,282	m3/hr	8,495	8,974
	scfmw	3,657	3,839	Nm3/hr	6,214	6,522
	lb/hr	17,451	18,321	kg/hr	7,915	8,310

3) ID FAN		INLET	OUTLET		INLET	OUTLET
TEMP	deg F	157.6	173.0	deg C	69.8	78.3
PRESSURE	in wg	(27.9)	0.5	mm wg	(708.7)	12.7
FLOW	acfm	34,577	32,413	m3/hr	58,746	55,070
	scfmw	24,908	24,908	Nm3/hr	42,320	42,320
	lb/hr	118,855	118,855	kg/hr	53,912	53,912
DENSITY	lb/ft3	0.057	0.061	kg/m3	0.918	0.979

TOTAL SYSTEM REQUIREMENTS

SYSTEM WATER DEMAND	10 US gpm	38 lpm
Cooling Water Rate	0 US gpm	1 lpm
Lime Slurry Rate @ 20% by wt	10 US gpm	38 lpm
SYSTEM COMP. AIR @ 0 PSIG	309 lb/hr	140 kg/hr
	69 scfm-68	117 m3/hr
CaO REQ'D @ 90.00 % PURITY	894 lb/hr	406 kg/hr
	10.7 TON/DAY	9.7 mTON/DAY
TOTAL WASTE RATE	2,123 lb/hr	963 kg/hr
	25 TON/DAY	23.1 mTON/DAY
GAS SATURATION TEMP.	126 deg F	52 deg C
APPROACH TO SATURATION TEMP	35 deg F	19 deg C
GSA STOICHIOMETRIC RATIO	2.13 MOL Ca(OH)2/MOL ACID GAS IN	
APPROX.CaCl2 @ 35 deg F AST	46 lb/hr	
	4 % of Lime Rate	

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:28 PM
Jobsite	:CER, TVA, Paducah, Kentucky	
Application	:Coal-Fired Boiler	Page No. 3
Condition	:Maximum case with Baghouse in Series with ESP	

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		G1	G2	G3	G3a	G3b
		GSA Gas Inlet lbs/hr	ESP Gas Inlet lbs/hr	ESP Gas Outlet lbs/hr	PJBH Gas Inlet lbs/hr	PJBH Gas Outlet lbs/hr
FLOW RATE	-lb/hr	113,886	118,412	117,985	17,451	18,321
	-acfm	38,828	33,848	33,806	5,000	5,282
	-scfm-32	23,101	24,729	24,728	3,657	3,839
	-gpm	....	....	....	....	....
PR	-in wg	(18.00)	(26.50)	(27.90)	(27.90)	(33.90)
	-psig	....	....	....	....	....
TEMP	-deg F	320	161	158	158	152
DENSITY	-lb/cf	0.049	0.058	0.058	0.058	0.058
O2	-vol % dry	7.12	7.18	7.18	7.18	7.92
H2O	-vol %	7.66	13.69	13.70	13.70	13.07
SO2	-ppmd	1,873	297	150	150	14
@ 7% O2	-ppmd	1,890	301	152	152	15
	-lb/mmBtu	....	....	....	....	....
HCl	-ppmd	19	0	0	0	0
@ 7% O2	-ppmd	19	0	0	0	0
	-lb/mmBtu	....	....	....	....	....
Dust	-gr/dscf	2.806	2.035	0.012	0.012	0.000
	-mg/dNm3	6,892	4,999	30	30	0
	-lb/mmBtu	0.882	0.640	0.004	0.001	0.000
@ 7% O2	-gr/dscf	2.831	2.062	0.012	0.012	0.000
@ 7% O2	-mg/dNm3	6,952	5,063	30	30	0
Cl-	-ppm	....	....	....	....	....

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:28 PM
Jobsite	:CER, TVA, Paducah, Kentucky	
Application	:Coal-Fired Boiler	Page No. 4
Condition	:Maximum case with Baghouse in Series with ESP	

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		G4	G5	A1	A2
		Stack Gas Inlet lbs/hr	Stack Gas Outlet lbs/hr	GSA Atomz Air lbs/hr	PJBH Leak.air lbs/hr
FLOW RATE	-lb/hr	118,855	118,855	309.4	874.9
	-acfm	32,413	32,420	9.1	202.1
	-scfm-32	24,908	24,908	64.4	184.1
	-gpm	....	....	....	....
PR	-in wg	0.50	0.00	....	....
	-psig	....	....	100	0
TEMP	-deg F	173	172	80	80
DENSITY	-lb/cf	0.061	0.061	0.569	0.072
O2	-vol % dry	7.29	7.29	....	....
H2O	-vol %	13.60	13.60	....	....
SO2	-ppmd	129	129	....	....
@ 7% O2	-ppmd	132	132	....	....
	-lb/mmBtu	....	....	....	....
HCl	-ppmd	0	0	....	....
@ 7% O2	-ppmd	0	0	....	....
	-lb/mmBtu	....	....	....	....
Dust	-gr/dscf	0.010	0.010	....	....
	-mg/dNm3	25	25	....	....
	-lb/mmBtu	0.003	0.003	....	....
@ 7% O2	-gr/dscf	0.011	0.011	....	....
@ 7% O2	-mg/dNm3	26	26	....	....
Cl-	-ppm	....	....	....	....

AirPol ref	:RD 43	14-Jul-94
Customer	:D.O.E. Clean Coal Technology	02:28 PM
Jobsite	:CER, TVA, Paducah, Kentucky	
Application	:Coal-Fired Boiler	Page No. 5
Condition	:Maximum case with Baghouse in Series with ESP	

PROCESS FLOW PER GSA SYSTEM - English Units

Stream No.		R1	R2	SS1	W1	W2
		Pebble lime lbs/hr	Lime Slury to GSA lbs/hr	GSA/Filter Solid Wast lbs/hr	Cooling H2O to GSA lbs/hr	Lime Slury Water lbs/hr
FLOW RATE	-lb/hr	894.5	5,765.6	2,122.7	147.1	4,612.5
	-acfm	....	....	....	....	....
	-scfm-32	....	....	....	....	....
	-gpm	....	10.15	....	0.29	9.23
PR	-in wg	....	....	....	....	....
	-psig	....	100	....	100	....
TEMP	-deg F	....	78	....	68	68
DENSITY	-lb/cf	56.000	70.910	....	62.40	62.40
O2	-vol % dry	....	....	....	....	....
H2O	-vol %	....	....	....	....	....
SO2	-ppmd	....	....	....	....	....
@ 7% O2	-ppmd	....	....	....	....	....
HCl	-ppmd	....	....	....	....	....
@ 7% O2	-ppmd	....	....	....	....	....
Dust	-gr/dscf	....	....	....	....	....
0	-mg/dNm3	....	....	....	....	....
@ 7% O2	-gr/dscf	....	....	....	....	....
@ 7% O2	-mg/dNm3	....	....	....	....	....
Cl-	-ppm	....	....	....	....	....

AirPol ref	RD 43	14-Jul-94
Customer	D.O.E. Clean Coal Technology	02:28 PM
Jobsite	CER, TVA, Paducah, Kentucky	
Application	Coal-Fired Boiler	
Condition	Maximum case with Baghouse in Series with ESP	

MASS BALANCE

ITEM		IN	OUT
1) GSA/ESP			
TEMP	-DEG F	320	161
PRESSURE	-IN WG	(18.00)	(26.50)
FLUE GAS	-LBS/HR	113,886	---
WATER	-LBS/HR	147	---
SLAKED LI	-LBS/HR	5,766	---
COMP. AIR	-LBS/HR	309	---
CaCl2 ADD	-LBS/HR	46	---
DUST RECY	-LBS/HR	50,713	50,713
ESP			
TEMP	-DEG F	161	158
PRESSURE	-IN WG	(26.50)	(27.90)
FLUE GAS	-LBS/HR	---	117,985
WASTE PRO	-LBS/HR	---	2,169
COMP. AIR	-LBS/HR	0	---
LEAK. AIR	-LBS/HR	0	---
TOTAL	-LBS/HR	120,154	120,154
2) PJBH			
TEMP	-DEG F	158	152
PRESSURE	-IN WG	(27.90)	(33.90)
FLUE GAS	-LBS/HR	17,451	18,321
LEAK. AIR	-LBS/HR	875	---
WASTE PRO	-LBS/HR	---	5
TOTAL	-LBS/HR	18,326	18,326
3) EXHAUST FAN			
TEMP	-DEG F	158	173
PRESSURE	-IN WG	(27.90)	0.50
FLUE GAS	-LBS/HR	118,855	118,855
4) HYDRATED LIME			
HYD'D LIM	-LBS/HR	1,153	---
WATER	-LBS/HR	4,612	---
LIME SLUR	-LBS/HR	---	5,766 @ 20 % by wt solution
TOTAL	-LBS/HR	5,766	5,766

ITEM	IN LBS/HR	OUT LBS/HR
SO2	428	34.4
HCl	2	0.0
DUST	551	2.0

ENERGY BALANCE

		IN	OUT
GSA	mmBTU/HR	17.11	17.11
ESP	mmBTU/HR	14.80	14.80
PJBH	mmBTU/HR	2.20	2.20

3.4 UTILITY AND REAGENT REQUIREMENTS

Utility and usage of the utility and reagent required for the GSA system under design condition is listed below.

Fan Power	246	KW
Compressed Air	281	lbs/hr @100 psi
Motors	13	KW
Heaters	1.5	KW
Pebble Lime	813	lbs/hr
Water	9	gpm

3.5 DESIGN CONSIDERATIONS

General Arrangement - In laying out the general arrangement of the GSA system, design consideration was given to the following factors:

1. Minimizing material and construction cost by making the connecting duct system as compact as possible, while providing adequate gas flow pattern throughout the system.

2. Providing an enclosure to enclose the most frequently serviced area of the GSA system. The enclosure will provide personnel protection in the injection lance area and the feeder box area, and shields the air sluice, slurry and water pipes from inclement weather.

3. Designing the access system to provide direct access to the lower operating area (injection nozzle level) and to save costs by utilizing the existing stair tower.

Utilization of Existing Equipment - Existing equipment that is suitable for the new GSA system use is reused to minimize interface work and save equipment cost. The equipment being reused includes the following:

Air compressor

Lime preparation system

Slurry pump

ESP and ash handling system

Motor control panel is modified to add additional circuit breakers for the added motors.

Instrumentation: Inlet and outlet gas flow measurement; inlet flue gas SO_2 & O_2 monitors; temperature measurement at outlet of the GSA cyclone; slurry flow measurement.

The existing Foxboro Control will be used for the GSA system control, and that the start-up and shut-down sequence will be manually performed. This is consistent with the present operation of the spray dryer system and is preferred by TVA operating/testing unit. the Foxboro Control will be programmed to perform the GSA control and alarm annunciations.

Pre-assembly of Steel Structures

For the purpose of reducing field labor and construction time, the support structure/access facility was designed to be shop assembled in four bulk shipping pieces.

Heating and Insulation

In view of the fact that the GSA outlet gas temperature is close to the saturation temperature of the flue gas, special design consideration was given in heating and insulation for the vessels and gas duct to prevent condensation. Basically, all of the main equipment such as reactor, cyclone, baghouse and feeder box as well as ductwork are designed for external insulation with flat sheet aluminum lagging. The lower portion of the cyclone and feeder box are equipped with electric heaters which are controlled by RTD sensors.

Provision for Interface with Existing Equipment

Since the GSA system is retrofitted into the existing system, special consideration was given in the design of all interface to allow for field discrepancies.

Modification Made During Construction and Start-up

Modifications made during the construction stage are mostly in the area where the GSA system interfaces with the existing equipment. Field modifications of ductwork and platform were made to allow proper connection to the existing duct and platform. The request of modifications has resulted from the discrepancy between the TVA supplied built drawings and the actual structure. However, all discrepancies were minor and were rectified without major modification work. Minor modifications were also performed due to interference between the support and the reactor. This was formed to be a result of lack of interference check between the two equipment during the design stage.

3.6 NORMAL OPERATION

Reference: Figure 3.6, Process Flow Diagram

Figure 2.4.1-3, GSA Process Control Schematic Diagram

During normal operation, the GSA system is under the control of an automatic process control system which consists of three control loops.

Recycled Solid Control - This control loop continuously controls the flow of recycled solids to the reactor, based on the amount of flue gas entering the system. The large reaction area and even distribution in the reactor of the absorbent provides for efficient mixing of the lime with the flue gas. At the same time, the large volume of dry material prevents the slurry from adhering to the sides of the reactor. The rate of solid recirculation is an operating parameter determined by the operator.

Feed Water Rate Control - This control loop ensures that the flue gas is sufficiently cooled to optimize the chemical processes. This is achieved by the addition of extra water along with the lime slurry. The amount of water added into the system is governed by the temperature of the flue gas exiting the reactor to avoid any risk of acid condensation. The temperature set point is calculated as the sum of the flue gas saturation temperature and the approach to saturation temperature (AST), which is set by the operator.

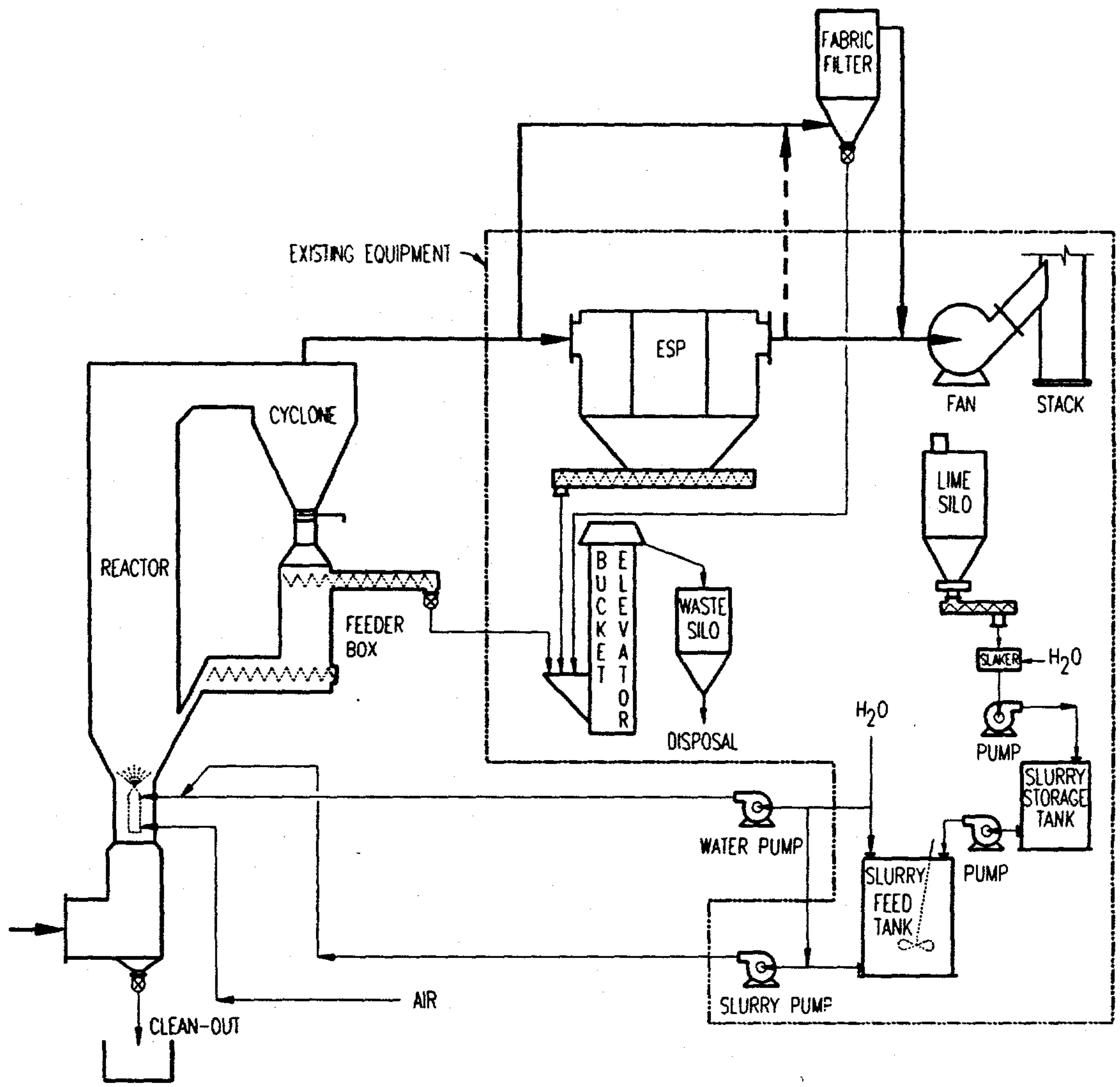
Lime Feed Rate Control - The third control loop controls lime addition. This is accomplished by continuously monitoring the acid content in the outlet flue gas and comparing it with the required emission level. This control loop enables direct proportioning of lime feed according to monitored results and further contributes to maintaining a low level of lime consumption.

The setting of the control parameters are adjusted during initial start-up and can be changed during normal operation if required by a significant change in the operating condition.

Any failure of mechanical or process equipment, such as pumps, motor, air compressor , etc. during operation, will be annunciated on the Foxboro control.

Figure 3.6

PROCESS FLOW DIAGRAM
10 MW DEMONSTRATION OF GSA



3.7 START-UP/SHUT DOWN CONDITIONS

During start-up of the GSA system the equipment in the system shall be started up in a sequential order as follows:

1. Plant ash conveying system
2. GSA ash conveying system and associated heating system
3. ESP
4. I.D. fan
5. Solid recirculation system
6. Water pump
7. Lime slurry pump

When shutting down the GSA system, the above sequence shall be reversed. The heaters for the ash/solid handling and storage system shall remain on until the ash/solid is completely emptied.

3.8 ENVIRONMENTAL CONSIDERATIONS

Operation of the GSA should not result in additional air pollution since:

1. GSA's SO_2 removal efficiency (> 91%) is expected to equal or exceed that of the existing spray dryer system (90%).

2. Particulate emissions from the GSA is controlled by an ESP (> 98% efficient).

4.0 EHSS CONSIDERATIONS

EHSS impacts associated with the GSA system are expected to be minimal. The consequence of both construction and operation of the project on various environmental conditions are discussed as follows:

Land Impacts

Land impacts will be insignificant since no additional lands outside the TVA Shawnee Steam Plant boundaries will be required for the GSA unit and the unit is to be constructed on previously impacted land between an existing spray dryer building and an electrostatic precipitator located at the CER.

Water Quality and Solid Waste Impacts

The solid waste by-product resulting from the operation of the GSA unit is expected to have the same composition as the spray dryer waste by-product. In keeping with the existing practices, these non-recycled solids will be diluted with water to generate a slurry containing approximately 10% solids before being pumped to an existing ash pond for ultimate disposal. change in ash pond effluent as a result of the operation of the GSA are not expected.

Ecological Impacts

No adverse ecological impacts to either terrestrial or aquatic environments are expected for the GSA project. The GSA unit will be constructed on previously disturbed land located beyond the 500 year flood plain of the Ohio River. Effluent from its operation will constitute less than 0.001% of the total Shawnee Steam Plant waste water balance discharged to the Ohio River. Although wetlands are present within the broader confines of the Shawnee Steam Plant, The GSA unit will not be installed by, nor will it discharge to any wetland or lake.

Socioeconomic Impacts

Because of the GSA project's size, no employees are expected to relocate in the Paducah area to work on the project. Labor for the installation will be drawn from the local labor post and its size should not exceed 12 workers.

Aesthetic/Cultural Resources Impacts

No impacts are expected. See Section 3.6 for complete discussion.

Transportation Requirements

A minor increase in traffic volume at the construction site is expected for the construction period, primarily due to construction material deliveries and commuting workers. The increase in traffic is within the capacity of the local road network, and no reduction in the level of service being provided is anticipated.

Impact Summary

The majority of the potential additional environmental consequences resulting from the installation, operation and testing of the GSA can be categorized as insignificant because TVA's existing SD/ESP and AirPol's GSA process are essentially identical and the GSA is to replace the SD/ESP. However, two potential positive environmental impacts are identifiable: (1) the GSA may consume less lime than the existing system; (2) and may, therefore, generate less solid waste by-product.

5.0 PROJECT SCHEDULE

The project was amended in May of 1992 to reflect a one year delay in operation/testing phase, and was amended in October 1992 to reflect the project extension as a result of adding the fabric filter testing and air toxic testing to the project work scope. The final project schedule is presented as follows:

	Tasks	Period
	Phase I Tasks	
1.1	Proj./Contract Mgt.	11/01/90 - 12/31/91
1.2	Process Design	11/01/90 - 09/30/91
1.3	Environ. Analysis	11/01/90 - 09/30/91
1.4	Engineering Design	11/01/90 - 09/30/91
	Phase II Tasks	
2.1	Proj./Contract Mgt.	01/01/92 - 09/30/92
2.2	Proc./Furnish Matl.	01/01/92 - 04/30/92
2.3	Constr./Commission	05/01/92 - 09/30/92
	Phase III Tasks	
3.1	Project Management	10/01/92 - 09/30/93
3.2	Start-up/Training	10/01/92 - 10/14/92
3.3	Testing/Reporting	10/15/92 - 06/30/95

6.0 <u>EQUIPMENT</u>

6.1 EQUIPMENT SPECIFICATION

Equipment specification classified by different working areas with the design criteria is listed in Table 6.1-1 and identified on Figure 6.1. The reactor is designed for bottom inlet, which is included a dropout hopper and a double dump valve with motion sensor. The dropout section is for elimination of materials accumulated during start-up and shut-down of the system. The unit also includes rod out ports, access doors and a single view port. The separating cyclone is sized to handle the dried reaction products from the reactor. Approximately 99% of the dry solids collected are to be separated and discharged to the recirculation feed system. The remaining 1% is to be collected in the ESP/fabric filter as by-product. The bottom cone of the cyclone is to discharge directly into the recycle feeder box. Feeder box recycles approximately 99% of the solids back to the reactor via a multiple screw conveyor (10 inch diameter by 5 feet long), and an overflow screw conveyor is incorporated to discharge excess by-product for disposal. A ladder for access to the top of the unit is provided as part of the feeder box assembly. The box is designed for negative 18" pressure and a maximum temperature of 650 °F. The lower portion of the feeder box is provided with thermostatically-controlled electric heaters to prevent build-up.

Figure 6.1

PROCESS FLOW DIAGRAM FOR EQUIPMENT LIST
10 MW DEMONSTRATION OF GSA

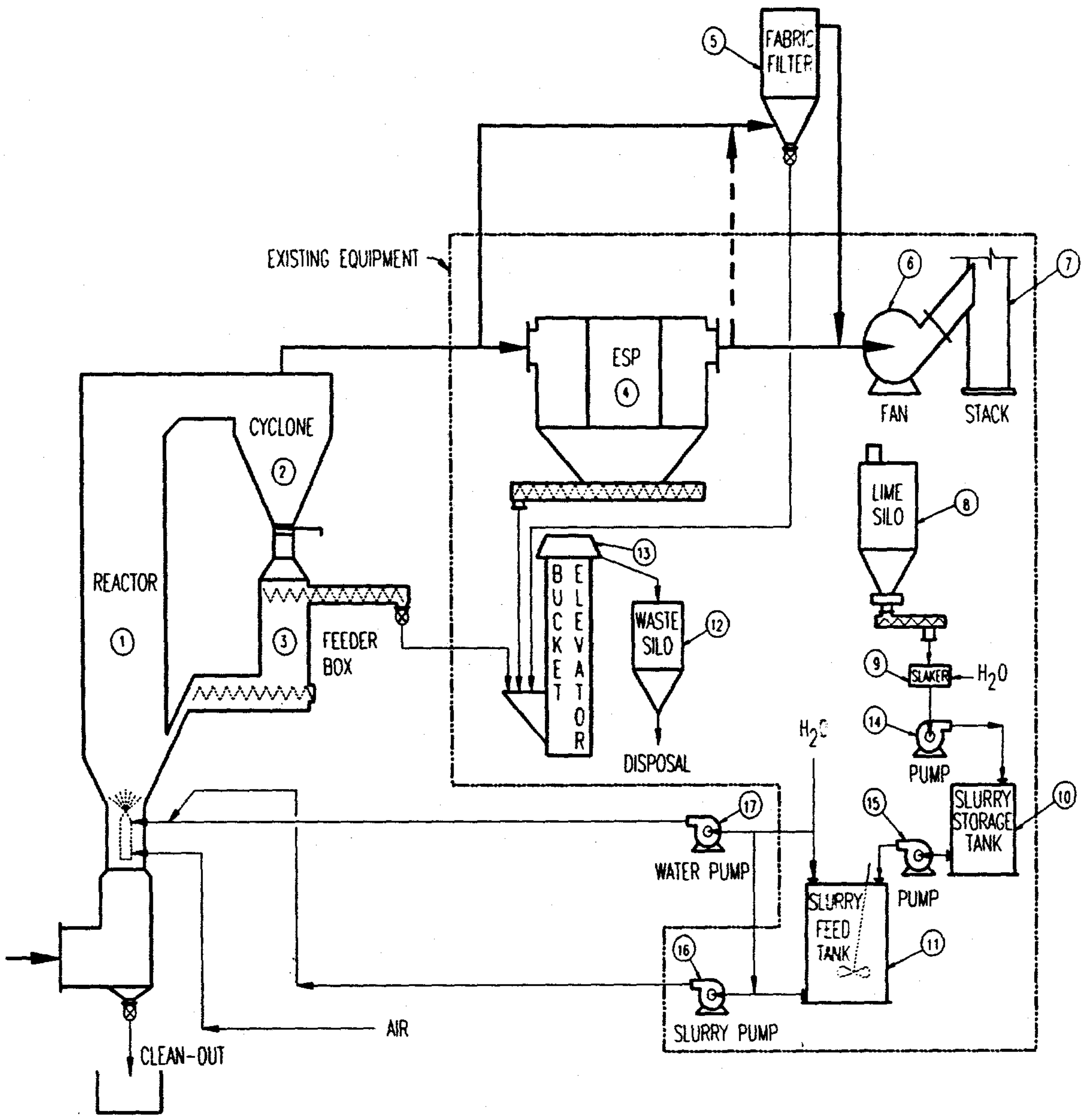


Table 6.1-1

EQUIPMENT DESIGN SPECIFICATION

Item No.	Item Name	Quantity	Design Characteristics	Material of Construction	Remark
GSA					
1.	Reactor	1	Temp.: 350 °F Press.: -25" WG Volume: 1,000 cu.ft.	A-36 C.S. 3/16" ASTM	Size: Proprietary
2.	Cyclone	1	Temp.: 350 °F Press.: -30" WG Volume: 740 cu.ft.	A-36 C.S. 3/16" Shell & 1/4" Top Plate, ASTM	Size: Proprietary
3.	Feeder Box	1	10" Dia. x 5 ft Screw Feeder 5" Round Rotary Valve, 1/2 HP	A-36 C.S. ASTM	Size: Proprietary
DUST COLLECTING & OTHERS					
4.	ESP	1	Total Collecting Area: 13,523 ft^2 No. of Fields: 4 Max. Static Pressure: -32"WG	Cor-Ten Grade A	Existing
5.	Fabric Filter	1	No. of Bags: 48 Air-to-cloth Ratio: 4 $acfm/ft^2$ Fabric Type: Dralon-T Max Oper. Temp.: 260 °F	-	Refer to the text for further description
6.	Fan	1	38,025 ACFM @ 41.9" WG	C.S.	Existing
7.	Stack	1	-	-	Existing

Table 6.1-1 (Continued)

Equipment Design Specification

Item No.	Item Name	Quantity	Design Characteristics	Material of Construction	Remark
REAGENT FEEDING & WASTE HANDLING					
8.	Lime Storage Silo	1	12' Dia. x 30'-6" 3,450 cu.ft.	A-36 C.S. ASTM	Existing
9.	Lime Slaker	1	2,000 lbs/hr	A-36 C.S. ASTM	Existing
10.	Lime Slurry Storage Tank	1	8'-1/2" Dia. x 21'-0", 1,055 cu.ft. 7,520 gals	S.S.	Existing
11.	Lime Slurry Feed Tank	1	10' Dia. x 9'-0" 707 cu.ft. 5,200 gals	C.S.R.L.	Existing
12.	Waste Silo	1	8'-9" Dia. x 9'-0" 540 cu.ft.	S.S.	Existing
13.	Bucket Elevator	1	10 tons/hr 55 ft.	A-36 C.S. ASTM	Existing
14.	Slaker Pump	1	-	S.S.	Existing
15.	Lime Slurry Storage Pump	1	35 gpm (max)	C.S.R.L.	Existing
16.	Lime Slurry Feed Pump	1 in Use, 1 Spare	15 gpm (max)	Hard Rubber Stator	Existing
17.	Water Pump	1	11 gpm (max) @ 60 psig	C.S.	Hose Type

Table 6.1-1 (Continued)

EQUIPMENT DESIGN SPECIFICATION

Item No.	Item Name	Quantity	Design Characteristics	Material of Construction	Remark
ACCESSARIES					
18.	Air Compressor	1	237 lbs/hr @ 100 psi	-	Existing
19.	Ductwork	GSA inlet: 65' GSA outlet:50' Stack inlet: Existing	Temp.: 320 °F Press.: -18"WG Temp.: 161 °F Press.: -28"WG Temp.: 154 °F Press.: -31"WG	A-36 C.S. ASTM A-36 C.S. ASTM A-36 C.S. ASTM	GSA inlet: 3'-8" Dia. GSA outlet: 3'-4" Dia. Stack inlet: Existing
20.	Insulation	2620 sq.ft.	6 inch Thick.	Fiber Glass	See the text
21.	Lagging	2620 sq.ft.	1 inch Thick.	Corrug. Alum. 22 Ga.	See the text
22.	Enclosure Siding & Roofing	-	10 ft x 20 ft x 63 ft (H) 1 inch Thick.	Corrug. Alum. 22 Ga.	-
23.	System Control	-	-	-	GSA control program incorporated into existing FOXBORO Control
24.	Instrumentation	-	-	-	See Table 6.1-2 for Instrumentation

Table 6.1-1 (Continued)

EQUIPMENT DESIGN SPECIFICATION

Item No.	Item Name	Quantity	Design Characteristics	Material of Construction	Remark
DESIGN CRITERIA					
25.	Wind Load	-	70 mph	-	-
26.	Seismic Load	-	Per ANSI Zone 3	-	-
27.	Live Load	-	100 psf	-	-
28.	Snow Load	-	15 psf	-	-
29.	Dust Density	-	75 lbs/cu.ft	-	-

Table 6.1-2

INSTRUMENT SPECIFICATION
10 MW DEMONSTRATION OF GSA

QTY	LOOP NO.	EQUIPMENT NO.	MANUFACTURER	MODEL NO.	INPUT	OUTPUT	SCALE RANGE	POWER REQ'D	ALARM LOW	ALARM LO-LO	ALARM HIGH	ALARM HI-HI	LOCATION	DESCRIPTION/COMMENTS
1	1	DPT-1	ROSEMOUNT	1151DR		4-20mA	-.5/+.5"W.C.	24VDC	-0.08"W.C.	-0.04"W.C.	-0.31"W.C.	-0.39"W.C.	FIELD	REACTOR DIFFERENTIAL PRESS.
1	2	DPT-2	ROSEMOUNT	1151DR		4-20mA	-2/0" W.C.	24VDC	-0.75"W.C.				FIELD	REACTOR VENTURI DIFFERENTIAL PRESS
1	1	PT-1	ROSEMOUNT	1151GP		4-20mA	0/-25"W.C.	24VDC					FIELD	INLET GAS PRESSURE
1	5	PT-5	ROSEMOUNT	1151GP		4-20mA	0/150 PSI	24VDC	80 PSI	70 PSI			FIELD	AIR PRESSURE
1	6	PT-6	ROSEMOUNT	1151GP		4-20mA	0/150 PSI	24VDC	50 PSI		90 PSI		FIELD	WATER PRESSURE
1	1	TT-1	ROSEMOUNT	244		4-20mA	0/400°F	24VDC					FIELD	INLET GAS TEMPERATURE
1	2	TT-2	ROSEMOUNT	244		4-20mA	0/300°F	24VDC					FIELD	REACTOR TEMPERATURE, CENTER
1	1	WT-1	KISTLER-MORSE	DISC II	WT.CELLS	4-20mA	0/4000 LB.	120VAC	1400 LB.	700 LB.			FIELD	FEEDER WEIGHT
1	5	TIC-5	SHIMADEN	SR27-2Y40000	RTD	4-20mA	0/400°F	120VAC	150°F				HTR CNTL ENCL	CYCLONE HEATER CONTROL (S.P. = 150°F)
1	6	TIC-6	SHIMADEN	SR27-2Y40000	RTD	4-20mA	0/400°F	120VAC	150°F				HTR CNTL ENCL	FEEDER HEATER CONTROL (S.P. = 150°F)

6.2 EQUIPMENT COST

Table 6.2 shows the breakdown equipment cost of the GSA system. The base year for the cost is 1991. Estimated costs are given for the lime preparation system and ash handling system as well as some of the auxiliary equipment, which were existing facilities.

Table 6.2

MAJOR EQUIPMENT COSTS
10 MW DEMONSTRATION OF GSA

Item No.	Item Name	Equipment Cost/Unit	Sales Tax/Unit	Freight Cost/Unit	Installation Cost/Unit	Total Cost/Unit	Quantity	Total Cost
GSA								
1	Reactor	$16,000	Incl'd in Eqpt. $	Incl'd in Eqpt. $	$235,200	$442,900	1	$442,900
2	Cyclone	$13,000	"	"	Incl'd in Item No.1	Incl'd in Item No.1	"	Incl'd in Item No.1
3	Feeder Box	$44,000	"	"	"	As Total Mechanical Equipment	"	As Total Mechanical Equipment
4	Injection Lance	$3,600	"	"	"	"	"	"
WASTE HANDLING								
5	Ash Handling System	$121,900	"	"	"	"	"	$121,900
ACCESSARIES								
6	Support/Access Steel	$85,000	"	"	"	"	"	"
7	Ductwork	$27,000	"	"	"	"	"	"

Table 6.2 (Continued)

MAJOR EQUIPMENT COSTS
10 MW DEMONSTRATION OF GSA

Item No.	Item Name	Equipment Cost/Unit	Sales Tax/Unit	Freight Cost/Unit	Installation Cost/Unit	Total Cost/Unit	Quantity	Total Cost
ACCESSARIES								
8	Roofing & Siding	$8,500	Incl'd in Eqpt. $	Incl'd in Eqpt. $	Incl'd in Item No.1	As Total Mechanical Equipment	1	As Total Mechanical Equipment
9	Expansion Joints	$5,200	"	"	"	"	"	"
10	Insulation	Incl'd in Install.	-0-	-0-	$78,200		"	$78,200
PUMPS AND PIPING								
11	Water Pumps	$5,700	Incl'd in Eqpt. $	Incl'd in Eqpt. $	Incl'd in Item No.13	Incl'd in Item No.13	"	Incl'd in Item No.13
12	Lime Slurry Pumps	$8,200	"	"	"	"	"	$8,200
13	Piping & Valves	$3,000	"	"	$5,600	$14,300	"	$14,300

Table 6.2 (Continued)

MAJOR EQUIPMENT COSTS
10 MW DEMONSTRATION OF GSA

Item No.	Item Name	Equipment Cost/Unit	Sales Tax/Unit	Freight Cost/Unit	Installation Cost/Unit	Total Cost/Unit	Quantity	Total Cost
INSTRUMENTATION AND OTHERS								
14	Instrument & Control	$11,000	Incl'd in Eqpt. $	Incl'd in Eqpt. $	Incl'd in Item No.15	Item No. 15	1	Incl'd in Item No.15
15	Electrical	$4,000	"	"	$30,700	-	"	$45,700
16	Foundation	-0-	-0-	-0-	$30,000	-	"	$30,000
LIME PREPARATION SYSTEM								
17	Lime Prep. System	Incl'd in Total $	Incl'd in Total $	Incl'd in Total $	Incl'd in Total $	Incl'd in Total $	"	$158,800
	TOTAL	**$231,400**	-	-	**$379,700**	-	-	**$900,000**

7.0 COSTS

7.1 PROJECT COSTS

The financing of the 10 MW Demonstration of GSA project is provided by TVA and AirPol Inc. with financial assistance from DOE under Cooperative Agreement No. DE-FC22-90PC-90542.

The budgeted cost of the project is $7,717,189. A breakdown of this total is shown in Table 7.1.

Table 7.1

PROJECT COST BREAKDOWN BY TASK
10 MW DEMONSTRATION OF GSA

ITEM	DESCRIPTION	COST
Precontract		$133,788
Phase I Tasks		
1.1	Project/Contract Management	$102,088
1.2	Process Design	$260,547
1.3	Environmental Analysis	$12,000
1.4	Engineering Design	$70,703
Phase II Tasks		
2.1	Project/Contract Management	$146,261
2.2	Procurement/Furnish Material	$472,174
2.3	Construction/Commission	$1,178,609
Phase III Tasks		
3.1	Project Management	$119,912
3.2	Start-up/Training	$12,174
3.3	Testing/Reporting	$4,202,343
TOTAL		$7,717,189

7.2 CAPITAL COSTS

Since the GSA demonstration unit will be retrofitted into an existing testing facility, the capital costs applicable to the demonstration project only pertain to new equipment added to the existing system. The new equipment items added are: flow diverting ductwork, GSA reactor and cyclone, feeder box, water pump and associated support, access and enclosure. The existing equipment reused for the demonstration project includes the followings: gas preheater and cooler, lime preparation system, lime pump, electrostatic precipitator, ash handling system, and I.D. fan. The demonstration unit is typical of a retrofitted GSA system in that the dust collector and the I.D. fan were existing. In order to present a complete cost picture for a retrofit system an estimated cost was included for the lime system and lime slurry pump, which existed at the demonstration site due to the presence of an existing spray dryer.

The installation cost for the demonstration system is grouped into mechanical and electrical segments, since this is usually how the construction work is contracted. Therefore no breakdown cost for installation of the individual equipment is available.

The breakdown of equipment and installation cost is shown in Table 6.2.

7.3 START-UP COSTS

Start-up costs are presented in accordance with the estimated basis since there are many miscellaneous items affecting the results. Operating labor and commodity costs constitute the major start-up costs. A breakdown of the estimated start-up costs is shown in Table 7.3.

7.4 OPERATING AND MAINTENANCE COSTS

A breakdown of the estimated operating and maintenance costs is shown in Table 7.4. The major cost items include process flues, sorbents, chemicals, water, auxiliary power, and waste disposal.

Table 7.3

START-UP COSTS
10 MW DEMONSTRATION OF GSA

Start-up Cost Element	Cost, $
Operating Labor Cost	100,000
Maintenance and Materials Cost	10,000
Administrative and support Cost	5,000
Commodity Cost	100,000

* Includes process fuels, sorbents, chemicals, water, auxiliary power, and waste disposal.
* Base year: 1991

Length of Start-up Period, (months)	1.5 Months

Table 7.4

OPERATING AND MAINTENANCE COSTS
10 MW DEMONSTRATION OF GSA

ANNUAL FIXED OPERATING COST	
Operating Labor Cost Details Number of Operators per Shift: 2 Number of Shifts per Week: 21 Operating Pay Rate per Hour 35	**Cost, $/yr**
1. Total Annual Operating Labor Cost	613,200
2. Total Annual Maintenance Labor Cost	500,000
3. Total Annual Maintenance Material Cost	50,000
4. Total Annual Administrative and support Labor Cost	200,000
5. **TOTAL ANNUAL FIXED O & M COST**	1,363,200

VARIABLE OPERATING COST				
Commodity*	**Unit**	**$/Unit**	**Quantity/hr**	**Cost $/hr**
Electricity	KW Hr	0.04	400	16
Water	Gal.	1.00	540	540
Lime	Ton	70	0.4	28
Waste Disposal	Ton	6	0.96	5.76
TOTAL VARIABLE OPERATING COST				589.76

* Includes process fuels, sorbents, chemicals, water, auxiliary power, and waste disposal.
* Base year: 1991

8.0 PROJECTED PERFORMANCE

8.1 PROJECTED TECHNICAL PERFORMANCE

The projected technical performance of the GSA system in removal of acid gases from the boiler flue gas is summarized as follows:

	System Inlet	System Outlet	Efficiency
SO_2 (lb/hr)	388.91	31.23	91.97 %
HCl (lb/hr)	2.21	0	100 %

8.2 PROJECTED ENVIRONMENTAL PERFORMANCE

8.2.1 Projected Environmental Performance in Air Quality

Since the GSA is expected to be more efficient in SO_2 removal than the existing spray dryer unit, the air quality is expected to be improved by the implementation of this project.

8.2.2 Projected Environmental Performance in Water Quality

There will be no liquid discharge from the GSA system.

8.2.3 Projected Environmental Performance in Solid Waste Quality

The solid waste by-product resulting from the operation of the GSA unit is expected to have the same composition as the spray dryer waste by-product. In keeping with the existing practices, these non-recycled solids will be diluted with water to generate a slurry containing approximately 10% solids before being pumped to an existing ash pond for ultimate disposal. Changes in ash pond effluent as a result of the operation of the GSA are not expected.

8.3 PROJECTED ECONOMICS

The economics of the GSA system is projected as a general comparison to a conventional spray dryer and a wet system.

A comparison of the space to be occupied by the GSA to the existing spray dryer test unit shows that the space requirement of a GSA is much lower than that of a spray dryer. Due to its comparatively simple design and less number of equipment, the GSA is projected to be more economical than the spray dryer in capital cost. Based on the fact that the GSA has less number of power consuming equipment and is expected to achieve higher removal efficiency as compare to the spray dryer, the GSA is projected to be more economical in operating cost.

It has been projected that the capital cost for a GSA system is lower below the 1,000,000 ACFM range, where the wet system becomes less expensive.

The space requirements and disposal costs are higher for the wet system. The operating cost of a GSA system is close to the wet system.

A detailed economic analysis and evaluation of the GSA process will be conducted upon completion of the demonstration project.

9.0 COMMERCIAL APPLICATIONS

One of the objectives of this demonstration project is for AirPol to establish its capability in designing, fabricating, and constructing the GSA system so that the demonstrated technology can be effectively commercialized for the benefit of the U.S. electric utility and industrial markets.

It is known that the site specific factors and coal properties could affect GSA system design. Although GSA system is much more suitable for the retrofit application, the layout and arrangement of equipment is still affected by the availability of the space. Wind load and seismic factors will influence the material thickness and necessary supports, and finally will impact the overall cost of the system.

Coal composition plays an important role in the initial design. The sulfur in the coal yields sulfur dioxide on combustion. The higher the sulfur content, the greater the quantity of sulfur dioxide produced. In order to meet a specified SO_2 emission requirement, the SO_2 removal efficiency will be greater at higher inlet SO_2 concentrations. This, in turn, will affect the operating parameters such as outlet temperature and lime consumption rate, and hence equipment sizing. Chlorine, moisture and ash content of the coal will also have some influence on the design. It is known that chlorine in the coal will form hydrogen chloride gas upon combustion, and calcium chloride on neutralization with lime. Up to a point and under certain operating conditions, calcium chloride has proven to be beneficial to the GSA system, thereby reducing lime consumption. Moisture in the coal, and hence in the flue gas will aid in determining the flue gas saturation temperature. A water balance and then be conducted accordingly. Ash content may influence the solid recirculation rate and also the solid handling equipment.

During the course of designing the demonstration unit, an effort was made by AirPol to standardize the process design, equipment sizing, and detailed design so that the installation of a commercial unit can be accomplished within a relatively short time frame. An effort was also made during the design phase to achieve simplicity in the equipment design, which later proved to contribute to reduced material and construction costs. With the confidence, the GSA system is capable of achieving the required levels of performance.

The domestic market for this technology appears to be limited at the present time. The current unknown status of clean air act regulations as to level of cleaning requirements and the timing for meeting the requirement offers a serious problem in entering the market. Will the requirements be limited to only larger units? How much improvement in gas cleaning is needed by these units to reach compliance? These uncertainties make the market extremely difficult to quantify at this time. Currently we project the major market for GSA to develop between the year 2000 to 2010.

AirPol anticipates a market size of one (1) domestic order for a smaller boiler over the next five (5) years. The market should then grow at a 50 percent rate per year over the following ten (10) years. The order for the GSA technology are expected to grow from \$3 ~ 5 million to \$15 ~ 30 million.

AirPol is currently soliciting both utility and industrial boiler projects*.

*The City of Hamilton, Ohio, with a grant received from the Ohio Coal Board in 1994, is proceeding with a 50 MW GSA installation at its municipal power plant. The unit is scheduled for operation in 1996.

10.0 CONCLUSIONS

During the design phase and construction phase, the effort has been aimed at the proper development of the GSA technology for the successful installation of the demonstration unit. Having accomplished the design and construction of the demonstration unit, effort is now made on optimizing the GSA for maximum operating efficiency and economics.

As presented in the this report, the GSA process has been designed with proper considerations for existing site condition, cost economization, environmental impact and operation concerns. The demonstration unit is expected to achieve all the projected performance and be commercialized in time for the intended market.

It is expected that this demonstration project will truly fulfill the goal of the Clean Coal Technology Program.

11.0 REFERENCES

1. Comprehensive Report to Congress Clean Coal Technology Program, 10 MW Demonstration of Gas Suspension Absorption. U.S. Department of Energy, Assistant Secretary for Fossil Energy, Office of Clean Coal Technology, July 1990.

2. Environmental Information Volume, 10 MW Demonstration of Gas Suspension Absorption, Clean Coal Technology III Program. AirPol Inc., Tennessee Valley Authority.

3. The Clean Coal Technology Program: 10 MW Demonstration of Gas Suspension Absorption for Flue Gas Desulfurization, Frank E. Hsu, Sharon K. Marchant.