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LIFAC DEMONSTRATION
AT
RICHMOND POWER AND LIGHT
WHITEWATER VALLEY UNIT #2:
PUBLIC DESIGN REPORT VOLUME 2:
PROJECT PERFORMANCE AND ECONOMICS

Sponsored by:

U.S. Department of Energy
LIFAC North America
Richmond Power and Light
State of Indiana
Electric Power Research Institute
Black Beauty Coal Company

Cooperative Agreement No. DE-FC22-90PC90548

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ABSTRACT

This publication discusses the demonstration of the LIFAC sorbent injection technology at Richmond Power and Light's Whitewater Valley Unit No. 2, performed under the auspices of the U.S. Department of Energy's (DOE) Clean Coal Technology Program. LIFAC is a sorbent injection technology capable of removing 75 to 85 percent of a power plant's SO₂ emissions using limestone at calcium to sulfur molar ratios of between 2 and 2.5 to 1.

The site of the demonstration is a coal-fired electric utility power plant located in Richmond, Indiana. The project is being conducted by LIFAC North America (LIFAC NA), a joint venture partnership of Tampella Power Corporation and ICF Kaiser Engineers, in cooperation with DOE, RP&L, and Research Institute (EPRI), the State of Indiana, and Black Beauty Coal Company.

The purpose of *Public Design Report Volume 2: Project Performance and Economics* is to consolidate, for public use, the technical efficiency and economy of the LIFAC Process. The report has been prepared pursuant to the Co-operative Agreement No. DE-FC22-90PC90548 between LIFAC NA and the U.S. Department of Energy.

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LIST OF ABBREVIATIONS, ACRONYMS AND TERMS

CaCO_3	Calcium carbonate
CaO	Calcium oxide
CaSO_3	Calcium sulfite
CaSO_4	Calcium sulfate
Ca(OH)_2	Calcium hydroxide, hydrated lime
Ca/S	Calcium/sulfur molar ratio
CCT	Clean Coal Technology
DOE	Department of Energy
EER	Energy and Environmental Research Center
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ESP	Electrostatic precipitator
FGD	Flue Gas Desulfurization
ICF KE	ICF Kaiser Engineers
ID fan	Induced draft fan
LIFAC	Limestone Injection into the Furnace with Activation of unreacted Calcium oxide (Registered trademark of Tampella desulfurization process)
LIFAC NA	LIFAC - North America partnership
LIMB	Lime Injection to Multistage Burner, registered trademark of EPA desulfurization process
LNCFS	Low- NO_x Concentric Firing System
MgCO_3	Magnesium carbonate
NO	Nitrogen oxide
NO_x	Nitrogen oxides
O_2	Oxygen
PLC	Programmable Logic Control
PMS	Process Monitoring System
RP&L	Richmond Power & Light
SCA	Specific collecting area
SO_2	Sulfur dioxide
SO_3	Sulfur trioxide
ΔT	Temperature difference between actual flue gas temperature and saturation temperature (Approach to saturation)
Injection	Pulverized limestone injection into the furnace through several injection nozzles at the furnace walls
Activation	Activation of the remaining CaO particles with water for further sulfur dioxide capture
Recycling	Recycling of ash and sorbent from ESP hoppers back to the reactor inlet ductwork

EXECUTIVE SUMMARY

The Clean Coal Technology Program (CCT) has been recognized in the National Energy Strategy as a major initiative whereby coal will be able to reach its full potential as a source of energy for the nation and the international marketplace. Attainment of this goal depends upon the development of highly efficient, environmentally sound, competitive coal utilization technologies responsive to diverse energy markets and varied consumer needs. The CCT Program is an effort jointly funded by government and industry whereby the most promising of the advanced coal-based technologies are being moved into the marketplace through demonstration. The CCT Program is being implemented through a total of five competitive solicitations.

LIFAC North America, a joint venture partnership of ICF Kaiser Engineers, Inc. and Tampella Power Corporation, is currently demonstrating the LIFAC flue gas desulfurization technology developed by Tampella Power. This technology provides sulfur dioxide emission control for powerplants, especially existing facilities with tight space limitations. Sulfur dioxide emissions are expected to be reduced by up to 85% by using limestone as a sorbent. The LIFAC technology is being demonstrated at Whitewater Valley Unit No. 2, a 60-MWe coal-fired powerplant owned and operated by Richmond Power and Light (RP&L) and located in Richmond, Indiana. The Whitewater plant consumes high-sulfur coals with sulfur contents ranging from 2.0 - 2.9 percent.

The project, co-funded by LIFAC North America and DOE, is being conducted with the participation of Richmond Power and Light, the State of Indiana, the Electric Power Research Institute, and the Black Beauty Coal Company. The project has a total cost of 21.4 million dollars and a duration of 48 months from the preliminary design phase through the testing program.

The sponsors of this project believe that LIFAC has the potential to be a new and important SO₂ control option for U.S. utilities subject to the Clean Air Act's acid rain regulations. To be considered as a commercially feasible option in this particular emissions control market, LIFAC must demonstrate a high SO₂ removal rate while remaining competitive with other options on a cost per ton of SO₂ removed basis.

The LIFAC system combines conventional limestone injection into the upper furnace region with a post-furnace humidification reactor located between the air preheater and the ESP. The process produces a dry, stable waste product that is removed from both the bottom of the humidification reactor and the ESP.

Finely pulverized limestone is pneumatically conveyed and injected into the upper region of the boiler where temperatures are approximately 1800 to 2200 degrees Fahrenheit. At these temperatures the limestone (CaCO₃) calcines to form lime (CaO) which readily reacts with the SO₂ to form calcium sulfate (CaSO₄). Most of the sulfur trioxide (SO₃) reacts with the CaO to form CaSO₄.

Approximately 25 percent of the sulfur dioxide removal occurs in the boiler with the remaining 75 percent and the unreacted lime passing through the air preheater to the vertical elongation of ductwork known as the LIFAC activation reactor. There the flue gas is sprayed with atomized water that allows the unreacted lime to hydrate to Ca(OH)_2 which more readily reacts with the sulfur dioxide and forms CaSO_3 . A combination of the proper water droplet size and residence time allows for effective hydration of the lime and complete water evaporation to create a dry reactor bottom product.

After exiting the humidification reactor, the flue gas is reheated before entering the ESP. Sixty percent of the LIFAC-produced spent sorbent and fly ash is collected by the ESP with the other 40 percent collected by the humidification reactor. Both the reactor and ESP ash may be recycled to a point ahead of the reactor to improve sorbent utilization and to improve the SO_2 removal efficiency of the system to the range of 75 to 85 percent.

LIFAC is similar to other current sorbent injection technologies but has unique advantages with its use of a patented vertical humidification reactor. And while LIFAC's sulfur dioxide removal efficiency is not as high as traditional wet flue gas desulfurization systems, its cost and simplicity of design, construction and operation offer other advantages over these alternative systems. In particular the advantages of the LIFAC system are:

- High SO_2 removal rates - Currently available sorbent injection systems have been unable to sustain high SO_2 removal rates with any consistency. LIFAC has proven in the past and is demonstrating during this project the ability to achieve and sustain high SO_2 removal rates of 75 to 85 percent over long operating periods.
- By-products - Wet lime and limestone scrubbing systems create a wet byproduct ash that must be further treated before disposal. LIFAC produces a dry solid waste ash containing calcium sulfide, calcium sulfate and fly ash. This waste is easily disposed of under U.S. regulatory requirements, may be recycled to increase LIFAC's efficiency and may have commercial applications in the construction material industry.
- Compatibility and Adaptability - LIFAC has minimal impact on the host's site and systems, primarily the boiler, ESP and ID fan. In addition, LIFAC requires little space and few utilities and therefore is easily installed even in small or cramped powerplant sites.

Construction of the LIFAC system occurred in two phases over a period of one and a half years. The first phase of construction was completed during a routine plant outage in March, 1991. This period was utilized to install tie-ins to the host site's existing systems.

Ductwork and three dampers were installed between the air preheater and ESP to allow flue gas flow to the LIFAC activation reactor. Tie-ins were also made to the powerplant's steam, condensate and river-water supplies.

The medium-pressure steam is required to reheat the flue gas exiting the LIFAC reactor and the water is needed for flue gas humidification inside the reactor. Injection ports were also installed in the boiler walls about 10 feet above the nose elevation.

The second phase of construction began in the Fall of 1991 with the driving of reactor piling and the installation of underground conduit runs. Work continued through to the Summer of 1992 with no need for plant downtime other than normally scheduled outages. During this time the limestone storage area was completed and the injection system was installed on Unit #2. The activation reactor was constructed and then tested with both cold air during a scheduled Unit #2 outage and hot flue gas during a low electricity demand period. Other powerplant tie-ins such as the steam and condensate system were also tested during low demand periods in the evenings or on weekends.

All of the construction work associated with the LIFAC system was performed in close proximity to the exterior of the powerplant or in cramped areas inside the plant. The ductwork tie-ins and new steelwork required inside the plant are located in small, difficult to access work areas. The reactor structure is approximately ten feet from the powerplant with the outside ductwork and piping crossing ovetop of offices and the plant maintenance area. All of these new structures and equipment were constructed with no interference to daily plant operations.

The schedule for the LIFAC demonstration program extended over a four year period from the beginning of preliminary design in August 1990 through the testing program to be completed in early August 1994. The LIFAC system was originally scheduled to come on-line in June of 1992 but due to delays in receiving construction permits and some minor startup problems, this date was moved to March 1993. Testing was performed through the summer of 1994.

The test plan for the LIFAC demonstration was composed of five distinct phases, each with its own objective. The first of these phases consisted of the initial baseline testing portion of the project. Measurements were taken to characterize the operation of the host boiler and associated subsystems prior to the use of the LIFAC system. The results were used for comparison purposes with the LIFAC system in operation and with data collected at the end of the project to determine any changes in the host's systems.

The second, or parametric, phase of testing was performed to determine the best combination of LIFAC process variables for SO₂ removal. The variables studied included the limestone injection nozzles' angle and location, the Ca/S molar ratio, the need for supplemental injection air at the boiler, the water droplet size and injection nozzle arrangement in the reactor, the ash recycling ratio and the approach to saturation temperature of the flue gas exiting the activation reactor. The best combination of these variables were then chosen at the conclusion of this phase and used for the remainder of the test program.

Optimization tests were conducted to examine the effects of different coal and limestone feeds on the SO₂ capture rate. Coals with sulfur contents as high as 3.3 percent were tested to determine LIFAC's compatibility with high sulfur U.S. coals. Limestones with different compositions were also tested to determine the LIFAC system's adaptability to local sorbent sources.

Long-term testing was also performed to demonstrate LIFAC's performance under commercial conditions. The LIFAC system was in operation 24 hours per day for several weeks using the powerplant's baseline coal, high calcium limestone and the optimum combination of process variables. In addition to process performance measurements, during this phase the operation and maintenance requirements of the system were examined.

The final phase of testing consisted of the post-LIFAC tests. The baseline tests were repeated to gather information on the condition of the boiler and its associated subsystems. Comparisons were made to the original baseline data to identify any changes either caused by the LIFAC system or independent of its operation.

It has been shown at RP&L and other LIFAC installations that the system can be installed without effecting normal powerplant operations. The demonstration proved that the system can economically reduce SO₂ emissions when compared with other flue gas desulfurization technologies.

1.0 PROJECT OVERVIEW

1.1 Purpose of the Project Performance and Economics Report

The purpose of this Project Performance and Economics Report is to provide a technical and economic overview of the LIFAC desulfurization project. The report shall serve as a reference for the demonstration technology and its future commercialization. Final Report Volume 2: Project Performance and Economics has been prepared pursuant to the Co-operative Agreement No. DE-FC22-90PC90548 between LIFAC NA and DOE titled "LIFAC Demonstration at Richmond Power and Light Whitewater Valley Unit #2."

1.2 Description of the Project

1.2.1 Project History

In 1983, Finland enacted acid rain legislation which applied limits on SO₂ emissions sufficient to require that flue gas desulfurization systems have the capability to remove about 80 percent of the sulfur dioxide in the flue gas. This level could be met by conventional wet limestone scrubbers but not by then available sorbent injection technology. Tampella, therefore, began developing an alternative sorbent injection system which resulted in the LIFAC process.

In 1986, the first full scale test was performed at Imatran Voima's Inkoo power plant using a 70 megawatt side-stream from a 250 megawatt boiler. A 76 percent SO₂ removal rate with 1.5% sulfur coal was reached. A second LIFAC activation reactor was constructed to handle an additional 125 megawatt sidestream. This newer reactor is achieving removal rates of 75 to 80 percent while using Ca/S molar ratios of between 2 and 2.5 to 1. Also, in 1988 the first tests with high sulfur U.S. coals were run at the Neste Kullo Laboratory. A Pittsburgh No. 8 Seam coal containing 3 percent sulfur was tested and an SO₂ removal rate of 77 percent was achieved at a Ca/S molar ratio of 2 to 1.

The U.S. Department of Energy has emphasized the use and further development of coal as an energy source for utilities and the industrial sector. At the same time environmental responsibility has been mandated by the passage of the Clean Air Act Amendments of 1990. This Act establishes new lower emission levels of sulfur dioxide from utility powerplants with Phase One of the regulations coming into effect in January 1995 and the more stringent Phase Two regulations beginning in January 2000. To realize full potential of coal as an energy source while still complying with the new air pollution regulations, the Department of Energy initiated the Clean Coal Technology (CCT) Program.

The CCT Program is an effort jointly funded by DOE and private industry whereby the most promising clean coal technologies are moved to the marketplace through demonstration. Five rounds of competitive solicitations comprise the CCT Program with four of these rounds having been completed. The LIFAC system was one of thirteen projects selected for funding under Round III of the CCT Program and a Cooperative Agreement between DOE and LIFAC-NA was signed in November, 1990. Due to scheduled outages at the host site, Richmond Power & Light's (RP&L) Whitewater Valley Unit #2 in Richmond, Indiana, design and procurement of critical equipment began in August 1990, with DOE funding contingent on final signing of the Cooperative Agreement.

1.2.2 Project Organization

The LIFAC demonstration is being conducted by LIFAC North America, a joint venture partnership between ICF Kaiser Engineers and Tampella Power Corporation. ICF KE is a U.S. company based in Oakland, California, and a subsidiary of ICF Kaiser International, Inc. based in Fairfax, Virginia. Tampella Power is a subsidiary of a large diversified international company, Tampella Corporation, based in Tampere, Finland and the original developer of the LIFAC technology.

LIFAC NA is responsible for the overall administration of the project and for providing the 50 percent matching funds. With the exception of project administration, most of the actual work is being performed by the two parent firms under service agreements with LIFAC NA. Both parent firms work closely with Richmond Power and Light and the other project team sponsors, including ICF Resources, the Electric Power Research Institute (EPRI), Indiana corporation for Science and Technology (ICS&T), and Black Beauty Coal Company. LIFAC NA is having ICF Kaiser Engineers manage the demonstration project out of its Pittsburgh office, which provides excellent access to the DOE representatives of the Pittsburgh Energy Technology Center. A project organization chart is provided in Figure 1-1.

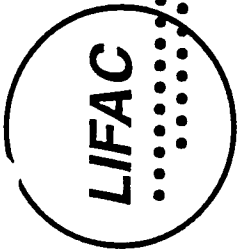
1.2.3 Host Site

The project site for the LIFAC demonstration is Richmond Power and Light's Whitewater Valley Unit 2 pulverized coal-fired power station (60MW), located in Richmond, Indiana. Richmond is approximately 75 miles east of Indianapolis, Indiana and nearly 40 miles west of Dayton, Ohio. Whitewater Valley Unit 2, which began service in 1971, is a Combustion Engineering, tangentially-fired boiler which uses high-sulfur bituminous coal from Western Indiana. Actual power generation produced by the unit approaches 65 megawatts.

Whitewater Valley 2 has several important qualities as a LIFAC demonstration site. One of these is that Whitewater Valley 2 was the site of a prior joint EPA/EPRI demonstration of LIMB sorbent injection technology. Much of the sorbent injection equipment remains on site and is being used in the LIFAC demonstration. Another advantage of the site is that Whitewater Valley 2 was a challenging candidate for a retrofit due to the cramped conditions at the site. The plant is thus typical of many U.S. power plants which are potential sites for application of LIFAC. In addition, the Whitewater Valley 2 boiler is small relative to its capacity; hence, it has high-temperature profiles relative to other boilers. This situation requires sorbent injection at higher points in the furnace to minimize deadburning of the reagent, but it decreases residence times needed for sulfur removal. Whitewater Valley 2 will show LIFAC's performance under operational conditions most typical of U.S. power plants. The project will demonstrate LIFAC on high-sulfur U.S. coals and is a logical extension of the Finnish demonstration work which is important for LIFAC's commercial success in the U.S.

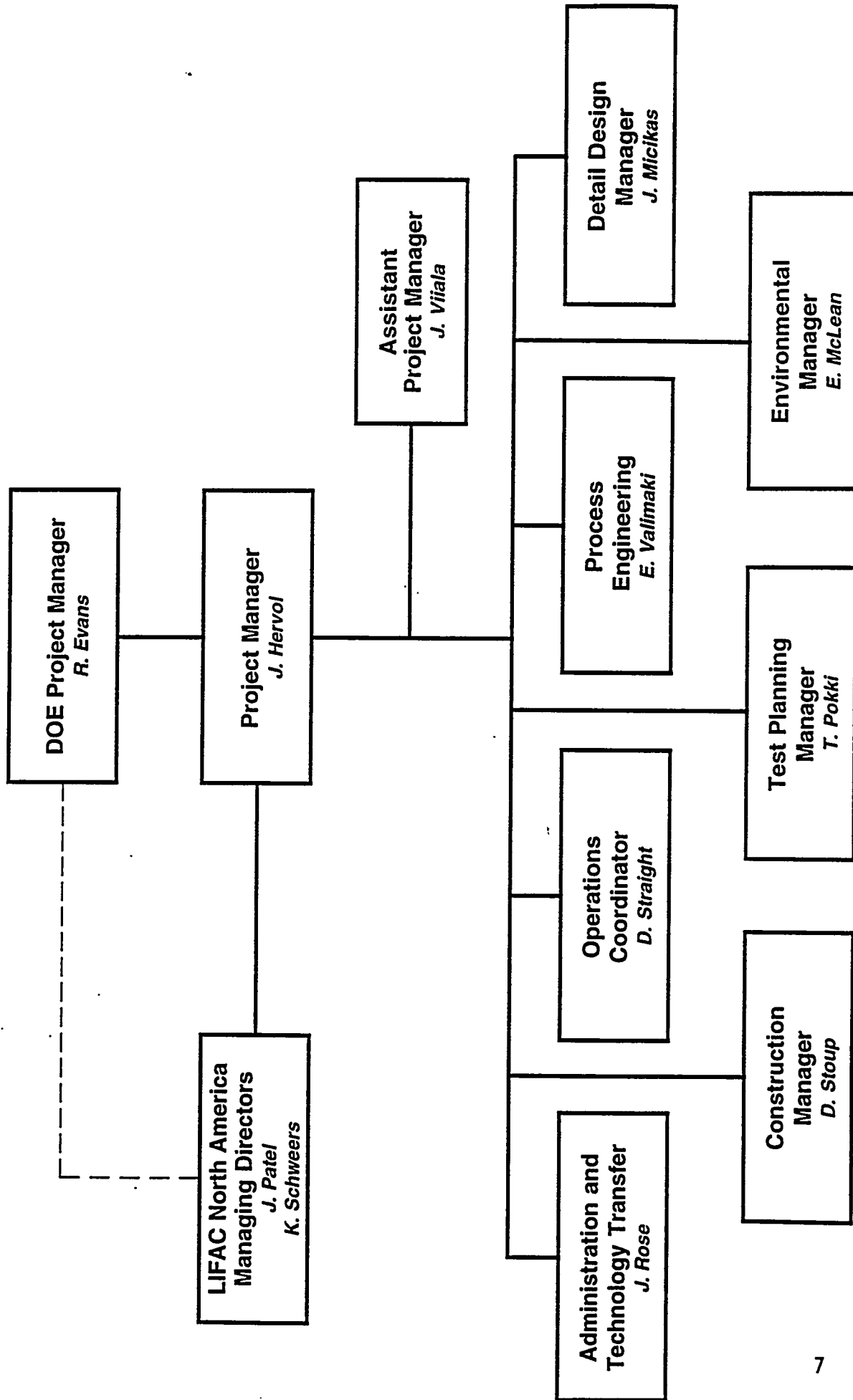
1.2.4 Project Schedule

To demonstrate the technical viability of the LIFAC process to economically reduce sulfur emissions from the Whitewater Valley Unit No. 2, LIFAC NA is conducting a three-phase project.



Project Organization (Revised July 1991)

Figure 1-1



Phase I: Design
Phase IIA: Long Lead Procurement
Phase IIB: Construction
Phase III: Operations

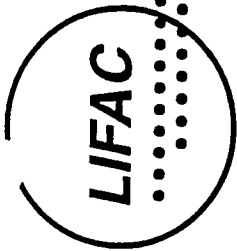
Except Phase IIA, each phase is comprised of three (3) tasks, a management and administration task, a technical task and an environmental task. The design phase began on August 8, 1990 and was scheduled to last six (6) months. Phase IIA, long lead procurement, overlaps the design phase and was expected to require about four (4) months to complete. The construction phase was then to continue for another seven (7) months, while the operations phase was scheduled to last about twenty-six (26) months. Figure 1-2 shows the original estimated project schedule which is based on an August 8, 1990 start date and a planned outage of Whitewater Valley 2 during March 1991.

It is during this outage that all the tie-ins and modifications to existing Unit No. 2 equipment were made. This required that the construction phase begin in early February, 1991 and be completed by the end of August 1991. Operations and testing were to begin in September 1991 and continue for 26 months. However, the project encountered delays in receiving its construction permit. These delays, along with some design changes, and an approved expansion in project scope required that the Design Phase be extended by about eleven months. Therefore, construction was not completed until early June 1992. This represents a nine-month extension in the overall schedule. During the last half of 1992, problems were encountered during startup and commissioning of some of the LIFAC components and systems. These problems required the parametric tests to be delayed until the first quarter 1993 which subsequently required adjustments in the entire testing schedule. During the initial parametric tests conducted, problems were encountered with increased opacity levels. These problems forced an extension in the parametric test schedule, and consequently, an adjustment was made to the testing schedule as shown in Figure 1-3. These delays, however, will not impact the overall duration of the Operations Phase and the total project duration will remain at 48 months.

1.3 Project Objectives

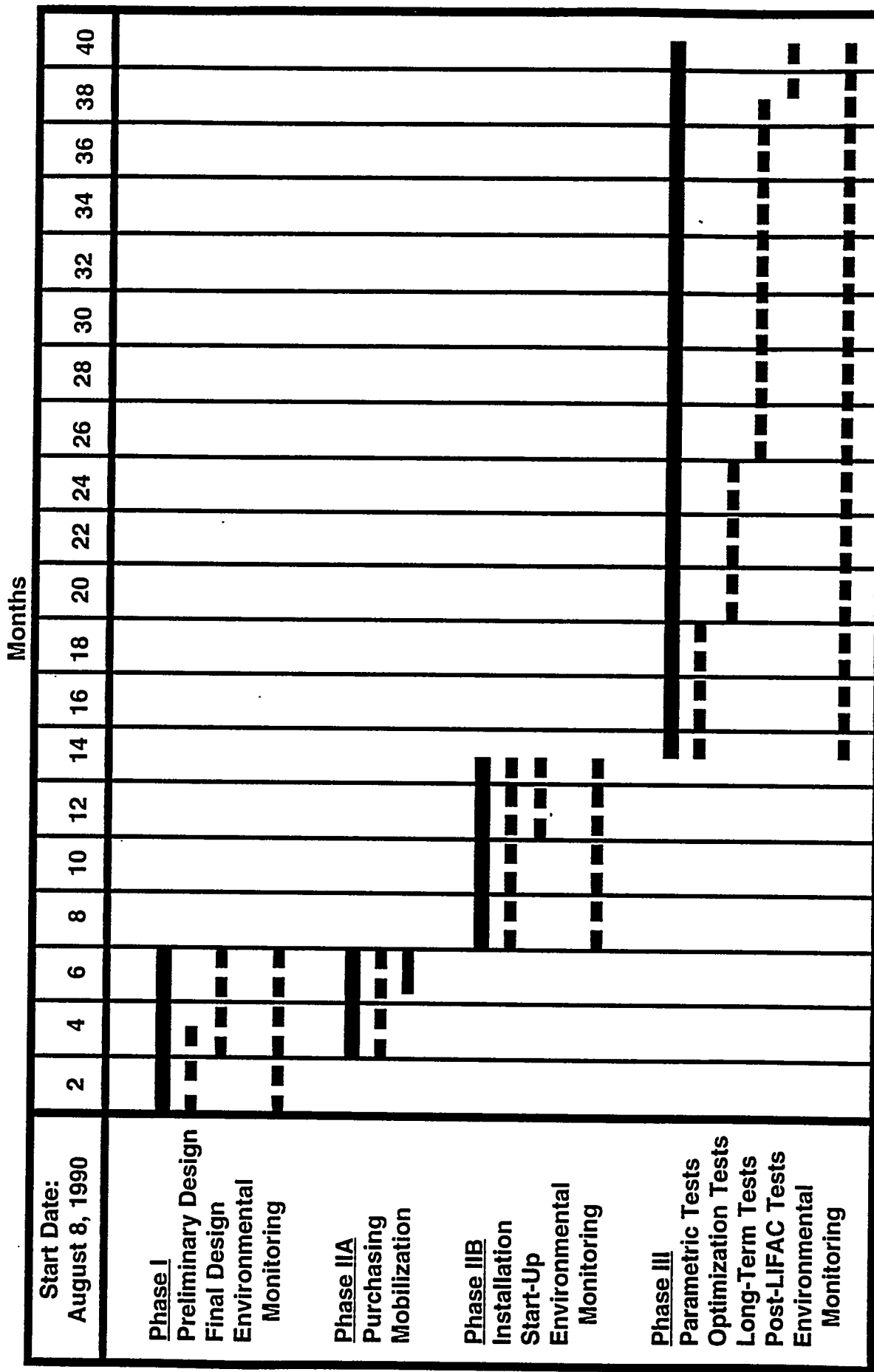
The sponsors of this project believe that LIFAC has the potential to be a new and important SO₂ control option for U.S. utilities subject to the Clean Air Act's acid rain regulations. To be considered as a commercially feasible option in this particular emissions control market, LIFAC must demonstrate a high SO₂ removal rate while remaining competitive with other options on a cost per ton of SO₂ removed basis. To this end, the sponsors of this project have designed the demonstration with the following objectives in mind:

- **Sustained High SO₂ Removal Rate** - Incorporated into the test plan are several periods of long-term testing which are intended to demonstrate LIFAC's SO₂ removal and reliability characteristics under normal operating conditions.
- **Cost** - LIFAC must compete with both low capital cost, low SO₂ removal rate options such as sorbent injection and high capital cost, high SO₂ removal rate options such as wet scrubbing. This project will demonstrate LIFAC's competitiveness on a cost per ton of SO₂ removed basis with these currently available alternatives.



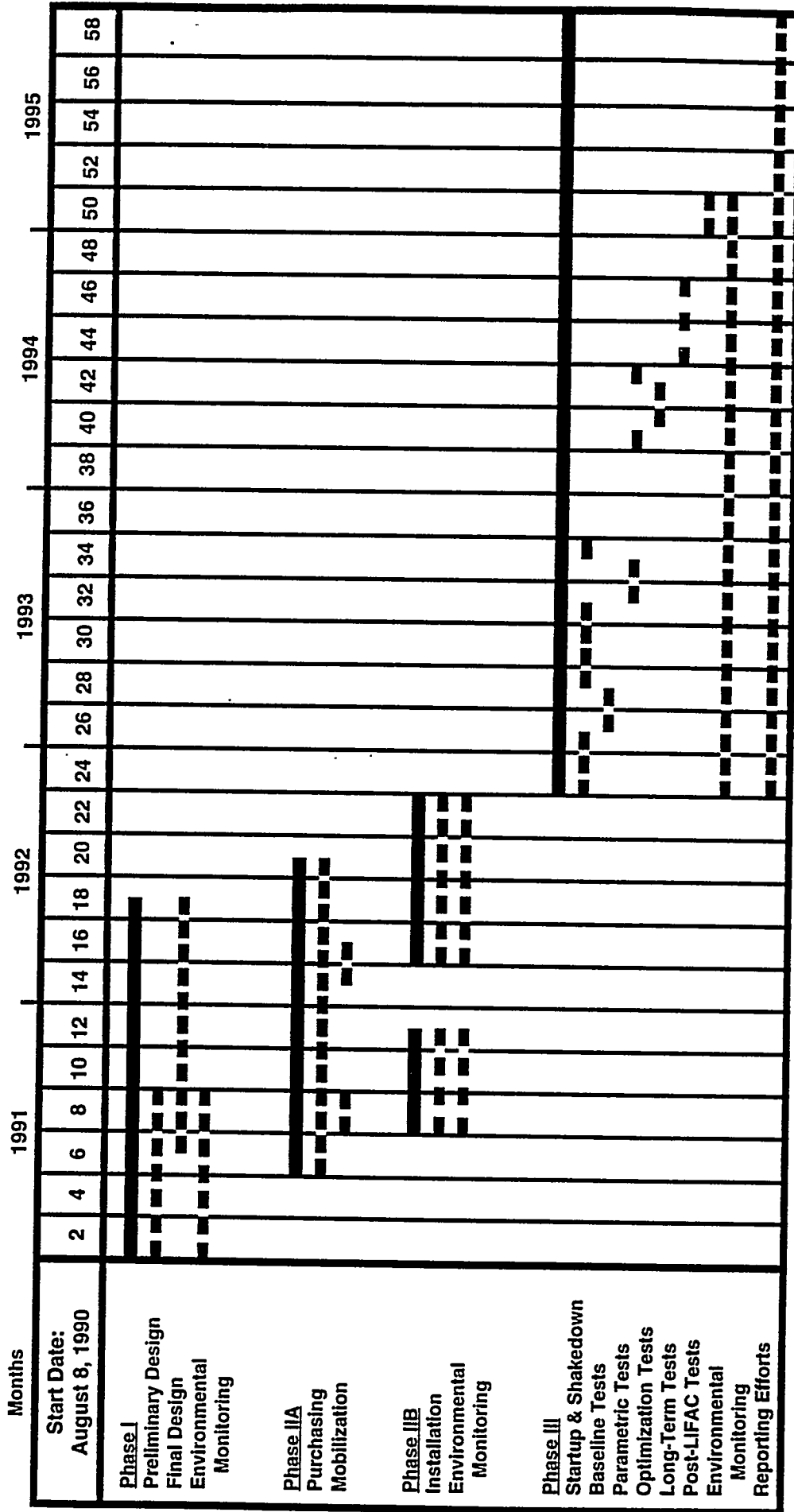
LIFAC Demonstration
Original Project Schedule

Figure 1-2



LIFAC Demonstration **Current Project Schedule** (Revised July 1994)

Figure 1-3



PM39/LIFAC94

- **Retrofit Adaptability** - The host site chosen required a retrofit with tight construction conditions that will prove LIFAC's ability to be installed where other technologies might not be possible. Construction will also demonstrate LIFAC's ability to be built and brought on-line with zero plant down time other than scheduled outages.
- **System Compatibility** - A major concern of utilities is the degree of compatibility of SO₂ removal systems with their existing operations. This demonstration will show LIFAC's minimal impact on the host site's boiler and associated subsystems.

1.4 Significance of the Project

1.4.1 Potential for Commercialization

Wet Scrubbers are the most prevalent scrubber technology and account for approximately 90% of U.S. scrubber systems. Wet FGD systems that use lime or limestone remove about 90% of the SO₂ and usually produce a sulfite/sulfate sludge waste product. Although the LIFAC process cannot match the high removal rates (90%) achieved by conventional wet scrubbers, the process does offer several advantages including:

- The technology can be more easily retrofit onto most powerplants because the vertical activation chamber requires less space.
- The technology has lower capital costs which is especially attractive to existing plants that have fewer years to amortize capital investments as compared to new long-lived powerplants.
- The technology uses a widely available reagent material, limestone, rather than more expensive materials such as lime.
- The need for slurry preparation/handling equipment is eliminated.
- The waste product is dry and easy to handle. In comparison, conventional wet limestone scrubbers produce a wet sludge which requires special handling and treatment.
- The technology is typically compatible with other plant systems such as ESPs and ID fans, thereby minimizing costly retrofit plant modifications in order to employ the technology.

The LIFAC system also has potential advantages over less conventional sorbent injection systems now being tested. These include:

- Use of limestone as opposed to lime or other more expensive sorbents.
- Removal rates of 75-85% which exceed the removal rates of many dry sorbent injection systems.
- Improved control of slagging and fouling associated with humidification in a vertical chamber as opposed to in-duct humidification.

The LIFAC technology's potential for commercialization is increased by its ability to remove 75-85% of the SO₂, its low space requirement, and its low retrofit costs.

1.4.2 Process Advantages

The LIFAC process offers many advantages compared with other FGD systems. These technical and economic advantages are expected to gain industry acceptance of LIFAC as a viable SO₂ removal alternative. LIFAC's favorable attributes include:

- The LIFAC process has lower initial capital requirements and is less expensive to operate than other FGD systems, in particular, wet scrubbers.
- The system is suitable for retrofit applications since it requires less space than many other FGD systems.
- The system is capable of removing more sulfur (75-85%) than other technologies competing with wet scrubbers. This level of removal makes LIFAC suitable for use with high-sulfur coal, unlike other dry sorbent injection processes.
- The LIFAC Process uses limestone, which is relatively inexpensive, as the reagent.
- The selection of the RP&L Whitewater Valley Unit 2 is particularly appropriate for demonstrating the LIFAC process. The host boiler has been designed to be very compact, making retrofit particularly difficult. This boiler burns high-sulfur coal and has a high utilization rate which will demonstrate the effectiveness and reliability of the process under U.S. operating conditions.
- The site also offers several advantages not related to the technical merits of the LIFAC process. The site was used previously to demonstrate another upper-furnace sorbent injection technology and the equipment for sorbent handling and injection is available to the LIFAC demonstration, thus holding down project costs. The site is also located close to the nation's leading high-sulfur coal areas and has good transportation access to those areas.

1.5 DOE's Role in the Project

The DOE shall be responsible for monitoring all aspects of the project and for granting or denying all approvals required by the Cooperative Agreement. The DOE Contracting Officer is DOE's authorized representative for all matters related to the Cooperative Agreement.

The DOE Contracting Officer will appoint a Contracting Officer's Technical Representative (COTR) who is the authorized representative for all technical matters and has the authority to issue "Technical Advice" which may:

- Suggest redirection of the Cooperative Agreement effort, recommend a shifting of work emphasis between work areas or tasks, and suggest pursuit of certain lines of inquiry which assist in accomplishing the Statement of Work.

- Approve those reports, plans, and items of technical information required to be delivered by the Participant to DOE under the Cooperative Agreement.
- All technical advice shall be issued in writing by the DOE COTR.

The DOE COTR does not have the authority to issue any technical advice which:

- Constitutes an assignment of additional work outside the Statement of Work.
- In any manner causes an increase or decrease in the total estimated cost or the time required for performance of the Cooperative Agreement.
- Interferes with the Participant's right to perform the terms and conditions of the Cooperative Agreement.

2.0 TECHNOLOGY DESCRIPTION

2.1 Chemical Theory

The LIFAC (Limestone Injected into the Furnace with Activation of unreacted Calcium oxide) technology combines upper-furnace limestone injection followed by post-furnace humidification in an activation reactor located between the air preheater and the ESP. The process produces a dry and stable by-product product that is partially removed from the bottom of the activation reactor and partially removed at the ESP.

Finely pulverized limestone is pneumatically conveyed and injected into the upper part of the furnace. Since the temperatures at the point of injection are in the range of 1800 - 2200° F, the limestone (CaCO_3) thermally decomposes to form calcium oxide (CaO). As the CaO passes through the furnace, initial desulfurization reactions occur. A portion of the sulfur dioxide (SO_2) reacts with CaO to form calcium sulfate (CaSO_4). Essentially all of the sulfur trioxide (SO_3) reacts with CaO to form CaSO_4 .

The flue gas, unreacted CaO , and ash exit the boiler and pass through the air preheater. On leaving the air preheater, the gas/ CaO /ash mixture is directed to the LIFAC activation reactor. In the reactor, additional SO_2 capture occurs after the flue gas is humidified with a water spray. Humidification converts CaO to calcium hydroxide (Ca(OH)_2), which enhances further SO_2 removal. The primary reaction product in the activation reactor is calcium sulfite (CaSO_3). The activation reactor is designed to allow time for effective humidification of the flue gas, activation of the CaO , and reaction of the SO_2 with the sorbent. All the water droplets evaporate before the flue gas leaves the activation reactor. The net effect: at a Ca/S ratio in the range of 2:1 to 2.5:1, 75-85% of the SO_2 is removed from the flue gas.

The flue gas leaving the activation reactor then enters the existing ESP where the spent sorbent and fly ash are removed from the flue gas and sent to the disposal facilities. The solids collected by ESP consist of fly ash, CaCO_3 , CaO , Ca(OH)_2 , CaSO_4 , and CaSO_3 . To improve utilization of the calcium, and increase SO_2 reduction, a portion of the spent sorbent collected in the bottom of the ESP hoppers is recycled back into the ductwork just ahead of the activation reactor. A schematic of the LIFAC Process at Richmond Power & Light is shown in Figure 2-1.

3.0 UPDATE OF THE PUBLIC DESIGN REPORT

3.1 Design and Equipment Changes

In order to improve operability and efficiency of the LIFAC process, several modifications/changes to the system were made since the completion of construction and the issuance of Final Report Volume I - Public Design. This section includes a brief description of each of these modifications/changes:

The Variable Frequency Drive (VFD) failed several times during the demonstration program. The VFD was installed as part of the project to increase the efficiency of the induced draft fan, which experiences higher loading when LIFAC is engaged. In the absence of VFD, the main bypass damper was 10-15% open to lessen the system pressure drop. An unknown amount of unreacted lime was also bypassed through the damper. The VFD failures also contributed to the interruption of

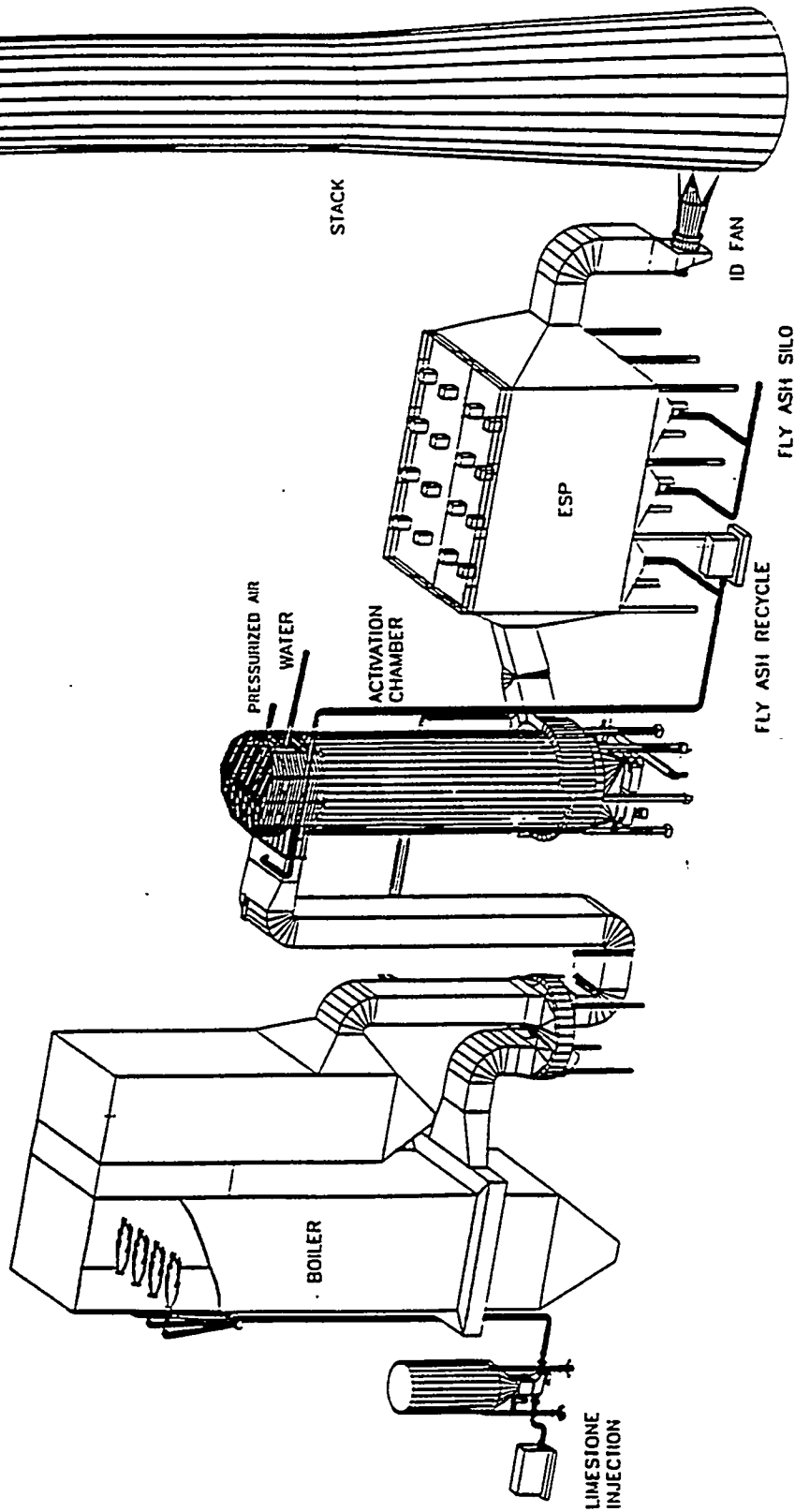


FIGURE 2-1: A Schematic of the LIFAC Process at Richmond Power & Light

many tests and significant process downtime. The VFD was eventually deemed unreliable and placed out-of-service for most of the demonstration.

Proximity limit switches were installed on the double dump valves after the existing mechanical switches continued to fail and hinder the process. The new switches have no mechanical parts and are more suitable for the dirty environment.

A reheat bypass duct was installed between the area slightly above Unit No. 2 boiler's economizer and the activation reactor outlet ductwork. This reheating is designed to complement the existing steam reheat system. The duct is equipped with a damper which can be controlled automatically using the process monitoring system.

Gas distribution through the ESP was improved twofold. Ladder turning vanes were positioned in the ESP inlet, replacing the existing turning vanes. Also, perforated plates were installed on both the inlet and outlet ducts of the ESP.

4.0 DEMONSTRATION PROGRAM

4.1 Test Plan

The LIFAC test program had two main objectives. The first was to showcase the LIFAC system by demonstrating the:

- LIFAC system for U.S. utilities
- Economic feasibility of the system suitability of the process for different coals and limestones
- System's effectiveness at reducing SO₂ emissions when burning high sulfur coals.

The second objective was to perform an in-depth evaluation of the LIFAC system's effect on the host site's boiler and associated equipment. In meeting this objective, the test program provided data for the following activities:

- Study the effects on other boiler emissions such as NO and particulates.
- Optimization of the system's performance in the host boiler's environment.
- Evaluate the impacts of LIFAC on the host boiler and its associated subsystems.
- Evaluate any changes in boiler performance during and after LIFAC testing that are or are not related to the LIFAC system.

The test program at RP&L was divided into a series of five separate sets of tests. The first set of tests was designed to gather baseline data of the boiler and other plant operation conditions. The LIFAC system was then optimized and tested with various coal and limestone feeds. Finally, post-LIFAC testing provided data for comparison to pre-LIFAC baseline data. The series of tests, along with brief descriptions, are in chronological order as follows:

Baseline Tests - Baseline testing was performed prior to start-up of the LIFAC system. This testing provided data on the current operating conditions of the host boiler which will be used for comparison throughout the demonstration program.

Parametric Tests - Parametric testing followed baseline testing and was designed to evaluate the different possible combinations of LIFAC process parameters and their effectiveness. Also during this test period, five different types of sorbent were to be tested. This testing will determine the optimum combination and settings of process parameters which will then be used throughout the remaining demonstration.

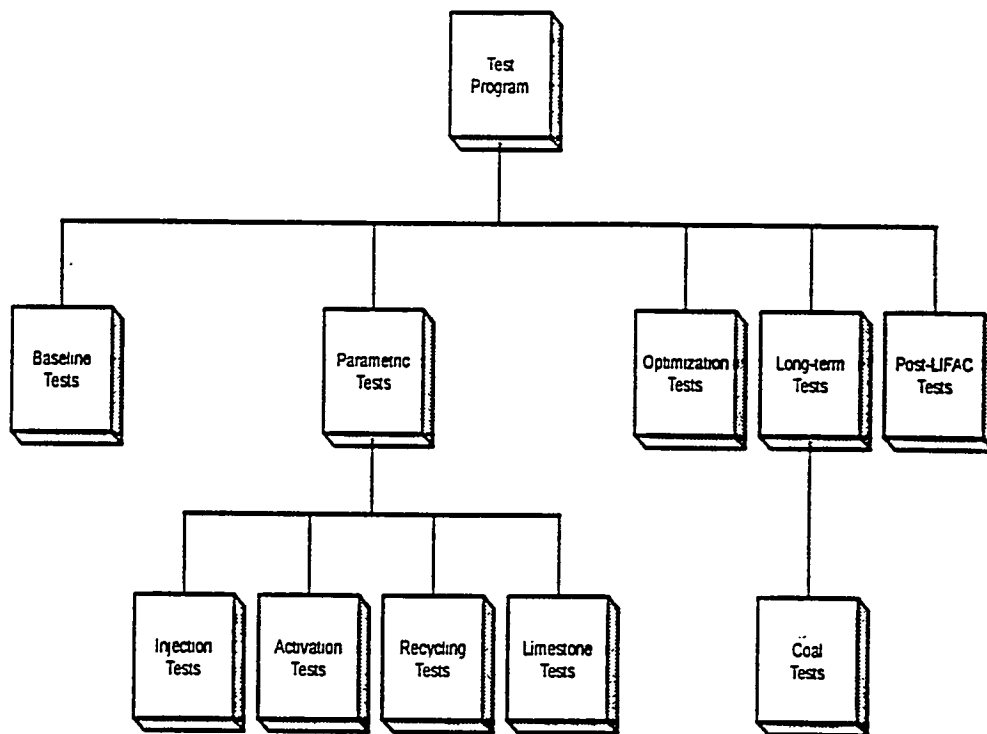
Optimization Tests - Optimization testing was performed after the parametric tests to determine the reliability and capability of the LIFAC process over short, continuous operation periods. These tests were performed continuously 24 hours a day in actual operating conditions, as opposed to the short 8- to 12-hour parametric tests performed previously. The baseline coal and limestone along with the optimum parametric settings were used during this phase of testing.

Long-Term Tests - Long-term testing was performed after the optimization tests to determine the reliability and capability of the LIFAC process over long, continuous operation periods. This set of tests was performed continuously over several hundreds of hours. One coal quality was selected for this test period. Also, following this phase and preceding the post-LIFAC tests, selected parametric and optimization tests were repeated.

Post-LIFAC Tests - Post-LIFAC testing was similar to baseline testing. Data was gathered without the LIFAC system operating which, when compared with the baseline data, will yield evidence of the impacts LIFAC may have had on the host site's boiler and associated subsystem.

The test program was staffed by a combination of personnel from RP&L, ICF KE, and Tampella. The test program, including all five sets of tests, occurred for approximately 2,800 hours over a 26-month period. The structure of the test plan at Richmond Power & Light is shown in Figure 4-1.

Figure 4-1 Structure of the LIFAC Demonstration Test Plan



4.2 Operating Procedures

4.2.1 Instrumentation and Data Acquisition

- **Process Control and Data Collection System**

The impact of the LIFAC process on gaseous and particulate emissions was determined by measuring sulfur dioxide (SO_2), sulfur trioxide (SO_3), oxygen (O_2), nitrogen oxide (NO), opacity and particulate content of flue gas. During the test program, SO_2 and O_2 content of flue gas and opacity were measured continuously. Effects of the LIFAC process on NO and SO_3 emissions and on ash resistivity were determined by short periodic tests. Particulate emission measurements were performed periodically in connection with ESP testing. The emission measurement locations are shown on in Figure 6.1. The emission measurement procedures are then summarized in Appendix II.

The operation of the LIFAC process is controlled by the PLC (Programmable Logic Controller) system. The process control system is used only for the LIFAC equipment. The operation of the boiler equipment and associated subsystems is controlled by the power plant's original control system and some of the measurements are only monitored by LIFAC's monitoring computers.

The process control system hardware consists of two identically installed IBM 756 Industrial computers with 19" VGA color monitors. Both computers are located in the boiler control room. One unit is needed to control the

entire LIFAC process. The second unit is identical and serves as a spare unit. A printer for alarm reporting is connected to this computer. Both computers are intended to monitor and collect measured data.

All the commands from the control computer to the equipment, feedback information, and measured data from the instruments are transported through three input/output (I/O) racks. Rack #1 is for the boiler house equipment and instruments, rack #2 is for the limestone area equipment and instruments, and rack #3 is for the activation reactor area equipment and instruments. The system has a total of 329 input or output points; 29 RTD's, 51 analog inputs, 34 analog outputs, 160 digital inputs and 58 digital outputs.

● SO₂ Monitoring

For continuous SO₂ monitoring two in-situ Lear Siegler SM8100 microprocessor-based gas analyzers were used. As a back-up analyzer there was an extractive system Monitor-Labs analyzer down stream of the reactor prior to the ESP. The Monitor Labs analyzer uses a diluting probe. One pair of SO₂ and O₂ analyzers were located after the air preheater before the activation reactor inlet. The second pair of analyzers were located after flue gas reheating and before the ESP inlet. The equipment utilizes a second derivative spectroscopic measurement technique, measuring the narrow band absorption of ultraviolet energy by SO₂ molecules. The measurement was performed on moist gas and the output is corrected to standard temperature and pressure. The maximum measurement range of the equipment is 3000 ppm and was calibrated for 0 to 3000 ppm gas range monitoring. A detailed description of the SO₂ analyzer is presented in Appendix II.

Baseline flue gas sulfur dioxide content ranged from 1000 to 3000 ppm, depending on the coal quality. A typical value of 1750 ppm corresponds to a 2.5% sulfur coal. With the LIFAC process in operation, the SO₂ content varied from approximately 260 to 900 ppm.

The physical conditions where SO₂ is monitored are demanding. In the sampling location before the activation reactor, the flue gas contains a large quantity of solids, typically $1,800 \times 10^{-6}$ lb/SCF (29,000 mg/Nm³). Down stream of the reactor, the humidity of flue gas is typically 15% and particulate loading is typically $2,500 \times 10^{-6}$ lb/SCF (40,000 mg/Nm³). Loading after the reactor is higher due to the recycle load.

The minimum temperature of the flue gas after the reactor was approximately 190°F. At these low temperatures the Lear Siegler analyzer after the reactor was unreliable. Low temperatures cause ash buildup in the analyzer probe. The Monitor Labs SO₂ analyzer probe was equipped with a heater and there was no ash buildup in that probe. Ash buildup will partially absorb SO₂, hampering the output of the analyzer.

The ductwork is fitted with flanges for in-situ analyzers at both SO₂ measuring locations. Grid measurements for excess O₂ content in the flue gas will be performed to verify the consistency of SO₂ and O₂ concentration patterns across the duct sections.

The reliability of the in-situ SO_2 analyzers will be verified at times during the test program with a portable analyzer. The verification measurements were performed under baseline conditions at the beginning of baseline testing and during post-LIFAC tests. To verify the reliability of SO_2 measurements in the dusty conditions before the reactor, and in the dusty and high moisture conditions after the reactor, verification measurements were also taken at the beginning of injection and activation testing. Verification was performed anytime during testing if there was any doubt about the accuracy of the measurements. Indication of an unreliable reading was obtained if the reading of the two stationary analyzers were not equal when the reactor was not in operation.

Throughout the test program, the analyzer readings were compared to the calculated sulfur dioxide content of flue gas based on the sulfur content in the coal.

● SO_3 Monitoring

SO_3 emissions were monitored using EPA reference Method 8. The description of this method is presented in Appendix II. SO_3 content was measured by subcontractors who performed ESP efficiency and performance measurements.

SO_3 emissions are typically based on SO_2 emissions since they are generally on the order of 0.5 to 1.0% of the flue gas SO_x content. In earlier studies at RP&L, baseline SO_3 emissions have been nearly 18 ppm during combustion of high sulfur coal (SO_2 4000 ppm).

Sorbent injection is expected to remove all or most of the SO_3 normally present in the flue gas, since SO_3 reacts rapidly with calcium oxide formed during the calcium carbonate decomposition reaction. SO_3 content was measured after the ESP. All SO_3 measurements were coupled with ESP performance testing.

● O_2 Measurement

O_2 measurements were performed using two in-situ Lear Siegler Dynatron 401 oxygen monitoring systems. The equipment uses a solid-state zirconium oxide fuel cell sensor to measure oxygen content of flue gas. Measurements were made on a moist, total sample basis using the Nernst relationship. The maximum measurement range of the equipment is from 0 to 25%. A detailed description of the O_2 analyzer is presented in Appendix 6.2. O_2 analyzers were installed in the flue gas duct in the same locations as the SO_2 analyzers before and after the activation reactor.

Typical flue gas oxygen content after the boiler was from 2 to 5 weight %. The O_2 measurements will be carried out in the same demanding conditions as the SO_2 measurements. However, the moist ash layer on the probe does not effect to O_2 measurement as long as the gas can penetrate the ash layer and filter.

The continuous oxygen measurement reading was used for correcting the results of SO_2 measurements to a 6% O_2 content. Verification of the O_2 analyzers were used to measure concentration patterns of flue gas in selected monitoring locations.

- **NO Measurement**

For NO measurements, the same two in-situ Lear Siegler analyzers were used. Dual exit slits on the monochromator of the analyzer allow two separate wave lengths: one corresponding to SO₂ and the other to NO, to impinge on the detector. Sequential time separation of the SO₂ and NO signals is accomplished with a small shutter in the monochromator. This shutter moves back and forth between the two beams at one minute intervals, providing one minute sequential SO₂ and NO concentration outputs.

Baseline NO content of flue gas was measured during the baseline tests. During parametric testing, NO levels were measured by the subcontractor who performed stack testing as part of the Environmental Monitoring Program.

- **Particulate Emissions**

Particulate emissions were monitored using EPA reference Method 17 and Method 5. The description of these methods are described in Appendix II.

The particulate load measuring locations are in the activation reactor and ESP inlet ducts. Emissions were measured in the duct breaching between the Unit No.2 ID fan and the stack.

After the boiler and before the ESP, typical baseline particulate content of flue gas is 650×10^{-6} lb/SCF. Limestone injection into the furnace increases this particulate load to between $1,300 \times 10^{-6}$ and $3,500 \times 10^{-6}$ lb/SCF. The variation depends mainly on the Ca/S molar ratio and the limestone quality used for injection. In the activation reactor the flue gas is humidified and a portion of the particulates are removed from the bottom of the reactor. After the reactor and before the ESP, the particulate content of the flue gas varies from 700×10^{-6} to $1,900 \times 10^{-6}$ lb/SCF without ash recycling. With ash recycling in operation, the particulate load may increase to nearly $3,600 \times 10^{-6}$ lb/SCF.

The efficiency of the ESP increases with LIFAC in operation due to an increase in inlet solids loading with the same outlet emissions. During baseline operating conditions, the ESP efficiency varies from 98 to 98.4%. With the LIFAC process, it was estimated to increase to 99.3%. Particulate emissions are typically $10-12 \times 10^{-6}$ lb/SCF without LIFAC. Ash recycling may increase particulate load to 29×10^{-6} lb/SCF for short periods of time.

The purpose of the particulate measurements was to evaluate the efficiency of the ESP under different conditions and evaluate the ash separation capabilities of the activation reactor. A list of particulate measurements are shown in ?. All particulate measurements were collected in accordance with EPA Method 17.

- **Opacity**

Opacity of the combined flue gas from both Unit 1 and Unit 2 was measured by an in-situ instrument located in the stack. The opacity limit was 40%

in the beginning of the project. During the demonstration, the plant received a new 30% opacity limit.

- **Moisture**

The measurement of flue gas moisture content was done simultaneously with particulate measurements. EPA reference Method 17 was used to collect this data. The description of this method is shown in Appendix II.

- **ESP Performance**

ESP performance measurements were performed periodically during the entire test program. The final measurements will be taken during long-term testing and reported in the long-term test report.

Ash resistivity was measured with an in-situ, point-to-plane resistivity probe system. The resistivity probe electrostatically collects a layer of ash while flue gas conditions are maintained at constant values. Collection of the ash is accomplished by applying a high voltage across the point-to-plane electrodes in the probe. At a sufficient voltage, a highly compressed electric field or corona forms in the vicinity of the point (negative electrode) and ionizes gas molecules in this region. Dust particles in the gas are then charged by the negative ions formed in the corona and are attracted by electrical forces onto the collection plate (positive electrode). This method of ash collection is intended to simulate the behavior of ash in an actual ESP.

From earlier studies at RP&L, the average resistivity of fly ash was 5.9×10^{10} ohm-cm, as determined by the V-I method.

Ash resistivity measurements were performed during optimization tests, with and without the LIFAC process in operation. This testing will only be done during 65-MW boiler loads. The measurement is taken in the ductwork before the ESP.

- **Boiler Performance**

To optimize limestone injection into the furnace and evaluate its impact on boiler performance, certain boiler operating conditions were measured. Measurements were performed using on-line instruments which send information to the process control computer for handling and processing.

The coal feed rate measurement was used to calculate flue gas volume formed during coal combustion and the amount of sulfur entering the furnace. The coal feed rate was measured with a mechanical counter in the coal weigh feeder buckets. To verify the accuracy of these measurements, the weigh feeders were calibrated at the beginning of the baseline tests. During the tests, continuous verification will be made by back-calculating the coal feed rate from the generated steam rate.

The quantity of combustion air and excess oxygen were measured for flue gas calculation purposes. The primary goal of the excess oxygen measurement was to attain optimum combustion conditions in the furnace. Steam generation and spray water flow measurements were used as indicators of boiler performance changes.

Two new thermocouples were installed in the furnace to measure injection level temperatures. During the baseline and run-in tests, a suction pyrometer will be used to verify these measurements.

Fouling in the economizer and air preheater was evaluated from pressure drop and temperature analyses in both locations. These measurements were continuously monitored during the demonstration.

The activation reactor also caused an increase in the system pressure drop. It was important to study this pressure drop effect on the ID fan's suction pressure, fan speed and motor current.

● Temperature Measurement

By measuring flue gas temperatures before, within, and after the activation reactor, pertinent conditions in the reactor were determined. Flue gas temperature before the reactor is measured by four temperature elements which accurately indicate any changes in the reactor inlet temperatures.

There are four temperature elements installed at different elevations along the reactor. They were used as key indicators of humidification and evaporation processes within the reactor.

Reactor outlet temperature is measured at the bottom of the reactor and controls humidification water flow to the reactor. Optimum process efficiency is achieved when reactor outlet temperature is minimized while evaporation is maximized. A dry ash by-product is essential to the process.

There are three units installed in the reactor outlet ductwork to sufficiently reheat the flue gas before the ESP. Each duct is furnished with a temperature element after these units to verify the efficiency of each individual reheating unit. The gas temperatures after the three outlet ducts are compared, and the lowest temperature is selected to control reheat steam flow to the heat exchangers.

● Pressure Measurement

Flue gas pressure is measured in the ductwork before the reactor, in the reactor, after each reheater, and before the ESP. The pressure measurements are used to determine LIFAC induced pressure changes in the system and predict ash buildups in the activation reactor. Individual pressure gauges measure the total pressure of the flue gas. Pressure differences are calculated by the PLCs.

● Flow Measurement

The average flue gas flow rate before the activation reactor was measured by pitot tube-type flow elements. Three flue gas traverse probes consisting of multiple flow sensors mounted on self-averaging signal manifolds are positioned on an equal area basis to the duct. The flow element system is furnished with an instrument air purge system to protect

the internal mechanism of the transmitter from the migration of airborne particulates.

The flue gas flow measurement gives an early signal to the humidification water control system to increase or decrease the water flow to match an increase or decrease in the flue gas flow.

Humidification water flow is measured by an orifice plate and controlled by a motor-operated control valve. The quantity of humidification water sprayed into the activation reactor is controlled by flue gas temperature measurements after the reactor. Air flow to the dual fluid nozzles is controlled by controlling the air pressure with a motor-operated control valve.

Steam flow to the reheaters is controlled by the flue gas temperature ahead of the ESP. A motor-operated control valve controls steam flow. The reheating steam is verified by calculations from the flue gas temperature increase measurement or by counting the discharge cycles of the condensate return tank.

- **Limestone and Recycle Ash Feed Measurements**

The limestone and recycle ash feed measurements are divided into three categories: silo measurements before the silo shut-off valve; feeder measurements from the silo discharge opening to pneumatic conveying line; and pneumatic conveying system measurements. The feeders and silo were used to measure the limestone feed rate into the furnace.

- **Silo Measurements**

The limestone quantity in the feed and storage silos were determined by weigh cell measurements. Both the feed and storage silos are equipped with two weigh cells that measure the load bearing columns' compression and calculate the weight. The storage capacity of the feed silo is 270,000 lbs. and the storage silo is 530,000 lbs. The ESP ash surge tank has two weigh cells and a storage capacity of 20,000 lb.

The feed silo has two level switches for low and high levels. The limestone storage silo has three level switches for low, high, and high/high levels. The ESP ash surge tank has one high level switch.

- **Feeder Measurements**

Limestone mass flow to the boiler injection nozzles is measured by a gravimetric weigh feeder system which consists of two screws and a rotary feeder arranged in series. The rotary feeder controls the mass flow from the silo to the first screw feeder, and both are connected to the same variable speed controller. The screw feeder is used to ensure smooth flow of limestone to the second weigh screw which measures the mass flow. The weigh screw is mounted on load cells, operates at a constant speed, and determines the feed rate by measuring the weight of the screw multiplied by screw speed. The limestone flow measurement will be verified by comparing it to limestone feed silo weight measurements.

The ESP ash recycling ratio is measured and adjusted by two ESP hopper rotary feeders. The rotary feeders are installed in the bottom of the first two parallel ESP hoppers and feed ESP ash to the pneumatic conveying system for recycling. Ash flow for recycling from the ESP ash surge tank is measured and controlled by variable speed drive rotary feeders under the tank. Reactor ash flow to the recycling system from the reactor bottom conveyor is measured and controlled by a variable speed drive screw feeder. The ESP ash flow measurements were to be verified by comparing them with the ESP ash surge tank weight measurements.

- **Pneumatic Conveying Measurements**

The LIFAC process contains four pneumatic transport air blowers: two for the limestone injection into the furnace and two for ash recycling. In addition, the limestone injection system is furnished with a booster air blower to increase the initial velocity of the limestone particles injected into the boiler. All of the limestone transport air, booster air, ESP ash recycling air, and recycling mix transport air blowers are operated at constant speeds.

Limestone transport air flow is measured using an orifice plate. The pressure and temperature of the air was also monitored. The transport air flow (1,060 SCFM) is controlled with a pneumatic control valve. Booster air flow rate was approximately 6,360 SCFM.

In addition, pressures of the air from the ESP ash recycling air flow were measured. By measuring pressure changes in these flows, potential blockages in the piping and nozzles could be identified.

4.2.2 Sampling and Analysis

Coal, limestone, and ash samples were taken manually during the demonstration. Aqueous samples were also monitored as part of the Environmental Monitoring Plan (EMP). Sampling locations are shown in Figure 6.1. While, sampling methods are presented in Table 4.2.

TABLE 4-2 SAMPLING FREQUENCY, METHOD AND LOCATION

SAMPLE	SAMPLING FREQUENCY	METHOD	LOCATION
Coal	Once per hour or three times per hour during special tests	Grab sample	Coal pulverizer feeder
Limestone	Occasionally	Grab sample	Feeding silo discharge
ESP ash	Occasionally	Grab sample	ESP hopper
Reactor ash	Occasionally	Grab sample	Truck hopper at reactor ash discharge
Air preheater ash	During EMP sampling	Grab sample	Air preheater hoppers

Coal samples were taken from the feeder belt before each of the pulverizers. Coal was grabbed once per hour from each feeder and a composite sample was formed for a three hour period. Samples were shipped in double layer plastic bags to a laboratory for analysis.

Special one hour coal samples were collected during stack testing. One hour samples were also taken during baseline and calibration periods.

Since the sulfur content of the feed coal dictates the limestone feed rate, it was the most significant coal quality parameter studied during the demonstration. Sulfur analyses were also used to calculate the baseline SO_2 content of the flue gas. During the demonstration, feed coal sulfur content ranged between 1.6 and 2.8%.

Most analyses were performed by one laboratory. However, other labs were often utilized to ensure reliable results. The scope of coal analyses included: short proximate, ultimate, and mineral analysis.

Mineral analysis included components as listed below: See also Appendix 7.1 for typical coal analysis.

- Silicon dioxide (SiO₂)
- Aluminium oxide (Al₂O₃)
- Titanium dioxide (TiO₂)
- Calcium oxide (CaO)
- Potassium oxide (K₂O)
- Magnesium oxide (MgO)
- Sodium oxide (Na₂O)
- Phosphorous pentoxide (P₂O₅)
- Ferric oxide (Fe₂O₃)
- Sulfur trioxide (SO₃)
- Base/Acid ratio
- Slag viscosity
- Fouling index
- Slagging index
- Silica value
- % alkali as Na₂O

The limestone supplier was obligated to monitor their product's quality once per hour and the data was made available to the LIFAC test team. Therefore, only periodic verification samples and analyses were performed.

The most significant limestone parameters are the calcium carbonate (CaCO₃) content and particle size. Additional information was also provided by the supplier and is shown in Table 4.3 below.

TABLE 4-3
LIMESTONE ANALYSIS COMPONENTS OF THE FINE QUALITY (80%<325 MESH) LIMESTONE

COMPONENT	TYPICAL CONTENT IN WEIGH %
Na ₂ O	0.12
MgO	1.50
Al ₂ O ₃	0.68
SiO ₂	2.87
SO ₃	0.14
K ₂ O	0.16
CaO	51.86
TiO ₂	0.05
Fe ₂ O ₃	0.35
LOI	42.27
TOTAL	100.00
Calcium and Magnesium Oxides	
CaCO₃	92.6
MgCO₃	3.15

Ash samples were grabbed from four different locations during the demonstration and are listed below:

Economizer Ash - collected from the economizer hoppers;

ESP Ash - collected from the ESP hoppers; ESP ash samples were taken from the first two parallel hoppers;

Reactor Ash - collected from the activation reactor bottom conveyor;

Boiler Bottom Ash - collected from dewatering bin (Unit No.2 only);

During baseline and post-LIFAC tests, fly ash samples were collected every eight hours. During parametric and long-term test periods, ESP and reactor ash samples were collected during each individual test.

During the tests in which particulate measurements were performed, all ash samples were analyzed for calcium compounds, elemental analysis, and particle size distribution. A resistivity analysis of ESP fly-ash was performed on samples collected during on-line ash resistivity measurements.

4.2.3 Data Analysis Methodology

Test data was acquired in many different ways, depending on the type of data and required procedures. Test data for LIFAC was for the most part, recorded automatically by the process control computer. Necessary additional information was recorded manually to a logbook and log sheets either in the control room or in the plant.

Data was recorded from the boiler, activation reactor, electrostatic precipitator, and all input and output streams. A test coordinator kept the log book where all pertinent information of the testing was recorded, such as injection settings and recycling methods.

Particulate emission measurement data was recorded on forms shown in the EPA Method 17 description in Appendix II. All other manually measured data was recorded on specific forms. Samples requiring laboratory analysis were recorded on laboratory supplied forms.

The process control system (PLC = Programmable Logic Controller) with Process Monitoring System (PMS) software was used to collect and handle the automatically measured data. The process computers read measured values from the instrumentation every third second, typically calculates three-minute averages, and saves them for further use in the computer's hard drive. Data from the PMS was converted into a format that can be imported to a Lotus 1-2-3 spreadsheet. Data will be transferred via disk to a personal computer on-site to perform on-site data processing.

The Ca/S molar ratio is a factor which reflects the efficiency and economy of the LIFAC desulfurization process. It is calculated using equation (1). In equation (1) limestone mass flow $m(l_s)$ is measured by the limestone feeder. $CaCO_3$ content of the limestone is found in the limestone analyses and is constant if limestone comes from the same location. Coal flow is measured at the coal feeders. Coal sulfur content S is also found through analyses. Estimated values of these parameters were stored in the process monitoring computer, but the corrected values were used for adjustments during data handling procedures on a spreadsheet program.

Ca/S molar ratio

$$Ca/S = \frac{m(ls) \times p(ls) \times 100.09}{m(coal) \times s \times 32.09} \quad (1)$$

where

Ca/S is a ratio of number of moles of calcium injected in to the furnace vs. number of moles of sulfur burned in the furnace

m(ls) is limestone mass flow (#/min)
p(ls) is limestone CaCO₃ content (weight %)
100.09 is molecular weigh of CaCO₃
m(coal) is coal flow (#/min)
32.09 is molecular weigh of sulfur

Variations of boiler reactor operation conditions cause variations in flue gas composition such as SO₂ and O₂ levels. Different measuring techniques of in-situ and extractive type of verification SO₂ analyzers cause variations in the measured results as well. In order to compare different SO₂ measurements, the measured values were corrected by the constant O₂ content and the moisture level of flue gas. Sulfur dioxide content in the flue gas is corrected to a 6% O₂ content. Correction equations are shown below. O₂ correction is in equation (2), moisture correction is in equation (3).

$$SO_2(6\%) = SO_2(m) \frac{21 - 6}{21 - O_2(m)} \quad (2)$$

where

SO₂(6%) is a sulfur dioxide content in the flue gas corrected to 6% O₂ content (ppm = parts per million)

SO₂(m) is a sulfur dioxide content of the flue gas in actual flue gas O₂ content (ppm = parts per million)

21 21% O₂ content in the air

O₂(m) is measured O₂ content at the same place where SO₂ is measured

Flue gas moisture correction calculations were performed because SO₂ before and after the reactor is measured in moist flue gas conditions.

$$SO_2(w) = SO_2(6\%) \frac{1 - c(wb)/100}{1 - C(wr)/100} \quad (3)$$

where

$SO_2(w)$ is corrected SO_2 content to the same moisture as the SO_2 is in the boiler

$SO_2(6\%)$ is measured SO_2 content of the flue gas and corrected into 6% O_2 content

$C(wb)$ is the flue gas moisture in the boiler (estimated to be constant 8.5 vol-% because no constant measurement is available)

$C(wr)$ is the flue gas moisture in the reactor (estimated to be constant 15 vol-% because no constant measurement is available)

Total SO_2 reduction is calculated with the equation (4). For this equation baseline SO_2 content of the flue gas is needed. It is a SO_2 content of the flue gas formed during the combustion. Since this value cannot be measured continuously it is calculated with the separate computer program. Occasionally process was shut down for short period of time for this baseline SO_2 level measurement.

SO_2 reduction calculation:

$$SO_2(tot) = \frac{100 \times (C(base)) - C(r)}{C(base)} \quad (4)$$

where

$XSO_2(tot)$ is total SO_2 reduction in the system

$C(base)$ is calculated SO_2 content formed in combustion

$C(r)$ is SO_2 content after the reactor

4.3 Operability and Reliability

4.3.1 Critical Component Failure Analysis

A detailed discussion of critical component failures which occurred during operation is important to the commercialization of the LIFAC process. Since the project was a demonstration in nature, and utilized old equipment from an earlier demonstration, component failures were to be expected. Critical component failures are those which upset normal process operation, causing prolonged downtime and decreasing process efficiency. The incidents which occurred during this demonstration are thoroughly addressed in this section. Many failures can be avoided in future installations with an understanding of these demonstration experiences. Component failure analyses are broken down into the following five process areas:

- Limestone Storage and Handling Area
- Boiler Injection Area

- Activation Reactor Area
- ESP Ash Recycle Area
- Process Monitoring and Control System

Limestone Handling and Storage Area

The limestone feeding silo used by EER did not have sufficient capacity for the LIFAC demonstration. However, the project utilized the silo and its limestone feeding equipment in conjunction with a newly installed storage silo. The limestone screw feeder is part of the remaining EER equipment. During the long-term test period the screw feeder below the feeding silo failed to operate, causing process downtime. When limestone is no longer being injected, it is necessary to decrease humidification and toggle recycle to off. After several unsuccessful re-start attempts by the LIFAC test team and RP&L personnel, a manufacturer's representative was called to the site. The representative isolated three problems with the feeder: 1) a shorted silicon controlled rectifier (SCR) in the west motor control center; 2) a faulty tachometer near the feeder; and 3) a sticking rotor cuff under the weigh feeder. These problems were corrected on site, and no more incidents occurred with the limestone feed system.

The feeding silo fluidizers were not effective when the amount of limestone in the feeding silo dropped below 50,000 lbs. These fluidizers were also part of the remaining EER equipment. Poor condition of those fluidizers resulted in unstable limestone flow. When limestone was no longer injected into the boiler, it was necessary to decrease or stop humidification. In most cases, flow was restored periodically by physically hammering the bottom of the silo. The problem was avoided by maintaining a weight greater than 50,000 lbs. in the feeding silo. To solve the problem fluidizing elements need to be replaced.

Boiler Injection Area

Process components involved in boiler injection consisted of a two-stage splitter, injection nozzles, and piping. No critical component failures were experienced in this area.

Rubber flex-hose was used for limestone injection between the splitters and the injection nozzles. These hoses needed to be changed periodically due to the abrasiveness of the sorbent. No downtime was experienced during replacement.

ID Fan Speed Control System

Several problems were experienced with the variable frequency drive (VFD) which was installed as part of LIFAC system. Since the induced draft (ID) fan operates at full capacity without LIFAC, the VFD interfaces with the fan and increases its capacity. A VFD failure causes the boiler to trip. Unit No.2 tripped five times as a result of VFD difficulties during the LIFAC demonstration. Consequently, many hours of process testing were interrupted. Manufacturer's representative(s) visited the site after each incident, isolated deficiencies, corrected them, and tested the unit prior to each start-up. However, the unit is currently still inoperational.

Activation Reactor Area

Some problems occurred with the proprietary spray nozzle assemblies located in the humidification nozzle headers. The impact bolts which are situated within the

nozzle sheared during operation. These specially designed bolts are composed of two dissimilar metals (stainless steel and tungsten carbide) and are designed to have increased hardness for their application. However, after prolonged exposure to high-pressure water, the tungsten carbide tip separated from the bolt and hindered the atomization effect of the nozzle. After three impact bolts sheared in succession, the test team decided to replace them all with uniform stainless steel bolts. The river water used for humidification at RP&L is not abrasive enough to justify a tungsten carbide tip. Nozzle supplier admitted that this failure was due to manufacturing failure.

The original humidification water control valve failed to accurately respond to control signals from the process monitoring system. The actuator motor and V-ball valve were insufficient for this application. The unit was replaced by a globe valve coupled with a pneumatic actuator.

The mechanical limit switches installed on the ash disposal double dump valves failed to perform after hours of operation in the soiled environment. If a switch failed to meet its limit, an alarm signal was sent to the PMS and the conveyors stopped. Periodically, the switches needed to be disassembled, cleaned, then reassembled. The switches were eventually replaced by proximity limit switches. These new switches have no mechanical parts and are more suitable for the dusty environment.

The three air compressors, which are also remnants of EER's LIMB project, began to overheat and trip during LIFAC operation when the weather outside became hot. The compressors were originally designed for outdoor applications and became excessively hot after the LIFAC project enclosed them in the new limestone storage and handling building. The compressor intercoolers were also more susceptible to fouling since the building became dusty at times. Manufacturer's representatives came to the site to clean the intercoolers and remove the covers which were necessary for outdoor use only. The compressors operated at normal temperatures for the remaining test days.

ESP Ash Recycle Area

The recycle rotary feeder located under ESP hopper #7 ceased operating during parametric testing. After running a series of mechanical diagnostics on the feeder, it was determined that the problem existed in its variable speed controller. A replacement transformer inverter was ordered after consultation with a manufacturer's representative. However, this repair limited the testing of the recycle rate parameter because the rotary feeder would only operate at a fixed speed. Subsequently, the controller was removed and sent to the manufacturer for repair. Some surface mount resistors were replaced at the factory and the unit was sent back to be re-installed. No further problems were encountered with the controller.

Process Monitoring and Control System

A grounding problem was discovered by a manufacturer's representative in the east motor control center I/O panel. The fault was recognized by LIFAC personnel when the process values, which are transmitted and controlled by this I/O rack, remained constant for prolonged periods. The I/O rack needed to be reset. Prior to resetting the rack, the test team needed to bring the entire process down since vital equipment (i.e. conveyors, water pump) was effected when the unit was reset.

4.3.2 Impact on Plant Systems

Power plants are often concerned about how a pollution control system will affect existing equipment and procedures at their facility. Since the LIFAC system is installed between the air preheater and the ESP, it does have an impact on the host's operations.

Boiler

Limestone is injected into the upper region of the furnace prior to the superheater section. This injection location creates a potential for increased superheater and wall tube fouling with certain limestone qualities and injection rates. Fine limestone is typically injected at a rate of 130 lb/min when Unit No. 2 load is 60 MW. This high rate of injection is attributed to the 950 lb/min of high sulfur coal which is consumed by Unit No. 2 at this load. Under these conditions, sootblowing frequency needed to be increased from every six hours to every 4.5 hours.

The soot blowing sequence was initiated when limestone particles coated the superheater tubes and insulated them from desuperheat spray water effects. No fouling effects attributed to limestone injection was discovered on the boiler walls, in the economizer, or air preheater. The economizer is not equipped with sootblowing and the frequency in the air preheater remained unchanged. Also, the boiler's wet bottom ash pulling system continued to operate normally.

The LIFAC flue gas reheat system utilizes medium pressure steam from the host facility. This steam is extracted from a water heater in the boiler house and condensate is returned to a deaerator tank. The steam reheat system did not have any noticeable effects on normal operations. Additional reheating was implemented during the course of the demonstration. A small reheat duct was installed between the economizer inlet and reactor outlet ductwork. This bypass contributed an additional 30°F of reheat to the exiting flue gas. The flue gas reheat duct bypasses approximately 5% of the total gas volume generated in the boiler and had no noticeable effect to plant operations.

ID Fan

The LIFAC process introduces additional air and water into the power plant systems downstream of the reactor causing occasional fluctuations in flue gas density, pressure and particulate loading. These variations have the potential to cause excessive stress on the ID fan. Pressure drop through the LIFAC reactor is currently 4.5 "wg. If the steam reheaters were replaced with a hot flue gas reheat system, the pressure drop is predicted to be close to 2.0 "wg.

ESP

The low temperature, high humidity flue gas conditions created by the process caused opacity excursions during the transient periods associated with startup and shutdown. These excursions were directly related to the emission of particles from the ESP. Excursions were observed even when only humidification was engaged to drop the gas temperature with no change in ESP inlet mass or particle size distribution. The maximum opacity limit was 40% during the demonstration, and startup of the LIFAC process had caused opacity levels to exceed acceptable limits. The Southern Research Institute (SRI) was contracted under EPRI to assess the causes and suggest solutions to the opacity problems.

SRI determined that the electrical operating conditions of the ESP were satisfactory and there was no indication that high opacity occurred because the fundamental collection performance of the ESP was degraded. The source of the excursions appeared to be a release of residual dust from the ESP collection plates. At any given time there are tens of thousands of pounds of fly ash in the collected dust layer and the release of only a minute quantity would create the observed excursions.

The low temperature, high humidity flue gas conditions generated by the LIFAC process cause re-entrainment of the fly ash on the ESP collection plates. Re-entrainment results from a reduction in resistivity and tensile strength of the fly ash. The electrical clamping force of the ESP is a function of resistivity and current density. When the flue gas is humidified, current density increases only slightly and ash resistivity significantly decreases resulting in a 2 to 3 order of magnitude drop in the electrical clamping force. SRI concluded that the most likely cause of the high opacity excursions is a combination of reduced holding force and poor gas distribution in the ESP.

The following recommendations were made by the SRI/EPRI evaluation in regards to improving the operation of the Whitewater Valley Unit No. 2 ESP during LIFAC operations:

- Increase the amount of reheat to decrease the relative humidity of the flue gas until acceptable ESP performance is achieved.
- Upgrade the ESP so that the gas flow distribution is uniform.
- Allow sufficient time for transient conditions to pass by gradually decreasing ESP inlet temperature until design operating conditions are reached.

5.0 TECHNICAL PERFORMANCE

5.1 Effects of Operating Parameters on Results

Parametric testing results represent a summary of the data which was collected during the numerous test periods between January and December of 1993. Many preliminary, short duration tests were performed between October, 1992 and January, 1993. This data is not included with the report summary data. However, it provided valuable preliminary information to assess the effects of parameters on process performance and their impacts on the host facility. Parametric test results encompass data from several different test periods. Data points were grouped according to corresponding operating conditions, for ease of comparison and evaluation.

Since there were many conditions and equipment functions which effected final SO₂ reduction readings, some test results were deemed unreliable. Most tests were performed during a constant boiler load. However, load was unsteady at times due to fluctuating power demands. Combustion coal quality varied slightly during operations. An attempt was made to burn constant quality coal for most of the demonstration. Sootblowing frequency increased from 6 to 4.5 hours with LIFAC engaged. SO₂ analyzer readings were unreliable during sootblowing.

Deviations from the original test plan were necessary since the project experienced several operational interruptions. Unacceptable opacity excursions occurred during LIFAC startup periods. Hence, more time was spent on ESP evaluations than originally planned. Equipment and instrument malfunctions

occurred periodically and SO₂ analyzers failed to give reliable readings at times. Process parameters and their respective test ranges are shown in Table 5-1.

Limestone Injection Nozzle Settings

There are twelve limestone injection nozzles at two elevations on the boiler. The six upper nozzles were used during most of the testing. Several nozzle combinations were tested with the full range of boiler loads. Most tests were performed to find the optimum injection locations for SO₂ reduction in the furnace. During most of the injection tests the main flue gas by-pass damper was 10 to 15% open because the ID fan could not handle full gas flow through the reactor with the VFD inoperational.

Only slight changes in process efficiency resulted during the testing of various injection nozzle combinations. With low boiler loads (40-50 MW), the lower six nozzles performed nearly 5% points better than the high level. If limestone is injected in the lower level at low loads, there is ample residence time for limestone reactions in an ideal temperature window. The upper injection level proved to be 2 to 3% points more efficient during high loads. This is probably due to extreme temperatures at the lower level. Figure 5-2 shows the results of injection nozzle combination testing. Overall, SO₂ reduction rates seemed to improve when the upper injection level was utilized. Figure 5-3 shows SO₂ reduction in the furnace only.

Injection nozzle heads can be tilted 15° vertically. However, all tests were performed with the nozzles in a horizontal position.

Booster air for limestone injection was tested only briefly because it increased loading on the ID fan which was already operating at full capacity. The secondary air fan also exceeded noise levels in the boilerhouse. Additional noise protection or soundproofing would have been required to continue to operate the fan. Therefore, no results of booster air's effect on SO₂ capture were obtained.

Limestone Quality

Two different qualities of limestone were tested. One was a coarse ground 85% < 200 mesh and the other was a fine ground 85% < 325 mesh. Both had high calcium carbonate content ranging from 90 to 95 %. These sedimentary limestones were shipped from two different quarries. The coarse limestone was shipped from southwest Indiana and the fine came from northern Kentucky.

Fine limestone proved to significantly improve process efficiency as compared to the coarse limestone. Figures 5-4 and 5-5 show the results of limestone quality testing at both high and low boiler loads. Fine limestone increases process efficiency 15 to 20 % points. This quality was injected during most of the parametric and long-term tests. Despite of large variation of results the trend is evident: smaller particle size provides more active surface area for reduction reactions to take place.

Boiler Load

The nameplate load of Unit No.2 is 60 MW. However, the unit can be operated as high as 65 MW. During parametric testing, the load ranged from 40 to 61 MW. Most parametric tests were performed at a high boiler load due to high power demands.

TABLE 5-1 - PARAMETERS AND RANGES TESTED

PARAMETER	TEST RANGE
Coal Quality	Sulfur content varied from 1.4% to 2.8%. The average sulfur content was approximately 2.25%.
Limestone Quality	Two qualities were tested. Coarse quality proved to be less effective and fine limestone was selected as the optimum sorbent.
Boiler Load	Boiler load ranged from 40MW to 62MW, the unit's nameplate size is 60MW.
Ca/S	Ca/S molar ratios between 1.0 and 3.0 were evaluated based on efficiency and economy.
High Level Injection Setting	Ports 1, 2, 3, 4, 5, 6 in use
Low Level Injection Setting	Ports 7, 8, 9, 10, 11, 12 in use
Right Side Injection Setting	Ports 4, 5, 6, 10, 11, 12 in use
Left Side Injection Setting	Ports 1, 2, 3, 7, 8, 9 in use
Middle Position Injection Setting	Ports 2, 3, 4, 5, 10, 11 in use
Injection Nozzle Angle	The angle of injection nozzles can be directed up to +/- 15° from horizontal, but only 0 was tested.
Booster Air	Booster air tests were not done.
dT	The temperature difference between the reactor flue gas outlet temperature and the saturation temperature of flue gas. Temperatures between 4 and 11 °F above saturation were tested.
Water Droplet Size and Nozzle Position	Droplet size and nozzle position were tested during the early stages of parametric testing. Droplet size is proprietary information.
Ash Recycling Ratio	The recycling ratio is the mass flow rate of recycled ash versus the mass flow rate of boiler ash. Ash recycling ratio varied from zero to maximum. The maximum ratio equates to nearly 4-5 tons per hour.

Figure 5-2 Total SO₂ Reduction at High and Low Injection Settings

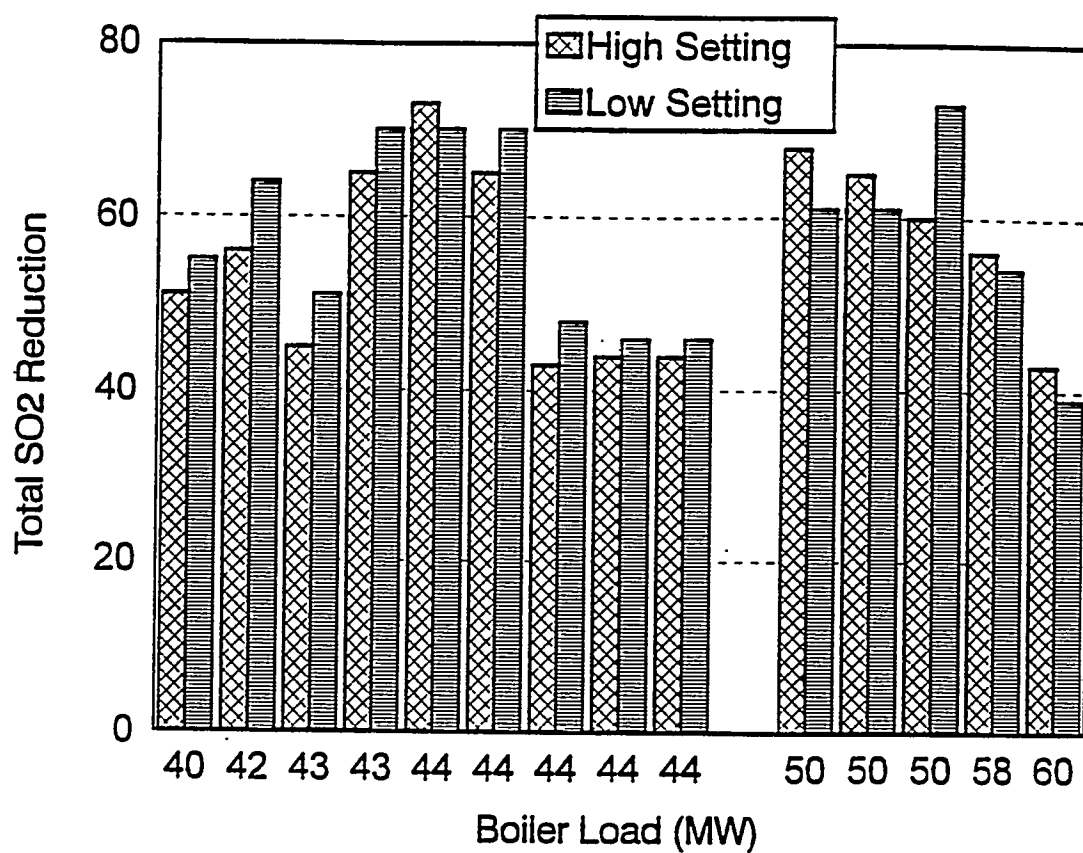


Figure 5-3 Effects of Limestone Injection Setting on Furnace SO₂ Reduction

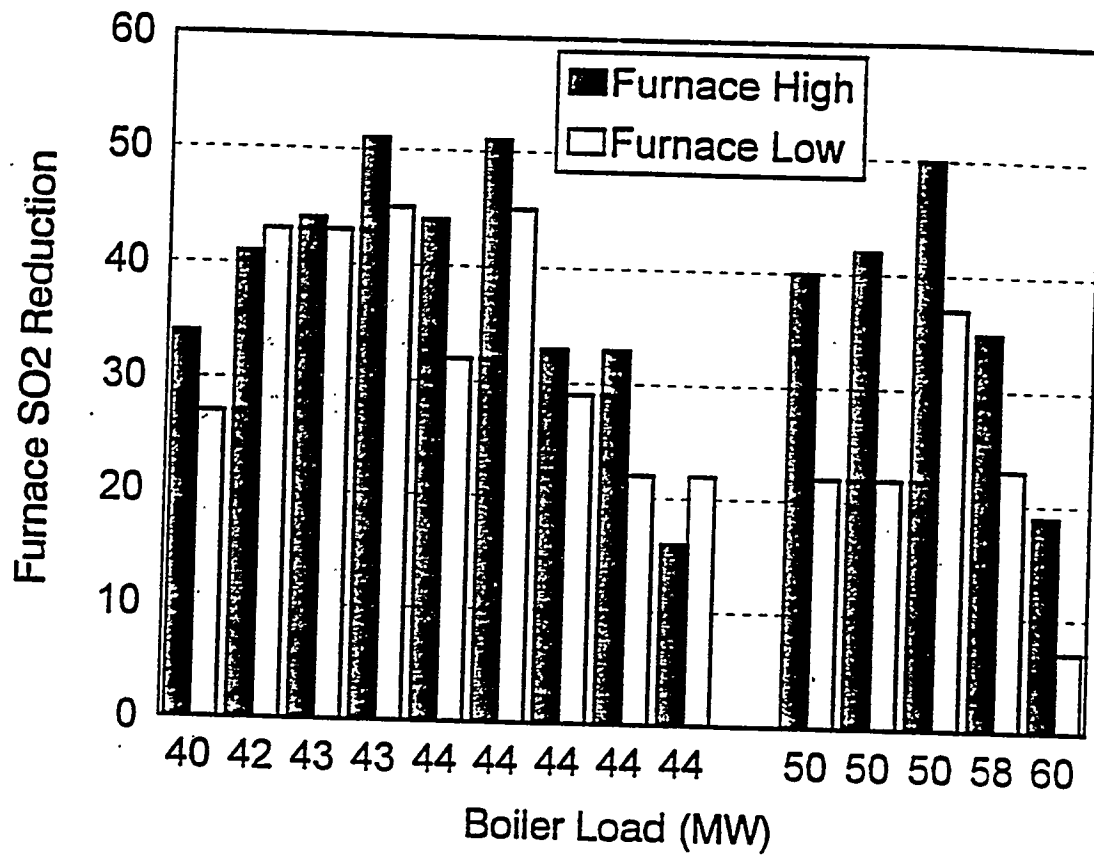


Figure 5-4 Limestone Quality Effect on Total SO₂ Reduction during High Boiler Load (59-61 MW)

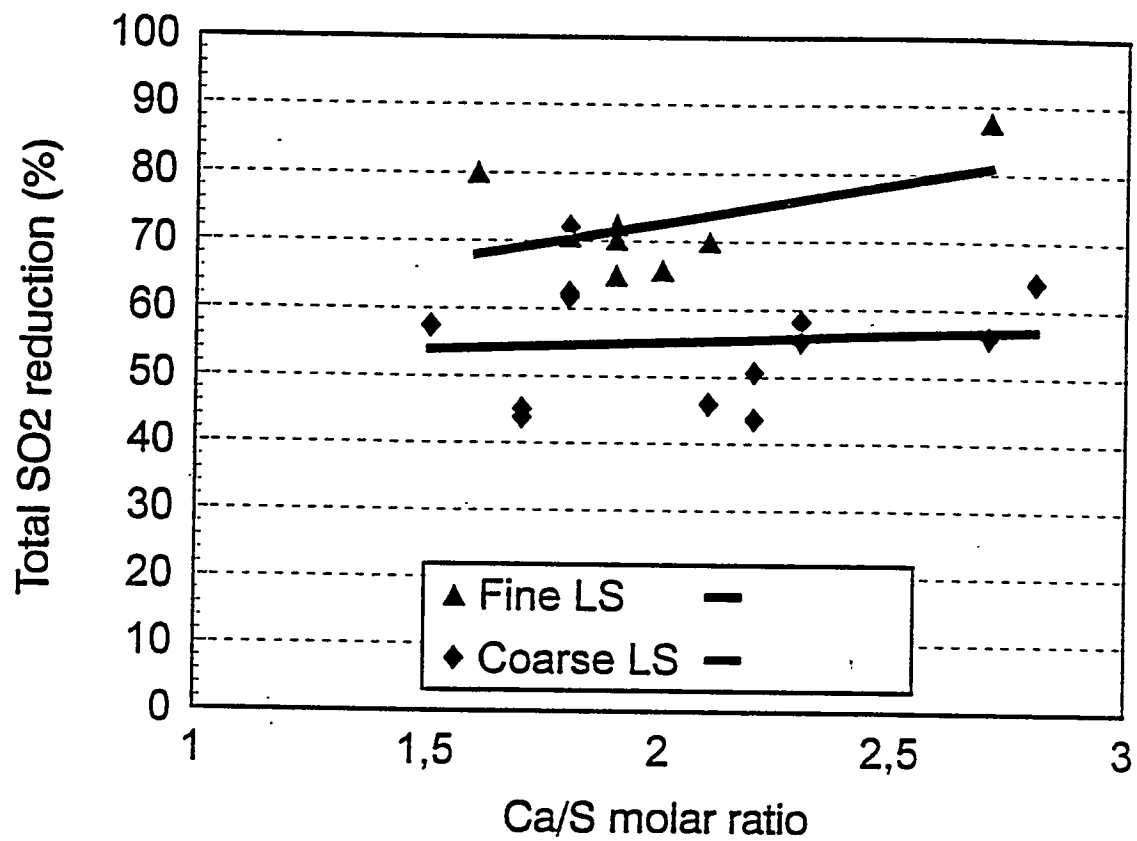
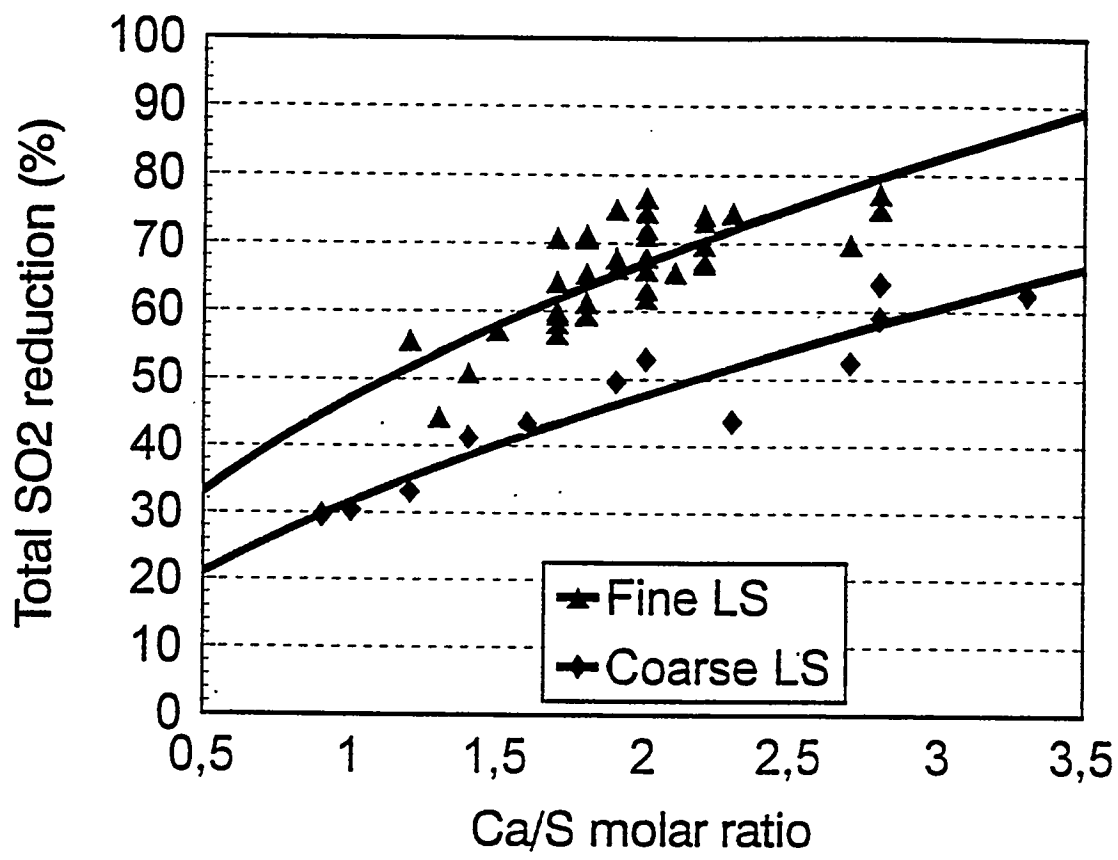


Figure 5-5 Limestone Quality Effect on Total SO₂ Reduction during Low Boiler Load (41-44 MW)



Boiler load was decreased during weekends and overnight. Due to the unavailability of low load results at similar operating conditions, a comparison of boiler load effects on SO_2 was not possible. Load was held constant during parameter measurements by adjusting the non-LIFAC boiler (Unit No.1) to suit power demand.

Boiler load effect on SO_2 reduction was not as significant as expected. Unit No.2 is small for its capacity and burns hot. Low loads should have improved efficiency. Instead, the difference between high and low load efficiency is unclear. The effect of boiler load will be studied again during long-term testing if low load periods are available. SO_2 capture in furnace and reactor at a range of boiler loads are shown in Figures 5-6 and 5-7.

Coal Quality

Test coal was shipped from three locations in three different states. Small amounts of low sulfur coal came from Kentucky and Ohio. The majority of the test coal (high sulfur) was shipped from southwest Indiana.

Sulfur content of the coal often changed during testing and caused slight inaccuracies in the results. Coal samples were grabbed once per hour from each of three feeders to get a representative samples of the test coal quality.

Sulfur content varied between 1.4 and 2.8 wt% sulfur. It was not possible to evaluate the effects of coal sulfur content on SO_2 capture since other conditions were not stable during testing. Figure 5-8 shows the sulfur content of the coal during the parametric tests.

Ca/S Molar Ratio

Limestone flow rate to the furnace is determined by a calcium/sulfur molar ratio. The ratio is calculated from the coal sulfur content and limestone quality, along with their respective flow rates. The calculation is described in Section 8.3. Ca/S ratios ranged between 1.0 and 3.0 during the parametric test period. The Ca/S molar ratio setpoint was maintained at 2.0 for most of the testing. Baseline coal sulfur content was determined from the sulfur dioxide concentration in the flue gas. This coal sulfur setpoint was entered into the PMS and remained unchanged until the next baseline adjustment and calibration period. The actual ratio varied according to boiler load and was, at times, inaccurate if the sulfur content of the combustion coal changed during operation. The actual ratio was later calculated from the lab analyses of the coal and incorporated into data analysis.

Ca/S molar ratio parameter testing was performed with a range of boiler loads, two different limestone qualities, and with recycle on and off. The effects of limestone quality and ash recycling are reported in the respective sections. Under all test conditions, sulfur dioxide capture increases as the Ca/S molar ratio increases. Figure 5-9 illustrates the effect of the Ca/S ratio with reduced boiler loads. According to previous LIFAC testing, Ca/S ratios higher than 3.0 slightly improve process efficiency, but degrade the economy of the system. The optimum settings were determined to be between 1.5 and 2.5 which result in a 60 to 75% SO_2 capture. Figure 5-10 shows the effects of Ca/S molar ratios at higher boiler loads.

Activation Reactor Outlet Temperature

Figure 5-6 SO₂ Reduction in the Furnace Versus Boiler Load

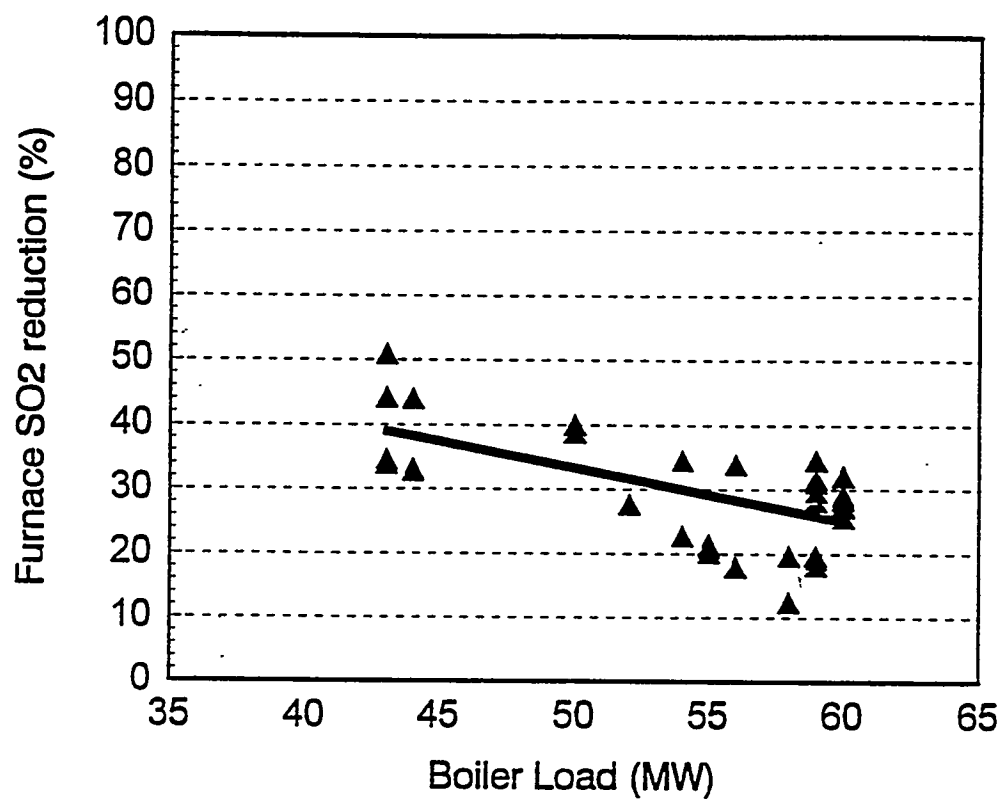


Figure 5-7 Total SO₂ Reduction Versus Boil Load

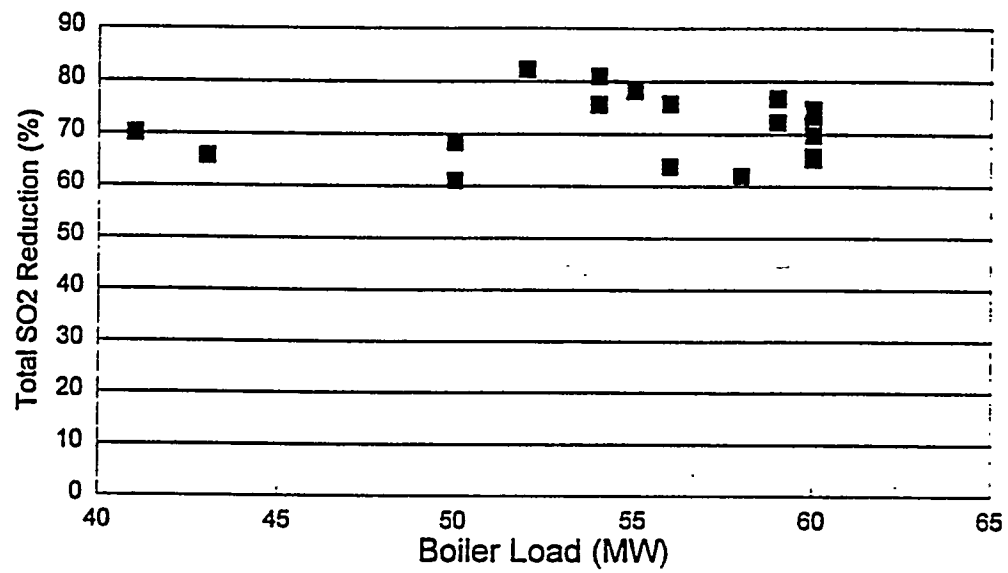


Figure 5-8 Sulfur Content of the Combustion Coal during Parametric Testing

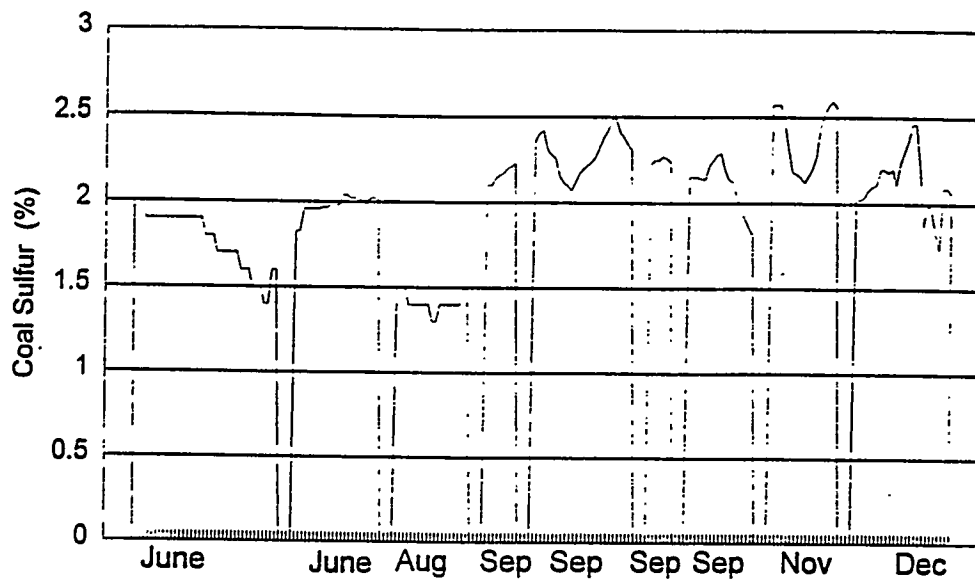


Figure 5-9 Total SO₂ Reduction Versus Ca/S Molar Ratio during Low Boiler Load

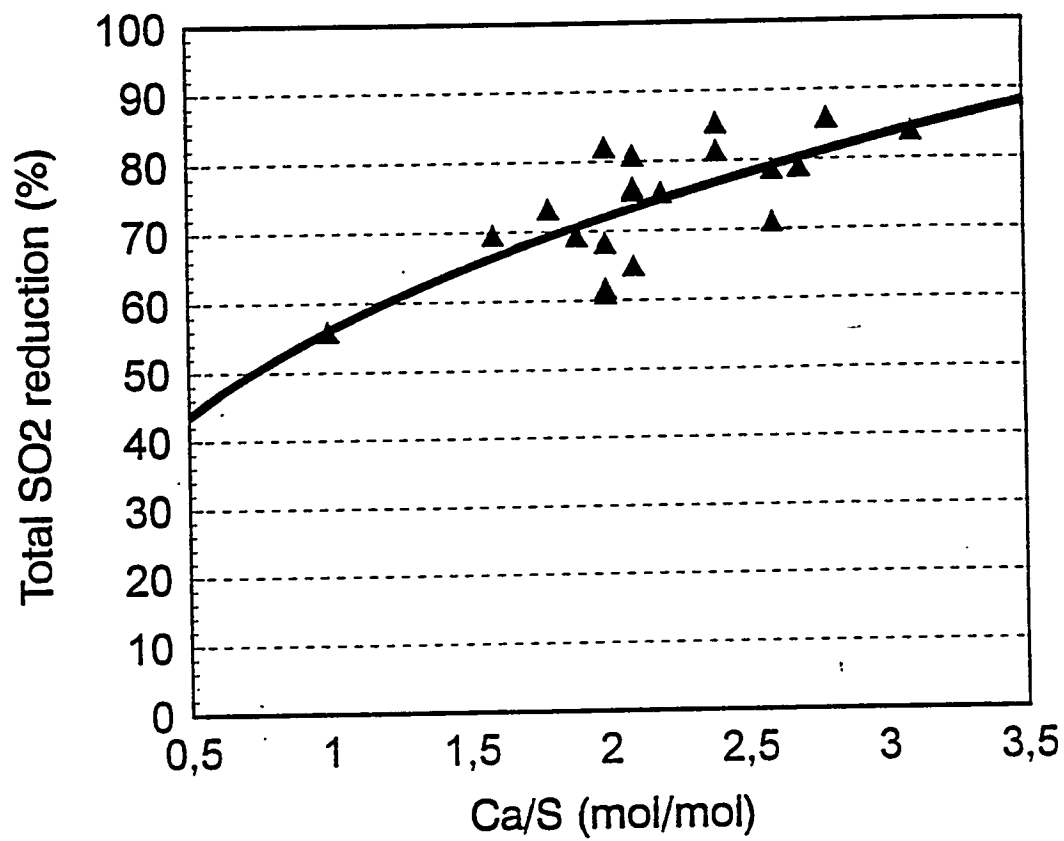
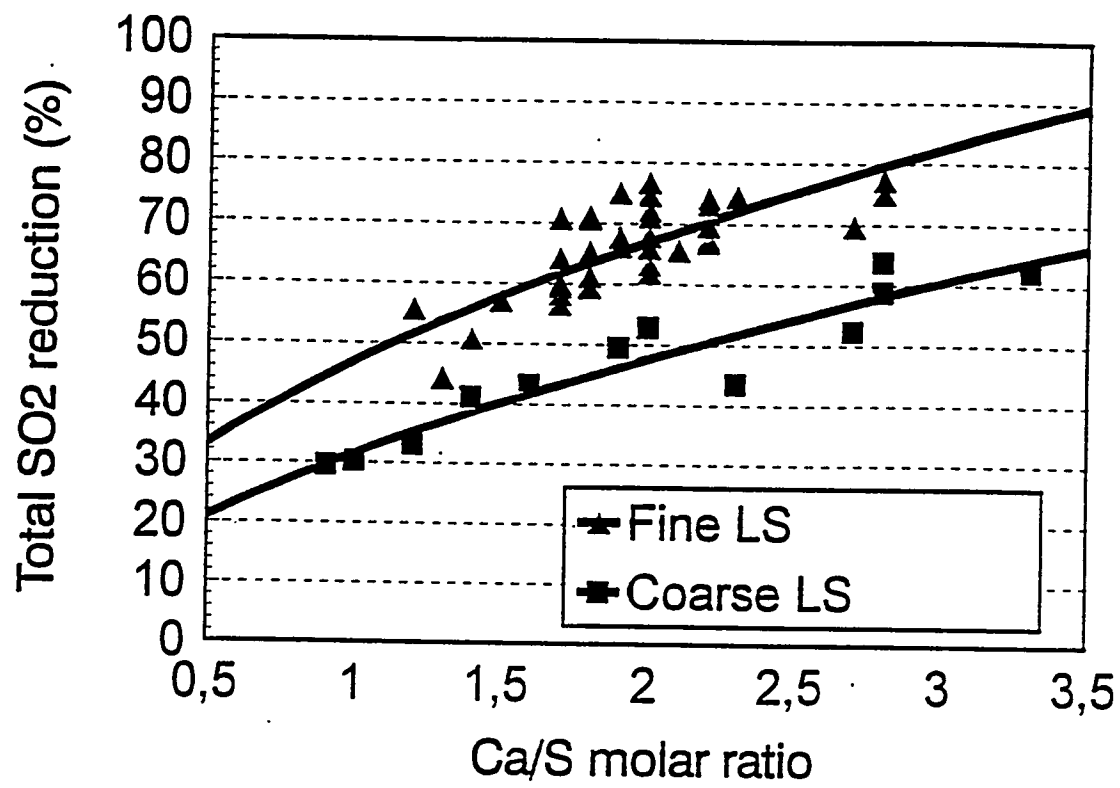


Figure 5-10 Total SO₂ Reduction Versus Ca/S Molar Ratio during High Boiler Load



Total SO₂ capture improves as reactor bottom temperature approaches the flue gas saturation temperature. It is necessary to keep the reactor outlet temperature above the flue gas saturation temperature (~126°F). If the exiting temperature is too low, the reactor bottom ash will become too moist. The ash handling system is designed to transport only dry ash. With the improved reactor design at Richmond Power & Light, a closer approach to saturation was possible. The design value was 11°F above saturation. Parametric tests were performed with temperatures as low as 3°F. Even at these low temperatures the reactor bottom ash was dry and easy to handle and dispose at a landfill. Typical bottom ash consisted of between 5 and 20% moisture content. Figure 5-11 shows the effect of reactor bottom temperature on process efficiency.

Humidification Nozzle Arrangement

It is possible to move each of the seven nozzle headers up and down. In the beginning of the tests the headers were at their lowest position. During the tests the headers were lifted to a higher position. There was a danger that ash would accumulate on the reactor's internal sealing if the nozzles were too high. The effects of the nozzle positions on sulfur capture was not documented. It is expected that a higher header position is beneficial because the mixing of the flue gas and water should improve and result in better SO₂ capture.

Water Droplet Size

Atomizing air pressure controls humidification water droplet size in the reactor. Air pressures between 38 and 65 psig were tested. The goal is to efficiently evaporate the droplets during their residence in the reactor. With low air pressure forming large water droplets, complete evaporation may not take place. This will create a wet ash byproduct. Conversely, smaller water droplets may evaporate too quickly and decrease SO₂ capture efficiency.

Ash Recycling

Fly ash containing unreacted calcium is recycled from two ESP hoppers to the reactor inlet duct. The quantity of the recycled material was limited because the reactor separated more ash than expected. All ash collected in the bottom of the reactor was disposed at a landfill.

The quantity of ash recycled was limited by the availability of fly ash collected in the ESP hoppers. Ash from the first two ESP hoppers was recycled back to reactor. If ash recycle quantity was increased, the hoppers emptied and the process became unsteady.

Ash recycling improved SO₂ reduction between 15 and 20% points. Increased recycling would foster improved SO₂ reduction. However, with the current installation arrangement, only small quantities of ash could be recycled. Ash recycling results, with high and low boiler loads, are shown in Figures 5-12 and 5-13.

5.2 Correlation of Results

Data was carefully selected from periods which represented stable process operation conditions and provided reliable results. Data representing certain parameter combinations and operating conditions were selected from a summary

Figure 5-11 Reactor Bottom Approach to Saturation Temperature and Its Effect on Process Efficiency

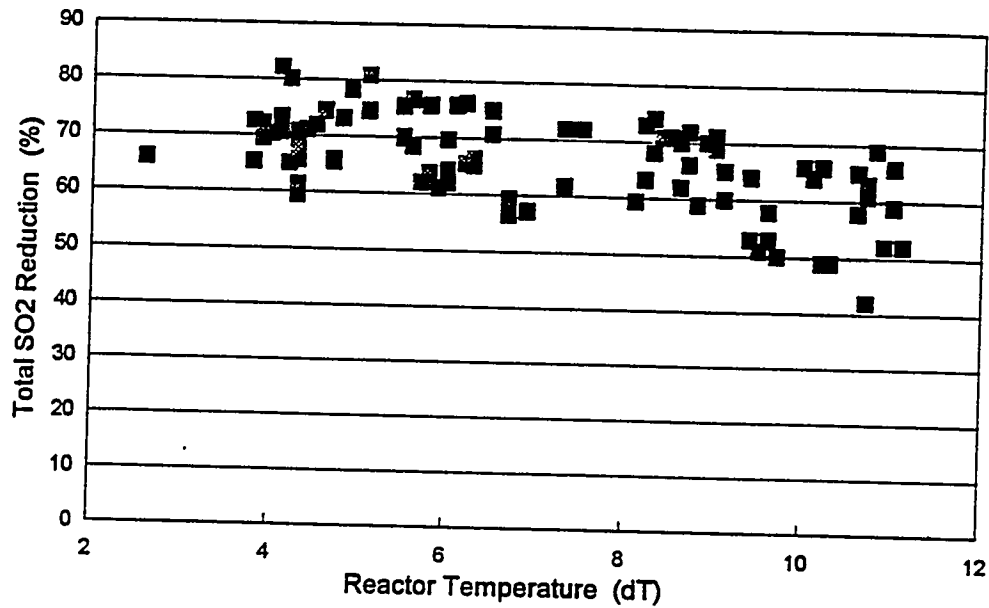


Figure 5-12 Unspent Sorbent Recycling Effect on Total SO₂ Capture during High Boiler Load

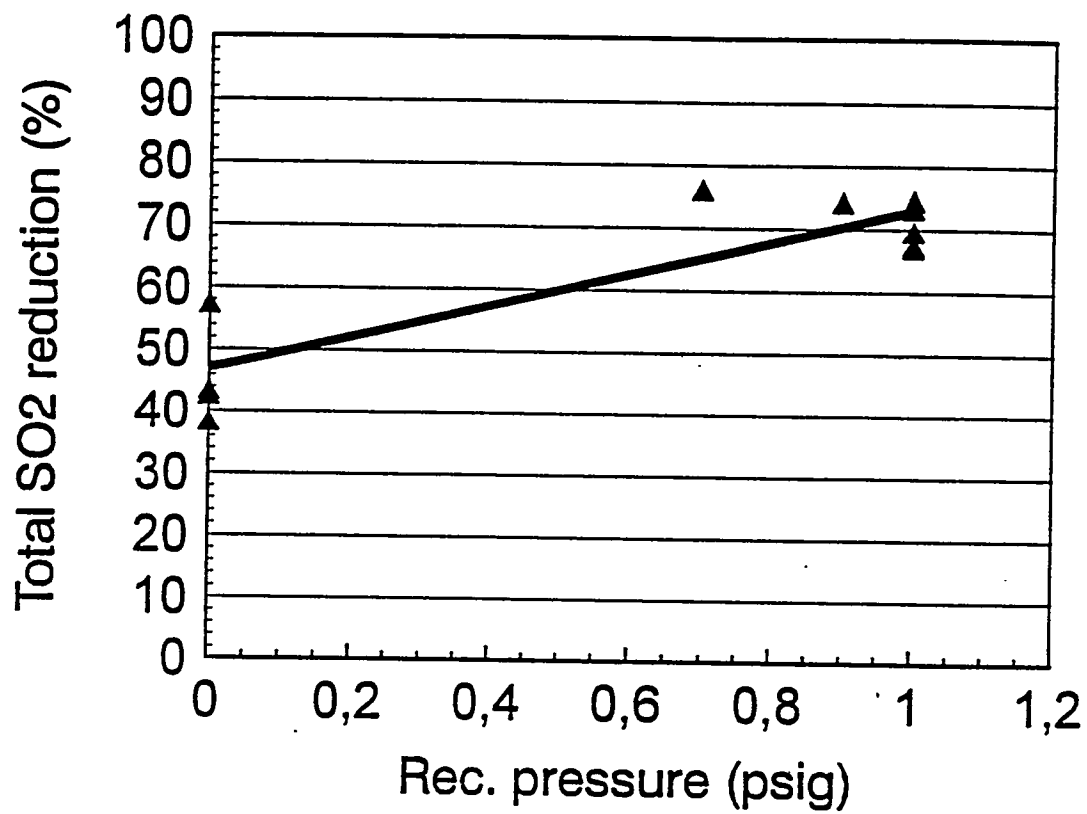
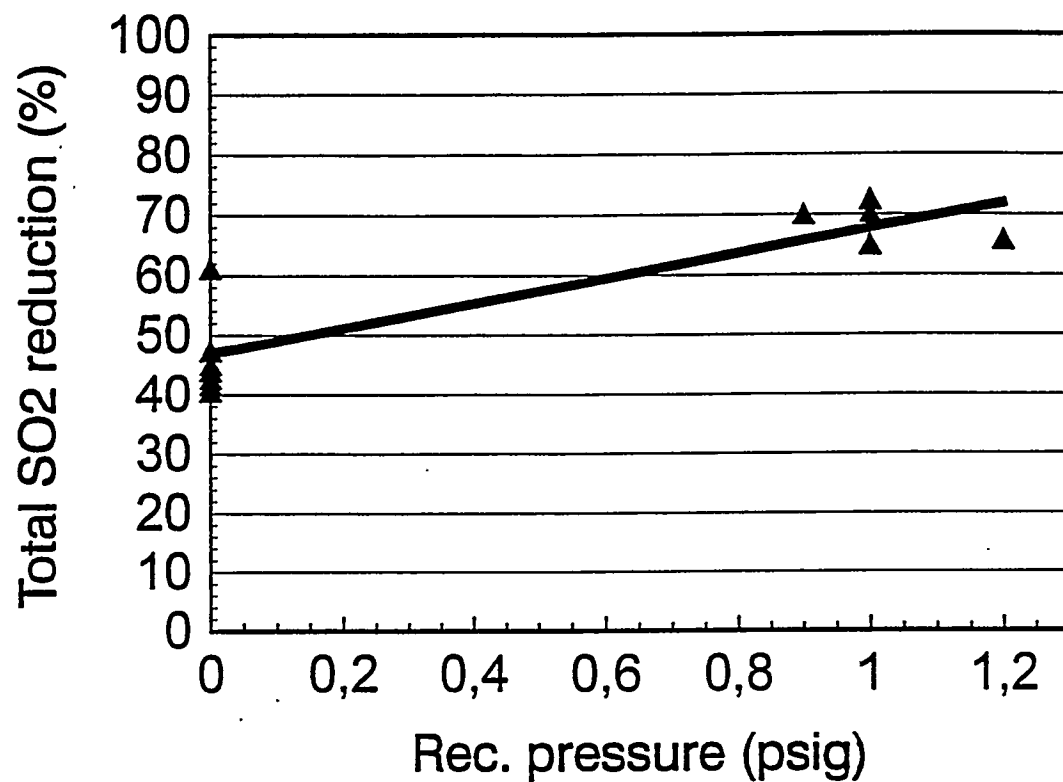


Figure 5-13 Unspent Sorbent Recycling Effect on Total SO₂ Capture during High Boiler Load



sheet by eliminating non eligible test points. Trends and curves were generated using these selected data points.

Several factors impacted the reliability of the test results and the planned procedures. Measurements were acquired during normal boiler operation, which were not always favorable for the test program. However, Richmond Power & Light employs two separate boilers and load demand was usually met with the non-LIFAC (Unit No. 1) boiler, when possible. Attempts were made to inject constant quality coal into the Unit No. 2 Boiler during testing. Sootblowing Frequency on Unit No. 2 was 4.5 and 6.0 hours. SO₂ measurements were deemed unreliable during these sootbuilding periods.

Due to the increase in pressure drop caused by LIFAC and the limited capacity of the ID fan motor, the bypass damper was kept 15% open during parameters testing. This bypassed flue gas contained an unknown amount of unreacted lime, thus decreasing the actual Ca/S molar ratio in the reactor. This problem was eventually corrected and long-term tests were performed with the bypass damper fully closed.

5.3 Optimum Settings for Long-Term Operation

Parametric test results were used to establish process settings for the remainder of the test program. Selection criteria was based on optimum sulfur dioxide capture and overall system performance.

Combustion coal burned during long-term testing will have a sulfur content of nearly 2.25%. This is the quality the RP&L has been burning during the last few years. A higher coal sulfur content would require a higher limestone feedrate if the Ca/S ratio is maintained at 2.0.

A Ca/S molar ratio of 2.0 was selected as the optimum limestone flow setting. This ratio yields the highest sulfur capture without interfering with process or boiler operability. Higher Ca/S molar ratios would increase boiler superheater fouling, thus the sootblowing sequence would need to be increased. Smaller Ca/S molar ratios may be more economical. Process economy will be studied during long-term testing.

Two different limestone qualities were tested. Fine quality (80% < 325 mesh) was significantly better than the coarse quality (80% > 200 mesh) and will be used during long-term testing. Sulfur capture was 20% points higher when fine quality limestone was employed. Sootblowing frequency was greater during injection of fine limestone. Coarse limestone was more abrasive on limestone transport hoses. Coarse quality was less expensive partly because of the grinding cost.

The most important parameter for effective sulfur capture in the reactor is the reactor bottom temperature. During long-term tests the reactor bottom temperature needs to be as low as possible. Lower temperatures induce a higher sulfur capture in the reactor. The temperature setpoint was limited to 9°F (135°F) above saturation temperature because the reheat steam coils in the exiting ductwork may become plugged. Without ash recycling, the reactor temperature setpoint was limited to 14°F (140°F) above the saturation temperature.

Humidification nozzles will be situated at their second highest position. In this position the internal sealing remains intact and the humidification effect and gas mixing is ideal.

Atomizing air pressure will be maintained between 55 and 60 psig. This pressure generates an optimum humidification water droplet size. If droplets are too large, they will not completely evaporate during their residence in the reactor. Hence, the ash exiting the reactor will be moist. Smaller droplets may evaporate too fast and reduce sulfur capture in the reactor.

Flue gas leaving the reactor will be reheated with both the steam heat exchanger coils and with the hot gas by-pass system. During initial ESP tests, it was discovered that ESP performance improved if the ESP temperature was above 195°F. Both reheater systems are needed to maintain this temperature. Further ESP tests will be performed during long-term testing with lower operating temperatures.

Ash recycling should be as high as possible. The quantity of recycled ash is limited by the availability from the ESP hoppers. Ash from the first two ESP hoppers is recycled back to reactor. If the ash quantity is increased, the hoppers may empty and the process will not be stable.

5.4 Optimization and Long-Term Test Implementation

The results of parametric data analyses enabled the test team to determine the optimum process values which would maximize the efficiency of the demonstration system. In order to perform a controlled study, a fine limestone (85% passing 325 mesh, 93% CaCO₃) and a consistent quality coal (2.25% Sulfur) were employed. The process parameters that were maintained during optimization testing were:

Ca/S Molar Ratio	2.0
Recycle Pressure	1.0 psig
Reactor Bottom Temperature	135°F
Atomizing Air Pressure	55-60 psig
ESP Inlet Temperature	200°F
Bypass Damper	0% open

Since the optimization tests were coupled with long-term testing, test procedures are similar. A detailed discussion of these procedures is provided below.

The process was in operation continuously for several days during each test period. Normal boiler operating procedures were followed by operators at Richmond Power & Light. The LIFAC Test Team consisted of one test coordinator and one field operator who were employed 24 hours per day during operations. The test coordinator operated the process, coordinated sampling, and regulated the process according to host facility fluctuations. Most coordination tasks were implemented in Richmond Power & Light's control room via the Process Monitoring System (PMS). The field operator's responsibilities were to maintain process equipment, grab samples, and coordinate by-product shipping and limestone receiving.

Limestone feed rate, which is determined by a Ca/S molar ratio automatically followed coal flow oscillations. Constant quality coal was specially blended and burned during long term testing. An accurate coal sulfur content of 2.25 wt% was preset in the Process Control System.

Humidification water flow pressure changes according to the reactor bottom temperature setting on the PMS. During long-term testing, a reactor bottom temperature of approximately 10°F above saturation temperature was sustained. This outlet temperature was not optimum, but was necessary to eliminate the possibility of plugging the steam reheaters in the exiting ductwork.

Limestone Injection & Boiler Operation

The six upper level limestone injection nozzles were used during optimization and long-term testing. Flue gas temperature is slightly cooler (~ 100°F) near these upper injection nozzles. A higher SO₂ reduction rate was observed in the upper level during parametric testing. SO₂ reduction in the furnace only was calculated using the analyzer situated between the furnace and the act reactor. The nozzle may be tilted up to 15° in the vertical direction. However, all tests were performed with the nozzles in a straight horizontal position. Tilting effects on SO₂ reduction would be minimal as compared to nozzle combination variations, which were also minimal.

The booster or secondary, air fan was not operated during long-term or optimization tests. Booster air was not tested for three reasons. With the VFD inoperation, the ID fan operated at capacity and additional flue gas volume may have been detrimental. Second, the booster air fan was extremely loud. Lastly, injection SO₂ reduction of the upper injection ports and nozzles.

Limestone flow rate to the furnace is determined by a Ca/S molar ratio. This ratio was held constant at 2.0 during optimization and long-term tests. In order to maintain this ratio, the limestone feed rate must follow coal quality and flow variations. A 2.25 wt% sulfur content of the feed coal was estimated. If coal quality changed during operation, a correction was made upon receipt of laboratory analyses. Parametric test results indicated that a 2.0 Ca/S molar ratio yields approximately 70% SO₂ reduction.

Limestone quality was consistent at all times. A high calcium (90-95% CaCO₃), fine grind (85% < 325 M) limestone was injected for long-term evaluations. A smaller size limestone proved to be more efficient during parametric testing. Coal sulfur content was steady, slightly above 2.0 wt%, for the duration of the testing. This feed coal is a typical quality burned at Richmond Power and Light.

Activation

The by-pass damper was 15% open during parametric tests in order to maintain a gas temperature of 200°F through the ESP. The reheat system was modified for long-term evaluations and only a small amount of hot gas (850°F) was by-passed this test period.

The saturation temperature of the flue gas is estimated to be approximately 126°F. Reactor bottom temperature was held ~10°F above saturation temperature during long-term tests. A lower reactor bottom temperature would have resulted in improved SO₂ capture; however, the possibility of plugging the steam reheaters constrained the process to these higher temperatures. Steam reheater cleaning is costly and days of downtime are experienced. At these reactor temperatures, the ash separated in the reactor contains 5 to 15% moisture content.

Humidification water droplet size is controlled inversely with atomizing air pressure. Air pressures between 50 and 60 psig were maintained for this test

period. These pressures create droplets small enough to maximize evaporation effects during its residence in the reactor. Droplets too small may evaporate too quickly, decreasing process efficiency. While, large droplets may not completely evaporate and cause the ash to moisten.

Humidification nozzle scrapers were employed to keep ash from building up on the headers. Each header is scraped six times per hour.

Ash Recycling

A mixture of fly ash and unreacted calcium compounds collected in the ESP is partially recycled back to the reactor inlet ductwork. The ratio between the recycled material and material coming from the reactor is called the recycle ratio.

Fly ash flow from the ESP hoppers is controlled with variable speed rotary feeders located under the hoppers. The feeders were programmed to operate at 30% speed as determined from parametric testing. This is the maximum attainable speed since the ESP hoppers will empty if it is increased. The reactor bottom ash recycling system was not completed for the demonstration.

ESP Performance Test

ESP performance parameters were recorded throughout the demonstration. EPRI and the Southern Research Institute conducted an extensive evaluation of unit No. 2 ESP's in two phases. The first phase of tests were performed during parametric testing in April of 1993. The second, and final, phase occurred during long-term tests in June, 1994 and the results can be viewed in Appendix II.

5.5 Optimization and Long-Term Test Results

Optimization and long-term tests were performed to evaluate the process' performance, economy, and operability over long, continuous operation periods. Any impacts on the host facility as a result of LIFAC operations were also studied. Extensive ESP performance evaluations were conducted during these steady process operating conditions.

Many process performance results were not reliable due to variations in both boiler and LIFAC operating conditions. The boiler operated normally and fluctuated according to power demand. The operability of the LIFAC system was evaluated during long-term tests, and the results are reported in Section 4.3 of this report.

SO₂ reduction in the furnace was calculated from an estimated level of sulfur dioxide created during combustion versus the amount of SO₂ measured after the furnace. The estimated SO₂ reduction levels were corrected after receiving coal analyses from the laboratory. During steady operation conditions, SO₂ reduction in the furnace varied from 63% to 78%. Boiler load was high (59-60 MW) for most of the test period. Load was slightly lower overnight and on weekends. The nameplate load of Unit No. 2 is 60 MW. Figure 5-14 shows total SO₂ reduction versus boiler load during long-term testing.

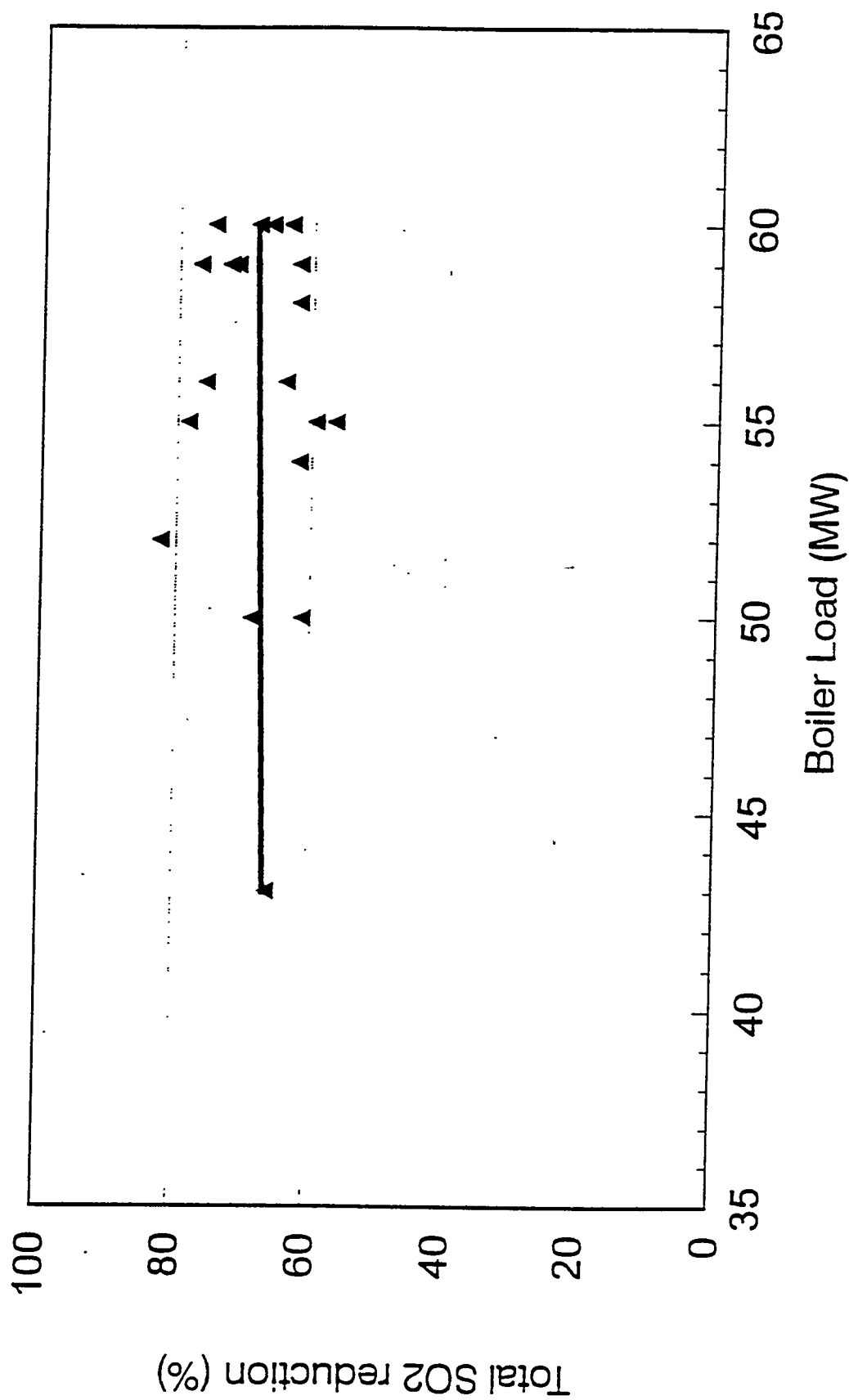


FIGURE 5-14: Long-Term SO₂ Reduction Versus Boiler Load

Limestone Injection

The six upper level injection nozzles were employed during this entire test period. This injection location yielded the highest SO₂ reduction rates during parametric testing. Injection nozzle headers can be tilted 15° vertically. All tests were performed with the nozzles in a straight horizontal position. The injection angle parameter would contribute little to sulfur dioxide reduction. With Ca/S ratios between 1.7 and 2.2, the total SO₂ reduction ranged from 55% to 77% as shown on Figure 5-15.

The booster, or secondary air fan was not operated during the demonstration. With VFD inoperational, the ID fan operated at capacity and additional flue gas volume may have been detrimental. Also, the booster air fan was extremely loud in the boiler house.

Limestone and coal qualities were consistent for all long-term evaluations. Limestone with a particle size of 85% 325 mesh and a 93% CaCO₃ content was injected during testing. This finely ground limestone proved to be ~ 20% points more effective than coarse (200 mesh) limestone. Coal with a sulfur percentage of 2.3% was burned at RP&L for this test period.

Activation

Reactor bottom temperature was maintained between 3°F and 9°F above the flue gas saturation temperature (~ 126°F). Lower activation temperatures would have yielded a higher process efficiency; however, lower temperatures produce moist exiting fly ash which may plug the matrix of fin-tubed steam reheaters. Fly ash moisture content typically ranged from 5 to 15% moisture with no water droplets entrained in the flue gas. Humidification water droplet size was stabilized with an atomizing air pressure of 55 psig. Humidification nozzle headers were fixed in the second highest vertical position. Figure 5-16 shows the correlation between reactor bottom temperature and process efficiency.

Ash Recycling

Fly ash containing unreacted calcium is recycled from two ESP hoppers to the reactor inlet duct. The quantity of ash recycled was limited by the availability of fly ash collected in the ESP hoppers. Ash from the first two ESP hoppers was recycled back to the reactor. Ash recycling improves SO₂ reduction between 15 and 20 percentage points as shown on Figure 5-17.

6.0 ENVIRONMENTAL PERFORMANCE

Environmental impacts of the technology were monitored to demonstrate the benefits of the technology such as the reduction of emissions of sulfur dioxide (SO₂) and oxides of nitrogen (No_x), but also to evaluate any potential impacts to any of the by-products or waste streams.

6.1 Impact on the Environment

6.1.1 Summary of the Environmental Monitoring Plan (EMP)

Environmental monitoring was conducted in accordance with the required Environmental Monitoring Plan, for which it had the following purpose:

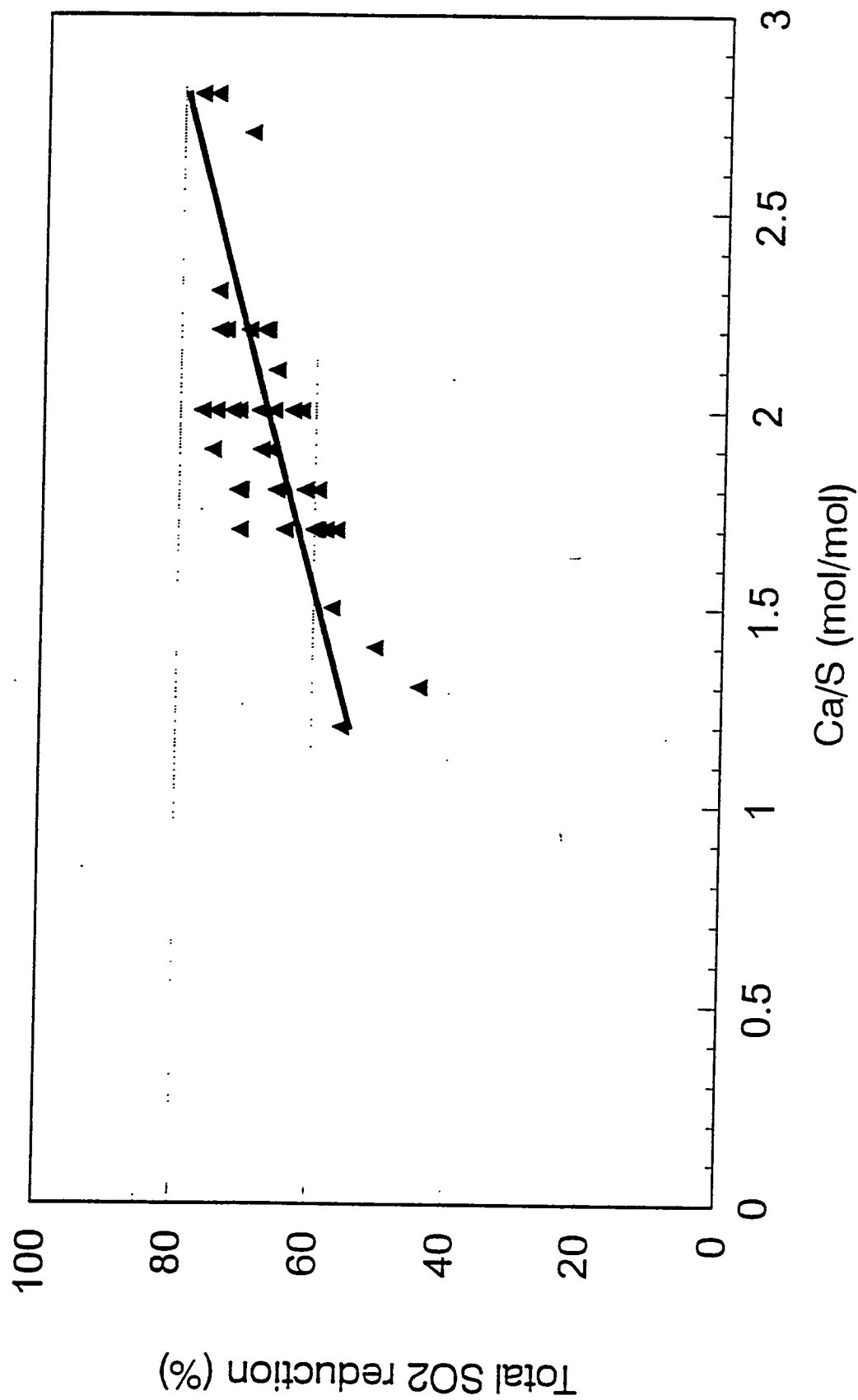


FIGURE 5-15: Long-Term SO₂ Reduction Versus Ca/s Molar Ratio

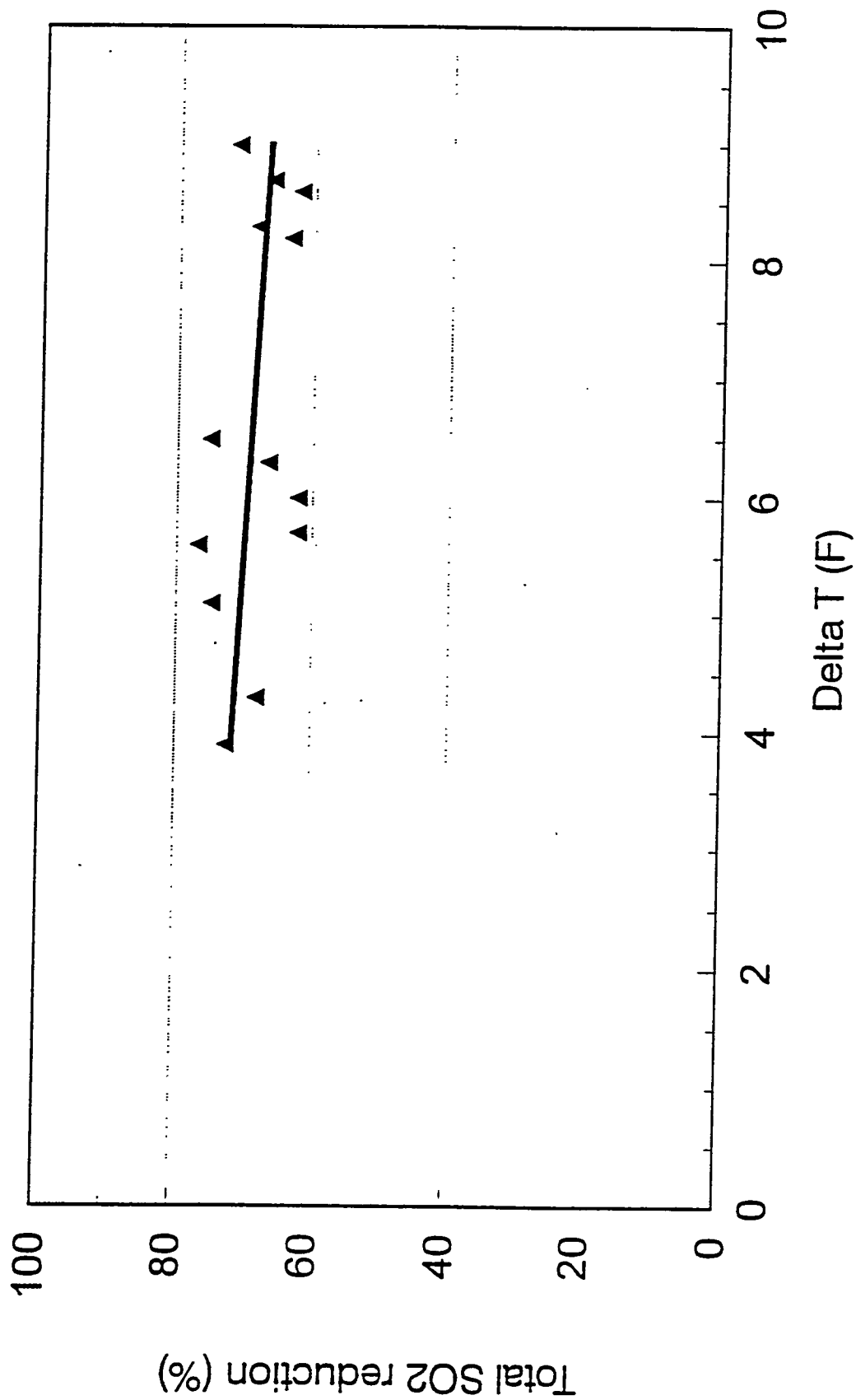


FIGURE 5-16: Long-Term Total SO₂ Reduction Versus Activation Temperature

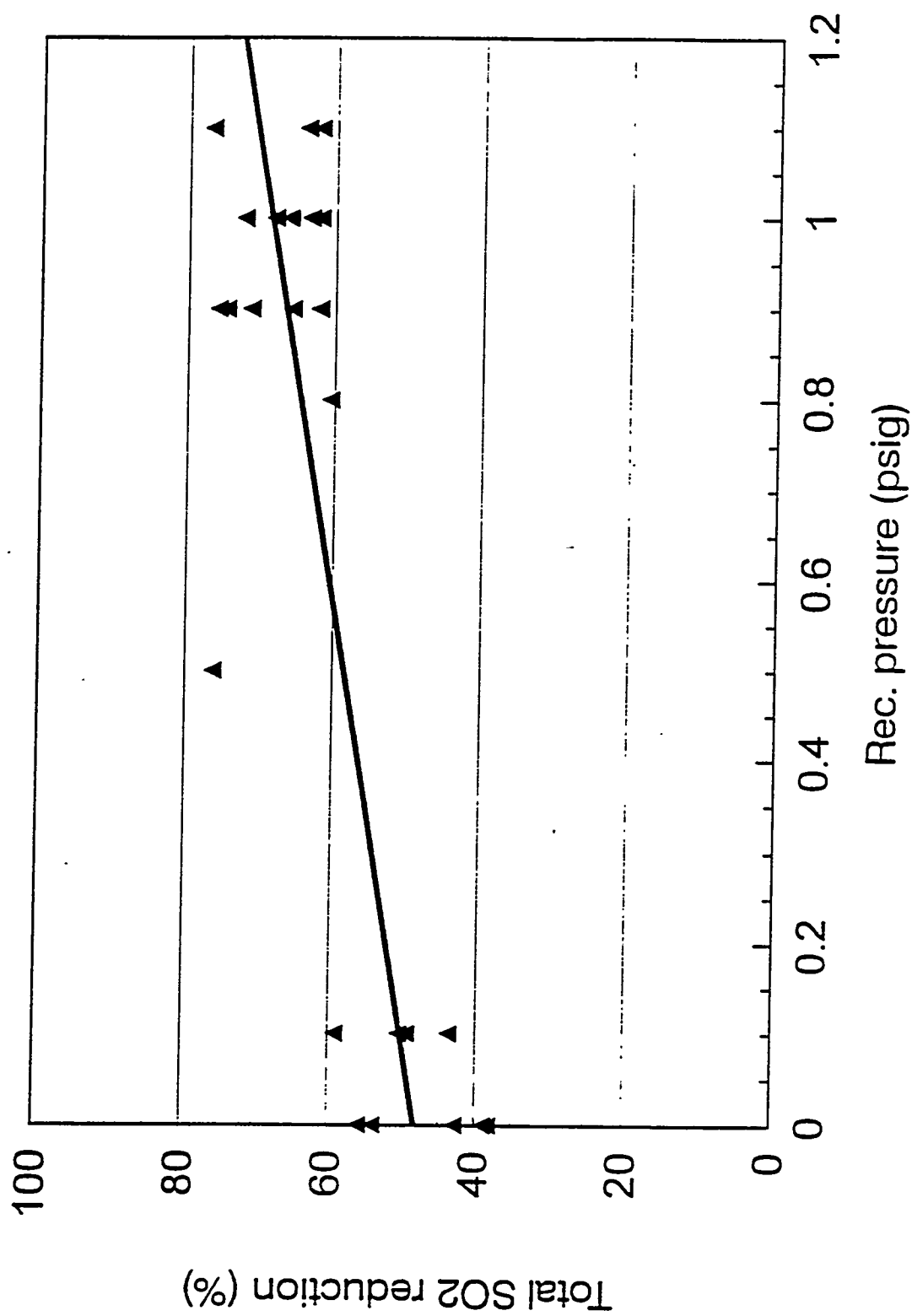


FIGURE 5-17: Long-Term Total SO₂ Reduction Versus Ash Recycling Pressure

1. To identify and characterize potential environmental and health impacts of the demonstration project, both on-site and off-site, and
2. To develop an information base for the assessment and mitigation of impacts associated with the replication of CCT projects.

Environmental monitoring was necessary to quantify the project-specific and site-specific environmental mitigation measures implemented as part of the project.

The EMP contained compliance and supplemental monitoring as defined below:

- **Compliance Monitoring:** Compliance monitoring is the monitoring required by agencies of Federal, state and local governments, other than DOE, to satisfy statutes, regulations and terms of leases, permits, grants, and other requirements.
- **Supplemental Monitoring:** Supplemental monitoring is monitoring required in addition to compliance monitoring to identify and characterize potential environmental and health impacts of the project, both on-site and off-site. This may include, but is not limited to, the measurement of processes, feedstocks, operating conditions, discharges, ambient environmental conditions, occupational health and safety, and industrial hygiene. The processes and operating parameters that are likely to affect environmental discharge rates and their compositions, waste generation, public health, ecological systems and other relevant environmental characteristics of construction and operation of the project.

A variance to operate Unit #2 for the testing performed during the different project stages was obtained from the Indiana Department of Environmental Management (IDEM). The variance required specific compliance tests to be conducted at milestones identified in the variance request. In addition to the compliance testing, the project also required supplemental monitoring to be performed. This supplemental monitoring focused on the measurement of coal feedstocks, boiler and generator operating conditions, gaseous and particulate discharges, and solid and aqueous process by-products. Measurement of coal feedstocks included coal analysis and feed rate to boiler. Boiler and generator operating conditions were recorded on operator log sheets. Measured discharges included total particulate matter, nitrogen oxides (NO_x), sulfur dioxide (SO₂), carbon monoxide (CO), carbon dioxide (CO₂), an oxygen (O₂). Determinations of alkalinity, pH, sulfate content, and any quantities of specified metals, organic compounds and volatile organic compounds (VOC) present in the process liquid and solid by-products were made. Tables 6-1 and 6-2 provide a summary of the required compliance and supplemental monitoring required under the EMP.

A schematic of the system is included as Figure 6-1, which identifies locations where environmental monitoring was performed.

The majority of the compliance and supplemental monitoring centered around the testing of particulate matter and gaseous parameters. The test programs utilized methodologies promulgated in 40 CFR 60, Appendix A, for the particulate matter and duct gas determinations necessary for the test program. EPA Methods 1, 2, 3A, and 4 were used for the determination of the sampling point locations, gas

TABLE 6-1
COMPLIANCE MONITORING
EMP

Parameter	Sample	Sample Frequency and Duration	Limit ¹	Sample Location (see Figure 2-1)
GASEOUS EMISSIONS				
SO ₂ ²	Calculation	Daily	6.0 lb/MBtu	9 - Breeching-duct downstream of the I.D. fan*
Total Suspended Particulates (TSP)	EPA Method 5 ³	2/year	0.22 lb/MBtu	9 - Breeching-duct downstream of the I.D. fan*
Opacity	CEM ⁴	Continuous	40%/30% ⁵	9 - Breeching-duct downstream of the I.D. fan*
AQUEOUS EFFLUENT (RP&L's NPDES Discharge Permit Requirements)				
Flow	Instantaneous	3 × Weekly	Report	6 - Weir at ponds system outfall
Total Suspended Solids (TSS)	Grab	2 × Weekly	70 mg/l	6 - Weir at ponds system outfall
Oil and Grease	Grab	2 × Weekly	15 mg/l	6 - Weir at ponds system outfall
Total Residual Oxidants (Chlorine)	Grab	2 × Weekly	0.02 mg/l	6 - Weir at ponds system outfall
Temperature	Instantaneous	2 × Weekly	Report	6 - Weir at ponds system outfall
Ammonia (NH ₃)	Grab	2 × Monthly	1.8 mg/l (summer) 2.6 (winter)	6 - Weir at ponds system outfall
Copper	Grab	2 × Monthly	0.05 mg/l	6 - Weir at ponds system outfall
Lead	Grab	2 × Monthly	0.02 mg/l	6 - Weir at ponds system outfall
Zinc	Grab	2 × Monthly	0.46 mg/l	6 - Weir at ponds system outfall
Aluminum	Grab	2 × Monthly	0.40 mg/l	6 - Weir at ponds system outfall
Iron	Grab	2 × Monthly	Report	6 - Weir at ponds system outfall
Total Polychlorinated Biphenols (PCBs)	Grab	2 × Monthly	Report	6 - Weir at ponds system outfall

¹ Limits for air emissions are based on the LIFAC Variance to the draft boiler Operating Permits. Limits for water discharges are daily limits.

² Complete coal analysis is performed as part of the Test Program.

³ 40 CFR Part 60.

⁴ Continuous Emissions Monitor.

⁵ Opacity Limit revised to 30% as per RP&L's variance from IDEM.

* Emissions tests can be conducted at the 250' level on the stack when Unit #1 is not in operation.

TABLE 6-2
SUPPLEMENTAL MONITORING
EMP

Parameter	Sample	Sample Frequency and Duration	Range	Sample Location (see Figure 2-1)
GASEOUS EMISSIONS				
NO _x	EPA Method 7 D&E ¹	Continuous or 3/condition	0-1 lb/MBtu	9 - Breeching-duct* downstream of the I.D. fan
SO ₂ ²	EPA Method, 6, 6C or 8	Continuous or 3/condition	0-6 lb/MBtu	9 - Breeching-duct* downstream of the I.D. fan
TSP	EPA Methods 1-5	Continuous or 3/condition	0-1 lb/MBtu	9 - Breeching-duct* downstream of the I.D. fan
PM ₁₀	EPA Method 201A	Continuous or 3/condition	0-1 lb/MBtu	9 - Breeching-duct* downstream of the I.D. fan
CO ₂	EPA Method 3	Continuous of 3/condition	0-500 lb/MBtu	9 - Breeching-duct* downstream of the I.D. fan
CO	EPA Method 10	Continuous or 3/condition	0-500 ppmv	9 - Breeching-duct* downstream of the I.D. fan
AQUEOUS EFFLUENT				
Alkalinity	EPA Method 310.2	1/Condition	mg CaCO ₃	6 - Weir at ponds system outfall
SOLID WASTE AND BY-PRODUCT				
TCLP	EPA Method 1311 TCLP Metals, Methods 8240 and 8270 for Organics	1/Condition	Various per parameter	3 - Economizer Hopper 4 - LIFAC Ash 5 - ESP Hoppers 10 - Bottom Ash
Sulfates	ASTM Extraction ³ EPA Method 9035	1/Condition	0-1,000 mg/l	3 - Economizer Hopper 4 - LIFAC Ash 5 - ESP Hoppers 10 - Bottom Ash
Alkalinity	ASTM Extraction Method EPA Method 310.2	1/Condition	mg CaCO ₃	3 - Economizer Hopper 4 - LIFAC Ash 5 - ESP Hoppers 10 - Bottom Ash
Organics	EPA Method 8240	1/Condition	0-1,000 mg/l	3 - Economizer Hopper 4 - LIFAC Ash 5 - ESP Hoppers 10 - Bottom Ash
pH	EPA Method 9045	1/Condition	0-14 H ⁺	3 - Economizer Hopper 4 - LIFAC Ash 5 - ESP Hoppers 10 - Bottom Ash

¹ 40 CFR Part 60 Appendix A.

² SO₂ monitoring will be performed as part of process monitoring.

³ Annual book of ASTM standards.

* Emissions tests can be conducted at the 250' level on the stack when Unit #1 is not in operation.

LOCATION	MEDIA	TEST PROGRAM	MONITORING PURPOSE	
			SUPPLEMENTAL	EMP COMPLIANCE
1	SOLID	X		
2	SOLID	X		
3	SOLID	X	X	
4	SOLID	X	X	
5	SOLID	X	X	
6	AQUEOUS	X		X
7	GASEOUS	X		
8	GASEOUS	X	X	
9	GASEOUS	X		
10	SOLID	X	X	X

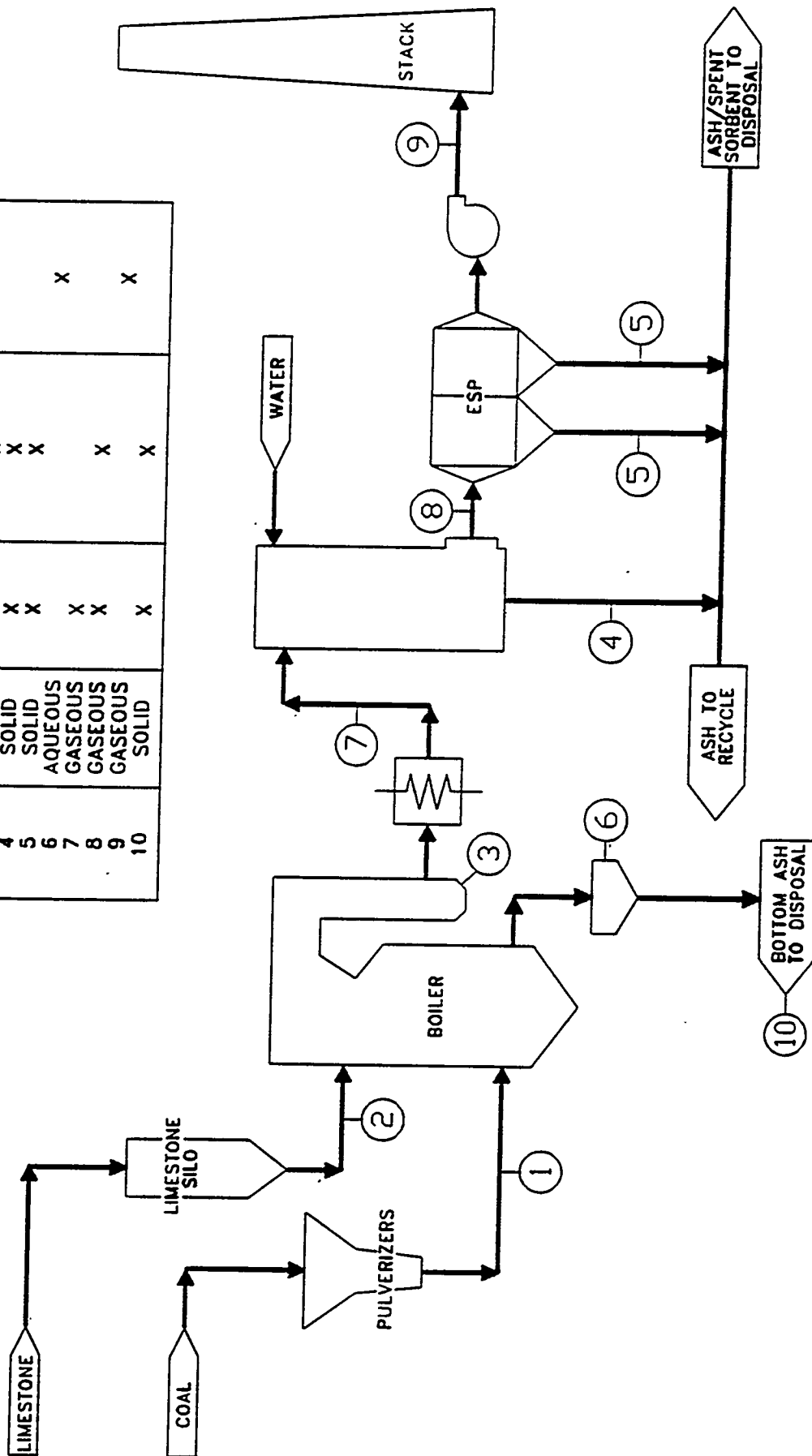


Figure 6-1
Whitewater Valley Unit No.2
LIFAC Demonstration Sampling Locations

velocities and volumetric flow rates, gas molecular weight on a dry basis, and percent moisture content, respectively. Particulate matter was determined using EPA Method 5. Gas concentrations of NO_x, SO₂, and CO were determined utilizing EPA Methods 7E, 6C, and 10, respectively. PM₁₀ was determined using EPA Method 201A. Also, verification tests for absence of cyclonic flow was performed each test day at the breech sampling location, in accordance with EPA Method 1, Section 2.5.

Analyses of the solid and aqueous LIFAC by-products followed EPA methods and ASTM extraction methods. The specific EPA methods which were referenced are cited in the footnotes on the actual analytical results provided by Antech Ltd. provided in the Baseline Report⁽¹⁾, Parametric and Optimization Report⁽²⁾, and the Operations and Post-Lifac Report⁽³⁾. Total alkalinity of both the aqueous and solid samples were determined by EPA Method 310.2. Before the alkalinity of the solid samples could be measured, they were extracted using ASTM extraction methods. The remaining analyses of the solid wastes were performed using the following EPA Methods: pH, 9045; sulfate, 9038 (using ASTM extraction method); metals, Toxicity Characteristics Leaching Procedures (TCLP) 1311, 6010, 7470, and 7740; organic materials, TCLP 8260 and 8270; and VOC, TCLP 8260.

6.1.2 LIFAC Test Parameters

Compliance and supplemental monitoring in accordance with the EMP was conducted during the following LIFAC operations tests.

- **Baseline Testing** (conducted September 2, 1992, December 18, 1992 and September 22, 1993): As defined in the Test Plan, Baseline Operations are conducted during the post-construction phase and before any on-line application of hardware or limestone absorbent that would normally be utilized by the LIFAC process. Baseline testing was conducted to develop a information base for normal plant operations to be utilized to evaluate technology and environmental impacts.

Compliance and supplemental tests were conducted each day including emissions testing. Since Units 1 and 2 were both in operation during the September 1992 and December 1992 testing, emissions monitoring was conducted at the test portals located in the duct breeching located downstream of the I.D. fan. The September 1993 tests were conducted at the 250' level of the stack, since Unit 1 was off-line.

Ash samples were collected at the economizer hoppers, ESP inlet and outlet hoppers, and the boiler bottom ash disposal bin.

- **Parametric Testing** (conducted September 23 and 24, 1993): As per the Test Plan, parametric testing is designed to evaluate the different possible combinations of LIFAC process parameters and their effectiveness. This set of tests was to determine the optimum combination and settings of process parameters which were then used throughout the remaining demonstration tests. Process parameters include sulfur content of coal, limestone quality, limestone calcium to sulfur ratio, injection ports combinations, injection nozzle angles, booster air, reactor outlet temperature, and ash recycling ratio.

Monitoring included compliance and supplemental emissions testing being conducted for each day. Since Unit 1 was off-line during the sampling

event, emissions were monitoring at the 250-foot level of the stack and not at the duct breeching as done during the 1992 baseline testing. Sootblowing was performed during one of the three PM tests for each of the two days.

Under supplemental monitoring ash samples were collected at the economizer hoppers, LIFAC bottom hoppers, ESP inlet and outlet hoppers, and boiler bottom ash disposal bin. Monitoring of the plant's feedwater was also conducted since its incoming quality was believed to be impacting compliance with effluent criteria in accordance with RP&L's NPDES Permit. Feedwater for the plant is either pumped from the river, or during dry seasons, is pumped from the local sanitary treatment plant's effluent discharge. Feedwater during the September tests was coming from the treatment plant effluent.

The boiler bottom ash discharge water was also sampled since it is believed that immediate impacts will not be seen at the pond outfall as a result of LIFAC operations due to the long residence time through the pond system. The team plans to utilize RP&L's pond discharge monitoring analyses as required under their NPDES permit to identify any long-term trends after LIFAC has been running.

LIFAC test parameters during the September 23 and 24, 1993 environmental monitoring are summarized in Table 6-3:

TABLE 6-3 PARAMETRIC TESTING - TEST PARAMETERS

	September 23, 1993	September 24, 1993
Boiler Load (MW)	60	60
Coal Quality - % S	2.23	2.18
- SO ₂ lb/MMBtu	4.09	3.87
Limestone Quality	85% - 200 Coarse	85% - 325 Fine
Ca/S Molar Ratio	1.8	2.0
Reactor Outlet Temperature (°F) (approach to saturation)	6	4
% Bypass ⁽¹⁾	30-35%	30-35%
Recycling ⁽²⁾	No	Yes

(1) % Bypass is the amount of flue gas that is bypassed around the reactor.

(2) Recycle is when spent sorbent from the inlet ESP hoppers is recycled through LIFAC to improve sorbent utilization and increase SO₂ reduction.

● Optimization Testing (conducted December 7 and 8, 1993): As defined in the Test Plan, optimization testing will be performed to determine the reliability and capability of the LIFAC process over short, continuous operation periods. This set of tests was performed continuously 24 hours a day to simulate actual operating conditions, as apposed to the short 8- to 12-hour parametric tests performed previously. The baseline coal and limestone along with the optimum parametric setting were used during this phase of testing.

Compliance and supplemental tests were conducted each day including emissions testing. Since Units 1 and 2 were both in operation, emissions monitoring was conducted at the test portals located in the duct breeching located downstream of the I.D. fan. Sootblowing was performed during one of the three PM tests for each of the two days.

Ash samples were collected at the economizer hoppers, LIFAC bottom hoppers, ESP inlet and outlet hoppers and the boiler bottom ash disposal bin. The sampling team also continued to monitor the feedwater to the plant which, at this time, was coming from the river, as well as the boiler bottom ash discharge water.

LIFAC test parameters during the December 7 and 8, 1993 environmental monitoring are summarized in Table 6-4:

TABLE 6-4 OPTIMIZATION TESTING - TEST PARAMETERS

	December 7, 1993	December 8, 1993
Boiler Load (MW)	63.3	58.5
Coal Quality - % S	2.24	2.14
- SO ₂ lb/MMBtu	3.93	3.75
Limestone Quality	85% - 325 Fine	85% - 325 Fine
Ca/S Molar Ratio	2.0	2.0
Reactor Outlet Temperature (°F) (approach to saturation)	8	7-8
% Bypass	40%	40-42%
Recycling	Yes	No

● **Operations (Long-Term) Testing** (conducted May 17, 1994): As per the Test Plan, operations (long-term) testing was performed after the optimization tests and the second set of parametric tests to determine the reliability and capability of the LIFAC process over long, continuous operations periods. This set of tests was performed continuously over 500 to 800 hours. Although three different coals were to be tested during this period to evaluate LIFAC's suitability for high sulfur Indiana coals, environmental monitoring was only conducted for coal #1.

Monitoring included compliance and supplemental emissions testing. With both units in operation, sampling was performed at the test portals located in the duct breeching, the point just prior to where exhaust from Unit #2 joins with Unit #1 exhaust, downstream of the I.D. fan. Sootblowing was performed during one of the three PM tests conducted that day.

Under supplemental monitoring ash samples were collected at the economizer hoppers, LIFAC bottom hoppers, ESP inlet and outlet hoppers, and boiler bottom ash disposal bin. Monitoring of the plant's feedwater was also conducted. Feedwater during the May test was coming from the river. The boiler bottom ash discharge water was also sampled.

LIFAC test parameters during the May 17, 1994 environmental monitoring are summarized in Table 6-5:

TABLE 6-5 OPERATIONS TESTING - TEST PARAMETERS

	May 17, 1994
Boiler Load (MW)	58
Coal Quality - % S	2.25
- SO ₂ lb/MMBtu	3.98
Limestone Quality	80% - 325 Fine
Ca/S Molar Ratio	2.0
Reactor Outlet Temperature (°F) (approach to saturation)	10
% Bypass ⁽¹⁾	0
Recycling ⁽²⁾	Yes

(1) % Bypass is the amount of flue gas that is bypassed around the reactor.

(2) Recycle is when spent sorbent from the inlet ESP hoppers is recycled through LIFAC to improve sorbent utilization and increase SO₂ reduction.

- **Post-LIFAC Testing** (conducted August 16, 1994): As defined in the Test Plan, post-LIFAC testing is similar to the baseline testing. Data will be gathered without the LIFAC system operating which, when compared with the baseline data, will yield evidence of the impacts LIFAC may have had on the host site's boiler and associated subsystem.

Compliance and supplemental tests were conducted, including emissions testing. Since Units #1 and #2 were both in operation, emissions monitoring was conducted at the test portals located in the duct breeching located downstream of the I.D. fan. Sootblowing was performed during one of the three PM tests for that day.

Ash samples were collected at the economizer hoppers, ESP inlet and outlet hoppers and the boiler bottom ash disposal bin. The sampling team also continued to monitor the feedwater to the plant which, at this time, was coming from the treatment plant's effluent discharge, as well as the boiler bottom ash discharge water.

LIFAC test parameters during the August 16, 1994 environmental monitoring are summarized in Table 6-6:

TABLE 6-6 POST-LIFAC TESTING - TEST PARAMETERS

	August 16, 1994
Boiler Load (MW)	64.0
Coal Quality - % S	2.20
- SO ₂ lb/MMBtu	4.05
Limestone Quality	--
Ca/S Molar Ratio	--
Reactor Outlet Temperature (°F) (approach to saturation)	--
% Bypass	--
Recycling	--

6.1.3 Environmental Monitoring Results

A summary of results for compliance and supplemental monitoring for particulate matter testing for LIFAC's baseline, parametric, optimization, operations and post-LIFAC testing are presented in Tables 6-7 and 6-8. Table 6-7, Summary of Particulate Matter Test Data, includes pertinent process conditions such as power generation in units of megawatts (MW), coal feed rates (lb/hr) and firing rates (MBtu/hr). It also includes correction to the particulate matter loading to account for sootblowing which IDEM required to be done during one of the three PM tests conducted each test day. Table 6-8 provides a summary of gaseous emissions as required under supplemental monitoring. This table indicates a reduction in SO₂ for parametric and optimization tests (41% and 55% reduction, respectively), however SO₂ was not measured during the operations testing. For detailed particulate matter test data, actual gaseous emission results and backup calculations, refer to the Baseline Monitoring Report⁽¹⁾ (for baseline information), Parametric and Optimization Report⁽²⁾, and Operations and Post-LIFAC Report⁽³⁾. Coal data for the different testing events is summarized in Table 6-9, with actual analysis provided in the above referenced reports.

The particulate matter mass loadings summarized in Table 6-7 are expressed in grains per dry standard cubic feet (gr/dscf), pounds per hour (lb/hr), and mass per heat input, expressed as pounds per million Btu (lb/MBtu). Mass emission per heat input was calculated using two different methods. The first method was based on actual process parameters such as coal feed rate to the boiler and coal heating value. The second method utilized EPA Method 19, also known as the F factor method. The following equation, extracted from the method, calculates a theoretical mass emission per heat input based on the F_d , which is the ratio of the gas volume of the products of combustion to the heat contents of the fuel (dependent on the type of coal), measured pollutant concentration, and the measured percent oxygen, with all variables being on a dry basis.

where E = Emission rate (lb/MBtu)
 F_d = Oxygen-based F factor (dscf/MBtu), dry basis
 (9780 dscf/MBtu for bituminous coal)
 C_d = Pollutant concentration (lb/dscf)
 $\%O_{2d}$ = Percent oxygen (%), dry basis

TABLE 6-7
SUMMARY OF
ENVIRONMENTAL MONITORING
PARTICULATE MATTER TEST DATA

	UNITS	Baseline		Parametric		Optimization		Operations	Post-LIFAC
		9-2-92	12-18-92	9-23-93	9-24-93	12-7-93	12-8-93	(5-17-94)	(6-18-94)
		Duct Breaching		Stack 250' Level		Duct Breaching		Duct Breaching	Duct Breaching
Process Conditions		65.1	65.8	62.3	60.6	63.3	58.5	58	64
Power Generation	MW	61220	59677	58860	54360	56800	53400	52817	57050
Coal Feed Rate	lb/hr	691.1	672.3	665.0	614.2	644.9	609.6	606.7	656.2
Heat Input	MBtu/hr								
Particulate Matter Loadings									
Concentration	gr/dscf	0.0135	0.0912	0.0425	0.0672	0.1335	0.1109	0.0511	0.0627
Mass Flow Rate	lb/hr	17.28	120.30	55.36	84.83	193.10	155.60	72.55	96.07
Mass Emission/Heat Input (1)	lb/MBtu	0.025	0.180	0.085	0.131	0.295	0.250	0.121	0.146
Mass Emission/Heat Input (2)	lb/MBtu	0.024	0.174	0.074	0.140	0.257	0.209	0.103	0.116
Mass Emission/Heat Input (2*)	lb/MBtu	--	--	0.072	0.128	0.253	0.206	0.103	0.116
Duct Conditions									
Average Flow Rate	acfm	247167	265939	236622	229237	264200	257800	245528	304100
Dry Standard Flow Rate	dscfm	149267	155968	152089	147086	168900	163600	165867	179367
Temperature	deg F	338	342	225	225	250	254	235	337
Percent Moisture	%	9.9	8.6	13.2	14.0	12.5	12.5	9.47	9.3
Percent O2	%	4.4	5.7	4.1	6.8	5.7	5.4	6.43	5.1
Percent CO2	%	14.8	14.2	14.0	13.0	13.3	13.8	13.33	13.8
Isokinetics	%	102.8	108.1	105.7	104.7	102.7	101.7	99	101
Opacity	%	--	--	12.6	12.1	19.7	15.7	12.3	8.0

(1) Based on measured coal feed rates and heating values.

(2) Based on EPA Method 19 (F factor method).

(2*) Corrected for sootblowing.

TABLE 6-8
SUMMARY OF
ENVIRONMENTAL MONITORING
GASEOUS EMISSIONS

PARAMETERS	LIMITS	BASELINE		PARAMETRIC		OPTIMIZATION		OPERATION (5-17-94) DUCT BREECHING	POST-LIFAC (8-16-94) DUCT BREECHING
		(9-2-92)	(12-18-92)	(9-23-93)	(9-24-93)	(12-7-93)	(12-8-93)		
TSP (lb/M btu)	0.22-0.40*	0.024	0.174	0.074	0.140	0.253	0.206	0.103	0.116
OPACITY	30%	-	-	8-25%	10-18%	19-21%	14-18%	11-14%	7.8-8.2%
SO ₂ lb / Mbtu (ppmv)	6.0	(1972)	-	(1411.8)	(891.9)	(844.3)	(925.8)	-	3.9
NO _x lb / Mbtu (ppmv)	0-1 (0-588)	(375.6)	-	(379.0)	(352.7)	(337.2)	(350.3)	-	0.6
PM - 10 lb/M btu (%)	0-1 (100%)	-	-	(77.1 >)	(51.1 >)	(55.27 >)	(50.66 >)	-	0.02
CO ₂ lb/M btu (%)	0-500 (0-50)	(14.8)	-	(22.9 <)	(48.9 <)	(44.73 <)	(49.34 <)	-	(13.8)
CO (ppmv)	0-500	19.9	-	(14.36)	(13.95)	(13.35)	(13.83)	-	6.0
				66.57	216.23	4.1	6.5	-	

* Per IDEM Variance

TABLE 6-9
SUMMARY OF
ENVIRONMENTAL MONITORING
COAL DATA

PARAMETERS	Baseline		Parametric		Optimization		Operations (5-17-94)	Post-LIFAC (8-16-94)
	9-2-92	9-22-93	9-23-93	9-24-93	12-7-93	12-8-93		
Btu/lb. (Rec'd)	11355	11307	11250	11253	11390	11417	11487	11513
Btu/lb. (Dry)	13084	12893	12967	12983	13016	13094	13274	13247
Moisture % (Rec'd)	13.22	12.30	13.24	13.33	12.49	12.81	13.46	13.09
Ash (Rec'd)	9.00	10.53	9.98	9.86	9.79	9.53	8.27	8.62
Ash (Dry)	10.37	12.00	11.50	11.37	11.19	10.93	9.56	9.91
Sulfur % (Rec'd)	2.46	2.25	2.20	2.18	2.24	2.14	2.12	2.34
Sulfur % (Dry)	2.83	2.57	2.54	2.51	2.56	2.45	2.45	2.69

Based on analysis conducted by Standard Laboratories, original laboratory results attached in Appendix F.

TABLE 6-10
SUMMARY OF
ENVIRONMENTAL MONITORING
SOLID WASTE AND BY PRODUCT
ECONOMIZER ASH

SAMPLE LOCATION : ECONOMIZER HOPPER (3)

PARAMETERS	REGULATORY LIMIT (mg/l)* (if established)	UNITS	BASELINE		PARAMETRIC		OPTIMIZATION		OPERATIONS (5-17-94)	POST-LIFAC (8-16-94)
			(9-2-92)	(9-22-93)	(9-23-93)	(9-24-93)	(12-7-93)	(12-8-93)		
Alkalinity	-	mg/l CaCO3	87.0	417	2540	2760	2090	2130	2430	858
pH	-	pH units	11.90	12.48	12.55	12.44	12.55	12.52	12.70	12.78
Sulfate	-	mg/l	100	170	1200	1200	1600	1700	1700	310
Percent Carbon	-	%	-	5.6	4.5	4.4	6.5	5.3	4.4	4.7
Total Metals:	-	mg/kg	-	-	-	-	47	35	23	34
Arsenic (Total)	-	mg/kg	-	-	-	-	-	-	-	-
TCPLP (5) Metals :										
Silver	5.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Arsenic	5.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Barium	100.0	mg/l	<10	<10	<10	<10	<10	<10	<10	<10
Cadmium	1.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Chromium	5.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Mercury	0.2	mg/l	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Lead	5.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Selenium	1.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
TCPLP Extraction Fluid Data:										
Extraction Fluid	-		No.1	No.1	No.2	No.2	No.2	No.2	No.2	No.1
pH w/ Deionized Water	-	pH Units	11.05	10.70	11.75	11.75	12.69	12.71	12.06	11.04
pH after Addition of 1 Normal HCL	-	pH Units	1.55	3.21	11.17	11.40	11.95	11.78	11.84	2.54
pH of TCPLP Extract	-	pH Units	5.15	5.33	12.31	12.37	12.30	12.59	12.16	6.03
Amount of Sample Extracted	-	g	100	100	100	100	100	100	100	80
TCPLP Volatile Organic Analysis : (8260)										
Benzene	0.5	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
2-Butanone	200.0	ug/l	<5000	<5000	<5000	<5000	<5000	<5000	<5000	<5000
Carbon Tetrachloride	0.5	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
Chlorobenzene	100.0	ug/l	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
Chloroform	6.0	ug/l	<500	<500	<500	<500	<500	<500	<500	<500
1,2-Dichloroethane	0.5	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
1,1-Dichloroethene	0.7	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
Tetrachloroethene	0.7	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
Trichloroethene	0.5	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
Vinyl Chloride	0.2	ug/l	<50	<50	<50	<50	<50	<50	<50	<25
TCPLP Base/Neutral Extractables : (8270)										
1,4-Dichlorobenzene	7.5	ug/l	<500	<500	<500	<500	<500	<500	<500	<500
2,4-Dinitrotoluene	0.13	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
Hexachlorobutadiene	0.5	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
Hexachlorobenzene	0.13	ug/l	<100	<100	<100	<100	<100	<100	<100	<100
Hexachloroethane	3.0	ug/l	<500	<500	<500	<500	<500	<500	<500	<500
Nitrobenzene	2.0	ug/l	<100	<100	<100	<100	<100	<100	<100	<100
Pyridine	5.0	ug/l	<500	<500	<500	<500	<500	<500	<500	<500

TABLE 6-10 (continued)
SUMMARY OF
ENVIRONMENTAL MONITORING
SOLID WASTE AND BY PRODUCT
ECONOMIZER ASH

SAMPLE LOCATION : ECONOMIZER HOPPER (3)

PARAMETERS	REGULATORY LIMIT (mg/l)* (if established)	UNITS	BASELINE (9-2-92) (9-22-93)	PARAMETRIC (9-23-93) (9-24-93)	OPTIMIZATION (12-7-93) (12-8-93)	OPERATIONS (15-17-94)	POST - LIFAC (18-16-94)
0							
Total Cresol	200.0	ug/l	<5000	<5000	<5000	<5000	<5000
Pentachlorophenol	100.0	ug/l	<5000	<5000	<5000	<5000	<5000
2,4,5-Trichlorophenol	400.0	ug/l	<5000	<5000	<5000	<5000	<5000
2,4,6-Trichlorophenol	2.0	ug/l	<100	<100	<100	<100	<100
Acetone	-	ug/kg	<500	<13000	<13000	<500	<500
Benzene	0.5	ug/kg	<25	<630	<630	<25	<25
Bromodichloromethane	-	ug/kg	<25	<630	<630	<25	<25
Bromoform	-	ug/kg	<25	<630	<630	<25	<25
Bromomethane	-	ug/kg	<50	<1300	<1300	<50	<50
2-Butanone	200.0	ug/kg	<500	<13000	<13000	<50	<50
Carbon Disulfide	-	ug/kg	<25	<630	<630	<25	<25
Carbon Tetrachloride	0.5	ug/kg	<25	<630	<630	<25	<25
Chlorobenzene	100.0	ug/kg	<25	<630	<630	<25	<25
Chlorodibromomethane	-	ug/kg	<25	<630	<630	<25	<25
Chloroethane	-	ug/kg	<50	<1300	<1300	<50	<50
Chloromethane	6.0	ug/kg	<25	<630	<630	<25	<25
1,1-Dichloroethane	-	ug/kg	<25	<630	<630	<25	<25
1,2-Dichloroethane	0.5	ug/kg	<25	<630	<630	<25	<25
1,1-Dichloroethene	0.7	ug/kg	<25	<630	<630	<25	<25
cis-1,2-Dichloroethene	-	ug/kg	<25	<630	<630	<25	<25
trans-1,2-Dichloroethene	-	ug/kg	<25	<630	<630	<25	<25
1,2-Dichloropropane	-	ug/kg	<25	<630	<630	<25	<25
cis-1,3-Dichloropropene	-	ug/kg	<25	<630	<630	<25	<25
trans-1,3-Dichloropropene	-	ug/kg	<25	<630	<630	<25	<25
Ethylbenzene	-	ug/kg	<25	<630	<630	<25	<25
2-Hexanone	-	ug/kg	<250	<6300	<6300	<250	<250
Mothylene Chloride	-	ug/kg	46	<630	<630	<25	<25
4-Methyl-2-Pentanone (MIBK)	-	ug/kg	<250	<6300	<6300	<250	<250
Styrene	-	ug/kg	<25	<630	<630	<25	<25
1,1,2,2-Tetrachloroethane	-	ug/kg	<25	<630	<630	<25	<25
Tetrachloroethene	0.7	ug/kg	<25	<630	<630	<25	<25
Toluene	-	ug/kg	<25	<630	<630	<25	<25
1,1,1-Trichloroethane	-	ug/kg	<25	<630	<630	<25	<25
1,1,2-Trichloroethane	-	ug/kg	<25	<630	<630	<25	<25
Trichloroethene	0.5	ug/kg	<25	<630	<630	<25	<25
Vinyl Chloride	0.2	ug/kg	<50	<1300	<1300	<50	<50
Xylenes (Total)	-	ug/kg	<25	<630	<630	<25	<25

* Regulatory limit units may differ from measured value units.

TABLE 6-11
SUMMARY OF
ENVIRONMENTAL MONITORING
SOLID WASTE AND BY PRODUCT
LIFAC ASH

SAMPLE LOCATION : REACTOR BOTTOM ASH (4)

PARAMETERS	REGULATORY LIMIT (mg/l)* (if established)	UNITS	PARAMETRIC (9-23-93) (9-24-93)	OPTIMIZATION (12-7-93) (12-8-93)	OPERATIONS (5-17-94)	POST-LIFAC (8-16-94)
Alkalinity		mg/l CaCO3	2220	1050	1850	2220
pH		pH units	12.33	12.42	12.41	12.72
Sulfate		mg/l	850	1500	990	1600
Percent Carbon		%	3.9	3.3	3.5	3.6
Total Metals:						
Arsenic (total)	5.0	mg/kg	-	32	23	29
TCLP Metals :						
Silver	5.0	mg/l	<0.10	<0.10	<0.10	<0.10
Arsenic	5.0	mg/l	<0.10	<0.10	<0.10	<0.10
Barium	100.0	mg/l	<10	<10	<10	<10
Cadmium	1.0	mg/l	<0.10	<0.10	<0.10	<0.10
Chromium	5.0	mg/l	<0.10	<0.10	<0.10	<0.10
Mercury	0.2	mg/l	<0.010	<0.010	<0.010	<0.010
Lead	5.0	mg/l	<0.10	<0.10	<0.10	<0.10
Selenium	1.0	mg/l	<0.10	<0.10	<0.10	<0.10
TCLP Extraction Fluid Data:						
Extraction Fluid			No.2	No.2	No.2	No.2
pH w/ Deionized Water		pH Units	11.65	12.46	12.52	11.99
pH after Addition of 1 Normal HCL		pH Units	11.09	11.23	11.88	11.77
pH of TCLP Extract		pH Units	12.02	12.02	6.74	11.94
Amount of Sample Extracted		g	100	100	100	100
TCLP Volatile Organic Analysis : (8260)						
Benzene	0.5	ug/l	<50	<50	<50	<50
2-Butanone	200.0	ug/l	<5000	<5000	<5000	<5000
Carbon Tetrachloride	0.5	ug/l	<50	<50	<50	<50
Chlorobenzene	100.0	ug/l	<1000	<1000	<1000	<1000
Chloroform	6.0	ug/l	<500	<500	<500	<500
1,2-Dichloroethane	0.5	ug/l	<50	<50	<50	<50
1,1-Dichloroethene	0.7	ug/l	<50	<50	<50	<50
Tetrachloroethene	0.7	ug/l	<50	<50	<50	<50
Trichloroethene	0.5	ug/l	<50	<50	<50	<50
Vinyl Chloride	0.2	ug/l	<50	<50	<50	<50
TCLP Base/Neutral Extractables : (8270)						
1,4-Dichlorobenzene	7.5	ug/l	<500	<500	<500	<500
2,4-Dinitrotoluene	0.13	ug/l	<50	<50	<50	<50
Hexachloro butadiene	0.5	ug/l	<50	<50	<50	<50
Hexachlorobenzene	0.13	ug/l	<100	<100	<100	<100
Hexachloroethane	3.0	ug/l	<500	<500	<500	<500
Nitrobenzene	2.0	ug/l	<100	<100	<100	<100
Pyridine	5.0	ug/l	<500	<500	<500	<500

TABLE 6-11 (continued)
SUMMARY OF
ENVIRONMENTAL MONITORING
SOLID WASTE AND BY PRODUCT
LIFAC ASH

SAMPLE LOCATION : REACTOR BOTTOM ASH (4)

PARAMETERS	REGULATORY LIMIT (mg/l)* (if established)	UNITS	PARAMETRIC (9-23-93) (9-24-93)	OPTIMIZATION (12-7-93) (12-8-93)	OPERATIONS (5-17-94)	POST-LIFAC (8-16-94)
TCPL Acid Extractables : (8270)						
Total Cresol	200.0	ug/l	<5000	<5000	<5000	--
Pentachlorophenol	100.0	ug/l	<5000	<5000	<5000	--
2,4,5-Trichlorophenol	400.0	ug/l	<5000	<5000	<5000	--
2,4,6-Trichlorophenol	2.0	ug/l	<100	<100	<100	--
Acetone		ug/kg	<13000	<13000	<500	--
Benzene	0.5	ug/kg	<630	<630	<25	--
Bromodichloromethane		ug/kg	<630	<630	<25	--
Bromoform		ug/kg	<630	<630	<25	--
Bromomethane		ug/kg	<1300	<1300	<50	--
2-Butanone	200.0	ug/kg	<13000	<13000	<50	--
Carbon Disulfide		ug/kg	<630	<630	<25	--
Carbon Tetrachloride	0.5	ug/kg	<630	<630	<25	--
Chlorobenzene	100.0	ug/kg	<630	<630	<25	--
Chlorodibromomethane		ug/kg	<630	<630	<25	--
Chloroethane		ug/kg	<1300	<1300	<50	--
Chloromethane		ug/kg	<1300	<1300	<50	--
Chloroform	6.0	ug/kg	<630	<630	<25	--
1,1-Dichloroethane		ug/kg	<630	<630	<25	--
1,2-Dichloroethane	0.5	ug/kg	<630	<630	<25	--
1,1-Dichloroethene	0.7	ug/kg	<630	<630	<25	--
cis-1,2-Dichloroethene		ug/kg	<630	<630	<25	--
trans-1,2-Dichloroethene		ug/kg	<630	<630	<25	--
1,2-Dichloropropane		ug/kg	<630	<630	<25	--
cis-1,3-Dichloropropene		ug/kg	<630	<630	<25	--
trans-1,3-Dichloropropene		ug/kg	<630	<630	<25	--
Ethylbenzene		ug/kg	<630	<630	<25	--
2-Hexanone		ug/kg	<630	<630	<25	--
Methylene Chloride		ug/kg	<6300	<6300	<250	--
4-Methyl-2-Pentanone (MIBK)		ug/kg	<630	<630	<25	--
Styrene		ug/kg	<6300	<6300	<250	--
1,1,2,2-Tetrachloroethane		ug/kg	<630	<630	<25	--
Tetrachloroethene	0.7	ug/kg	<630	<630	<25	--
Toluene		ug/kg	<630	<630	<25	--
1,1,1-Trichloroethane		ug/kg	<630	<630	<25	--
1,1,2-Trichloroethane		ug/kg	<630	<630	<25	--
Trichloroethene	0.5	ug/kg	<630	<630	<25	--
Vinyl Chloride	0.2	ug/kg	<630	<630	<25	--
Xylenes (Total)		ug/kg	<1300	<1300	<50	--
			<630	<630	<25	--

* Regulatory limit units may differ from measured value units.

TABLE 6-12
SUMMARY OF
ENVIRONMENTAL MONITORING
SOLID WASTE AND BY PRODUCT
ESP INLET HOPPER

SAMPLE LOCATION : ESP INLET HOPPERS #7 & #8 (5A)

PARAMETERS	REGULATORY LIMIT (mg/l)* (if established)	UNITS	BASELINE		PARAMETRIC		OPTIMIZATION		OPERATIONS (5-17-94)	POST - LIFAC (6-18-94)
			[9-2-92]	[9-22-93]	[9-23-93]	[9-24-93] (5A-1)	[9-24-93] (5A-2)	[12-7-93] (12-8-93)		
Alkalinity	-	mg/l CaCO3	299	2070	2920	3060	2780	2250	2400	2570
pH	-	pH units	11.60	12.65	12.51	12.44	12.50	12.42	12.60	12.69
Sulfate	-	mg/l	260	810.0	1400	1200	1100	1700	1600	1800
Percent Carbon	-	%	-	3.6	3.3	2.6	2.3	3.3	3.1	2.9
Total Metals:										
Arsenic (Total)	5.0	mg/kg	-	340	-	69	36	60	50	41
TCLP Metals :										
Silver	5.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Arsenic	5.0	mg/l	1.3	0.14	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Barium	100.0	mg/l	<10	<10	<10	<10	<10	<10	<10	<10
Cadmium	1.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Chromium	5.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Mercury	0.2	mg/l	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Lead	5.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Selenium	1.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
TCLP Extraction Fluid Data:										
Extraction Fluid	-		No.1	No.2	No.2	No.2	No.2	No.2	No.2	No.2
pH w/ Deionized Water	-	pH Units	11.50	11.18	11.74	11.76	11.76	12.61	12.71	12.21
pH after Addition of 1 Normal HCL	-	pH Units	1.90	10.39	11.60	11.37	11.59	11.48	12.20	11.95
pH of TCLP Extract	-	pH Units	5.20	6.31	12.44	12.55	12.45	12.36	12.66	12.15
Amount of Sample Extracted	-	g	100	100	100	100	100	100	100	100
TCLP Volatile Organic Analysis : (8260)										
Benzene	0.5	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
2-Butanone	200.0	ug/l	<5000	<5000	<5000	<5000	<5000	<5000	<5000	<5000
Carbon Tetrachloride	0.5	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
Chlorobenzene	100.0	ug/l	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
Chloroform	6.0	ug/l	<500	<500	<500	<500	<500	<500	<500	<500
1,2-Dichloroethane	0.5	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
1,1-Dichloroethene	0.7	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
Tetrachloroethene	0.7	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
Trichloroethene	0.5	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
Vinyl Chloride	0.2	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
TCLP Base/Neutral Extractables : (8270)										
1,4-Dichlorobenzene	7.5	ug/l	<500	<500	<500	<500	<500	<500	<500	<500
2,4-Dinitrotoluene	0.13	ug/l	<50	<50	<50	<50	<50	<50	<50	<50
Hexachlorobutadiene	0.5	ug/l	<100	<100	<100	<100	<100	<100	<100	<100
Hexachlorobenzene	0.13	ug/l	<100	<100	<100	<100	<100	<100	<100	<100
Hexachloroethane	3.0	ug/l	<500	<500	<500	<500	<500	<500	<500	<500
Nitrobenzene	2.0	ug/l	<100	<100	<100	<100	<100	<100	<100	<100
Pyridine	5.0	ug/l	<500	<500	<500	<500	<500	<500	<500	<500

TABLE 6--12 (Continued)
SUMMARY OF
ENVIRONMENTAL MONITORING
SOLID WASTE AND BY PRODUCT
ESP INLET HOPPER

SAMPLE LOCATION : ESP INLET HOPPERS #7 & #8 (5A)

REGULATORY		UNITS	BASELINE		PARAMETRIC		OPTIMIZATION	OPERATIONS	POST-LIFAC	
PARAMETERS	LIMIT (mg/l)* (if established)		(9-2-92)	(9-22-93)	(9-23-93)	(9-24-93)				(12-7-93)
TCLP Acid Extractables : (8270)										
Total Cresol	200.0	ug/l	<5000	<5000	<5000	<5000	<5000	<5000	<5000	<5000
Pentachlorophenol	100.0	ug/l	<5000	<5000	<5000	<5000	<5000	<5000	<5000	<5000
2,4,5-Trichlorophenol	400.0	ug/l	<5000	<5000	<5000	<5000	<5000	<5000	<5000	<5000
2,4,6-Trichlorophenol	2.0	ug/l	<100	<100	<100	<100	<100	<100	<100	<100
Acetone	-	ug/kg	<13000	<13000	<13000	<13000	<13000	<13000	<13000	<500
Benzene	0.5	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
Bromodichloromethane	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
Bromoform	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
Bromomethane	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
2-Butanone	200.0	ug/kg	<13000	<13000	<13000	<13000	<13000	<13000	<50	<50
Carbon Disulfide	-	ug/kg	<13000	<13000	<13000	<13000	<13000	<13000	<50	<50
Carbon Tetrachloride	-	ug/kg	730	<630	<630	<630	<630	<630	<25	<25
Chlorobenzene	0.5	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
Chlorodibromomethane	100.0	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
Chloroethane	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
Chloromethane	-	ug/kg	<1300	<1300	<1300	<1300	<1300	<1300	<50	<50
Chloroform	6.0	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
1,1-Dichloroethane	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
1,2-Dichloroethane	0.5	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
1,1-Dichloroethene	0.7	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
cis-1,2-Dichloroethene	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
trans-1,2-Dichloroethene	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
1,2-Dichloropropane	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
cis-1,3-Dichloropropene	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
trans-1,3-Dichloropropene	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
Ethylbenzene	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
2-Hexanone	-	ug/kg	<6300	<6300	<6300	<6300	<6300	<6300	<250	<250
Methylene Chloride	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
4-Methyl-2-Pentanone (MIBK)	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
Styrene	-	ug/kg	<6300	<6300	<6300	<6300	<6300	<6300	<250	<250
1,1,2,2-Tetrachloroethane	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
Tetrachloroethene	0.7	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
Toluene	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
1,1,1-Trichloroethane	-	ug/kg	2200	<630	<630	<630	<630	<630	<25	<25
1,1,2-Trichloroethane	-	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
Trichloroethene	0.5	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
Vinyl Chloride	0.2	ug/kg	<630	<630	<630	<630	<630	<630	<25	<25
Xylenes (Total)	-	ug/kg	<1300	<1300	<1300	<1300	<1300	<1300	<50	<50
			<630	<630	<630	<630	<630	<630	<25	<25

* Regulatory limit units may differ from measured value units.

TABLE 6-13
SUMMARY OF
ENVIRONMENTAL MONITORING
SOLID WASTE AND BY PRODUCT
ESP OUTLET HOPPER ASH

SAMPLE LOCATION : ESP OUTLET HOPPERS #5 & #6 (5B)

PARAMETERS	REGULATORY LIMIT (mg/l) * (if established)	UNITS	PARAMETRIC (9-23-93) (9-24-93)	OPTIMIZATION (12-7-93) (12-8-93)	OPERATIONS (5-17-94)	POST-LIFAC (8-16-94)
Alkalinity	-	mg/l CaCO3	2840	2560	2740	42.0
pH	-	pH units	12.47	12.52	12.70	8.21
Sulfate	-	mg/l	1700	1600	1700	720
Percent Carbon	-	%	NA**	2.7	2.9	6.0
Total Metals:						
Arsenic (total)	5.0	mg/kg	-	67	52	21
TCLP Metals :						
Silver	5.0	mg/l	<0.10	<0.10	<0.10	<0.10
Arsenic	5.0	mg/l	<0.10	<0.10	<0.10	0.29
Barium	100.0	mg/l	<10	<10	<10	<10
Cadmium	1.0	mg/l	<0.10	<0.10	<0.10	0.21
Chromium	5.0	mg/l	1.1	<0.10	<0.10	0.27
Mercury	0.2	mg/l	<0.010	<0.010	<0.010	<0.010
Lead	5.0	mg/l	<0.10	<0.10	<0.10	<0.10
Selenium	1.0	mg/l	<0.10	<0.10	<0.10	<0.10
TCLP Extraction Fluid Data:						
Extraction Fluid	-		No.2	No.2	No.2	No.1
pH w/ Deionized Water	-	pH Units	12.17	12.69	12.11	8.91
pH after Addition of 1 Normal HCL	-	pH Units	12.05	12.03	11.90	1.77
pH of TCLP Extract	-	pH Units	12.02	12.13	12.13	4.99
Amount of Sample Extracted	-	g	50.0	100	100	80
TCLP Volatile Organic Analysis : (8260) (3)						
Benzene	0.5	ug/l	<50	<50	<50	<50
2-Butanone	200.0	ug/l	<5000	<5000	<5000	<5000
Carbon Tetrachloride	0.5	ug/l	<50	<50	<50	<50
Chlorobenzene	100.0	ug/l	<1000	<1000	<1000	<1000
Chloroform	6.0	ug/l	<500	<500	<500	<500
1,2-Dichloroethane	0.5	ug/l	<50	<50	<50	<50
1,1-Dichloroethene	0.7	ug/l	<50	<50	<50	<50
Tetrachloroethene	0.7	ug/l	<50	<50	<50	<50
Trichloroethene	0.5	ug/l	<50	<50	<50	<50
Vinyl Chloride	0.2	ug/l	<50	<50	<50	<5.0
TCLP Base/Neutral Extractables : (8270) (3)						
1,4-Dichlorobenzene	7.5	ug/l	<500	<500	<500	<500
2,4-Dinitrotoluene	0.13	ug/l	<50	<50	<50	<50
Hexachlorobutadiene	0.5	ug/l	<50	<50	<50	<50
Hexachlorobenzene	0.13	ug/l	<100	<100	<100	<100
Hexachloroethane	3.0	ug/l	<500	<500	<500	<500
Nitrobenzene	2.0	ug/l	<100	<100	<100	<100
Pyridine	5.0	ug/l	<500	<500	<500	<500

TABLE 6-13 (Continued)
SUMMARY OF
ENVIRONMENTAL MONITORING
SOLID WASTE AND BY PRODUCT
ESP OUTLET HOPPER ASH

SAMPLE LOCATION : ESP OUTLET HOPPERS #5 & #6 (5B)

PARAMETERS	REGULATORY LIMIT (mg/l)* (if established)	UNITS	PARAMETRIC (9-23-93) (9-24-93)	OPTIMIZATION (12-7-93) (12-8-93)	OPERATIONS (5-17-94)	POST-LIFAC (8-16-94)
TCPL Acid Extractables : (8270) (3)						
Total Cresol	200.0	ug/l	<5000	<5000	<5000	<5000
Pentachlorophenol	100.0	ug/l	<5000	<5000	<5000	<5000
2,4,5-Trichlorophenol	400.0	ug/l	<5000	<5000	<5000	<5000
2,4,6-Trichlorophenol	2.0	ug/l	<100	<100	<100	<100
Acetone	-	ug/kg	<500	<13000	<13000	<100
Benzene	0.5	ug/kg	<25	<630	<630	<100
Bromodichloromethane	-	ug/kg	<25	<630	<630	<50
Bromoform	-	ug/kg	<25	<630	<630	<50
Bromomethane	-	ug/kg	<25	<630	<630	<50
2-Butanone	200.0	ug/kg	<50	<1300	<1300	<10
Carbon Disulfide	-	ug/kg	<25	<13000	<13000	<10
Carbon Tetrachloride	0.5	ug/kg	<25	<630	<630	<50
Chlorobenzene	100.0	ug/kg	<25	<630	<630	<50
Chlorodibromomethane	-	ug/kg	<25	<630	<630	<50
Chloroethane	-	ug/kg	<50	<1300	<1300	<10
Chloromethane	-	ug/kg	<50	<1300	<1300	<10
Chloroform	6.0	ug/kg	<25	<630	<630	<50
1,1-Dichloroethane	-	ug/kg	<25	<630	<630	<50
1,2-Dichloroethane	0.5	ug/kg	<25	<630	<630	<50
1,1-Dichloroethene	0.7	ug/kg	<25	<630	<630	<50
cis-1,2-Dichloroethene	-	ug/kg	<25	<630	<630	<50
trans-1,2-Dichloroethene	-	ug/kg	<25	<630	<630	<50
1,2-Dichloropropane	-	ug/kg	<25	<630	<630	<50
cis-1,3-Dichloropropene	-	ug/kg	<25	<630	<630	<50
trans-1,3-Dichloropropene	-	ug/kg	<25	<630	<630	<50
Ethylbenzene	-	ug/kg	<25	<630	<630	<50
2-Hexanone	-	ug/kg	<25	<630	<630	<50
Methylene Chloride	-	ug/kg	<250	<6300	<6300	<50
4-Methyl-2-Pentanone (MIBK)	-	ug/kg	900	<630	<630	30
Styrene	-	ug/kg	<250	<6300	<6300	<50
1,1,2,2-Tetrachloroethane	-	ug/kg	<25	<630	<630	<50
Tetrachloroethene	0.7	ug/kg	<25	<630	<630	<50
Toluene	-	ug/kg	<25	<630	<630	<50
1,1,1-Trichloroethane	-	ug/kg	40	<630	<630	50
1,1,2-Trichloroethane	-	ug/kg	<25	<630	<630	<50
Trichloroethene	-	ug/kg	<25	<630	<630	<50
Vinyl Chloride	0.5	ug/kg	<25	<630	<630	<50
Xylenes (Total)	0.2	ug/kg	<50	<1300	<1300	<10
	-	ug/kg	<25	<630	<630	<50

SAMPLE LOCATION : BOILER BOTTOM ASH BIN (6B)

<u>PARAMETERS</u>	<u>REGULATORY LIMIT (mg/l)* (if established)</u>	<u>UNITS</u>	<u>BASLINE (9-22-93)</u>	<u>PARAMETRIC (9-23-93) (9-23-93) (9-24-93) 6B-1 6B-2</u>	<u>OPTIMIZATION (12-7-93) (12-8-93)</u>	<u>OPERATIONS (5-17-94)</u>	<u>POST-LIFAC (8-16-94)</u>
Alkalinity	-	mg/l CaCO3	17	20	123	168	---
pH	-	pH units	8.57	10.47	11.14	11.86	7.96
Sulfate	-	mg/l	8.6	49	80	920	16
Percent Carbon	-	%	2.5	0.54	0.32	1.1	46.0
Total Metals:							
Arsenic (total)	5.0	mg/kg	10	--	9.6	8.7	0.56
TCLP (5) Metals :							
Silver	5.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10
Arsenic	5.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10
Barium	100.0	mg/l	<10	<10	<10	<10	<10
Cadmium	1.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10
Chromium	5.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10
Mercury	0.2	mg/l	<0.010	<0.010	<0.010	<0.010	<0.010
Lead	5.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10
Selenium	1.0	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10
TCLP Extraction Fluid Data: Extraction Fluid			No.1	No.1	No.1	No.2	No.1
pH w/ Deionized Water	-	pH Units	9.70	10.00	9.48	11.16	8.46
pH after Addition of 1 Normal HCl	-	pH Units	2.93	1.62	2.02	1.35	1.38
pH of TCLP Extract	-	pH Units	5.21	4.97	5.69	4.78	4.92
Amount of Sample Extracted	-	g	100	100	100	100	80
TCLP Volatile Organic Analysis : (8260)							
Benzene	0.5	ug/l	<50	<50	<50	<50	<50
2-Butanone	200.0	ug/l	<5000	<5000	<5000	<5000	<5000
Carbon Tetrachloride	0.5	ug/l	<50	<50	<50	<50	<50
Chlorobenzene	100.0	ug/l	<1000	<1000	<1000	<1000	<1000
Chloroform	6.0	ug/l	<500	<500	<500	<500	<500
1,2-Dichloroethane	0.5	ug/l	<50	<50	<50	<50	<50
1,1-Dichloroethene	0.7	ug/l	<50	<50	<50	<50	<50
Tetrachloroethene	0.7	ug/l	<50	<50	<50	<50	<50
Trichloroethene	0.5	ug/l	<50	<50	<50	<50	<50
Vinyl Chloride	0.2	ug/l	<50	<50	<50	<50	<50
TCLP Base/Neutral Extractables : (8270)							
1,4-Dichlorobenzene	7.5	ug/l	<500	<500	<500	<500	<500
2,4-Dinitrotoluene	0.13	ug/l	<50	<50	<50	<50	<50
Hexachlorobutadiene	0.5	ug/l	<50	<50	<50	<50	<50
Hexachlorobenzene	0.13	ug/l	<100	<100	<100	<100	<100
Hexachloroethane	3.0	ug/l	<500	<500	<500	<500	<500
Nitrobenzene	2.0	ug/l	<100	<100	<100	<100	<100
Pyridine	5.0	ug/l	<500	<500	<500	<500	<500

TABLE 6-14 (Continued)
SUMMARY OF
ENVIRONMENTAL MONITORING
SOLID WASTE AND BY PRODUCT
BOILER BOTTOM ASH (SOLID)

SAMPLE LOCATION : BOILER BOTTOM ASH BIN (6B)

PARAMETERS	REGULATORY LIMIT (mg/l)*	UNITS	BASELINE (9-22-93)		PARAMETRIC (9-23-93) (9-23-93) (9-24-93)		OPTIMIZATION (12-7-93) (12-8-93)	OPERATIONS (5-17-94)	POST-LIFAC (8-16-94)	
			6B-1	6B-2	6B-1	6B-2				
TCLP Acid Extractables : (8270)										
Total Cresol	200.0	ug/l	<5000	<5000	<5000	<5000	<5000	<5000	<5000	
Pentachlorophenol	100.0	ug/l	<5000	<5000	<5000	<5000	<5000	<5000	<5000	
2,4,5-Trichlorophenol	400.0	ug/l	<5000	<5000	<5000	<5000	<5000	<5000	<5000	
2,4,6-Trichlorophenol	2.0	ug/l	<100	<100	<100	<100	<100	<100	<100	
Acetone	-	ug/kg	<100	<100	<100	<13000	<100	<13000	<100	
Benzene	0.5	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<5.0	
Bromodichloromethane	-	ug/kg	<5.0	<5.0	<5.0	<630	<630	<25	<25	
Bromoform	-	ug/kg	<5.0	<5.0	<5.0	<630	<630	<25	<25	
Bromomethane	-	ug/kg	<10	<10	<10	<1300	<10	<630	<25	
2-Butanone	200.0	ug/kg	<100	<100	<100	<13000	<100	<1300	<50	
Carbon Disulfide	-	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<50	
Carbon Tetrachloride	0.5	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
Chlorobenzene	100.0	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
Chlorodibromomethane	-	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
Chloroethane	-	ug/kg	<10	<10	<10	<1300	<10	<630	<25	
Chloromethane	-	ug/kg	<10	<10	<10	<1300	<10	<1300	<50	
Chloroform	6.0	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<50	
1,1-Dichloroethane	-	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
1,2-Dichloroethane	0.5	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
1,1-Dichloroethene	0.7	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
cis-1,2-Dichloroethene	-	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
trans-1,2-Dichloroethene	-	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
1,2-Dichloropropane	-	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
cis-1,3-Dichloropropene	-	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
trans-1,3-Dichloropropene	-	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
Ethylbenzene	-	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
2-Hexanone	-	ug/kg	<50	<50	<50	<6300	<50	<630	<25	
Methylene Chloride	-	ug/kg	<5.0	8.0	<50	<6300	<50	<630	<250	
4-Methyl-2-Pentanone (MIBK)	-	ug/kg	<50	<50	<50	<6300	13	<630	12	
Styrene	-	ug/kg	<50	<50	<50	<6300	<50	<630	<50	
1,1,2,2-Tetrachloroethane	-	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<50	
Tetrachloroethene	-	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
Toluene	0.7	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
1,1,1-Trichloroethane	-	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
1,1,2-Trichloroethane	-	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
Trichloroethene	-	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
Vinyl Chloride	0.5	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	
Xylenes (Total)	0.2	ug/kg	<10	<10	<10	<1300	<10	<1300	<50	
	-	ug/kg	<5.0	<5.0	<5.0	<630	<5.0	<630	<25	

* Regulatory limit units may differ from measured value units.

(See footnotes for methodology on actual laboratory analytical reports attached in Appendix B)

TABLE 6-15
SUMMARY OF
ENVIRONMENTAL MONITORING
BOILER BOTTOM ASH (AQUEOUS)

SAMPLE LOCATION : BOILER BOTTOM ASH (AQUEOUS) (6A)

PARAMETERS	LIMITS (RP&L's NPDES Permit)	BASELINE (9-2-92)	PARAMETRIC (9-23-93) (9-23-93) (9-24-93)		OPTIMIZATION (12-7-93) (12-8-93)	OPERATIONS (5-17-94)	POST-LIFAC (8-16-94)
FLOW	REPORT	-	6A-1	6A-2	-	-	-
TSS (mg/l)	70	-	17	1	30	38	31
OIL & GREASE (mg/l)	15	-	<1.0	<1.0	<1.0	<1.0	<1.0
TOT. RESID. OXIDANTS (mg/l)	0.02	-	<1.0	<1.0	<1.0	<1.0	<0.050
TEMPERATURE (F)	REPORT	-	-	-	-	-	-
AMMONIA (NH3) (mg/l)	1.8 (summer) 2.6 (winter)	-	0.11	0.13	<0.10	0.37	<0.10
COPPER (mg/l)	0.05	-	0.014	<0.010	<0.010	0.012	0.012
LEAD (mg/l)	0.02	-	<0.10	<0.10	<0.10	<0.10	<0.10
ZINC (mg/l)	0.46	-	0.026	0.023	0.011	0.020	0.046
ALUMINUM (mg/l)	0.40	-	0.59	0.60	0.46	0.53	0.34
IRON (mg/l)	REPORT	-	0.20	0.18	0.16	0.11	0.33
PCBS (mg/l)	REPORT	-	<1.0	<1.0	<1.0	<1.0	<1.0
ALKALINITY (mg CaCO3)	(per EMP)	111	182	200	31.1	40	186

(See footnotes for methodology on actual laboratory analytical reports attached in Appendix B)

TABLE 6-16
SUMMARY OF
ENVIRONMENTAL MONITORING
RP&L's NPDES DISCHARGE AND FEEDWATER
(1993)

PARAMETERS	LIMITS	RP&L MONTHLY MONITORING (1993)*							FEEDWATER SAMPLE LOCATION (Z)			
		JULY	AUG.	SEPT.	OCT.	NOV.	DEC.		(9-22-93)	(9-23-93)	(9-24-93)	(12-7-93) (12-8-93)
FLOW	REPORT											
TSS (mg/l)	70	17.9	20.4	19.1	13.1	19.5	15.4		2	73	<1	9
OIL & GREASE (mg/l)	15	<1.0	<1.0	<1.1	<2.72	<1.82	<1.34		1.0	1.8	<1.0	<1.0
TOT. RESID. OXIDANTS (mg/l)	0.02	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		<0.10	<1.0	0.12	<1.0
TEMPERATURE (F)	REPORT	88.2	85.2	77.1	64.7	61.2	61.3		-	-	-	-
AMMONIA (NH3) (mg/l)	1.8 (SUM)	0.16	0.09	0.110	0.18	0.03	0.062		<0.10	0.14	0.14	<0.10
	2.6 (WIN)											<0.10
COPPER (mg/l)	0.05	0.033	0.038	0.057	0.046	0.064	0.020		0.035	<0.01	0.013	<0.010
LEAD (mg/l)	0.02	0.007	0.007	0.006	0.006	0.004	0.002		<0.10	<0.10	<0.10	<0.10
ZINC (mg/l)	0.46	0.053	0.046	0.054	0.071	0.098	0.040		0.035	0.026	0.023	0.019
ALUMINUM (mg/l)	0.40	1.094	1.045	1.066	0.824	0.528	0.880		0.63	0.31	0.29	0.36
IRON (mg/l)	REPORT	1.281	0.612	0.936	1.040	1.747	0.280		0.056	0.20	0.099	0.057
pH (pH units)	6.0 MIN/9.0 MAX	7.5	7.5	7.7	7.4	7.7	7.8		-	-	-	-
PCBS (mg/l)	(EMP)	-	-	-	-	-	-		<1.0	<1.0	<1.0	<1.0
ALKALINITY (mg CaCO3)	(EMP)	-	-	-	-	-	-		232	61	205	262
												248

*RP&L monthly monitoring reports attached in Appendix E.

(See footnotes for methodology on actual laboratory analytical reports attached in Appendix B)

TABLE 6-16
SUMMARY OF
ENVIRONMENTAL MONITORING
RP&L's NPDES DISCHARGE AND FEEDWATER
(1994)

PARAMETERS	LIMITS	RP&L MONTHLY MONITORING (1994)*												FEEDWATER SAMPLE LOCATION (Z)	
		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	(5-17-94)	(8-16-94)				
FLOW	REPORT														
TSS (mg/l)	70	16.9	11.6	9.4	14.8	20.9	18.6	15.4	11.4	-	-	1	3		
OIL & GREASE (mg/l)	15	<1.4	<1.09	2.31	1.78	<1.25	<1.31	<1.29	<1.1	-	-	1.1	<1.0		
TOT. RESID. OXIDANTS (mg/l)	0.02	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	<0.05	<0.05		
TEMPERATURE (F)	REPORT	59.5	60.3	64.2	66.2	75.6	84.4	-	-	-	-	-	-		
AMMONIA (NH3) (mg/l)	1.8 (SUM)	0.25	0.183	0.140	0.164	0.226	0.182	-	-	-	-	<0.10	<0.10		
	2.6 (WIN)														
COPPER (mg/l)	0.05	0.028	0.026	0.030	0.015	0.045	0.044	0.053	0.054	<0.010	<0.010	<0.010	<0.010		
LEAD (mg/l)	0.02	0.004	0.004	0.008	0.004	0.009	0.010	0.009	0.006	<0.10	<0.10	<0.10	<0.10		
ZINC (mg/l)	0.46	0.060	0.112	0.106	0.086	0.078	0.097	0.230	0.102	0.040	0.040	0.040	0.041		
ALUMINUM (mg/l)	0.40	<0.003	1.243	0.834	1.440	1.149	0.960	0.580	0.400	0.14	0.14	0.14	<0.10		
IRON (mg/l)	REPORT	0.606	0.566	0.438	1.840	0.700	0.646	0.714	0.447	0.045	0.045	0.045	0.051		
pH (pH units)	6.0 MIN/9.0 MAX	7.6	7.7	8.0	7.6	7.7	7.8	7.5	7.7	-	-	-	-		
PCBS (mg/l)	(EMP)	-	-	-	-	-	-	-	-	<1.0	<1.0	<1.0	<1.0		
ALKALINITY (mg CaCO3)	(EMP)	-	-	-	-	-	-	-	-	264	264	264	209		

*RP&L monthly monitoring reports attached in Appendix E.

(See footnotes for methodology on actual laboratory analytical reports attached in Appendix B)

TABLE 6-17

SOLID WASTE AND BY-PRODUCT EXCEEDING DETECTION LIMITS

PARAMETER	SAMPLE LOCATION									
	FRONT ESP HOPPER 9/2/92	FRONT ESP HOPPER 9/22/93	FRONT ESP HOPPER 8/16/94	BACK ESP HOPPER 9/23/94	BACK ESP HOPPER 5/17/94	BACK ESP HOPPER 8/16/94	BOTTOM ASH 9/24/94	BOTTOM ASH 12/7/93	BOTTOM ASH 8/16/94	
ECON. ASH 9/2/92	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	
TCLP METALS (mg/l)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	
	EXCEPT ARSENIC 1.3 mg/l	EXCEPT ARSENIC 0.14 mg/l	EXCEPT CADMIUM 0.13 mg/l	EXCEPT CHROMIUM 1.1 mg/l		EXCEPT ARSENIC 0.29 mg/l CADMIUM 0.21 mg/l CHROMIUM 0.27 mg/l				
TCLP VOLATILES ORGANICS (mg/l)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	
TCLP BASE/NEUTRAL EXTRACTABLES (mg/l)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	
TCLP ACID EXTRACTABLES (mg/l)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	
VOLATILE ORGANICS ug/kg (VOC)	BDL EXCEPT METHYLENE CHLORIDE 46 ug/kg	BDL	BDL	BDL EXCEPT METHYLENE CHLORIDE 900 ug/kg	BDL EXCEPT TOLUENE 5.0 ug/kg	BDL EXCEPT METHYLENE CHLORIDE 30 ug/kg	BDL EXCEPT METHYLENE CHLORIDE 8.0 ug/kg	BDL EXCEPT METHYLENE CHLORIDE 13.0 ug/kg	BDL EXCEPT METHYLENE CHLORIDE 12 ug/kg	
	CARBON DISULFIDE 730 ug/kg TOLUENE 2200 ug/kg									

(BDL - BELOW DETECTABLE LIMITS)

6.3 Potential Environmental Concerns

The presence of arsenic in the LIFAC ash is an environmental concern particularly to the workers exposed to the dust generated during its discharge into the dumpsters then its disposal. ICF Kaiser conducted an industrial hygiene test to determine if levels of exposure were dangerous. Although the results determined that they were not, it is recommended that steps be taken to control the dust and protect workers from exposure, such as wearing surgical masks. The arsenic levels in the ash are still acceptable to the landfill where the ash was disposed, however, in other locations or in the future this could cause a disposal problem. Another safety of concern is the noise level in the Limestone building, from the blowers. It was determined that hearing protection is warranted.

Finally the detection of methylene chloride in several ash samples is a concern, since its origin is unknown. Methylene chloride was detected in economizer ash during the baseline testing, ESP hopper ash (outlet) during parametric and post-LIFAC testing, and in boiler bottom ash during parametric, optimization and post-LIFAC testing. Although there is no current regulatory limit for methylene chloride, further evaluation may be required for future facilities.

7.0 ECONOMICS

7.1 Project Capital Cost

The capital cost breakdown of the LIFAC installation at Richmond Power & Light is unique. Since this installation was a retrofit to an existing facility and installed at the site of an earlier FGD demonstration, it is necessary to present a detailed structure of capital spending. Figure 7-1 shows the total capital cost of the LIFAC unit as it was installed. Engineering, reactor fabrication and erection, and structural / mechanical / piping consumed over half the capital expenditures. The total capital cost of the LIFAC demonstration at RP&L was approximately \$8,101,000.

Since RP&L was the site of an earlier FGD demonstration, capital cost savings were experienced. The equipment from the previous demonstration was donated to LIFAC. Each piece of equipment was selected to be utilized based on its operability and reliability for the LIFAC demonstration. This equipment can easily be replaced when LIFAC advances into a commercial operation mode at RP&L. The reactor ash disposal system was built for demonstration purposes only. Additional capital needs to be spent on ash conveyors and a storage silo before commercial operation. No back-up systems were installed as part of the demonstration. A commercial unit would require some redundancy systems such as: a limestone feeder bypass option, a backup water pump, and spare I/O cards for process control system.

The demonstrative nature of the project required additional capital spending. The LIFAC test program incorporates many testing and measuring techniques. For this reason, additional instrumentation and data collection devices needed to be purchased and utilized. Supplementary sampling ports and manholes were also required for the demonstration in order to inspect and assess the process' impact on the reactor and within the ductwork. Five limestone injection ports were installed on the boiler's walls to test several combinations of injection settings.

Capital Cost

Equipment & Materials :

Limestone Handling & Storage	\$160,000.00
Activation Reactor & Ductwork	\$669,000.00
Sorbent Recycle System	\$67,000.00
Electrical / Instrumentation	\$272,000.00
I.D. Fan Upgrade	\$255,000.00
Total Equip. & Materials	<u>\$1,423,000.00</u>

Subcontracts :

Foundations	\$324,000.00
Reactor Fab. & Erection	\$1,670,000.00
Structural / Mechanical / Piping	\$1,569,000.00
Electrical / Instrumentation	\$574,000.00
Insulation & Cladding	\$268,000.00
Misc. Fabrication	\$573,000.00
Total Subcontracts	<u>\$4,978,000.00</u>

Engineering : \$1,200,000.00

Management & Administration : \$300,000.00

Construction Supervision : \$200,000.00

Total Capital Cost **\$8,101,000.00**

Figure 7-1 Total Capital Cost of the LIFAC Demonstration as it was Installed at Richmond Power & Light

Additional capital costs also ensued as a result of retrofitting the LIFAC process to an existing facility. Extra engineering, construction, and equipment costs were realized. The following is a breakdown of additional costs assumed as a result of retrofitting:

LAYOUT

- Erected a building around existing outdoor EER equipment
- Provided two motor control centers
- Modified ESP ductwork with vanes and baffle plates
- Erected additional stairs in boilerhouse
- Extensively routed ductwork to/from reactor

CONSTRUCTION

- Some work was performed only during boiler outages
- Rerouted some existing plant piping
- Rerouted some existing plant electrical cables
- Cleanup after construction (paving, grass, painting, etc.)

EQUIPMENT

- Repaired, replaced, and calibrated remaining EER equipment
- Installed additional limestone silo for increased capacity
- A "Stand-alone" process control system was necessary
- Installed a VFD to increase ID fan efficiency
- Added an instrument air compressor for LIFAC instrumentation
- Installed moisturizing screw conveyor on ESP ash disposal silo
- Changed ESP fly ash removal from hydro vaere to blower-operated vacuum system

Fabrication of LIFAC's process elements were performed both in the shop and on-site. Prefabrication was initiated by the subcontractors at their respective facilities prior to shipment. Most of the structural steel applications were prefabricated including: reactor support, stair tower, reactor building, and the limestone building. All steel structures were provided with bolted connections. The steel was pre-painted, only touchup painting was required at the site. It was necessary for certain sections of ductwork to be assembled in the shop. Ducts were composed of flanges for easy bolt connections. No on-site painting of the ductwork was necessary.

On-site fabrication was performed on the grounds of Richmond Power & Light before erection. Most of the activation reactor vessel was assembled at RP&L. The humidification (top) and discharge (bottom) sections of the LIFAC reactor were prefabricated, cut in half, shipped to the site, then reassembled before installation. Each circular section of the reactor was welded on-site from three arcs, each one-third of the total circumference. The reactor and ductwork were fitted with insulation and cladding prior to erection. The remaining process equipment was shipped directly to the site for installation.

7.2 Projected Operating Cost

7.2.1 Fixed Operating Cost

During the two year demonstration period, the project will require a surplus of operation and test personnel. Labor costs will be greater during testing. Two additional operators per shift will be required for the test phase of the project. While, a unit in commercial operation

would require a limited operation staff. Minor maintenance tasks will be performed by the test team and the RP&L maintenance crew. Major repairs or modifications shall be executed by subcontractors. The LIFAC process will be demonstrated over short operation periods, from one day to three weeks of testing. Except for the onset of unexpected repairs, maintenance costs are expected to be low during the 2800 hours of the demonstration period. Table 7-2 shows the estimated annual fixed operating and maintenance cost of the RP&L LIFAC unit in continuous operation. The total fixed O & M cost is approximately \$581,200.

TABLE 7-2 ESTIMATED ANNUAL FIXED OPERATING AND MAINTENANCE COSTS

ANNUAL FIXED OPERATING COSTS, CONTINUOUS	
Operating Labor Cost Details:	
Number of Operators Per Shift	2
Number of Shifts Per Week	4.2
Operating Pay Rate Per Hour	25
	Cost, \$ / year
Total Annual Operating Labor Cost	499200
Total Annual Maintenance Labor Cost	25000
Total Annual Maintenance Material Cost	50000
Total Annual Administrative and Support Labor Cost	7000
Total Annual Fixed O & M Cost	581200

7.2.2 Variable Operating Cost

Variable operating cost includes all the commodities necessary for process operation. The major variable costs, which are presented in detail in Table 7-3, consist of: limestone, waste disposal, energy, and water. Limestone delivery contracts for the demonstration are short-term with the two suppliers, located 150 and 250 miles from Richmond. This type of contract and distance from the site will induced higher limestone prices. However, local limestone suppliers do not have the capacity or required quality for the demonstration. The price of limestone will range from 26 \$/ton to 37 \$/ton. The average commercial value of limestone is nearly 15 \$/ton. Ash disposal cost may vary during testing. Disposal cost is dependent upon the waste management company and landfill used. The price should range between 11 \$/ton and 35 \$/ton.

TABLE 7-3 VARIABLE OPERATING COSTS OF LIFAC SYSTEM AT RP&L

VARIABLE OPERATING COST (65MW, NORMAL FLOW)				
Commodity	Unit	\$/Unit	Quan./hr	\$ / hr
Limestone	tons	35.00	6	210.00
Reheat Steam	lbs	0.003	6180	18.50
Water	gals	0.00	6180	0.00
Aux. Power	kWh	0.02	360	7.20
Ash Removal	tons	17.00	5.4	91.80
Total Variable Operating Cost				327.50

Energy costs involve auxiliary power consumed by the process equipment and the reheating of exiting flue gas using medium pressure steam. The total connected horsepower for LIFAC is 736 kW. However, some equipment will not be used continuously for the demonstration and the estimated average consumption of auxiliary power will be approximately 362 kW. Steam energy is used to reheat the flue gas prior to entering the ESP. Nearly 100 #/min. of medium pressure steam will be needed to increase the gas temperature 35°F. Water will be provided by RP&L from the Whitewater river or plant recirculation system.

7.3 Startup and Checkout Costs

The startup and checkout period was initiated shortly after baseline testing in September of 1992. Since the process is easy to startup and shutdown, all checkouts were performed by operating the process for short periods of time. Most shakedown activities were accomplished by LIFAC personnel. Some equipment, especially the remaining EER units, needed the attention of manufacturer representatives for calibration or repair. RP&L maintenance also helped to expedite the checkout process. The estimated startup cost of the LIFAC process is shown in Table 7-4. The startup cost of the demonstration was nearly \$200,000.

TABLE 7-4 ESTIMATED STARTUP COST OF THE LIFAC PROCESS
BASE YEAR: 1993

Startup Cost Element	Cost, \$
Operating Labor Cost	\$110,000.00
Maintenance and Materials Cost	\$38,500.00
Administrative and Support Cost	\$38,500.00
Commodity Cost:	
Limestone	\$6,250.00
Reheat Steam	\$5,400.00
Water	\$0.00
House Power	\$1,600.00
Ash Removal	\$4,250.00
TOTAL	\$204,500.00

Length of Startup Period, months	2
---	----------

An extra set of gas analyzers were rented for calibration and verification. The limestone feeding system was calibrated by continuously filling a large bucket with limestone and observing the change in silo weight. It was discovered during the startup phase that some items needed modifications or replacement parts. Major modifications were made to the following items: the ID Fan's variable frequency drive failed several times; the flue gas dampers were sticking; the steam reheat condensate return system was inoperational; and the water control valve and ESP recycle rotary feeders were the wrong type.

The process control system was calibrated via the process computers in the RP&L control room while LIFAC was operating at reduced flows.

Several training classes were held for RP&L personnel to educate them on the various principles and operating procedures of the LIFAC process. More detailed training was given during the course of the demonstration.

8.0 COMMERCIALIZATION PLANS

The LIFAC flue gas desulfurization (FGD) system has a relatively low overall cost due to simplicity of design and low operation costs. The limestone sorbent used with LIFAC is cheaper and easier to handle than other FGD processes. Although LIFAC has been installed with new boilers, it is primarily a retrofit application. Existing power plants and industrial facilities do not have the rigid emission limits which are associated with new facilities. Also, existing plants have limited space available for FGD systems. A LIFAC unit can be installed with minimum space requirements and remove up to 85% of the sulfur dioxide from a plant's emissions.

LIFAC systems have been designed for coal-fired boilers ranging from 25 to 30 MW. The number of units needed is dependent upon the amount of flue gas generated and the size of the ESPs at the facility. Often, a 300 MW boiler will require two LIFAC units to treat two exiting gas streams (150 MW each). The LIFAC process is easy to operate from a process monitoring and control system located in the

plant's control room. Additional controls (i.e., dampers) may be incorporated into control room panels or isolated from plant operations.

Limestone injection into the furnace may effect certain boiler operations such as sootblowing frequency. However, its impact on the host is minimal. Sorbent injection rate is dependent on the sulfur content of the combustion coal. The ash byproduct generated in the desulfurization process does not require additional treatment before dumping at a landfill. Thus, waste handling and disposal are inexpensive. The byproduct is dry and may need to be moisturized to quell fugitive dust. Several utilization studies were conducted on the LIFAC ash for use in the construction material industry and the ash may be used for concrete block production and in the mining industry.

There are currently several LIFAC units in operation on boilers burning various types of coal, from low BTU lignite to high BTU bituminous coal. The first full-size LIFAC installation treating high sulfur (2.5%) coal emissions is the Richmond Power & Light Demonstration Facility. A listing of LIFAC installations worldwide is presented in Table 8-1.

**TABLE 8-1
LIFAC INSTALLATIONS WORLDWIDE**

CLIENT - PLANT	COUNTRY	DELIVERY YEAR	BOILER SIZE	AMT. OF FLUE GAS TO LIFAC REACTORS
Imatran Voima, Inkoo 4/1 Pilot	Finland	1986	250 MW	20%
Neste, Kulloo	Finland	1986	3 MW	100%
Imatran Voima, Inkoo 4/2	Finland	1988	250 MW	50%
Prommashimport, Baikal	Russia	1988	45 MW	100%
Imatran Voima, Inkoo 4/1	Finland	1989	250 MW	50%
Saskatchewan Power, Poplar River	Canada	1990	300 MW	50%
Richmond Power & Light, Whitewater Valley	USA	1992	60 MW	100%
Saskatchewan Power, Shand 1	Canada	1992	300 MW	50%
Kostamuksha, Mining Combine	Russia	1994	230 MW	100%
Xiaguan Power Station	China	1995	125 MW	100%

Utilities are concerned about spending capital funds on flue gas desulfurization systems. LIFAC capital costs are significantly less than those of conventional wet lime and limestone scrubbers. The LIFAC system is relatively simple employing a single patented vertical humidification reactor, utilizing a dry reagent, and producing a dry, safe, easy to handle byproduct. Table 8-2 shows a breakdown of total installed costs of the two most recent LIFAC installations: Richmond Power and Light (65 MW) and the Shand Power Station (300 MW) in Canada. The Shand station has a 300 MW boiler that was fitted with only one activation reactor (150 MW); however, the costs are presented for both a single reactor and for two reactors had it been necessary for compliance purposes. Also shown on the table is the estimated cost of a 300 MW wet scrubber for the Shand station. The capital costs for LIFAC range from about \$100/KW for a 65 MW system down to

about \$66/KW for a 300 MW system. This reduction in cost is due to economies or scale. In comparison, the cost of the wet scrubber for a 300 MW unit is on the order of \$205/KW.

Experience at RP&L Shand and other LIFAC installations have also shown that the incremental labor required for a LIFAC system is between 2000 and 3000 hours per year depending on the boiler size. This is well below that required for a wet scrubber system.

At this point, it has been shown at RP&L and other LIFAC installations that the system can be installed economically and operated without affecting normal powerplant operations.

TABLE 8-2 LIFAC INSTALLED COST COMPARISON

	Wet Scrubber (300MW)	Shand Station		RP & L
		Two LIFAC Reactors (300 MW)	One LIFAC Reactor (150 MW)	One LIFAC Reactor (65 MW)
CAPITAL COSTS (\$ Millions)				
Reactor and Auxiliaries	61.6	16.0	8.7	4.5
Sorbent injection	incl.	0.7	0.7	0.4
Solvent Processing	incl.	0.0	0.0	0.0
Delay ESP Duct Erection	incl.	0.4	0.4	0.0
Electrical Installation/Controls	incl.	0.7	0.7	1.1
Misc. Mechanical Installation	incl.	0.1	0.1	0.1
Air Compressor	incl.	0.2	0.2	incl.
Foundations	incl.	0.3	0.3	0.3
Ash System	incl.	0.2	0.2	incl.
Total	61.6	19.7	11.4	6.4
Cost (\$ / KW)	\$205	\$66	\$76	\$99

REFERENCES

1. *Baseline Environmental Monitoring Report - LIFAC Sorbent Injection Desulfurization Demonstration Project* presented to the U.S. Department of Energy dated October 13, 1993.
2. *LIFAC Demonstration at Richmond Power and Light Whitewater Valley Unit No. 2 - U.S. DOE Contract No. DE-FC22-90PC90548*, March 1992
3. *LIFAC Flue Gas Desulfurization* - Rose, J.; Hervol, J.; Viiala, J.; Koskinen, J.; Patel, J.; and Huffman, I. , March 1992
4. *LIFAC Process Evaluation Test Plan* - Pokki, T., August 1992
5. *Operations and Post-LIFAC Tests Environmental Monitoring Report - LIFAC Sorbent Injection Desulfurization Demonstration Project* presented to the U.S. Department of Energy dated October 31, 1994.
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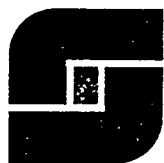
**THE EFFECTS OF THE LIFAC SO₂ CONTROL PROCESS
ON THE PERFORMANCE OF THE WHITEWATER
VALLEY UNIT 2 ESP**

Prepared for

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Southern Research Institute

The Effects of the LIFAC SO₂ Control Process on the Performance of the Whitewater Valley Unit 2 ESP

**Topical Report on EPRI Project 3005-1
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1

INTRODUCTION

Among the options available to utilities for controlling SO₂ emissions are the so-called "dry" SO₂ control processes which produce dry waste products composed of fly ash combined with reacted and unreacted sorbent products (calcium or sodium hydroxides, sulfites, and sulfates). These processes all involve introduction of large quantities of calcium or sodium sorbents which must be collected in the downstream particle control device along with the fly ash. The change in dust characteristics will influence the performance of particulate control systems. When such systems were initially introduced, complex and contradictory effects were sometimes observed, particularly on electrostatic precipitators (ESPs). Accordingly, the Electric Power Research Institute (EPRI) established research project RP3005-1 to investigate these effects and to develop guidelines for the use of particulate control downstream from SO₂ control processes.

One SO₂ control system investigated during this project was the Tampella LIFAC process (Limestone Injection into the Furnace with downstream Activation of Calcium). The system was installed at Whitewater Valley Unit 2 of Richmond Power and Light in Richmond, Indiana. The LIFAC demonstration was conducted under the Department of Energy Clean Coal Technology Program. EPRI funded the detailed evaluation of the effects of LIFAC on the downstream ESP, which is the subject of this report.

The LIFAC process uses calcium-based sorbent (limestone) injection into the furnace with a reactivation zone downstream of the air heater to combine the effects of both low and high temperature reactions between the calcium and flue gas SO₂. The high temperature reaction occurs at furnace exit temperatures (1800-2200°F) similar to simple furnace sorbent injection, which has also been evaluated during this project.¹ The reactivation occurs through cooling the flue gas to temperatures close to adiabatic saturation using water sprays into a large vertical reaction chamber. Reheat is used downstream of the reactivation chamber to provide temperatures of 170 to 200°F to the particle control device. Fly ash and partially-sulfated sorbent are recycled from the ESP hoppers to the activation chamber to improve sorbent utilization. Because of the low temperatures which result from the high degree of humidification, the effect of LIFAC on ESP performance is similar to other low-temperature processes, such as spray dryers.¹

Over the span of this project, two separate test programs were conducted on the LIFAC/ESP system. During the initial phases of the work at Whitewater Valley, high opacity during LIFAC startup impeded operation at the desired temperatures and sorbent addition rates. A limited test program was conducted in April 1993 to evaluate the cause of the high opacity and to

recommend solutions. Those results and recommendations were contained in a previous report.² The conclusions from that effort were:

- Electrical reentrainment of previously collected fly ash particles from the ESP was responsible for the transient opacity excursions during startup. Reduction of gas temperature should be done gradually over several hours or days to minimize the transient effect.
- Mixtures of sorbent and ash produced by the LIFAC process were found to have higher tensile strength than the Whitewater Valley fly ash alone. From this, it was inferred that long-term LIFAC operation might result in better ESP performance than that observed during the transient periods of short-term parametric tests.
- It was concluded that the reentrainment effect was dependent on temperature and that using additional reheat to maintain ESP temperature above 200°F should provide acceptable long-term performance. The use of a hot-gas bypass from the air heater inlet to the ESP inlet was suggested to obtain the additional reheat.
- Adjustment of the gas flow distribution in the ESP to reduce the very high gas velocities at the bottom of the ESP plates would also help to minimize the detrimental effects of particle reentrainment.

Following implementation of these recommendations, it was possible to operate the LIFAC system under the conditions necessary for good SO₂ removal and still achieve acceptable ESP performance. After a period of extended, continuous LIFAC operation to season the ESP, a comprehensive test of ESP performance was conducted in June of 1994. The results of this comprehensive test are the subject of this report.

Section 2 of this report will provide a discussion of the significant results from the comprehensive test program, although some comparison to previous data will be made. Section 3 will discuss the results of computer modeling and analysis of the ESP during LIFAC, while Section 4 will provide a summary of the significant findings. Cited literature references are listed in Section 5.

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TEST RESULTS

The operation and performance of an ESP can be significantly affected as a result of the upstream use of a low-temperature, SO₂ removal process. Among the changes with which an ESP must cope are:

- Increased inlet particle mass loading.
- Decreased flue gas temperature, gas volume flow, and gas viscosity.
- Modified particle size distribution.
- Reduced dust resistivity.
- Increased non-rapping reentrainment of dust from the ESP collecting plates.
- Increased rate of accumulation of discharge electrode deposits.

Most of these changes will act to increase particle emissions from the ESP, although some are beneficial and others can go either way depending on the magnitude of the change.

Measurements were made during this program to quantify all of these effects. The specific mechanisms that affect ESP performance associated with these changes will be discussed in detail in the subsections covering the measurements that illustrate them.

Process Conditions

During the three-day test program, the LIFAC process and the other plant systems were operated, to the extent possible, under constant conditions during testing. The LIFAC system used an average fresh limestone Ca/S stoichiometric ratio of 2.0 along with recycle from the ESP hoppers at a rate approximately equal to fresh limestone addition. Boiler load was held close to 60 MWe during testing. One change was purposefully made on the last day of testing when the amount of reheat was lowered and the ESP gas temperature reduced by 12°F. Table 1 provides a summary of the significant operating conditions for each test day.

The coal supply was restricted to a single mine for the test program. However, the coal analyses shown in Table 2 indicate that the coal sulfur content varied significantly, decreasing from a high of 2.1% on the first day to below 1.6% by the end of the tests. Despite this change, since the

LIFAC process operated consistently, adding essentially the same amount of sorbent and recycle, the effect of the sulfur variation on the ESP should not be significant.

Particle Mass Concentration and ESP Collection Efficiency

EPA Method 17 was used to quantify the total mass collection performance of the ESP during LIFAC operation, in addition to collecting a number of important pieces of information on the mechanisms that control ESP performance. The results of measurements that were made simultaneously at the inlet and outlet of the ESP on two of the test days are shown in Table 3. The table contains particle mass loadings, gas volume flows, gas temperature, gas moisture and gas oxygen content.

The mass loading measured at the ESP inlet with LIFAC was $17.15 \text{ lb}/10^6 \text{ Btu}$. This is approximately a factor of 2 higher than the value measured with LIFAC during the 1993 test program, which is consistent with the lack of recycle and lower limestone addition rate ($92 \text{ lb}/\text{min}$) during that earlier program. Based on the average ash content of the coal (8.8%), the EPRI data base⁷ predicts a fly ash mass loading for a bituminous coal of $4.9 \text{ lb}/10^6 \text{ Btu}$, indicating that LIFAC increased inlet mass slightly more than a factor of 3 over that expected with fly ash alone. The one measurement made with soot blowers in service gave a time-averaged value approximately 10% higher than the other inlet results. The correlations published in the EPRI SO_2 /particulate control guidelines¹ calculate an inlet mass loading of $18.3 \text{ lb}/10^6 \text{ Btu}$ for the operating conditions in Table 1. This prediction is in reasonable agreement (<7% error) with the measured value.

There is a discrepancy between the gas temperatures measured during LIFAC with the ESP outlet hotter than the inlet by an average by 17°F . Extensive calibration and direct comparison of the two measurement systems did not resolve the difference. Some of the temperature difference might be attributed to continuation of the exothermic reaction between the flue gas SO_2 (or CO_2) and the unreacted lime in the ESP, impaction of damp particles or unevaporated water droplets on the thermocouples at the ESP inlet, or to compressive heating in the ID fan. During the 1993 test, a similar temperature increase was observed from inlet to outlet during all water injection conditions (some, but not all, including sorbent addition), but not under baseline conditions. This suggests that most of the difference is caused by thermocouple effects at the ESP inlet and that the outlet value is the most appropriate temperature to correlate with ESP performance. Some gas flow differences were also observed between inlet and outlet that are probably related to the relatively poor sampling location at the ESP inlet. Since the outlet sampling location is much more conducive to collection of representative samples than is the inlet location, the outlet values will be considered correct and used for ESP analysis.

The gas temperature in the ESP was somewhat higher during this test than is typically expected downstream of a low-temperature SO_2 control process. Most particle control devices in such systems operate in the range of 165°F to 180°F rather than the 197°F to 210°F at Whitewater Valley. The higher temperature is a result of the additional reheat added to reduce particle reentrainment from the ESP. The particle reentrainment is thought to occur because of the low

electrical resistivity of the dust (resulting in low electrical clamping force in the ESP) and low tensile strength of the dust layer.¹ Both of these effects occur because of the low gas temperature and high relative humidity resulting from the low-temperature SO₂ control process. The effect of this reentrainment on ESP performance will be considered further in subsequent sections.

Table 4 shows a number of ESP performance indicators calculated from the inlet and outlet mass data of Table 3. The average collection efficiency was 99.3% with a particle emission rate of 0.119 lb/10⁶ Btu. As indicated by the high values of the Matts-Ohlfeldt particle migration velocity (ω_k), this level of performance is quite good for an ESP with a modest specific collection area (SCA) of 198 ft²/1000 acfm. Despite the 12°F lower ESP temperature on 6/9/94, there was no obvious effect on ESP emissions or collection efficiency. Apparently, even 198°F was sufficiently high to limit particle reentrainment to reasonable levels.

Note that the opacity value shown in the table is measured in a stack which is common to both Units 1 and 2. This value is useful in assessing compliance with environmental regulations, but is only a gross indicator of Unit 2 ESP performance with LIFAC.

Table 5 shows the ESP performance measured during the 1993 LIFAC test program. A value of ω_k similar to the 1994 LIFAC test was measured during the 1993 baseline test, although the emissions and efficiency were different. The similarity of these values indicates that the ESP was charging and collecting particles with the same proficiency during both programs. Therefore, the difference in efficiency (99.05% baseline vs. 99.3% LIFAC) is consistent with the change in SCA from 181 to 198 ft²/1000 acfm. The change in SCA was caused by the reduction in gas volume flow resulting from the lower temperature with LIFAC. Despite the higher collection efficiency with LIFAC, the greatly increased inlet mass loading resulted in increased particle emissions. The ESP collection performance with LIFAC will be further analyzed in the subsequent section on ESP modeling.

Particle Size Distribution and Fractional Efficiency

Particle size distributions entering and exiting the ESP during LIFAC were measured on the second day of the test program using cascade impactors. The size distributions measured at the ESP inlet during both the most recent test and the 1993 program are shown on a cumulative mass basis in Figure 1. The open symbols represent the baseline fly ash distribution and the solid symbols show the LIFAC data. The error bars associated with the symbols are 90% confidence intervals to the mean distribution.

The two LIFAC size distributions are essentially identical with two exceptions: 1) a lower concentration of particles smaller than 0.5 μ m was measured during the 1994 test, and 2) a higher total mass concentration was measured during the 1994 test. The lower concentration of submicron particles appears to be related to differences in the coal since the 1993 test indicated that the LIFAC and baseline distributions were identical in this range, and by the fact that the 1994 LIFAC distribution falls below the baseline data in this range. Collection of particles this small in the activation chamber is unlikely to be responsible for the lower concentration. As

discussed previously, the higher total mass loading during the 1994 test resulted from the addition of recycle material to the system and a higher limestone addition rate. The size distributions indicate that the recycle mass was mainly associated with particles or particle agglomerates larger than 10 μm . These large particles should be relatively easy to collect in the ESP and will contribute to higher overall collection efficiency.

Comparison of the LIFAC and baseline data indicate that the LIFAC process contributed only particles larger than 0.8-1.0 μm to the gas stream and that only 2% of the mass was smaller than 2 μm . Figure 2 shows the cumulative mass distribution for sorbent only calculated from the difference between the LIFAC and baseline distributions. This distribution is somewhat finer (more small particles) than measured for spray dryers, but somewhat coarser than for furnace injection of hydrated lime at Edgewater which contained significant numbers of particles down to 0.2 μm .¹ Particles in the 0.5 to 2.0 μm range contribute more to opacity per unit mass than do larger particles. Therefore, for constant collection efficiency, an increase in these particle sizes would be expected to increase opacity.

The small particles contributed by the LIFAC process will affect ESP performance by increasing the total suspended space charge in the ESP electrode space. The increased space charge can have both positive and negative effects on the ESP. Moderate increases in space charge will change the electric field profile in the electrode space resulting in increased electric field adjacent to the collecting plate and increased particle collection. However, excessive increases in particle loading can result in corona current quenching and degraded particle collection performance. The concentrations of small particles contributed by the LIFAC process were probably not high enough to cause corona quenching, but this will be evaluated further in a later discussion of ESP electrical operation.

Figure 3 shows the ESP collection efficiency as a function of particle size calculated from the inlet and outlet particle size distributions. These data indicate that the lowest collection occurred for particle sizes of 0.2 μm with increasing efficiency for larger particles. This behavior is normal and is consistent with ESP theory. The particle agglomerates reentrained during electrode rapping typically have a mean size of 6 μm ,³ producing a dip in the efficiency curve in that region. Although there is a slight dip in the efficiency curve, there is no evidence in these data of excessive reentrainment. However, because of the low tensile strength of the dust at low temperature, the particle agglomerates could decrepitate thus reducing efficiency over a wide size range. If this were the case, the effect of reentrainment might not be discernable in the size distribution data.

Dust Chemistry

Samples of the dust produced by the LIFAC process were collected from the ESP hoppers on each day of the test program. Chemical compositions of the samples are shown in Table 6. The samples collected from the inlet and outlet hoppers were analyzed separately for one test day, while on the other days proportional blends were prepared. The proportions from each hopper used in the blends were calculated from ESP theory to reproduce the dust composition in the

inlet gas stream.³ Also shown in the table is the average baseline fly ash composition from the 1993 test.

The most striking feature of the dust chemistry is the high level of calcium (~40%) contributed by the LIFAC process. Although no samples were obtained during the most recent tests, the baseline fly ash in 1993 had a CaO content of only 2.5%. Comparison of the inlet and outlet hopper samples indicates that a higher fraction of the sorbent particles are collected in the inlet field of the ESP. The drop in CaO from 41% to 26% from inlet to outlet is consistent with the relatively larger particle size distribution of the sorbent compared to the fly ash. The effect of the chemical composition on resistivity and ESP performance will be discussed in the following subsection.

One of the most significant degrading effects of low-temperature SO₂ control systems on ESP performance results from the reentrainment of dust from the ESP electrodes. This is thought to be a function of both low resistivity and low dust layer tensile strength. High chloride content in the dust has been associated with reducing the reentrainment problem and improving ESP performance, presumably by making the dust more adhesive. However, the chloride content of the samples shown in Table 6 are probably not sufficiently high to produce this effect. Chloride content over 1% has been required at other sites to improve performance.⁴ The use of chloride compounds to improve performance is not generally desirable because of the increased corrosion which can occur.

Dust Resistivity

One effect generally expected of a low-temperature SO₂ control process is low dust resistivity that allows excellent ESP electrical operation. When such a process is applied to a fly ash that has an inherently high resistivity under baseline conditions, ESP performance can actually be improved. Dust resistivity data collected in-situ with a point-plane resistivity probe are shown in Table 7. The resistivity values obtained from both methods of measurement with the probe (spark and V-I) are included in the table. The average resistivity measured with the spark method was 2×10^{10} ohm-cm, while most values obtained with the V-I method were below the lower limit of resolution of the technique at $\sim 5 \times 10^9$ ohm-cm. Both techniques have strengths and weaknesses, but the V-I method may be more valid in this case because of the characteristics of this dust. The dust cakes collected in the probe were fluffy and compressible, potentially causing poor contact with the movable electrode during the spark measurement. Thus the higher value with the spark measurement may actually be a result of high resistance in the interface between the dust layer and movable electrode. Regardless of which technique is considered, the resistivity is low enough not to significantly limit ESP operation.

The temperature measured with the resistivity probe was somewhat lower than those measured at the ESP inlet possibly because of incomplete mixing of the reheat gas and the discharge from the reactivation chamber or due to cooling of the probe by damp particles or residual water droplets. The resistivity measurements were made only a few feet downstream of the reheat gas entry point.

Figures 4 and 5 show the results of laboratory resistivity measurements made on the hopper samples from the test program. Figure 4 was measured in ascending-temperature mode, while the data in Figure 5 were collected in descending-temperature mode. As frequently seen with mixtures of ash and sorbent, the descending-temperature data indicate higher resistivity than the ascending data. Obviously some chemical changes occur in the sample at higher temperature, but it is not clear which condition is most representative of the conditions which exist in the ESP. As one might expect from the dust chemistry, only the outlet hopper sample is significantly different from the other samples. However, at the temperature of the Whitewater Valley ESP there is no significant difference between any of the samples.

If the temperature of the resistivity probe (173 °F) accurately described the conditions of the dust layer in the resistivity probe, the resistivity could be considerably higher than the in-situ measurements indicated at the ESP outlet temperature (200 °F). Figure 6 compares the in-situ and laboratory measurements for the 6/9/94 proportional blend. If both the spark and V-I methods are considered, the in-situ measurements, which should be most representative of the conditions experienced by the ESP, can be considered to agree with either of the lab measurements. If the lab measurements are used to estimate resistivity for the ESP outlet temperature, quite different results are obtained for the two curves. At 200 °F, the descending data indicate a resistivity value of 5×10^{11} ohm-cm while the ascending curve gives a value of 1.5×10^{10} ohm-cm. The lower value would result in excellent ESP performance, but the higher resistivity would significantly degrade ESP performance. In the following subsection, the ESP electrical conditions will be used to assist in this analysis.

Also shown on Figure 6 are resistivity predictions made by two techniques developed by Roy Bickelhaupt.^{5,6} As expected for ash/sorbent mixtures, there is poor agreement between the resistivity vs. temperature measured in the laboratory and that which is predicted. This is despite the fact that the resistivity predictions are based on correlations between lab measurements and ash chemistry. Our experience on this project has indicated that both resistivity models do a poor job on ash-sorbent mixtures. The very optimistic estimates of resistivity of ash-sorbent mixtures, particularly with high-temperature processes, makes the use of these models dangerous when estimating ESP performance effects.

ESP Electrical Operation

High dust electrical resistivity affects ESP performance primarily by limiting the useful power input to the ESP. The reduced voltage and current that occur with high resistivity result in poorer charging and collection of particles and increased emissions. The average electrical operating conditions of the ESP with LIFAC are shown by field in Table 8. As expected, the voltage is highest and current lowest in the inlet field because of the space charge associated with the high particle loading. Voltage is reduced and current increased toward the outlet of the ESP as the particles are collected and the space charge effect is reduced. This effect is typical of all ESPs and does not indicate a serious corona quenching problem resulting from the LIFAC process. The current density of 18 nA/cm² observed in the inlet field is typical of fly ash ESPs and will provide acceptable performance.

No sparking was occurring in any of the fields indicating that they were at some artificial limit and not controlled by the dust layer characteristics. The outlet field was at voltage limit, while the other fields were at the current limit of the power supplies. Normally, the current densities measured during LIFAC (20-25 nA/cm²) would be considered to represent a slight resistivity limitation, since most ESPs have current limits in the range of 50 nA/cm². However, a current limit of 25 nA/cm² is typical of the Lodge-Cottrell ESP design used at Whitewater Valley.

Even though relatively high values of voltage and current were observed in the ESP, back corona caused by high resistivity could still degrade ESP performance. Figure 7 shows voltage-current curves measured on the ESP on the last day of the test program. These curves show no evidence of back corona or other anomalous electrical behavior. Back corona would be indicated by infinite or negative slope in the V-I curve. Therefore, the average electrical conditions in Table 8 are completely useful for charging and collecting particles and should be representative of ESP performance.

Figure 8 compares the current density values during LIFAC with a correlation between resistivity and current density developed from the EPRI data base.⁷ The correlation generally confirms that the electrical conditions, at least up to the point where current limit is reached, are consistent with the in-situ measurements of dust resistivity. The high resistivity indicated by the descending-temperature lab resistivity data at 200°F is not consistent with the ESP operation.

One potential detrimental effect of low-temperature processes on ESP operation is the accumulation of excessive dust deposits on the discharge electrodes. Such buildups could quench corona current causing reduce charging effectiveness and degrading collection efficiency. Although the rapid accumulation of deposits has been observed with low-temperature SO₂ control on a pilot-scale ESP,⁹ problems have not been reported with full-scale installations. The lack of reported problems may imply that the deposits are removed by normal electrode rapping. As discussed above in the context of space charge corona suppression, the electrical conditions at Whitewater Valley do not indicate any such problems specific to the LIFAC process. There is no evidence of excessive electrode deposits during LIFAC operation.

3

ESP PERFORMANCE MODELING

Version 3 of the SRI Mathematical Model of ESP Performance⁸ was used to simulate the Whitewater Valley Unit 2 ESP under both baseline and LIFAC conditions. Modeling of the performance of the ESP under baseline conditions was done to calibrate of the model and to determine if the performance of the ESP was reasonable in the absence of the complicating effects of LIFAC. Modeling with LIFAC illustrates the mechanisms through which LIFAC affects ESP performance.

For modeling the baseline condition, two sets of model non-ideal conditions were used to estimate a range of expected performance. Two non-ideal conditions (s , σ_g) are used in the model to account for the combined effects of sneackage and reentrainment (s) and for the uniformity of the gas flow distribution in the ESP (σ_g). Sneackage describes the particles which bypass each electrified section of the ESP by flowing through hoppers and over the tops of plates, while reentrainment accounts for particles which are collected, but subsequently reentrain into the gas stream. The σ_g parameter is the coefficient of variation of the gas velocity profile in the ESP. For ESPs collecting fly ash, the performance range of typical ESPs can be represented by modeling with a lower limit of s and σ_g of 0.05 and 0.15 and an upper limit of 0.10 and 0.25.⁷

During the previous work in 1993, the baseline ESP model calculations could not be made to match the measured baseline performance. At that time, we speculated that incorrect voltage values displayed on the ESP power supply controls were probably responsible for the disagreement. Those voltages (labeled as "original" in Table 9), were considered too low for the current densities and electrode spacing of the Unit 2 ESP. During the recent test, the indicated voltage values were compared to a precision high-voltage probe and it was established that three of the four fields were indicating values that were low by up to 6.9 kV. The "corrected voltage" values in Table 9 are based on the assumption that the same voltage error was present in the 1993 data. The corrected baseline voltage values were used in the ESP model. The ESP control panel readouts were calibrated to the corrected values.

The hardware specifications of the Unit 2 ESP are shown in the top portion of Table 10. Other model inputs specific to the baseline operating conditions (documented in the previous report) are included in the lower portion of Table 10. In addition to the measured gas volume flow, the ESP was also modeled with 110% and 60% of the measured gas flow to simulate a range of performance for a typical range of boiler loads. The baseline model calculations are shown in Table 11 and plotted as particle emissions vs. SCA in Figure 9. The lower and upper limits of the shaded region on the figure represent model calculations with the better and poorer sets of typical non-ideal conditions described above. The ESP emission rate measured during the 1993

baseline test is indicated on the figure by the solid circle. In contrast to the poor agreement during the 1993 modeling, the model does a good job of predicting baseline performance with the corrected electrical conditions. Our ability to accurately predict baseline performance provides extra confidence in the LIFAC predictions.

Because of the increased reentrainment associated with low-temperature SO₂ control processes, it is generally necessary to use higher values of the ESP model's non-ideal conditions to accurately simulate actual performance.¹ The range of values established by the EPRI guidelines are a lower limit of $s = 0.25$, $\sigma_g = 0.25$ and an upper limit of $s = 0.40$, $\sigma_g = 0.25$. The ESP performance with LIFAC was modeled under both the non-ideal conditions typical of fly ash and these poorer values from the guidelines. The model results are shown in Table 12 and Figure 10 for a typical range of gas flow values. The measured emissions rates from both the 1993 and 1994 tests are also shown on the figure. The measured values fall between the two sets of non-ideal conditions indicating higher emissions than expected for fly ash, but lower than for most other low-temperature SO₂ control processes. This suggests that some increased reentrainment was occurring in the Unit 2 ESP with LIFAC, but that it is not as severe as expected. The improved performance with LIFAC at Whitewater Valley is attributed to the higher flue gas temperature resulting from the additional reheat.

Although it could not be demonstrated at this site because of the need to comply with opacity regulations, we expect that if the ESP temperature were reduced to 170°F the performance of the ESP would degrade substantially. The lower level of reentrainment at Whitewater Valley should not be taken to mean that the LIFAC process has a significantly different effect on ESP operation than do other low-temperature SO₂ control processes. We expect that reduced reentrainment would also be observed for other low-temperature processes if additional reheat were used to increase ESP temperature to 200°F. Therefore, if ESP temperatures will be significantly below 200°F, we recommend a conservative approach to estimating the effects of LIFAC on ESP performance by using the ESP model non-ideal conditions developed for spray dryers ($s = 0.25$, $\sigma_g = 0.25$ and $s = 0.40$, $\sigma_g = 0.25$) and documented in the EPRI guidelines.¹

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**THE EFFECTS OF THE LIFAC SO₂ CONTROL PROCESS ON THE
PERFORMANCE OF THE WHITEWATER VALLEY UNIT 2 ESP**

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Table 1
LIFAC Process Operating Conditions

Parameter	6/7/94	6/8/94	6/9/94	Avg.
Boiler Load, MWe	60	61	61	61
Calcium/Sulfur Stoichiometric Ratio ^a	2.2	1.8	1.9	2.0
Coal Sulfur Content, %	2.0	2.2	2.3	2.2
Coal Feed Rate, lb/min	943	952	912	936
Limestone Feed Rate, lb/min	141	122	132	132
Recycle Feed Rate, lb/min	133	133	133	133
Reactor Water Flow, gpm	64	63	68	65
Average Reactor Inlet Temperature, °F	341	337	346	341
Minimum Reactor Outlet Temperature, °F	136	136	136	136
Minimum Steam Reheater Outlet Temp, °F	166	165	164	165
Average ESP Inlet Temperature, °F	187	185	178	183
Reactor Outlet SO ₂ Concentration, ppm ^b	560	743	488	597
a. Assumes constant coal sulfur content of 2.25%. b. Corrected to 6% O ₂ and boiler outlet H ₂ O content.				

Table 2
Coal Chemical Composition

Component	6/7/94	6/8/94	6/9/94	Average
Sulfur Content, %	2.10	1.70	1.57	1.79
Ash Content, %	8.91	9.79	7.65	8.78
Moisture, %	10.97	10.17	11.98	11.04
Btu/lb Received	11602	11625	11659	11629

Table 4

ESP Performance Summary

Table 5
ESP Performance Summary From 1993 Test

Condition	ESP Efficiency, %	ESP Penetration, %	ESP ^a ω_k , cm/sec	ESP SCA, ft ² /kacfm	Particle Emissions, lb/10 ⁶ Btu	Stack ^b Opacity, %
Baseline	99.050	0.950	62	182	0.0490	10
Water Excursion	95.625	4.375	26	195	0.2192	22
LIFAC Excursion	96.056	3.944	27	198	0.3621	24
LIFAC Post-Exc.	99.195	0.805	58	208	0.0701	13

a. Effective Migration Velocity from Matts-Ohnfeldt Equation with k=0.5
b. Measured in Stack with Both Units On-Line.

Table 6
Chemical Composition of ESP Hopper Dust

Oxide	6/7/94		6/8/94 Proportional Blend	6/9/94 Proportional Blend	Average 1993 Fly Ash
	Inlet Hopper	Outlet Hopper			
Li ₂ O	0.01	0.01	0.01	0.01	0.04
Na ₂ O	0.53	0.39	0.58	0.50	0.71
K ₂ O	0.74	1.19	0.83	0.60	2.4
MgO	1.60	1.31	1.64	1.77	0.93
CaO	41.07	25.54	39.11	40.79	2.5
Fe ₂ O ₃	8.10	12.62	8.06	8.69	21.2
Al ₂ O ₃	10.11	16.32	11.55	9.72	22.8
SiO ₂	21.00	31.10	22.21	20.22	48.3
TiO ₂	0.44	0.70	0.46	0.39	1.2
P ₂ O ₅	0.28	0.34	0.34	0.29	0.48
SO ₃	15.94	10.25	15.02	16.65	0.55
LOI	4.81	7.11	5.30	5.68	4.6
Cl ⁻²	0.16	0.52	0.14	0.13	—

Table 7
In-Situ Dust Resistivity Measurements

Date	Temp- erature, °F	Layer Thickness, mm	Resistivity, ohm-cm	
			Spark	V-I
6/7/94	175	1.03	3.8×10^{10}	4.6×10^{10}
	175	1.00	1.0×10^{10}	2.6×10^{10}
	175	1.07	3.5×10^{10}	$<5 \times 10^9$
6/8/94	176	1.57	1.8×10^{10}	$<5 \times 10^9$
	175	2.06	2.9×10^{10}	$<5 \times 10^9$
	177	2.02	^a 4.1×10^{11}	$<5 \times 10^9$
6/9/94	168	2.54	8.1×10^9	$<5 \times 10^9$
	172	1.51	8.6×10^9	$<5 \times 10^9$
	167	1.42	8.6×10^9	$<5 \times 10^9$
	170	1.52	1.6×10^{10}	$<5 \times 10^9$
Average	173		1.9×10^{10}	$<5 \times 10^9$
a. Outlier - excluded from average.				

Table 8
ESP Electrical Operating Conditions

Date	ESP Field	ESP Voltage, kV	ESP Current, mA	Current Density, nA/cm ²
6/7/94	1	55.3	190	18.2
	2	50.9	220	21.1
	3	47.9	230	22.1
	4	47.8	250	24.0
6/8/94	1	55.7	197	18.9
	2	51.5	223	21.4
	3	48.6	237	22.8
	4	48.8	250	24.0
6/9/94	1	55.6	187	18.0
	2	51.9	217	20.8
	3	49.4	227	21.8
	4	49.2	247	23.7
Average	1	55.5	191	18.4
	2	51.4	220	21.1
	3	48.6	231	22.2
	4	48.6	249	23.9

Table 9
Baseline ESP Electrical Conditions

	ESP Field	ESP Voltage, kV	ESP Current, mA	Current Density, nA/cm ²
Original	1	43.4	180	17.3
	2	42.7	193	18.5
	3	47.1	203	19.5
	4	49.7	240	23.0
Corrected Voltage	1	47.7	180	17.3
	2	50.3	193	18.5
	3	50.9	203	19.5
	4	49.7	240	23.0

Table 10
ESP Model Input Data

ESP Hardware Specifications		
Fields in Direction of Gas Flow	4	
Collection Area per Field, ft ²	11,250	
Collecting Plate Spacing, in	11	
Collecting Plate Height, ft	30	
Collecting Plate Length, ft	30	
Number of Gas Passages	25	
Wire-to-Wire Spacing, in	9	
Number of Wires in Flow Direction	40	
Number of Baffled Sections	4	
Condition-Specific Model Input		
	Baseline	LIFAC
Inlet Mass Loading, gr/acf	1.61	5.93
Gas Volume Flow, acfm	248,000	216,000
Gas Temperature, °F	307	207
Gas Velocity, ft/sec	6.6	5.3
Gas Moisture Content, %	7.9	14.8
Gas Oxygen Content, %	5.6	5.5
Gas Viscosity, kg/(m*sec)	2.26x10 ⁻⁵	1.95x10 ⁻⁵

Table 11
Revised Baseline ESP Model Results

Data Source	ESP SCA, ft ² /kacfm	Model Non-Ideal Conditions	Collection Efficiency, %	Particle Emissions, lb/10 ⁶ Btu	Stack Opacity, %
Modeled with increased Gas Flow	165	0.05, 0.15 0.10, 0.25	98.87 98.27	0.055 0.084	13 17
Modeled with Measured Gas Flow	181	0.05, 0.15 0.10, 0.25	99.13 98.61	0.042 0.068	11 14
Modeled with Decreased Gas Flow	299	0.05, 0.15 0.10, 0.25	99.84 99.66	0.008 0.017	2 4
Measured	182	N.A.	99.05	0.049	10*
* - Measured in common stack with Unit 1.					

Table 12
ESP Model Results with LIFAC

Data Source	ESP SCA, ft ² /kacfm	Model Non-Ideal Conditions	Collection Efficiency, %	Particle Emissions, lb/10 ⁶ Btu	Stack Opacity, %
Modeled with Increased Gas Flow	166	0.05, 0.15	99.58	0.059	12
		0.10, 0.25	99.23	0.109	18
		0.25, 0.25	97.69	0.327	36
		0.40, 0.25	94.05	0.839	60
Modeled with Measured Gas Flow	207	0.05, 0.15	99.80	0.029	6
		0.10, 0.25	99.56	0.062	11
		0.25, 0.25	98.37	0.230	27
		0.40, 0.25	95.38	0.652	51
Modeled with Decreased Gas Flow	310	0.05, 0.15	99.96	0.006	1
		0.10, 0.25	99.86	0.019	3
		0.25, 0.25	99.26	0.105	13
		0.40, 0.25	97.46	0.358	35
Measured	207	N.A.	99.30	0.119	11*
* - Measured in common stack with Unit 1. Some dilution of the Unit 2 emissions.					

WHITEWATER VALLEY 2 ESP INLET CUMULATIVE MASS SIZE DISTRIBUTION

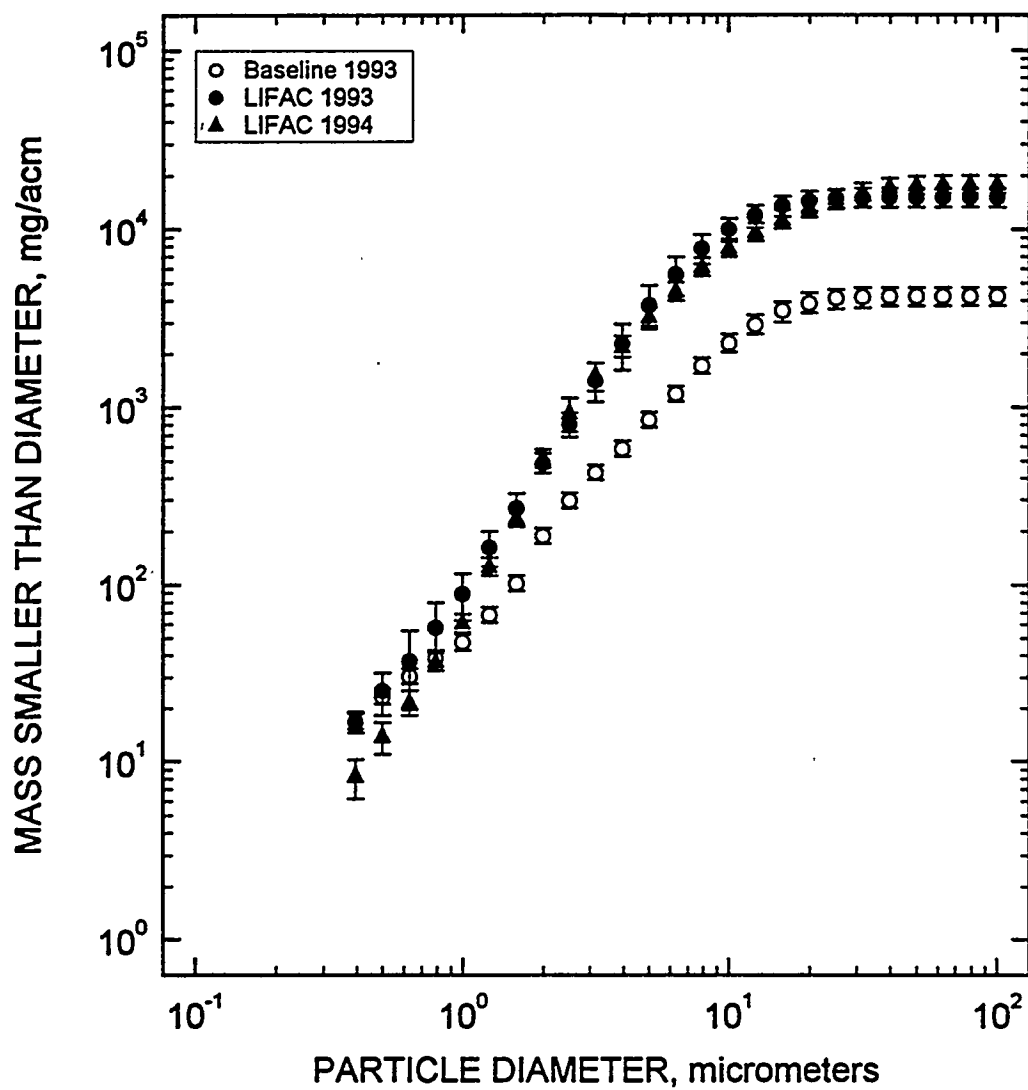


Figure 1
ESP Inlet Cumulative Mass Particle Size Distributions

PARTICLE MASS CONTRIBUTED BY LIFAC
PROCESS AT WHITEWATER VALLEY

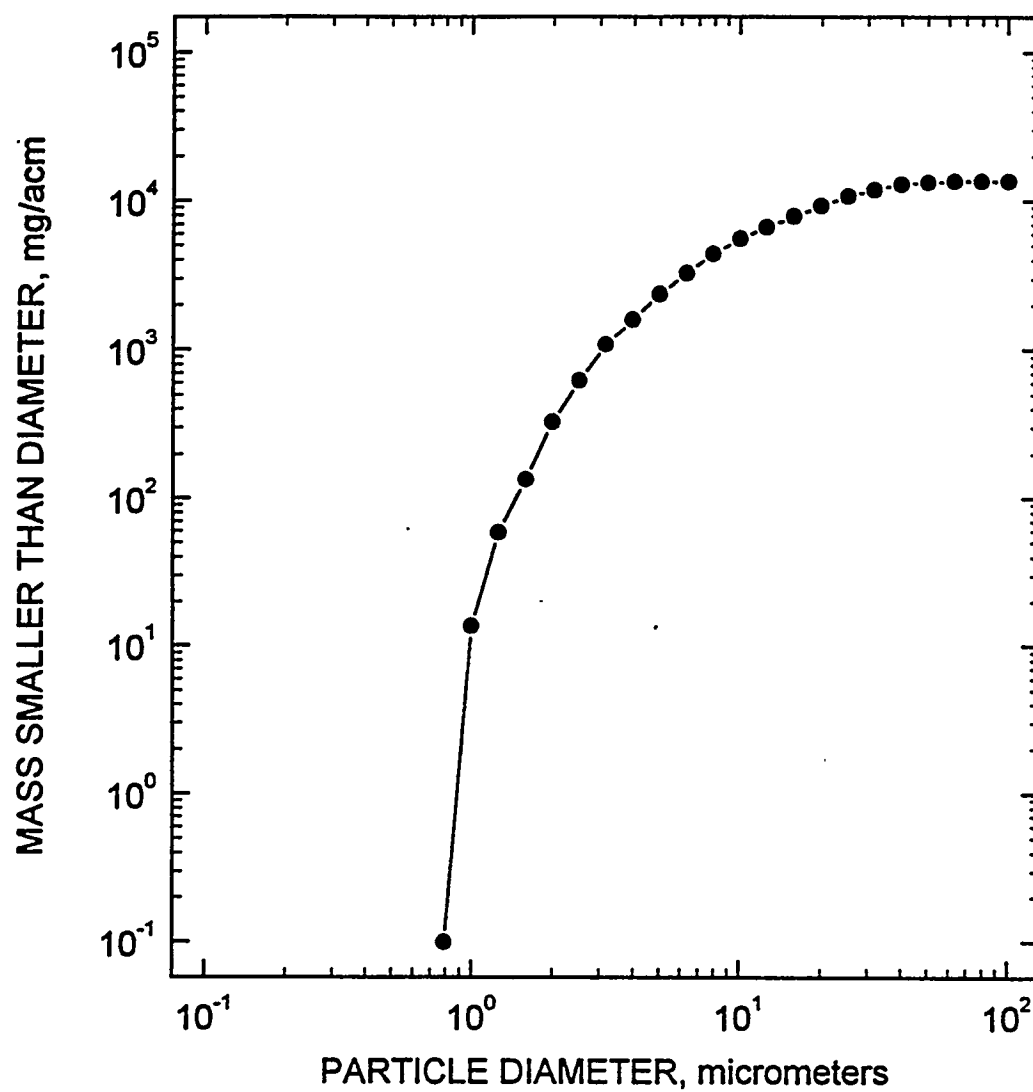


Figure 2
ESP Inlet Particle Mass Contributed by the LIFAC Process

WHITEWATER VALLEY ESP FRACTIONAL COLLECTION EFFICIENCY WITH LIFAC

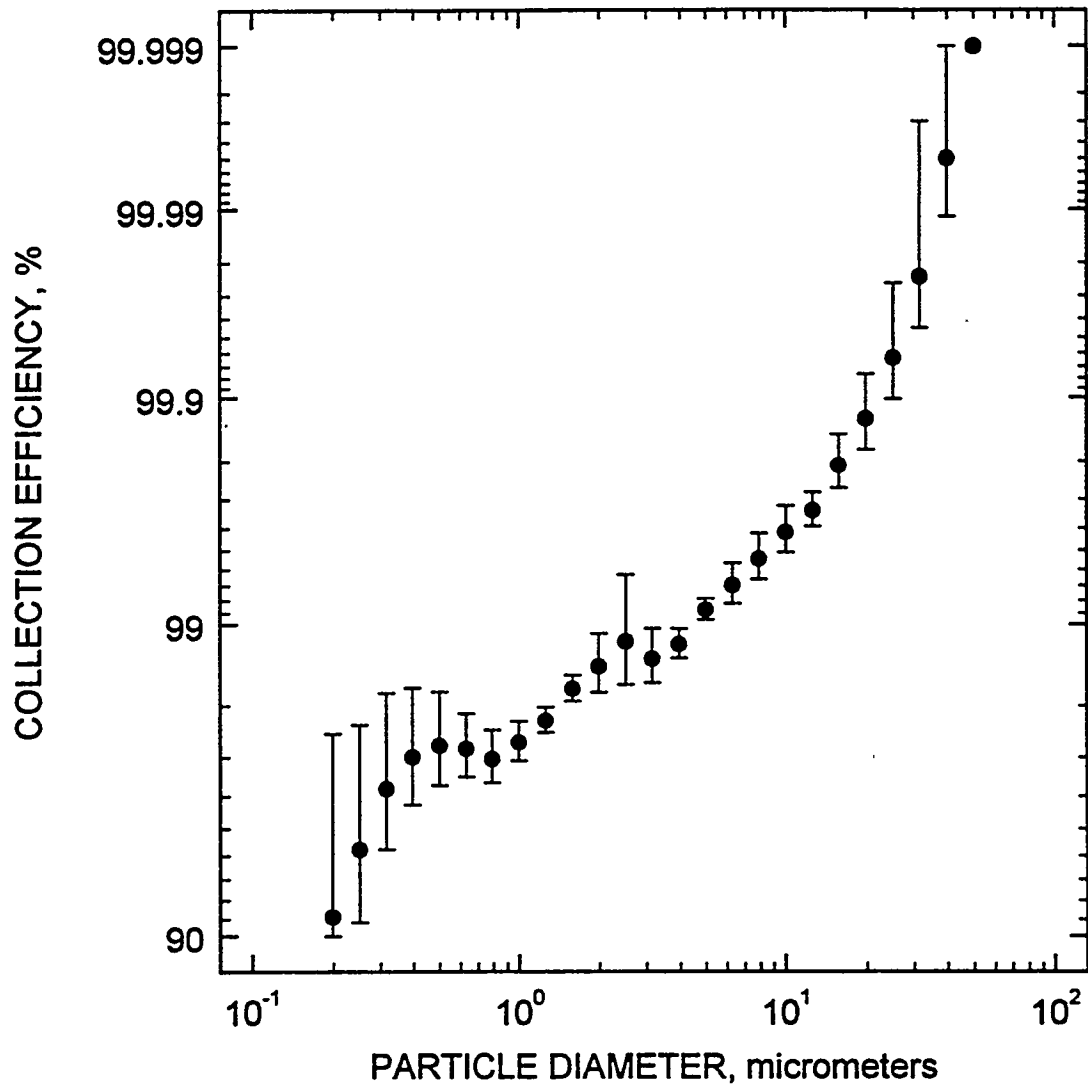


Figure 3
ESP Collection Efficiency as a Function of Particle Size During LIFAC

ASCENDING TEMPERATURE RESISTIVITY WHITEWATER VALLEY LIFAC SAMPLES

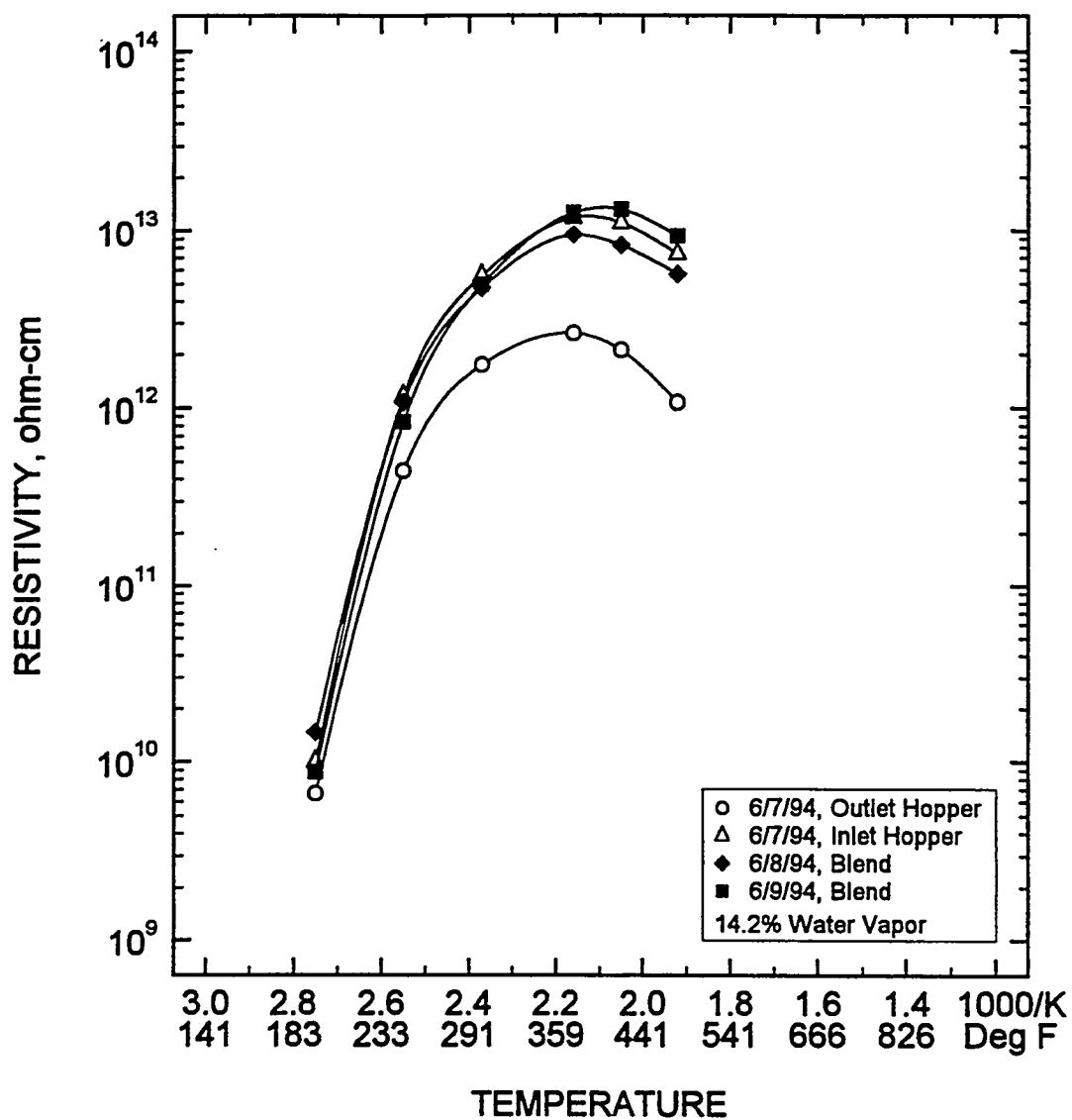


Figure 4
Ascending-Temperature Resistivity Measurement on LIFAC Samples

DESCENDING TEMPERATURE RESISTIVITY WHITEWATER VALLEY LIFAC SAMPLES

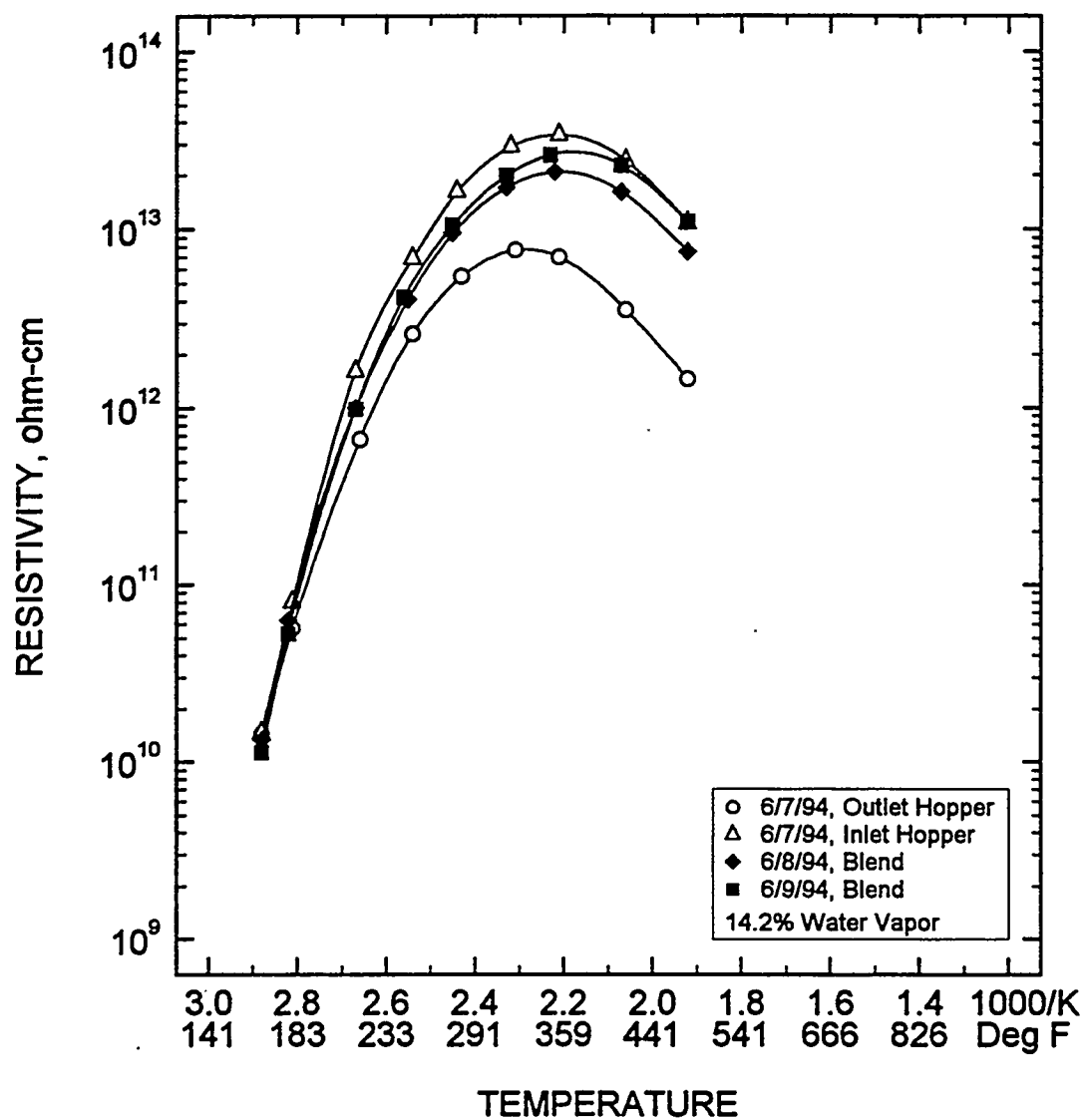


Figure 5
Descending-Temperature Resistivity Measurement on LIFAC
Samples

COMPARISON OF LIFAC DUST RESISTIVITY OBTAINED WITH SEVERAL TECHNIQUES

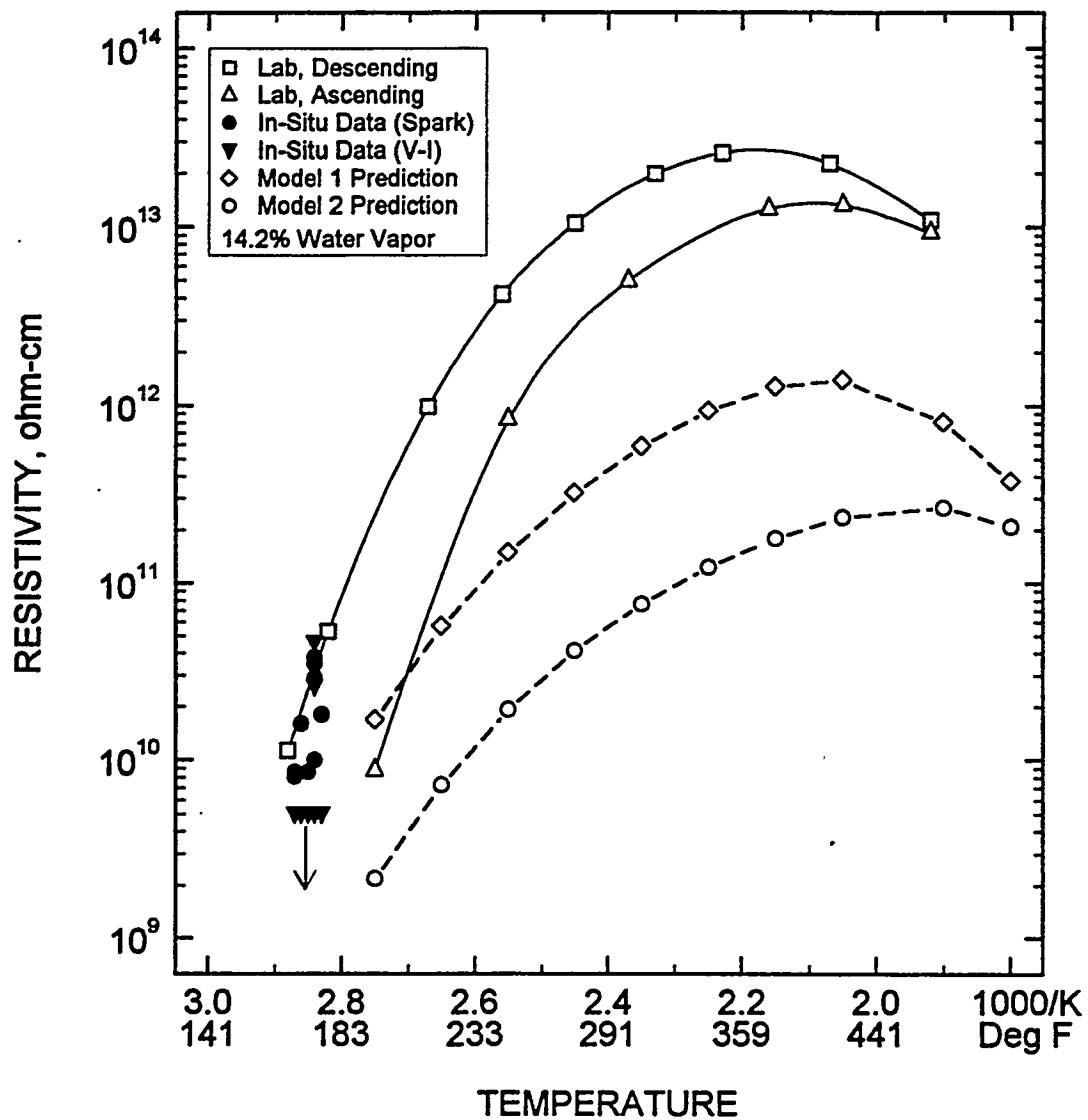


Figure 6
Comparison of LIFAC Dust Resistivity Obtained with Several Techniques

ESP ELECTRICAL CHARACTERISTICS WHITEWATER VALLEY LIFAC TEST

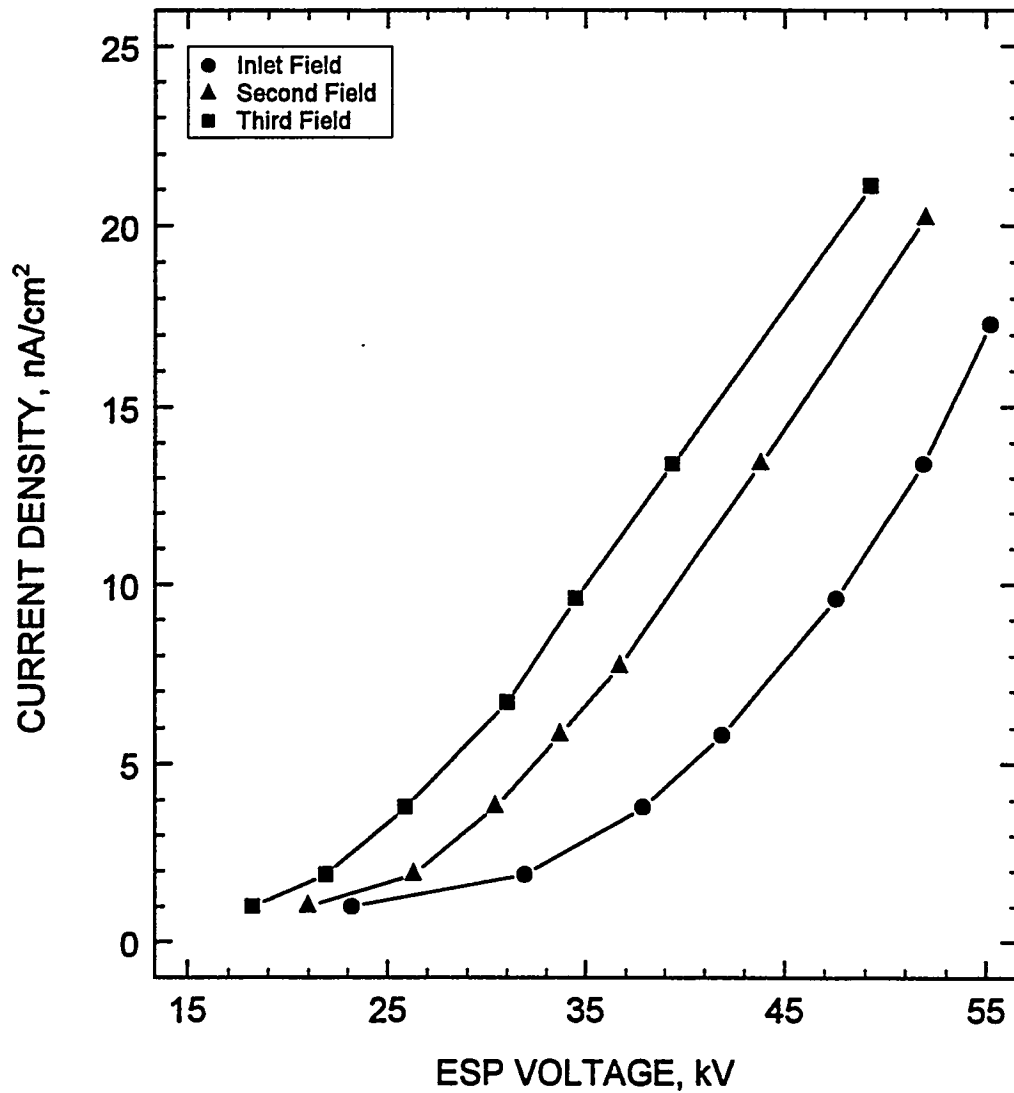


Figure 7
Whitewater Valley Unit 2 ESP Electrical Characteristics During LIFAC

COMPARISON OF ESP OPERATION WITH LIFAC TO RESISTIVITY/CURRENT DENSITY CORRELATION

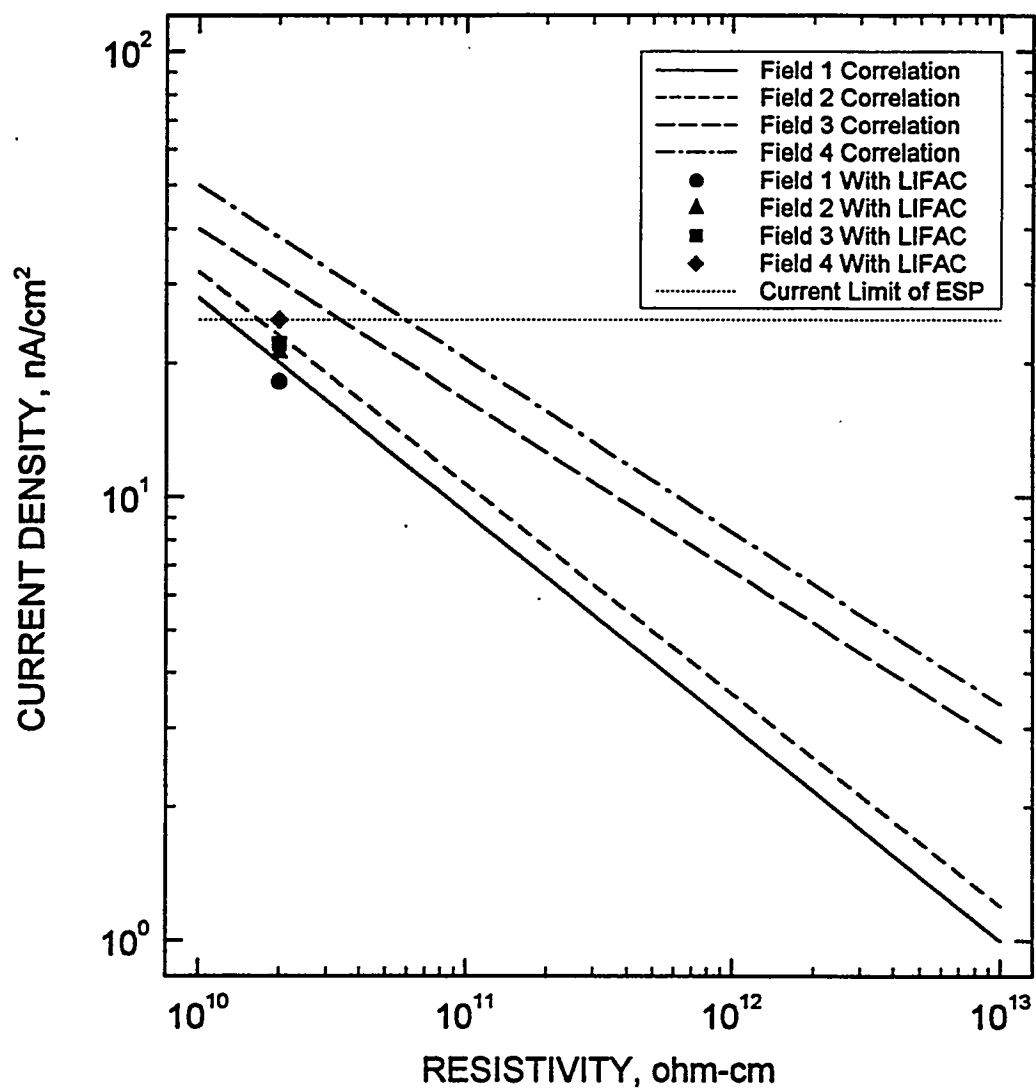


Figure 8
Comparison of ESP Operation with LIFAC to Typical Correlation
Between Resistivity and Current Density

MEASURED AND MODEL PREDICTED EMISSIONS WHITEWATER VALLEY UNIT 2 ESP WITH LIFAC

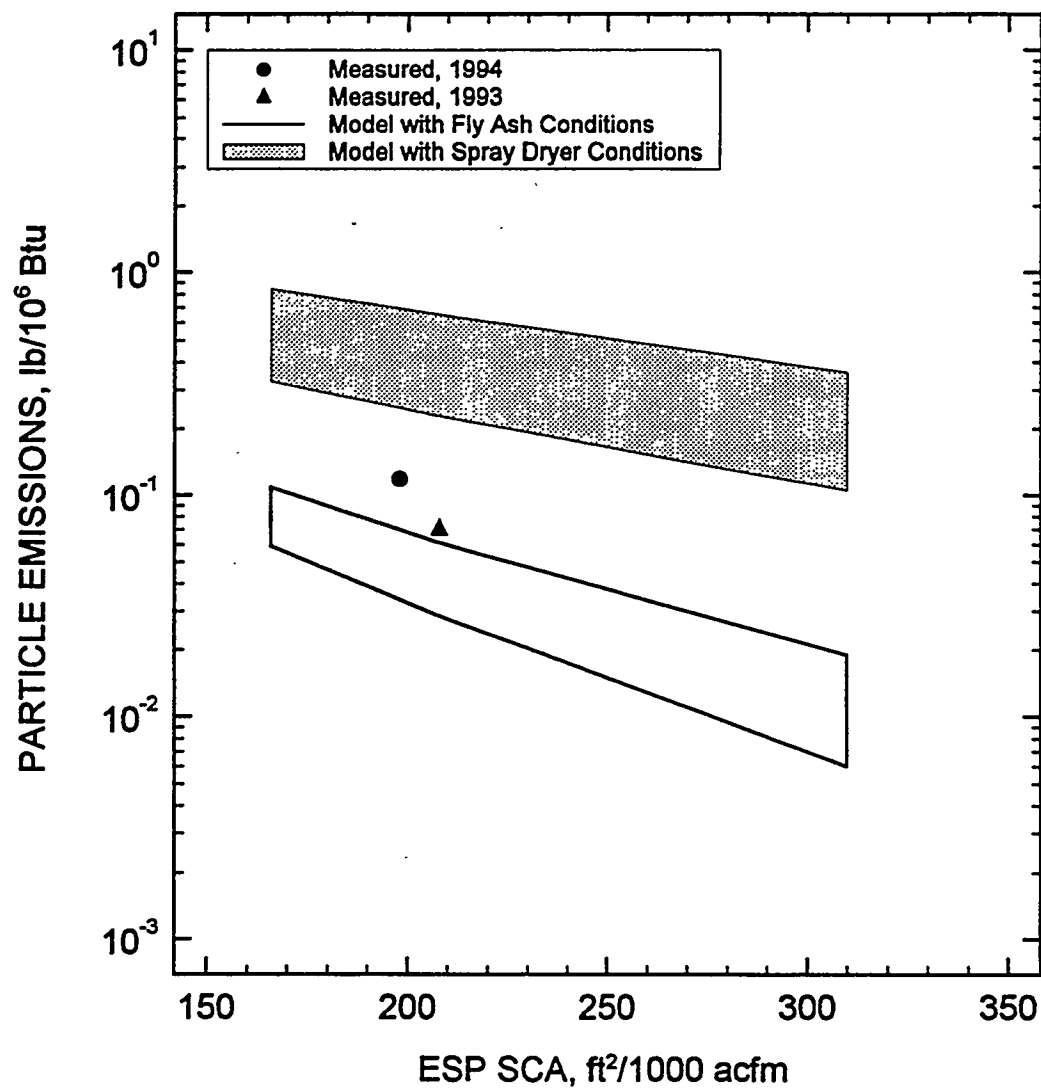


Figure 10
Comparison of Measured and Modeled ESP Emissions During LIFAC

MEASURED AND MODEL PREDICTED BASELINE
EMISSIONS FOR WHITEWATER VALLEY 2 ESP
(Adjusted ESP Voltages)

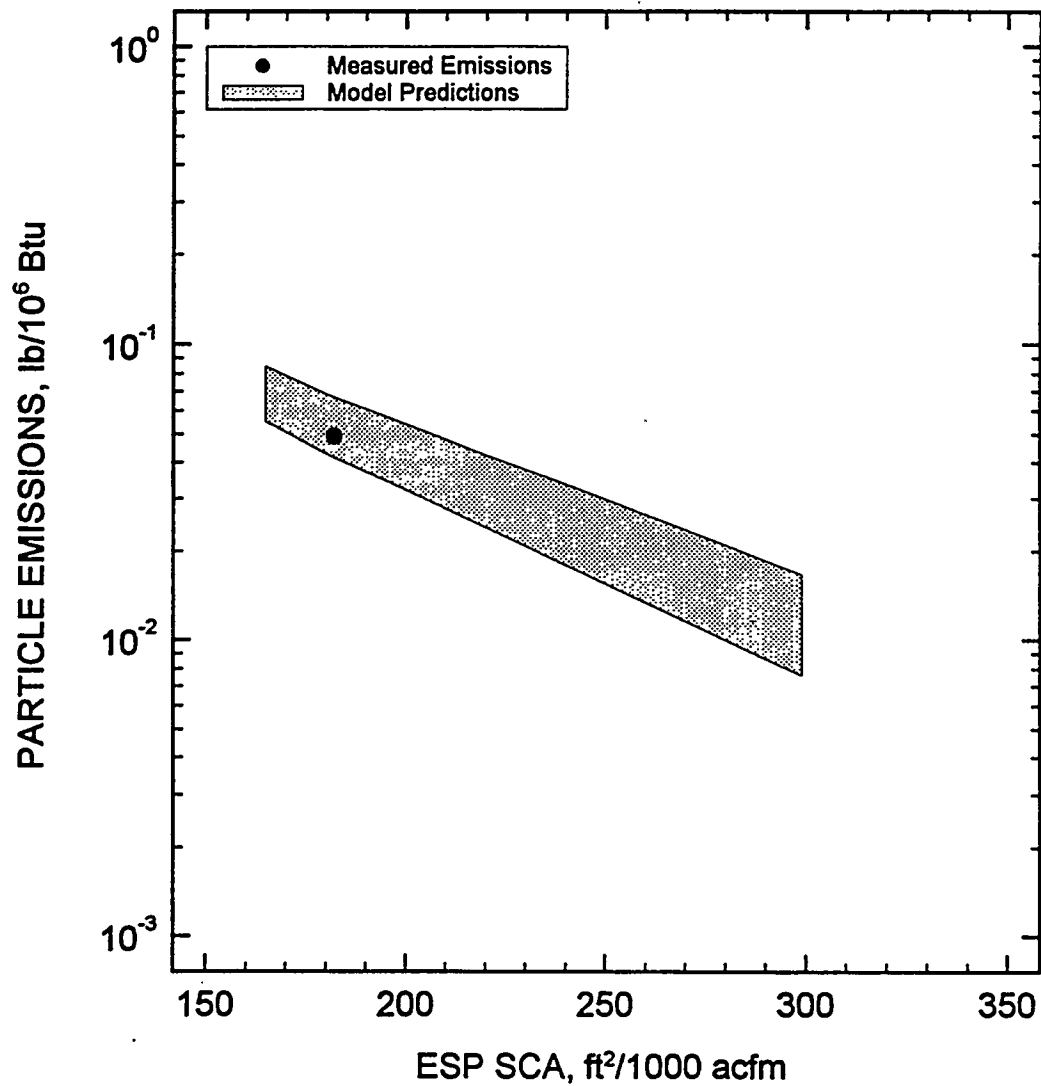


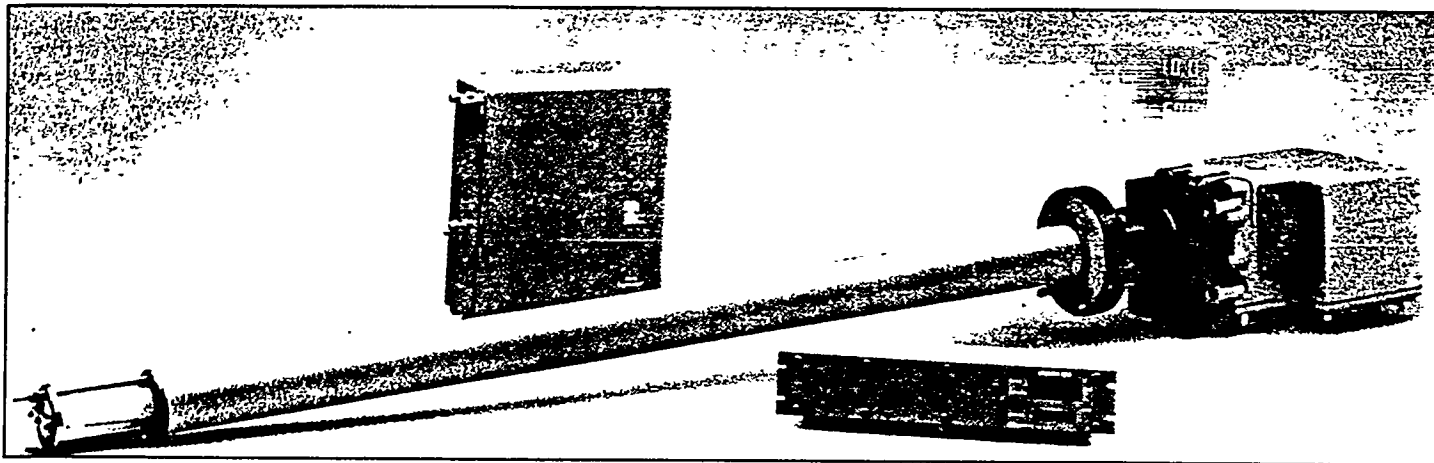
Figure 9
Comparison of Measured and Modeled Baseline ESP Emissions



LEAR SIEGLER
MEASUREMENT CONTROLS
CORPORATION

SM8100A

Microprocessor-Based Process Gas Analyzer



Ideal for Emissions Monitoring and Process Control

The SM8100A combines the latest in microprocessor-based electronics with a rugged in situ design, for a revolutionary approach to monitoring SO₂ and NO concentrations in industrial process emissions. Using a unique second-derivative spectroscopic measurement technique, the SM8100A measures a narrowband absorption of ultraviolet energy by SO₂ and NO molecules. Unlike some measurement techniques, this method does not require hazardous gases for reference or calibration, sample conditioning, pumps, or plumbing which can leak or cause the sample to change characteristics.

The SM8100A works in conjunction with Measurement Controls' UNICON 700 Universal Control Unit. The UNICON 700 is an extremely compact microprocessor-based control unit, designed for multiple monitoring requirements. It provides a series of self-diagnostics and calibration checks that allow the SM8100A to be easily maintained by plant personnel.

The SM8100A features a choice of calibration cross-checks, including AUTOMATIC DYNAMIC CALIBRATION which enables the system to be verified at the same temperature and pressure as the flue gas being measured, without requiring the operator to remove the instrument or climb the stack. Due to its capability to operate with gases having high water vapor content, high particulate loading and temperatures up to 800°F (426°C), the SM8100A is ideally suited to a variety of applications.

FEATURES

- **ACCURACY** — Superior accuracy is provided by a narrowband second-derivative spectroscopic measurement technique. All calibration cross-checks are related to a true zero, which is generated by flowing instrument air into the measurement cavity.
- **LOW MAINTENANCE** — With a time-tested ceramic diffuser, rugged design, and minimal electronics on the stack up to six months of reliable, maintenance-free operation is typical.
- **SPLIT-RANGE OPERATION** — Two independent gain adjustments allow the measurement range of SO₂ to be lower than the measurement range of NO.
- **CALIBRATION VERIFICATION** — Unequaled integrity is achieved through span cell checks or dynamic in situ calibrations.
- **CONTINUOUSLY COMPENSATED OUTPUTS** — SO₂ and NO outputs are continuously compensated for both the spectral and ideal gas law effects of measurement gas temperature. Outputs are corrected to standard temperature and pressure.
- **ADAPTABLE** — Ideally suited to a variety of applications, including multiple monitoring requirements.
- **INEXPENSIVE INSTALLATION** — Digital data is transmitted via two twisted, shielded pairs of wires, insuring low loss, over greater distances, without noise interferences.
- **CYLINDER GAS AUDITS** — Provide easy traceability to known standards to greatly reduce the effort and cost of U.S. EPA certification and periodic quality assurance audits.

General Description

SYSTEM COMPONENTS

IN SITU PROBE — The SM8100A's unique probe permits in situ gas measurement without any sample preparation or conditioning. The probe consists of a stainless steel tube, which includes a gas temperature sensor and gas measurement cavity (at its tip). The optical pathlength of the measurement cavity is precisely defined by a stationary quartz window and retroreflector assembly. As the gases diffuse through the measurement cavity, the ultraviolet absorption characteristics of the gases present, including SO₂ and NO, are imparted to the measurement beam.

Optical contamination is avoided by encasing the measurement cavity in a porous, nonreactive, ceramic diffuser. This element permits the gaseous components to diffuse into the measurement cavity, while blocking particulate matter. Clogging is prevented by an aerodynamic deflector that keeps particulate from accumulating on the sides of the diffuser.

This porous diffuser concept has been tested in thousands of industrial installations and has proved to provide extreme accuracy, high reliability, and low maintenance.

JUNCTION BOX ASSEMBLY — Mounted beneath the transceiver, the junction box assembly acts as a communication link between the UNICON 700 and the SM8100A. Analog signals are converted to digital data and transmitted to the UNICON 700 via an RS422 digital transmission link. The junction box, which is continuously purged with instrument air, contains gauges to regulate gas flow during calibrations. It also includes provision for an auxiliary 4–20 mA input from an oxygen monitor or other source, plus controls for fault indications, maintenance functions, system verification, and dynamic calibration.

UNICON 700 — The UNICON 700 is a compact, microprocessor-based control unit that continually monitors critical components, provides warnings for scheduled maintenance, and performs programmed calculations.

PRINCIPLE OF OPERATION

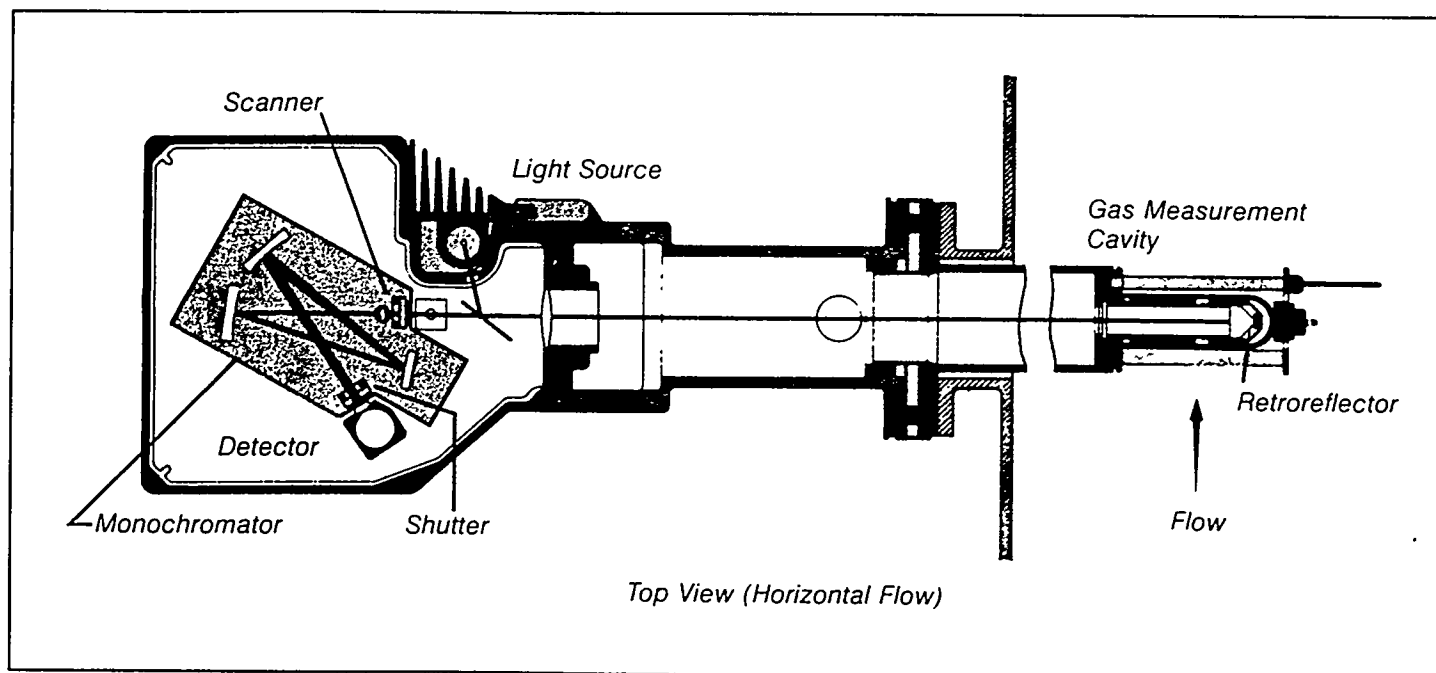
The SM8100A measures a narrowband absorption of ultraviolet radiation that is characteristic of and specific to SO₂ and NO molecules. Other gas monitors, using forms of **direct** absorption spectroscopy, encounter interference problems from particulate, moisture and other gases present in the measurement spectrum. These interferants **do not** affect the SM8100A's second-derivative measurement technique since the instrument is detecting and measuring the curvature, or second derivative, of the narrow absorption band. This gives the SM8100A a high degree of specificity.

Ultraviolet light from a deuterium source in the transceiver is projected through a gas measurement cavity at the end of the probe. A probe-mounted retroreflector returns the measurement beam to the transceiver where a tuned monochromator separates the light into discrete spectral bands. Dual exit slits on the monochromator allow two separate wavelengths, one corresponding to SO₂ and the other to NO, to impinge on the detector.

The wavelength of each of these two monochromatic beams is modulated with respect to time by a rotating quartz window scanner. As a result, the light reaching the detector is modulated across two narrow wavelength regions, coinciding with the desired SO₂ and NO absorption bands. This allows the second-derivative signal to be measured directly with substantial enhancement of the signal-to-noise ratio. The modulated light is then converted by a photomultiplier tube to an electrical signal.

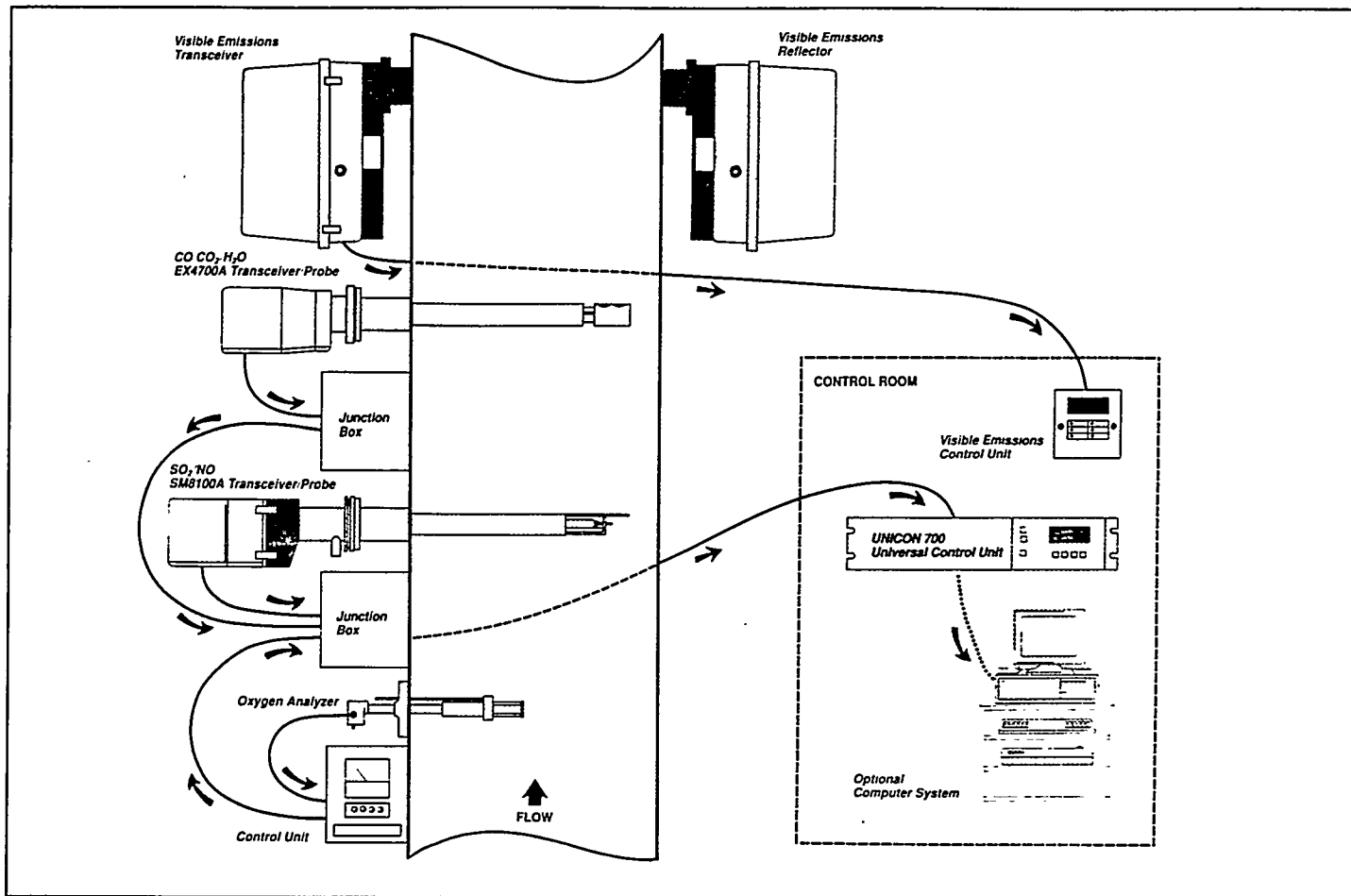
CALIBRATION

Two calibration cross-checks are possible with the SM8100A; both can be performed without removing the instrument from the process. Each is related to a true zero, generated by flowing instrument air into the cavity. All calibration values are available, free of interference from background gas concentration measurements.



SM8100A Optical System

General Description



Continuous Emissions Monitoring Systems

- **AUTOMATIC/MANUAL** — Self-calibration (including auto/zero correction, span checks and auto/span correction) can be initiated automatically at operator-selected intervals, ranging from one to 24 hours, or manually at any time. Span checks are performed using span cells, located inside the SM8100A transceiver. Zero checks use instrument air.
- **DYNAMIC** — By simply pushing a button on the front panel of the UNICON 700 or by a scheduled automatic calibration, a known gas concentration can be injected into the measurement cavity at process temperature and pressure to check the same optics used in normal gas measurement. By feeding a known gas concentration into a fitting in the junction box, the gas flows through a tube and is exhausted inside the ceramic filter into the measurement cavity. The slight positive pressure created within the filter precludes process gas diffusion into the filter.

MEASUREMENT RANGES

Different optical measurement cavity lengths are available for the SM8100A to accommodate a wide range of gas concentrations. The cavity is selected to accommodate the highest concentration of either of the gases measured.

The UNICON 700 allows strip chart recorder or data acquisition system analog outputs to be scaled for any integer value

between 25 and 75,000 ppm (7.5%) for SO₂ or between 75 and 75,000 ppm (7.5%) for NO as long as that value is within the optical full scale range.

CONTINUOUS EMISSIONS MONITORING

The SM8100A can be used in conjunction with other instruments to provide continuous emissions monitoring. For example, the SM8100A can be combined with an opacity monitor, an oxygen or CO/CO₂ analyzer, and the UNICON 700. A combination system provides continuous outputs for opacity, pollutant concentrations, excess air levels, temperature, total emission rates, and parts per million Btu. The measurement/calculations can then, depending on the application, be routed to a printer, Measurement Controls' data acquisition and reporting system or other computerized system.

TOTAL PRODUCT SUPPORT

The SM8100A is backed by Measurement Controls' Total Product Support Program of maintenance plans, training, on-site service, spare parts, and factory repair. Measurement Controls also provides field certification testing services to meet U.S. EPA requirements. For any assistance, call toll free (outside Colorado) 1-800-422-1499.

SM8100A Specifications

SYSTEM MEASUREMENT ACCURACY

Measurement outputs corresponding to SO₂ and NO concentrations are within the following U.S. EPA performance specifications, as defined in the October, 1975 *Federal Register*, 40 CFR 60, Appendix B.

Calibration Error: Within 5% of calibration gas value for values greater than 30% of maximum measurement range

Zero Drift (2-hours): Within 2% of full scale (½% typical)

Zero Drift (24-hours): Within 2% of full scale (½% typical)

Calibration Drift (2-hours): Within 2% of full scale

Calibration Drift (24-hours): Within 2.5% of full scale

Response Time: Less than 4 minutes

Operational Period: 3–6 months typical

Accuracy: Within 20% of U.S. EPA reference method value in typical application where measurement values are at least 30% of the maximum measurement range. Guaranteed performance is available at lower measurement level. Consult factory for special application requirements.

The above specifications include the typical effects of optical contamination, lamp degradation, opacity and other gaseous compounds in process gas.

CALIBRATION

Automatic, on stack, zero and span calibration at selectable intervals to 24 hours, with manual activation at any time.

MEASUREMENT RANGES

Measurement cavities are selectable to provide optical scaling for maximum concentrations of 3,000, 1,500, 750, 500, 375, and 208 ppm. Special configurations are available for ranges of 75,000 (7.5%), 12,000 (1.2%), 6,000, 1,000, and 75 ppm. Consult factory for other ranges.

OPERATING TEMPERATURE

Instrument Ambient: -35° to +60°C (-30° to +140°F)

Control Unit Ambient: +5° to +38°C (+40° to +100°F)

Process Gas: Corrected for temperatures of 52° to 426°C (125° to 800°F). Consult factory for higher temperatures.

Process Gas Pressure: Corrected for a fixed nominal value, typically within 20 to 40 inches of mercury. Consult factory for higher pressures.

OPTICAL SYSTEM

Light Source: Deuterium lamp, hollow cathode discharge, typical lifetime up to six months.

Spectral Bands: SO₂ monitored at 218.5 nm; NO monitored at 226.5 nm.

PHYSICAL

Transceiver (l x w x h): 38.1 x 30.5 x 25.4 cm (15 x 12 x 10 in); 22.7 kg (50 lbs)

Junction Box (w x h x d): 30.5 x 35.6 x 15.2 cm (12 x 14 x 6 in); 15 kg (33 lbs)

Probe Assembly: 8.9 cm (3.5 in) OD x 1.8 m (6 ft) overall length with 30.5l x 19.1w x 22.9h cm (12 x 7.5 x 9 in) adapter flange; standard; 13.6 kg (30 lbs)

UTILITY REQUIREMENTS

Transceiver/Junction Box: 115/220/240 VAC ±10%, 50/60 Hz, 220 watts nominal, 500 watts max.

Control Unit: 115/220/240 VAC ±10%, 50/60 Hz, 30 watts nominal, 50 watts max.

Instrument Air: For junction box and transceiver purge/transceiver calibration 6/40 SCFH

CONSTRUCTION

Probe: 316L stainless steel. Other materials available for special applications.

Transceiver: Cast aluminum alloy

Weatherproof Protective Housing Option: Factory-supplied housing hinges to top of mounting plate; lock-open/lock-closed mechanism; (l x w x h) 80 x 50.8 x 45.7 cm (31.5 x 20 x 18 in); 5.4 kg (12 lbs) plus 3.6 kg (8 lbs) for mounting plate

CONTROL UNIT/UNICON 700

Physical: 48.3 cm (19 in) rack mount; 8.9 cm (3.5 in) high, 30.5 cm (12 in) deep; 4.5 kg (10 lbs)

Outputs: Four (0–20 mA or 4–20 mA grounded current loop) or eight (4–20 mA) user-assigned recorder outputs. Full scale current loop output, user-assigned, to any value between zero and maximum concentration as determined by the measurement cavity size. External current loop isolators are optional. Process temperature signal linear with process gas temperatures from 52° to 426°C (125° to 800°F). Optional RS232 available.

Junction Box: Provides RS422 communication link between the transceiver and UNICON 700 via a single 22 AWG cable containing two individually twisted, shielded pairs. Accepts one additional 4–20 mA input for transmission to UNICON 700 over RS422.

INSTALLATION INTERFACES

Mounting Flanges: Factory-supplied mounting flange is welded to pipe barrel for customer installation: 10.2 cm (4 in) pipe barrel cut to length by factory for standard application. Larger flanges required for wet scrubber FGDS and other wet gas applications. Transceiver unit attaches to flange with four factory-supplied 0.95 cm (¾ in) N.C. bolts.

Mounting Plate: Required for optional weatherproof housing. Also provides shield to minimize transfer of radiated energy between mounting wall and transceiver.

Alignment: In situ probe is factory aligned. Test points and alignment procedures are provided for maintenance needs.

MADE IN THE U.S.A.

Lear Siegler Measurement Controls reserves the right to make changes in construction, design, specifications, and/or prices without prior notice.

FOR MORE INFORMATION

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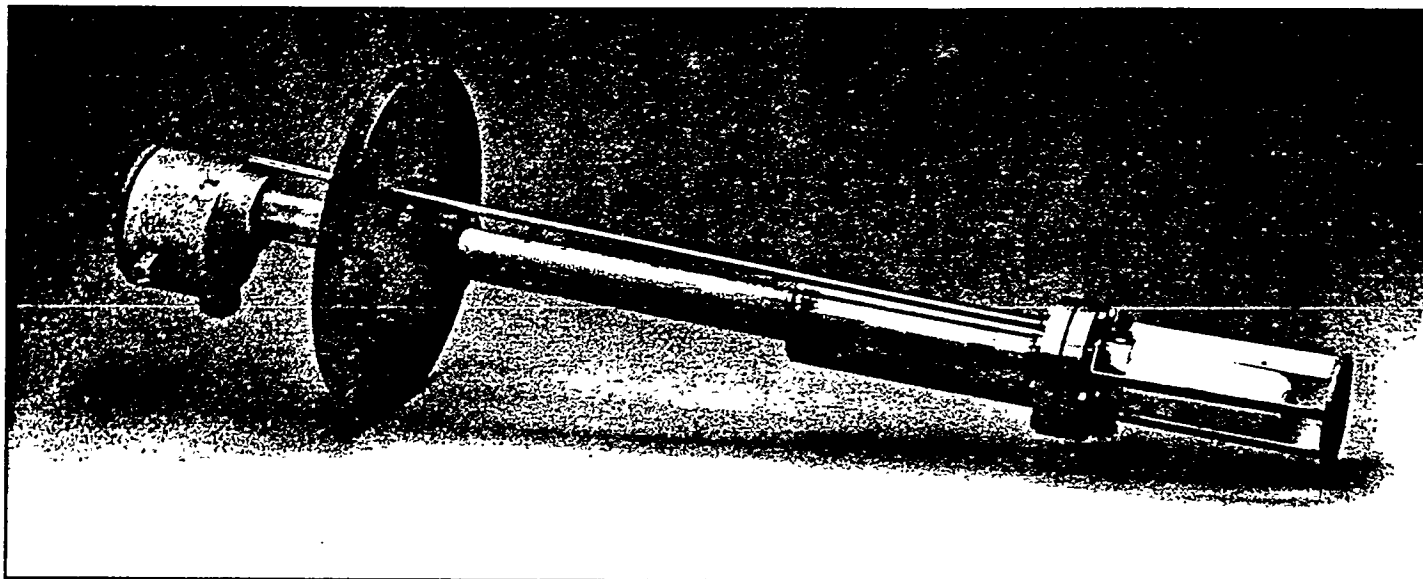
MEASUREMENT CONTROLS CORPORATION



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MEASUREMENT CONTROLS
CORPORATION

DYNATRON® 401

In Situ Oxygen Monitoring System



The 401 provides accurate measurement of oxygen in a variety of industrial applications.

The Dynatron® 401 Oxygen Monitoring System uses in situ technology and a solid-state zirconium oxide fuel cell sensor to provide accurate, reliable, and rapid oxygen measurement. The 401 is ideal for a variety of applications, including oil, coal, and gas-fired boilers, packaged boilers, incinerators, furnaces, dryers, process heaters, kilns, and other industrial combustion efficiency monitoring applications where a basic, economical oxygen monitor is required.

In situ oxygen analysis is the preferred method when rapid response, analytical accuracy, and low maintenance are the prime considerations. The 401 takes measurements at process gas temperatures that are at or above the dew point of the process gas, so sample conditioning systems and their associated maintenance are not required.

Typically, the 401 can pay for itself in less than a year by providing the feedback that enables an operator to lower excess air, improve combustion, reduce fuel consumption, and minimize air pollution.

FEATURES

- **ACCURATE** — At 2% oxygen concentration, the 401 is accurate within $\pm 0.1\%$ oxygen. System sensitivity and measurement accuracy actually increase with lower oxygen concentrations.
- **STABLE** — The oxygen sensor cell can operate for months without recalibration. It is insensitive to changes in process gas flow or temperature and is independent of fuel type.

- **LOW MAINTENANCE** — Long-term, continuous operation with a minimum amount of operator intervention is possible because the oxygen sensor is not affected by dirt accumulation as long as a portion of the platinum electrode is exposed.
- **RELIABLE** — Measurements are made on a "wet, total sample basis" using the well-known Nernst equation. Zirconium oxide fuel cell measurement of oxygen is currently used in thousands of installations worldwide.

SYSTEM COMPONENTS

PROBE — The 401 probe is available in different lengths and can withstand process temperatures up to 1400°F. It can be serviced in the field and is easily disassembled. Any component can be quickly replaced, including the zirconium oxide sensor cell, cell heater, and RTD temperature sensor.

The zirconium oxide sensor is located at the probe tip, encased in a ceramic diffuser. A particulate deflector protects the diffuser from erosion and creates a tangential flow across the sides of the diffuser. Two airfoils at 120° angles to the deflector divert heavy particulate, while rotating the gas sample to the sheltered downstream side of the diffuser. The flow of gas, combined with the abrasive nature of the gas, creates a self-cleaning effect that helps to keep the sides of the diffuser free from particulate buildup.

CONTROL UNIT — The control unit provides an analog output that can be interfaced to a remote strip chart recorder or process control system. It is housed in a rugged, wall-mount NEMA 12 enclosure for protection against severe environmental conditions.

Dynatron® 401 Specifications

The 401 meets or exceeds all U.S. EPA requirements as published in 40 CFR 60, Appendix B, Performance Specification 3.

SYSTEM MEASUREMENT ACCURACY

Calibration Error: Less than 0.5% O₂ in mid and high range

Zero and Calibration Drift (24 hours): Less than 0.5% O₂

Relative Accuracy: Better than $\pm 0.5\%$ O₂

Nominal Accuracy: $\pm 5\%$ of reading, at 2% O₂ the reading is accurate to $\pm 0.1\%$ O₂

With In Situ Calibration Gas: Better than $\pm 2\%$ of reading

Response Time: Amplifier <1 second
Cell <200 milliseconds
System (63%) <18 seconds
System (95%) <30 seconds

CALIBRATION

Manual calibration package, stack-mounted in a modified NEMA 12 enclosure, includes flow indicators for reference and calibration gas, pressure regulator for reference gas, manual zero/span selector switch, and associated fittings. Manual zero/span checks can be initiated at the stack. Automatic calibration package is available only when the 401 is used with a UNICON 700 Universal Control Unit, where the UNICON 700 controls zero/span calibration cycles.

OUTPUTS

4–20 mA linear analog output channel proportional to 0 to 25% oxygen, capable of driving a 1200 ohm load (grounded reference).

OPERATING TEMPERATURES

Instrument Ambient (at probe): -34° to +60°C (-30° to +140°F)

Control Unit Ambient: 0° to +52°C (+32° to +125°F)

Process Gas: Up to 760°C (1400°F); consult factory for higher temperatures.

PHYSICAL

Control Unit (h x w x d): 27.3 x 25.4 x 15.19 cm (10.75 x 10 x 6.25 in); 10 kg (22 lbs)

Probe: 10.2 cm (4 in) 150# ASA flange, 22.9 cm (9 in) OD, selectable lengths of 45.7 cm (18 in), 11.8 kg (26 lbs); 91.4 cm (36 in); 13.6 kg (30 lbs); 1.83 m (72 in), 15.4 kg (34 lbs). Select probe lengths of 30% stack diameter minimum. Consult factory for custom lengths.

UTILITY REQUIREMENTS

Control Unit: 115/230 VAC, 50/60 Hz., 1 PH $\pm 10\%$, 1 amp

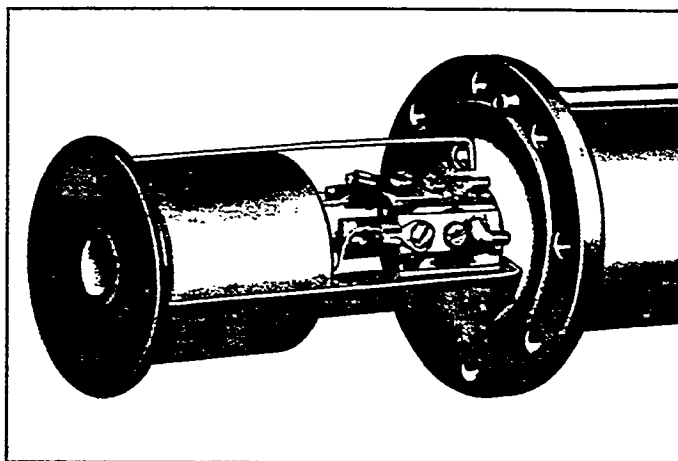
Reference Gas: Clean dry instrument air, 20.95% O₂, 1 liter/min. $\pm 20\%$

Calibration Gas: Zero check 2% O₂ balance N₂; span check 20.95% O₂ air (10% O₂ optional), 2 liters/min. $\pm 20\%$

CONSTRUCTION

Probe: 316L stainless steel; zirconium oxide cell detector; RTD temperature sensor; 5-micron ceramic probe tip filter

Control Unit Enclosure: Standard NEMA 12 with hinged, gasketed door, wall-mounted



Precision Zirconium Oxide Sensor

INSTALLATION INTERFACES

Probe: 10.2 cm (4 in) 150# ASA mounting flange, 22.9 cm (9 in) OD; 19.1 cm (7.5 in) bolt circle for 1.59 cm (.625 in) diameter bolts for welding to a length of 10.2 cm (4 in) diameter Schedule-40 pipe, required hardware, and mating gasket. 15.2 m (50 ft) maximum distance between probe and control unit, using 3 pair twisted shielded cable, 18 AWG; consult factory for longer distances.

TOTAL PRODUCT SUPPORT

The Dynatron® 401 is backed by a Total Product Support Program of maintenance plans, training, on-site service, parts, and factory repair. For any assistance, call toll free (outside Colorado) 1-800-422-1499.

MADE IN THE U.S.A.

Lear Siegler Measurement Controls Corporation reserves the right to make changes in construction, design, specifications, and/or prices without prior notice.

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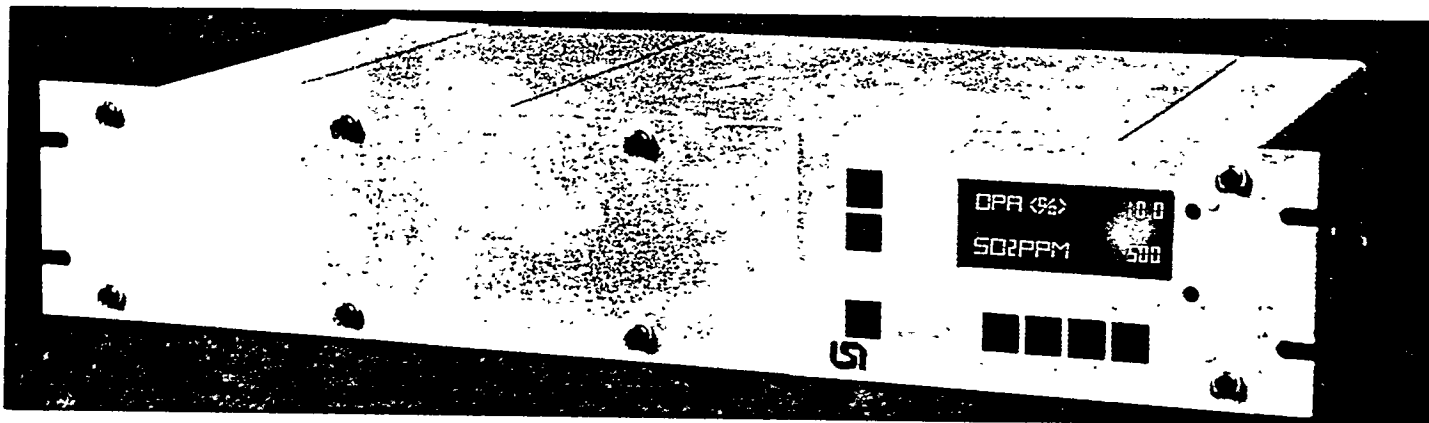
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DYNA401/PL/2/91

Universal Control Unit



Provides remote control and monitoring for up to four stack-mounted analyzers

The UNICON 700 Universal Control Unit is an extremely compact microprocessor-based instrument designed for multiple monitoring requirements. It interfaces with Measurement Controls' stack-mounted instruments and can provide simultaneous remote control and monitoring for up to four analyzers. Depending upon the application, this may include opacity, O₂, SO₂, NO, or several parameters associated with combustion control.

Eliminating the need for expensive instrumentation cable, digital data is transmitted from the stack-mounted instruments to the UNICON 700 via two twisted-shielded pairs of wires. The wires share communication between the UNICON 700 and up to four stack-mounted junction boxes, with each junction box having the provision for an additional auxiliary input. Any input channel remaining after initial installation is readily available for future expansion requirements.

The UNICON 700 features a unique, interactive front panel with a two-line alphanumeric readout which allows the operator to quickly select which items are to be displayed. Choosing from a large list of available measurements and calculations, the lower readout may, for example, be configured to display alarm or status information, with the requested measurement/calculation sharing the upper portion of the display. Select buttons further enable two levels of configuration to be accessed for input of specific application requirements. The first level provides for input of specific application parameters. The second list allows the operator to do such things as resetting alarms or initiating calibrations.

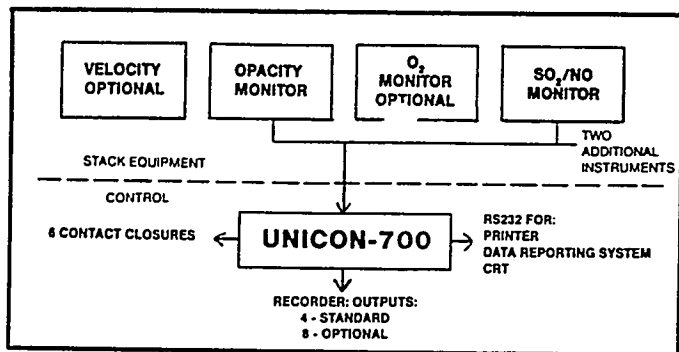
For maximum security, a data "lock" function allows the operator to select and change operational parameters while preventing unauthorized or accidental changes from being made. All configuration data is stored in non-volatile memory to prevent power interruptions from disturbing the setup data.

The UNICON 700 achieves a high level of confidence through a series of self-diagnostics and calibration checks. The microprocessor continually monitors critical components and, should a problem be detected, initiates an error message on the front panel display. It also provides a warning for scheduled maintenance and will immediately identify a malfunctioning card by lighting a red LED indicator. These and other diagnostics allow the system to be easily maintained by plant personnel.

Self-calibration, including auto/zero correction, auto/span checks, and span correction are available for most measurements. Auto span checks are performed through span devices internal to each stack-mounted instrument. Once a dynamic calibration is manually activated, the UNICON 700 automatically corrects the span of each measurement to agree with the value of the gas entered into the setup data. If the required span correction exceeds an allocated percentage of the inserted value, a span error status will be indicated and prior correction will be retained.

Instrument setup allows for the selection of measurement/calculation information, from a list similar to the front panel display, to be routed to any one of the four recorder outputs. An optional RS232 output can, additionally, be configured to accommodate most serial printers.

Unlike other analog or digital control units, the UNICON 700 can meet a variety of complex application requirements. A typical installation may include up to four breech mounted opacity monitors, each with an auxiliary velocity input. Another application may include up to four SO₂/NO measurements with auxiliary O₂ inputs, with the UNICON 700 providing the calculations required to obtain pounds per million BTU on both SO₂ and NO.



Typical compliance application with provision for future expansion

The UNICON 700 can provide remote control and monitoring for up to four instruments. In addition to performing all functions which are available through standard analog or digital control units, the UNICON 700 offers:

OPACITY:

- Number of Units — Four maximum. If less, remaining channels may be used for other instruments.
- Integrator — Standard, 0-60 minute range. Eliminates need for separate integrator required with analog remote control unit.
- Combiner — Provides combiner function for 2, 3 or 4 opacity measurements.

SO₂/NO:

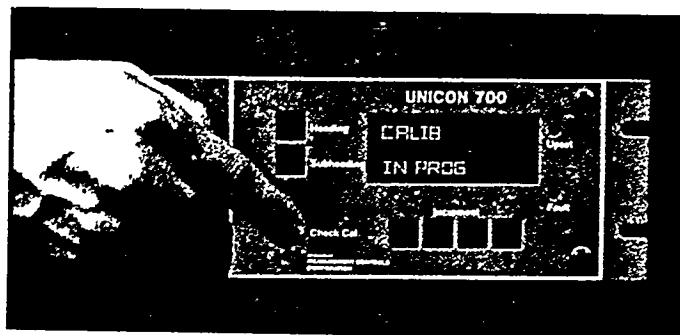
- Number of Units — Four maximum, single or dual gas. If less, remaining channels may be used for other instruments.
- Excess Air — Standard, lb/MBTU calculation using either O₂ or CO₂ (optional) as diluent. Eliminates need for separate excess air card required with analog remote control unit.

CO, CO₂, H₂O:

- Number of Units — Two maximum. If one or two instruments are installed, the remaining two or three channels (respectively) can be used for either opacity and/or SO₂/NO monitoring.

OXYGEN: The O₂ signal does not require a separate junction box. It is transmitted from the stack to the UNICON 700 through an auxiliary channel from a junction box of accompanying instrumentation. Either an opacity, SO₂/NO or CO/CO₂ monitor must interface with the UNICON 700 in order to obtain the O₂ signal.

VELOCITY: The velocity signal is transmitted from the stack to the UNICON 700 via an auxiliary channel from



All instruments calibrated simultaneously

an accompanying opacity, SO₂/NO or CO/CO₂ monitor and does not require a separate junction box.

AUXILIARY INPUTS: Each junction box has the capability to connect a linear 4-20 mA signal from any source. This signal will be transmitted to the UNICON 700 where it will be scaled and displayed, or logged.

SPECIFICATIONS

AMBIENT OPERATING TEMPERATURES: 40-100°F

ANALOG OUTPUTS: Standard configuration includes 4 analog outputs, 4-20 mA (400 ohms maximum); 8 outputs (500 ohms maximum) available as an option. Any parameter measured or calculated by UNICON 700 can be assigned to these outputs.

DIGITAL OUTPUT: Optional RS232 transmits ASCII data in data logger format.

COMPUTER INTERFACE: Offers direct interface with Measurement Controls' Computer System for a variety of data reporting needs.

DATA LOGGER: The RS232 output will drive most serial printers. Any parameter measured or calculated by the UNICON 700 can be assigned to this output. Report format is designated by front panel control.

CONTACT CLOSURE: 6 dry contacts: zero, span, high alarm, low alarm, process control, and fault; 24 VDC maximum at 1 amp.

ZERO/SPAN CORRECTION: Opacity is corrected for zero. SO₂, NO, CO, CO₂, and H₂O are corrected for both zero and span gas.

CALIBRATION: All instruments are calibrated simultaneously, either manually or automatically at operator selected times.

CONFIGURATION: The UNICON 700 will be factory configured for accompanying instrumentation. Information is stored in non-volatile memory, with start-up requiring a minimum of operator intervention. Configuration can be changed for site specific requirements at any time.

INSTALLATION: The UNICON 700 will recognize the instruments that are connected to it by the data that is transmitted from the junction box and automatically process all data. Software for all instruments is resident in the UNICON 700. Additional instruments can be added until all channels are in use.

INTERFACE: Barrier terminal block.

POWER REQUIREMENTS: 25 Watts typical, 90-130 VAC 2 amp; 180-260 VAC 1 amp optional.

PHYSICAL: 19" rack mount; 3½" high; 12" deep; 10 lbs.

Specifications given are for the UNICON 700 only. Please consult individual product brochure for system specifications.

PATENT NO. 4560873

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3.2.2 Connect the probe, insert it into the stack, and sample at a constant rate of 2 lpm (0.071 cfm). Continue sampling until the dry gas meter registers about 30 liters (1.1 ft³) or until visible liquid droplets are carried over from the first impinger to the second. Record temperature, pressure, and dry gas meter readings as required by Figure 4-5.

3.2.3 After collecting the sample, combine the contents of the two impingers and measure the volume to the nearest 0.5 ml.

3.3 Calculations. The calculation method presented is designed to estimate the moisture in the stack gas; therefore, other data, which are only necessary for accurate moisture determinations, are not collected. The following equations adequately estimate the moisture content, for the purpose of determining isokinetic sampling rate settings.

3.3.1 Nomenclature.

$B_{v,m}$ = Approximate proportion, by volume, of water vapor in the gas stream leaving the second impinger, 0.025.

$B_{v,w}$ = Water vapor in the gas stream, proportion by volume.

M_w = Molecular weight of water, 18.0 g/mole (18.0 lb/lb-mole).

P_m = Absolute pressure (for this method, same as barometric pressure) at the dry gas meter.

P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).

R = Ideal gas constant, 0.06236 (mm Hg) (m³)/(g-mole) (°K) for metric units and 21.85 (in. Hg) (ft³)/(lb-mole) (°R) for English units.

T_m = Absolute temperature at meter, °K (°R).

T_{std} = Standard absolute temperature, 293° K (528° R).

V_f = Final volume of impinger contents, ml.

V_i = Initial volume of impinger contents, ml.

V_m = Dry gas volume measured by dry gas meter, dcm (dscf).

$V_{m(dscf)}$ = Dry gas volume measured by dry gas meter, corrected to standard conditions, dscm (dscf).

$V_{w(dscf)}$ = Volume of water vapor condensed, corrected to standard conditions, scm (scf).

ρ_w = Density of water, 0.9982 g/ml (0.002201 lb/ml).

Y = Dry gas meter calibration factor.

3.3.2 Volume of water vapor collected, where:

$$V_{wv} = \frac{(V_f - V_i) \beta_w R T_{std}}{P_{std} M_w}$$

$$= K_1 (V_f - V_i)$$

Equation 4-5

$K_1 = 0.001333 \text{ m}^3/\text{ml}$ for metric units
 $= 0.04707 \text{ ft}^3/\text{ml}$ for English units.

3.3.3 Gas volume.

$$V_{m(stnd)} = V_m \left(\frac{P_m}{P_{std}} \right) \left(\frac{T_{std}}{T_m} \right)$$

$$= K_2 \frac{V_m P_m}{T_m}$$

Equation 4-6

where:

$K_2 = 0.3858 \text{ } ^\circ\text{K}/\text{mm Hg}$ for metric units
 $= 17.64 \text{ } ^\circ\text{R}/\text{in. Hg}$ for English units

3.3.4 Approximate moisture content.

$$B_{v,w} = \frac{V_{wv}}{V_{wv} + V_{m(stnd)}} + B_{v,m}$$

$$= \frac{V_{wv}}{V_{wv} + V_m} + (0.025)$$

Equation 4-7

4. Calibration

4.1 For the reference method, calibrate equipment as specified in the following sections of Method 5: Section 5.3 (metering system); Section 5.5 (temperature gauges); and Section 5.7 (barometer). The recommended leak check of the metering system (Section 5.6 of Method 5) also applies to the reference method. For the approximation method, use the procedures outlined in Section 5.1.1 of Method 6 to calibrate the metering system, and the procedure of Method 5, Section 5.7 to calibrate the barometer.

5. Bibliography

1. Air Pollution Engineering Manual (Second Edition). Danielson, J. A. (ed.). U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, N.C. Publication No. AP-40. 1973.

2. Devorkin, Howard, et al. Air Pollution Source Testing Manual. Air Pollution Control District, Los Angeles, Calif. November, 1963.

3. Methods for Determination of Velocity, Volume Dust and Mist Content of Gases. Western Precipitation Division of Joy Manufacturing Co., Los Angeles, Calif. Bulletin WP-50. 1968.

METHOD 5—DETERMINATION OF PARTICULATE EMISSIONS FROM STATIONARY SOURCES

1. Principle and Applicability

1.1 Principle. Particulate matter is withdrawn isokinetically from the source and collected on a glass fiber filter maintained at a temperature in the range of 120±14° C (248±25° F) or such other temperature as specified by an applicable subpart of the standards or approved by Administrator, U.S. Environmental Protection Agency, for a particular application. The particulate mass, which includes any material that condenses at or above the filtration temperature, is determined gravimetrically after removal of uncombined water.

1.2 Applicability. This method is applicable for the determination of particulate emissions from stationary sources.

2. Apparatus

2.1 Sampling Train. A schematic of the sampling train used in this method is shown in Figure 5-1. Complete construction details are given in APTD-0581 (Citation 2 in Bibliography); commercial models of this train are also available. For changes from APTD-0581 and for allowable modifications of the train shown in Figure 5-1, see the following subsections.

The operating and maintenance procedures for the sampling train are described in APTD-0576 (Citation 3 in Bibliography). Since correct usage is important in obtaining valid results, all users should read APTD-0576 and adopt the operating and maintenance procedures outlined in it, unless otherwise specified herein. The sampling train consists of the following components:

[Appendix A, Method 5]

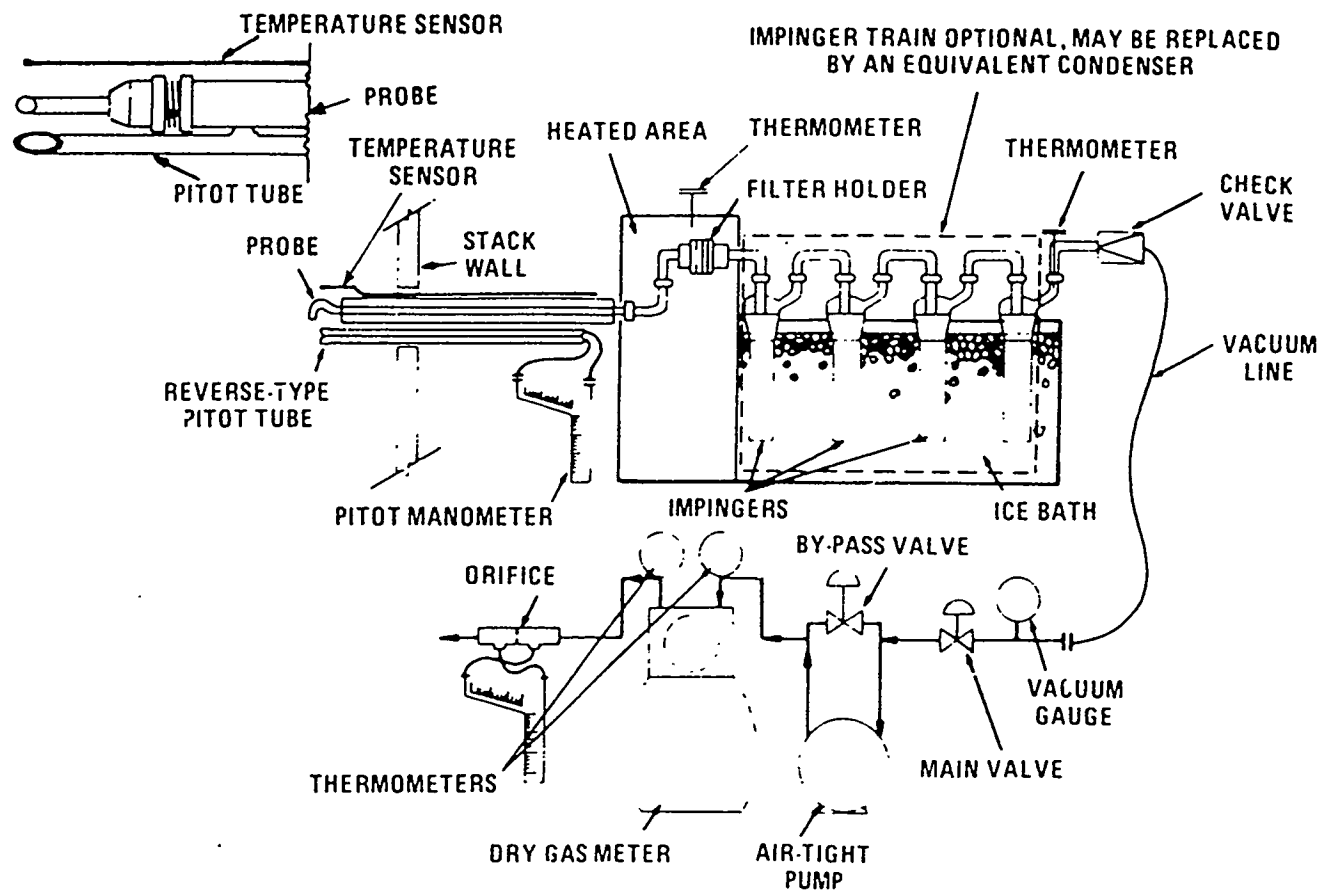


Figure 5-1. Particulate-sampling train

2.1.1 Probe Nozzle. Stainless steel (316) or glass with sharp, tapered leading edge. The angle of taper shall be $\leq 30^\circ$ and the taper shall be on the outside to preserve a constant internal diameter. The probe nozzle shall be of the button-hook or elbow design, unless otherwise specified by the Administrator. If made of stainless steel, the nozzle shall be constructed from seamless tubing; other materials of construction may be used, subject to the approval of the Administrator.

A range of nozzle sizes suitable for isokinetic sampling should be available, e.g., 0.32 to 1.27 cm ($\frac{1}{8}$ to $\frac{1}{2}$ in.)—or larger if higher volume sampling trains are used—inside diameter (ID) nozzles in increments of 0.16 cm ($\frac{1}{16}$ in.). Each nozzle shall be calibrated according to the procedures outlined in Section 5.

[2.1.1 amended by 52 FR 34639, September 14, 1987]

2.1.2 Probe Liner. Borosilicate or quartz glass tubing with a heating system capable of maintaining a gas temperature at the exit end during sampling of $120 \pm 14^\circ\text{C}$ ($248 \pm 25^\circ\text{F}$), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator for a particular application. (The tester may opt to operate the equipment at a temperature lower than that specified.) Since the actual temperature at the outlet of the probe is not usually monitored during sampling, probes constructed according to APTD-0581 and utilizing the calibration curves of APTD-0576 (or calibrated according to the procedure outlined in APTD-0576) will be considered acceptable.

Either borosilicate or quartz glass probe liners may be used for stack temperatures up to about 480°C (900°F) quartz liners shall be used for temperatures between 480 and 900°C (900 and $1,650^\circ\text{F}$). Both types of liners may be used at higher temperatures than specified for short periods of time, subject to the approval of the Administrator. The softening temperature for borosilicate

is 820°C ($1,508^\circ\text{F}$), and for quartz it is $1,500^\circ\text{C}$ ($2,732^\circ\text{F}$).

Whenever practical, every effort should be made to use borosilicate or quartz glass probe liners. Alternatively, metal liners (e.g., 316 stainless steel, Incoloy 825,² or other corrosion resistant metals) made of seamless tubing may be used, subject to the approval of the Administrator.

2.1.3 Pitot Tube. Type S, as described in Section 2.1 of Method 2, or other device approved by the Administrator. The pitot tube shall be attached to the probe (as shown in Figure 5-1) to allow constant monitoring of the stack gas velocity. The impact (high pressure) opening plane of the pitot tube shall be even with or above the nozzle entry plane (see Method 2, Figure 2-6b) during

² Mention of trade names or specific product does not constitute endorsement by the Environmental Protection Agency.

[Appendix A, Method 5]

sampling. The Type S pitot tube assembly shall have a known coefficient, determined as outlined in Section 4 of Method 2.

2.1.4 Differential Pressure Gauge. Inclined manometer or equivalent device (two), as described in Section 2.2 of Method 2. One manometer shall be used or velocity head (Δp) readings, and the other, for orifice differential pressure readings.

2.1.5 Filter Holder. Borosilicate glass, with a glass frit filter support and a silicone rubber gasket. Other materials of construction (e.g., stainless steel, Teflon, Viton) may be used, subject to approval of the Administrator. The holder design shall provide a positive seal against leakage from the outside or around the filter. The holder shall be attached immediately at the outlet of the probe (or cyclone, if used).

2.1.6 Filter Heating System. Any heating system capable of maintaining a temperature around the filter holder during sampling of $120 \pm 14^\circ \text{C}$ ($248 \pm 25^\circ \text{F}$), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator for a particular application. Alternatively, the tester may opt to operate the equipment at a temperature lower than that specified. A temperature gauge capable of measuring temperature to within 3°C (5.4°F) shall be installed so that the temperature around the filter holder can be regulated and monitored during sampling. Heating systems other than the one shown in APTD-0581 may be used.

2.1.7 Condenser. The following system shall be used to determine the stack gas moisture content: Four impingers connected in series with leak-free ground glass fittings or any similar leak-free non-contaminating fittings. The first, third, and fourth impingers shall be of the Greenburg-Smith design, modified by replacing the tip with 1.3 cm ($\frac{1}{2}$ in.) ID glass tube extending to about 1.3 cm ($\frac{1}{2}$ in.) from the bottom of the flask. The second impinger shall be of the Greenburg-Smith design with the standard tip. Modifications (e.g., using flexible connections between the impingers, using materials other than glass, or using flexible vacuum lines to connect the filter holder to the condenser) may be used, subject to the approval of the Administrator. The first and second impingers shall contain known quantities of water (Section 4.1.3), the third shall be empty, and the fourth shall contain a known weight of silica gel, or equivalent desiccant. A thermometer, capable of measuring temperature to within 1°C (2°F) shall be placed at the outlet of the fourth impinger for monitoring purposes.

Alternatively, any system that cools the sample gas stream and allows measurement of the water condensed and moisture leaving the condenser, each to within 1 ml or 1 g may be used, subject to the approval of the Administrator. Acceptable means are to measure the condensed water either gravimetrically or volumetrically and to measure the moisture leaving the condenser by: (1) monitoring the temperature and pressure at the exit of the condenser and using Dalton's

law of partial pressures; or (2) passing the sample has stream through a tared silica gel (or equivalent desiccant) trap with exit gases kept below 20°C (68°F) and determining the weight gain.

If means other than silica gel are used to determine the amount of moisture leaving the condenser, it is recommended that silica gel (or equivalent) still be used between the condenser system and pump to prevent moisture condensation in the pump and metering devices and to avoid the need to make corrections for moisture in the metered volume.

NOTE: If a determination of the particulate matter collected in the impingers is desired in addition to moisture content, the impinger system described above shall be used, without modification. Individual States or control agencies requiring this information shall be contacted as to the sample recovery and analysis of the impinger contents.

2.1.8 Metering System. Vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 3°C (5.4°F), dry gas meter capable of measuring volume to within 2 percent, and related equipment, as shown in Figure 5-1. Other metering systems capable of maintaining sampling rates within 10 percent of isokinetic and of determining sample volumes to within 2 percent may be used, subject to the approval of the Administrator. When the metering system is used in conjunction with a pitot tube, the system shall enable checks of isokinetic rates.

Sampling trains utilizing metering systems designed for higher flow rates than that described in APTD-0581 or APDT-0576 may be used provided that the specifications of this method are met.

2.1.9 Barometer, Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg). In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase or vice versa for elevation decrease.

2.1.10 Gas Density Determination Equipment. Temperature sensor and pressure gauge, as described in Sections 2.3 and 2.4 of Method 2, and gas analyzer, if necessary, as described in Method 3. The temperature sensor shall, preferably, be permanently attached to the pitot tube or sampling probe in a fixed configuration, such that the tip of the sensor extends beyond the leading edge of the probe sheath and does not touch any metal. Alternatively, the sensor may be attached just prior to use in the field. Note, however, that if the temperature sensor is attached in the field, the sensor must be placed in an interference-free arrangement

with respect to the Type S pitot tube openings (see Method 2, Figure 2-7). As a second alternative, if a difference of not more than 1 percent in the average velocity measurement is to be introduced, the temperature gauge need not be attached to the probe or pitot tube. (This alternative is subject to the approval of the Administrator.)

2.2 Sample Recovery. The following items are needed.

2.2.1 Probe-Liner and Probe-Nozzle Brushes. Nylon bristle brushes with stainless steel wire handles. The probe brush shall have extensions (at least as long as the probe) of stainless steel, Nylon, Teflon, or similarly inert material. The brushes shall be properly sized and shaped to brush out the probe liner and nozzle.

2.2.2 Wash Bottles—Two. Glass wash bottles are recommended; polyethylene wash bottles may be used at the option of the tester. It is recommended that acetone not be stored in polyethylene bottles for longer than a month.

2.2.3 Glass Sample Storage Containers. Chemically resistant, borosilicate glass bottles, for acetone washes, 500 ml or 1000 ml. Screw cap liners shall either be rubber-backed Teflon or shall be constructed so as to be leak-free and resistant to chemical attack by acetone. (Narrow mouth glass bottles have been found to be less prone to leakage.) Alternatively, polyethylene bottles may be used.

2.2.4 Petri Dishes. For filter samples, glass or polyethylene, unless otherwise specified by the Administrator.

2.2.5 Graduated Cylinder and/or Balance. To measure condensed water to within 1 ml or 1 g. Graduated cylinders shall have subdivisions no greater than 2 ml. Most laboratory balances are capable of weighing to the nearest 0.5 g or less. Any of these balances is suitable or use here and in Section 2.3.4.

2.2.6 Plastic Storage Containers. Airtight containers to store silica gel.

2.2.7 Funnel and Rubber Policeman. To aid in transfer of silica gel to container; not necessary if silica gel is weighed in the field.

2.2.8 Funnel. Glass or polyethylene, to aid in sample recovery.

2.3 Analysis. For analysis, the following equipment is needed.

2.3.1 Glass Weighing Dishes.

2.3.2 Desiccator.

2.3.3 Analytical Balance. To measure to within 0.1 mg.

2.3.4 Balance. To measure to within 0.5 g.

2.3.5 Beakers. 250 ml.

2.3.6 Hygrometer. To measure the relative humidity of the laboratory environment.

2.3.7 Temperature Gauge. To measure the temperature of the laboratory environment.

3. Reagents

3.1 Sampling. The reagents used in sampling are as follows:

[Appendix A, Method 5]

3.1.1 Filters. Glass fiber filters, without organic binder, exhibiting at least 99.95 percent efficiency (<0.05 percent penetration) on 0.3-micron dioctyl phthalate smoke particles. The filter efficiency test shall be conducted in accordance with ASTM standard method D2986-71 (Reapproved 1978) (incorporated by reference — see §60.17). Test data from the supplier's quality control program are sufficient for this purpose. In sources containing SO_2 or SO_3 , the filter material must be of a type that is unreactive to SO_2 or SO_3 . Citation 10 in Bibliography, may be used to select the appropriate filter.

[3.1.1 amended by 48 FR 3735, January 27, 1983; 55 FR 47472, November 14, 1990]

3.1.2 Silica Gel. Indicating type, 6 to 16 mesh. If previously used, dry at 175° C (350° F) for 2 hours. New silica gel may be used as received. Alternatively, other types of desiccants (equivalent or better) may be used, subject to the approval of the Administrator.

3.1.3 Water. When analysis of the material caught in the impingers is required, deionized distilled water shall be used. Run blanks prior to field use to eliminate a high blank on test samples.

[3.1.3 amended by 55 FR 47472, November 14, 1990]

3.1.4 Crushed Ice.

3.1.5 Stopcock Grease. Acetone-insoluble, heat-stable silicone grease. This is not necessary if screw-on connectors with Teflon sleeves, or similar, are used. Alternatively, other types of stopcock grease may be used, subject to the approval of the Administrator.

3.2 Sample Recovery. Acetone-reagent grade, <0.001 percent residue, in glass bottles—is required. Acetone from metal containers generally has a high residue blank and should not be used. Sometimes, suppliers transfer acetone to glass bottles from metal containers; thus, acetone blanks shall be run prior to field use and only acetone with low blank values (<0.001 percent) shall be used. In no case shall a blank value of greater than 0.001 percent of the weight of acetone used be subtracted from the sample weight.

3.3 Analysis. Two reagents are required for the analysis:

3.3.1 Acetone. Same as 3.2.

3.3.2 Desiccant. Anhydrous calcium sulfate, indicating type. Alternatively, other types of desiccants may be used, subject to the approval of the Administrator.

4. Procedure

4.1 Sampling. The complexity of this method is such that, in order to obtain reliable results, testers should be trained and experienced with the test procedures.

4.1.1 Pretest Preparation. It is suggested that sampling equipment be maintained according to the procedures described in APTD-0576.

[4.1.1 amended by 50 FR 1165, January 9, 1985]

Weigh several 200 to 300 g portions of silica gel in air-tight containers to the nearest 0.5 g. Record the total weight of the silica gel plus container, on each container. As an alternative, the silica gel need not be preweighed, but may be weighed directly in the impinger or sampling holder just prior to train assembly.

Check filters visually against light for irregularities and flaws or pinhole leaks. Label filters of the proper diameter on the back side near the edge using numbering machine ink. As an alternative, label the shipping containers (glass or plastic petri dishes) and keep the filters in these containers at all times except during sampling and weighing.

Desiccate the filters at 20±5.6° C (68±10° F) and ambient pressure for at least 24 hours and weigh at intervals of at least 6 hours to a constant weight, i.e., 0.5 mg change from previous weighing; record results to the nearest 0.1 mg. During each weighing the filter must not be exposed to the laboratory atmosphere for a period greater than 2 minutes and a relative humidity above 50 percent. Alternatively (unless otherwise specified by the Administrator), the filters may be oven dried at 105° C (220° F) for 2 to 3 hours, desiccated for 2 hours, and weighed. Procedures other than those described, which account for relative humidity effects, may be used, subject to the approval of the Administrator.

4.1.2 Preliminary Determinations. Select the sampling site and the minimum number of sampling points according to Method 1 or as specified by the Administrator. Determine the stack pressure, temperature, and the range of velocity heads using Method 2; it is recommended that a leak-check of the pitot lines (see Method 2, Section 3.1) be performed. Determine the moisture content using Approximation Method 4 or its alternatives for the purpose of making isokinetic sampling rate settings. Determine the stack gas dry molecular weight, as described in Method 2, Section 3.6; if integrated Method 3 sampling is used for molecular weight determination, the integrated bag sample shall be taken simultaneously with, and for the same total length of time as, the particulate sample run.

Select a nozzle size based on the range of velocity heads, such that it is not necessary to change the nozzle size in order to maintain isokinetic sampling rates. During the run, do not change the nozzle size. Ensure that the proper differential pressure gauge is chosen for the range of velocity heads encountered (see Section 2.2 of Method 2).

Select a suitable probe liner and probe length such that all traverse points can be sampled. For large stacks, consider sampling from opposite sides of the stack to reduce the length of probes.

Select a total sampling time greater than or equal to the minimum total sampling

time specified in the test procedures for the specific industry such that (1) the sampling time per point is not less than 2 min (or some greater time interval as specified by the Administrator), and (2) the sample volume taken (corrected to standard conditions) will exceed the required minimum total gas sample volume. The latter is based on an approximate average sampling rate.

It is recommended that the number of minutes sampled at each point be an integer or an integer plus one-half minute, in order to avoid timekeeping errors. The sampling time at each point shall be the same.

In some circumstances, e.g., batch cycles, it may be necessary to sample for shorter times at the traverse points and to obtain smaller gas sample volumes. In these cases, the Administrator's approval must first be obtained.

4.1.3 Preparation of Collection Train. During preparation and assembly of the sampling train, keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.

Place 100 ml of water in each of the first two impingers, leave the third impinger empty, and transfer approximately 200 to 300 g of preweighed silica gel from its container to the fourth impinger. More silica gel may be used, but care should be taken to ensure that it is not entrained and carried out from the impinger during sampling. Place the container in a clean place for later use in the sample recovery. Alternatively, the weight of the silica gel plus impinger may be determined to the nearest 0.5 g and recorded.

Using a tweezer or clean disposable surgical gloves, place a labeled (identified) and weighed filter in the filter holder. Be sure that the filter is properly centered and the gasket properly placed so as to prevent the sample gas stream from circumventing the filter. Check the filter for tears after assembly is completed.

When glass liners are used, install the selected nozzle using a Viton A O-ring when stack temperatures are less than 260° C (500° F) and an asbestos string gasket when temperatures are higher. See APTD-0576 for details. Other connecting systems using either 316 stainless steel or Teflon ferrules may be used. When metal liners are used, install the nozzle as above or by a leak-free direct mechanical connection. Mark the probe with heat resistant tape or by some other method to denote the proper distance into the stack or duct for each sampling point.

Set up the train as in Figure 5-1, using (if necessary) a very light coat of silicone grease on all ground glass joints, greasing only the outer portion (see APTD-0576) to avoid possibility of contamination by the silicone grease. Subject to the approval of the Administrator, a glass cyclone may be used between the probe and filter holder when the total particulate catch is expected to exceed 100 mg or when water droplets are present in the stack gas.

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Place crushed ice around the impingers.

4.1.4 Leak-Check Procedures.

4.1.4.1 Pretest Leak-Check. A pretest leak-check is recommended, but not required. If the tester opts to conduct the pretest leak check, the following procedure shall be used.

After the sampling train has been assembled, turn on and set the filter and probe heating systems at the desired operating temperatures. Allow time for the temperatures to stabilize. If a Viton A O-ring or other leak-free connection is used in assembling the probe nozzle to the probe liner, leak-check the train at the sampling site by plugging the nozzle and pulling a 380 mm Hg (15 in. Hg) vacuum.

NOTE: A lower vacuum may be used, provided that it is not exceeded during the test.

If an asbestos string is used, do not connect the probe to the train during the leak-check. Instead, leak-check the train by first plugging the inlet to the filter holder (cyclone, if applicable) and pulling a 380 mm Hg (15 in. Hg) vacuum (see Note immediately above). Then connect the probe to the train and leak-check at about 25 mm Hg (1 in. Hg) vacuum; alternatively, the probe may be leak-checked with the rest of the sampling train, in one step, at 380 mm Hg (15 in. Hg) vacuum. Leakage rates in excess of 4 percent of the average sampling rate or 0.00057 m³/min (0.02 cfm), whichever is less, are unacceptable.

The following leak-check instructions for the sampling train described in APTD-0576 and APTD-0581 may be helpful. Start the pump with bypass valve fully open and coarse adjust valve, completely closed. Partially open the coarse adjust valve and slowly close the bypass valve until the desired vacuum is reached. Do not reverse direction of bypass valve; this will cause water to back up into the filter holder. If the desired vacuum is exceeded, either leak-check at this higher vacuum or end the leak-check as shown below and start over.

When the leak-check is completed, first slowly remove the plug from the inlet to the probe, filter holder, or cyclone (if applica-

ble) and immediately turn off the vacuum pump. This prevents the water in the impingers from being forced backward into the filter holder and silica gel from being entrained backward into the third impinger.

4.1.4.2 Leak-Checks During Sample Run. If, during the sampling run, a component (e.g., filter assembly or impinger) change becomes unnecessary, a leak-check shall be conducted immediately before the change is made. The leak-check shall be done according to the procedure outlined in Section 4.1.4.1 above, except that it shall be done at a vacuum equal to or greater than the maximum value recorded up to that point in the test. If the leakage rate is found to be no greater than 0.00057 m³/min (0.02 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction will need to be applied to the total volume of dry gas metered; if, however, a higher leakage rate is obtained, the tester shall either record the leakage rate and plan to correct the sample volume as shown in Section 6.3 of this method, or shall void the sampling run.

Immediately after component changes, leak-checks are optional; if such leak-checks are done, the procedure outlined in Section 4.1.4.1 above shall be used.

4.1.4.3 Post-test Leak-Check. A leak-check is mandatory at the conclusion of each sampling run. The leak-check shall be done in accordance with the procedures outlined in Section 4.1.4.1, except that it shall be conducted at a vacuum equal to or greater than the maximum value reached during the sampling run. If the leakage rate is found to be no greater than 0.00057 m³/min (0.02 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction need be applied to the total volume of dry gas metered. If, however, a higher leakage rate is obtained, the tester shall either record the leakage rate and correct the sample volume as shown in Section 6.3 of this method, or shall void the sampling run.

4.1.5 Particulate Train Operation. During the sampling run, maintain an isokinetic sampling rate (within 10 percent of

true isokinetic unless otherwise specified by the Administrator) and a temperature around the filter of 120 ± 14° C (248 ± 25° F), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator.

For each run, record the data required on a data sheet such as the one shown in Figure 5-2. Be sure to record the initial dry gas meter reading. Record the dry gas meter readings at the beginning and end of each sampling time increment, when changes in flow rates are made, before and after each leak-check, and when sampling is halted. Take other readings required by Figure 5-2 at least once at each sample-point during each time increment and additional readings when significant changes (20 percent variation in velocity head readings) necessitate additional adjustments in flow rate. Level and zero the manometer. Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse.

Clean the portholes prior to the test run to minimize the chance of sampling deposited material. To begin sampling, remove the nozzle cap, verify that the filter and probe heating systems are up to temperature, and that the pitot tube and probe are properly positioned. Position the nozzle at the first traverse point with the tip pointing directly into the gas stream. Immediately start the pump and adjust the flow to isokinetic conditions. Nomographs are available, which aid in the rapid adjustment of the isokinetic sampling rate without excessive computations. These nomographs are designed for use when the Type S pitot tube coefficient is 0.85 ± 0.02, and the stack gas equivalent density (dry molecular weight) is equal to 29 ± 4. APTD-0576 details the procedure for using the nomographs. If C_s and M_s are outside the above stated ranges do not use the nomographs unless appropriate steps (see Citation 7 in Bibliography) are taken to compensate for the deviations.

[4.1.5 amended by 48 FR 39011, August 26, 1983]

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nozzle from the stack, turn off the pump, record the final dry gas meter reading, and conduct a post-test leak-check, as outlined in Section 4.1.4.3. Also, leak-check the pitot lines as described in Method 2, Section 3.1; the lines must pass this leak-check, in order to validate the velocity head data.

4.1.6 Calculation of Percent Isokinetic. Calculate percent isokinetic (see Calculations, Section 8) to determine whether the run was valid or another test run should be made. If there was difficulty in maintaining isokinetic rates due to source conditions, consult with the Administrator for possible variance on the isokinetic rates.

4.2 Sample Recovery. Proper cleanup procedure begins as soon as the probe is removed from the stack at the end of the sampling period. Allow the probe to cool.

When the probe can be safely handled, wipe off all external particulate matter near the tip of the probe nozzle and place a cap over it to prevent losing or gaining particulate matter. Do not cap off the probe tip tightly while the sampling train is cooling down as this would create a vacuum in the filter holder, thus drawing water from the impingers into the filter holder.

Before moving the sample train to the cleanup site, remove the probe from the sample train, wipe off the silicone grease, and cap the open outlet of the probe. Be careful not to lose any condensate that might be present. Wipe off the silicone grease from the filter inlet where the probe was fastened and cap it. Remove the umbilical cord from the last impinger and cap the impinger. If a flexible line is used between the first impinger or condenser and the filter holder, disconnect the line at the filter holder and let any condensed water or liquid drain into the impingers or condenser. After wiping off the silicone grease, cap off the filter holder outlet and impinger inlet. Either ground-glass stoppers, plastic caps, or serum caps may be used to close these openings.

Transfer the probe and filter-impinger assembly to the cleanup area. This area should be clean and protected from the wind so that the chances of contaminating or losing the sample will be minimized.

Save a portion of the acetone used for cleanup as a blank. Take 200 ml of this acetone directly from the wash bottle being used and place it in a glass sample container labeled "acetone blank."

Inspect the train prior to and during disassembly and note any abnormal conditions. Treat the samples as follows:

Container No. 1. Carefully remove the filter from the filter holder and place it in its identified petri dish container. Use a pair of tweezers and/or clean disposable surgical gloves to handle the filter. If it is necessary to fold the filter, do so such that the particulate cake is inside the fold. Carefully transfer to the petri dish any particulate matter and/or filter fibers which adhere to the filter holder gasket, by using a dry Nylon bristle brush and/or a sharp-edged blade. Seal the container.

Container No. 2. Taking care to see that dust on the outside of the probe or other exterior surfaces does not get into the sample, quantitatively recover particulate matter or any condensate from the probe nozzle, probe fitting, probe liner, and front half of the filter holder by washing these components with acetone and placing the wash in a glass container. Distilled water may be used instead of acetone when approved by the Administrator and shall be used when specified by the Administrator; in these cases, save a water blank and follow the Administrator's directions on analysis. Perform the acetone rinses as follows:

Carefully remove the probe nozzle and clean the inside surface by rinsing with acetone from a wash bottle and brushing with a Nylon bristle brush. Brush until the acetone rinse shows no visible particles, after which make a final rinse of the inside surface with acetone.

Brush and rinse the inside parts of the Swagelok fitting with acetone in a similar way until no visible particles remain.

Rinse the probe liner with acetone by tilting and rotating the probe while squirting acetone into its upper end so that all inside surfaces will be wetted with acetone. Let the acetone drain from the lower end into the sample container. A funnel (glass or polyethylene) may be used to aid in transferring liquid wastes to the container. Follow the acetone rinse with a probe brush. Hold the probe in an inclined position, squirt acetone into the upper end as the probe brush is being pushed with a twisting action through the probe; hold a sample container underneath the lower end of the probe, and catch any acetone and particulate matter which is brushed from the probe. Run the brush through the probe three times or more until no visible particulate matter is carried out with the acetone or until none remains in the probe liner on visual inspection. With stainless steel or other metal probes, run the brush through in the above prescribed

manner at least six times since metal probes have small crevices in which particulate matter can be entrapped. Rinse the brush with acetone, and quantitatively collect these washings in the sample container. After the brushing, make a final acetone rinse of the probe as described above.

It is recommended that two people minimize sample losses. Between sampling runs, keep brushes clean and protected from contamination.

After ensuring that all joints have been wiped clean of silicone grease, clean the inside of the front half of the filter holder by rubbing the surfaces with a Nylon bristle brush and rinsing with acetone. Rinse each surface three times or more if needed to remove visible particulate. Make a final rinse of the brush and filter holder. Carefully rinse out the glass cyclone, also (if applicable). After all acetone washings and particulate matter have been collected in the sample container, tighten the lid on the sample container so that acetone will not leak out when it is shipped to the laboratory. Mark the height of the fluid level to determine whether or not leakage occurred during transport. Label the container to clearly identify its contents.

[4.2 Container No. 2 amended by 52 FR 34639, September 14, 1987]

Container No. 3. Note the color of the indicating silica gel to determine if it has been completely spent and make a notation of its condition. Transfer the silica gel from the fourth impinger to its original container and seal. A funnel may make it easier to pour the silica gel without spilling. A rubber policeman may be used as an aid in removing the silica gel from the impinger. It is not necessary to remove the small amount of dust particles that may adhere to the impinger wall and are difficult to remove. Since the gain in weight is to be used for moisture calculations, do not use any water or other liquids to transfer the silica gel. If a balance is available in the field, follow the procedure for container No. 3 in Section 4.3.

Impinger Water. Treat the impingers as follows: Make a notation of any color or film in the liquid catch. Measure the liquid which is in the first three impingers to within ± 1 ml by using a graduated cylinder or by weighing it to within ± 0.5 g by using a balance (if one is available). Record the volume or weight of liquid present. This information is required to calculate the moisture content of the effluent gas.

Discard the liquid after measuring and recording the volume or weight, unless analysis of the impinger catch is required (see Note, Section 2.1.7).

If a different type of condenser is used, measure the amount of moisture condensed either volumetrically or gravimetrically.

Whenever possible, containers should be shipped in such a way that they remain upright at all times.

4.3 Analysis. Record the data required on a sheet such as the one shown in Figure 5-3. Handle each sample container as follows:

Container No. 1. Leave the contents in the shipping container or transfer the filter and any loose particulate from the sample container to a tared glass weighing dish. Desiccate for 24 hours in a desiccator containing anhydrous calcium sulfate. Weigh to a constant weight and report the results to the nearest 0.1 mg. For purposes of this Section, 4.3, the term "constant weight" means a difference of no more than 0.5 mg or 1 percent of total weight less tare weight, whichever is greater, between two consecutive weighings, with no less than 6 hours of desiccation time between weighings.

Plant _____

Date _____

Run No. _____

Filter No. _____

Amount liquid lost during transport _____

Acetone blank volume, ml _____

Acetone wash volume, ml _____

Acetone blank concentration, mg/mg (equation 5-4) _____

Acetone wash blank, mg (equation 5-5) _____

Alternatively, the sample may be oven dried at 105° C (220° F) for 2 to 3 hours, cooled in the desiccator, and weighed to a constant weight, unless otherwise specified by the Administrator. The tester may also opt to oven dry the sample at 105° C (220° F) for 2 to 3 hours, weigh the sample, and use this weight as a final weight.

Container No. 2. Note the level of liquid in the container and confirm on the analysis sheet whether or not leakage occurred during transport. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results. Measure the liquid in this container either volumetrically to ± 1 ml or gravimetrically to ± 0.5 g. Transfer the contents to a tared 250-ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to a constant weight. Report the results to the nearest 0.1 mg.

Container No. 3. Weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g using a balance. This step may be conducted in the field.

"Acetone Blank" Container. Measure acetone in this container either volumetrically or gravimetrically. Transfer the acetone to a tared 250-ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to a constant weight. Report the results to the nearest 0.1 mg.

NOTE.—At the option of the tester, the contents of Container No. 2 as well as the acetone blank container may be evaporated at temperatures higher than ambient. If evaporation is done at an elevated temperature, the temperature must be below the boiling point of the solvent; also, to prevent "bumping," the evaporation process must be closely supervised, and the contents of the beaker must be swirled occasionally to maintain an even temperature. Use extreme care, as acetone is highly flammable and has a low flash point.

4.4 Quality Control Procedures. The following quality control procedures are suggested to check the volume metering system calibration values at the field test site prior to sample collection. These procedures are optional for the tester.

4.4.1 Meter Orifice Check. Using the calibration data obtained during the calibration procedure described in Section 5.3, determine the ΔH_o for the metering system orifice. The ΔH_o is the orifice pressure differential in units of in. H₂O that correlates to 0.75 cfm of air at 528°R and 29.92 in. Hg. The ΔH_o is calculated as follows:

CONTAINER NUMBER	WEIGHT OF PARTICULATE COLLECTED, mg		
	FINAL WEIGHT	TARE WEIGHT	WEIGHT GAIN
1			
2			
TOTAL			
Less acetone blank			
Weight of particulate matter			

	VOLUME OF LIQUID WATER COLLECTED	
	IMPINGER VOLUME, ml	SILICA GEL WEIGHT, g
FINAL		
INITIAL		
LIQUID COLLECTED		
TOTAL VOLUME COLLECTED		g* ml

* CONVERT WEIGHT OF WATER TO VOLUME BY DIVIDING TOTAL WEIGHT INCREASE BY DENSITY OF WATER (1g/ml).

$$\frac{\text{INCREASE, g}}{1 \text{ g/ml}} = \text{VOLUME WATER, ml}$$

Figure 5-3. Analytical data.

[Appendix A, Method 5]

$$\Delta H_{\theta} = 0.0319 \Delta H \frac{T_m}{P_{bar}} \frac{\theta^1}{Y^1 V_m^1}$$

Eq. 5-9

Where:

 ΔH = Average pressure differential across the orifice meter, in. H₂O. T_m = Absolute average dry gas meter temperature, °R. P_{bar} = Barometric pressure, in. Hg. θ = Total sampling time, min. Y = Dry gas meter calibration factor, dimensionless. V_m = Volume of gas sample as measured by dry gas meter, dcf.

$$0.0319 = (0.0567 \text{ in. Hg./}^\circ\text{R}) \times (0.75 \text{ cfm})^2$$

Before beginning the field test (a set of three runs usually constitutes a field test), operate the metering system (i.e., pump, volume meter, and orifice) at the ΔH_{θ} pressure differential for 10 minutes. Record the volume collected, the dry gas meter temperature, and the barometric pressure. Calculate a dry gas meter calibration check value, Y_c , as follows:

$$Y_c = \frac{10}{V_m} \left[\frac{0.0319 T_m}{P_{bar}} \right]^{1/2} \quad \text{Eq. 5-10}$$

Where:

 Y_c = Dry gas meter calibration check value, dimensionless.

10 = 10 minutes of run time.

Compare the Y_c value with the dry gas meter calibration factor Y to determine that:

$$0.97Y < Y_c < 1.03Y$$

If the Y_c value is not within this range, the volume metering system should be investigated before beginning the test.

4.4.2. Calibration Critical Orifice. A calibrated critical orifice, calibrated against a wet test meter or spirometer and designed to be inserted at the inlet of the sampling meter box, may be used as a quality control check by following the procedure of Section 7.2.

[4.4.2 Amended by 52 FR 9658, March 26, 1987]

5. Calibration. Maintain a laboratory log of all calibrations.

5.1 Probe Nozzle. Probe nozzles shall be calibrated before their initial use in the field. Using a micrometer, measure the inside diameter of the nozzle to the nearest 0.025 mm (0.001 in.). Make three separate measurements using different diameters each time, and obtain the average of the measurements. The difference between the high and low numbers shall not exceed 0.1 mm (0.004 in.). When nozzles become nicked, dented, or corroded, they shall be reshaped, sharpened, and recalibrated before use. Each nozzle shall be permanently and uniquely identified.

[5.1 amended by 52 FR 34639, September 14, 1987]

5.2 Pitot Tube. The Type S pitot tube assembly shall be calibrated according to the procedure outlined in Section 4 of Method 2.

5.3 Metering System.

[5.3 revised by 50 FR 1165, January 1985]

5.3.1 Calibration Prior to Use. Before its initial use in the field, the metering system shall be calibrated as follows: Connect the metering system inlet to the outlet of a wet test meter that is accurate to within 1 percent. Refer to Figure 5.5. The wet test meter should have a capacity of 30 liters/rev (1 ft³/rev). A spirometer of 400 liters (14 ft³) or more capacity, or equivalent, may be used for this calibration, although a wet test meter is usually more practical. The wet test meter should be periodically calibrated with a spirometer or a liquid displacement meter to ensure the accuracy of the wet test meter. Spirometers or wet test meters of other sizes may be used, provided that the specified accuracies of the procedure are maintained. Run the metering system pump for about 15 minutes with the orifice manometer indicating a median reading as expected in field use to allow the pump to warm up and to permit the interior surface of the wet test meter to be thoroughly wetted. Then, at each of a minimum of three orifice manometer settings, pass an exact quantity of gas through the wet test meter and note the gas volume indicated by the dry gas meter. Also note the barometric pressure, and the temperatures of the wet test meter, the inlet of the dry gas meter, and the outlet of the dry gas meter. Select the highest and lowest orifice settings to bracket the expected field operating range of the orifice. Use a minimum volume of 0.15 m³ (5 cf) at all orifice settings. Record all the data on a form similar to Figure 5.6, and calculate Y , the dry gas meter calibration factor, and ΔH_{θ} , the orifice calibration factor, at each orifice setting as shown on Figure 5.6. Allowable tolerances for individual Y and ΔH_{θ} values are given in Figure 5.6. Use the average of the Y values in the calculations in Section 6.

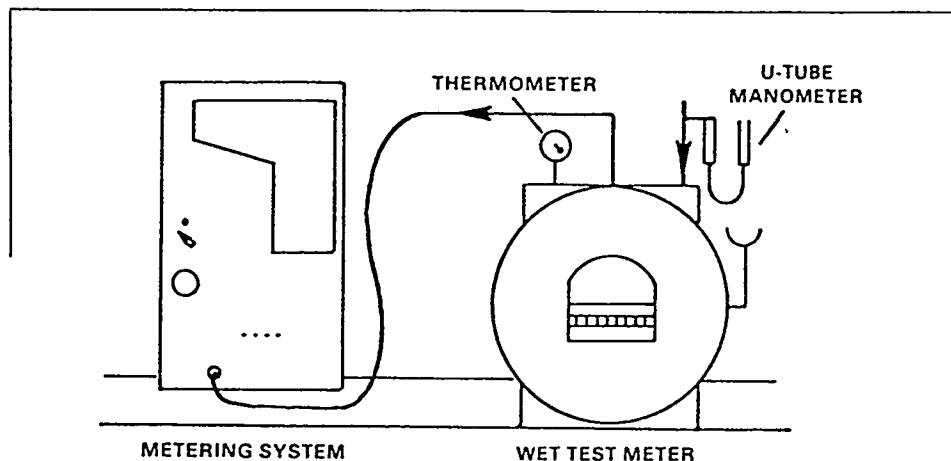


Figure 5.5 Equipment arrangement for metering system calibration.

[Appendix A, Method 5]

Date _____ Metering System Identification: _____
 Barometric pressure, P_b = _____ in. Hg

Orifice manometer setting ΔH in. H ₂ O	Spirometer (wet meter) gas volume V_w ft ³	Dry gas meter volume V_m ft ³	Temperatures			Time θ min
			Spirometer (wet meter) t_w °F	Dry Gas Meter Inlet t_i °F	Outlet t_o °F	Average t_m °F

Calculations

ΔH in. H ₂ O	Y	ΔH_q
	$\frac{V_w P_b (t_m + 460)}{V_m \left[\frac{P_b}{13.6} + \frac{\Delta H}{13.6} \right] (t_w + 460)}$	$\frac{0.0317 \Delta H}{P_b (t_o + 460)} \left[\frac{(t_w + 460) \theta}{V_w} \right]^2$
Average		

Y = Ratio of reading of wet test meter to dry test meter; tolerance for individual values ± 0.02 from average.

ΔH_q = Orifice pressure differential that equates to 0.75 cfm of air @ 68°F and 29.92 inches of mercury, in. H₂O; tolerance for individual values ± 0.20 from average.

Figure 5.6. Example data sheet for calibration of metering system (English units).

[Figure 5.6 revised by 52 FR 34639, September 14, 1987]

Before calibrating the metering system, it is suggested that a leak-check be conducted. For metering systems having diaphragm pumps, the normal leak-check procedure will not detect leakages within the pump. For these cases the following leak-check procedure is suggested: make a 10-minute calibration run at 0.00057 m³/min (0.02 cfm); at the end of the run, take the difference of

the measured wet test meter and dry gas ate orifice setting (based on the previous meter volumes; divided the difference by 10, field test), with the vacuum set at the maximum to get the leak rate. The leak rate should not exceed 0.00057 m³/min (0.02 cfm).

5.3.2 Calibration After Use. After each metering system. Calculate the average value filled use, the calibration of the metering of the dry gas meter calibration factor. If system shall be checked by performing the value has changed by more than 5 per three calibration runs at a single, intermediate, recalibrate the meter over the full

[Appendix A, Method 5]

range of orifice settings, as previously detailed.

Alternative procedures, e.g., rechecking the orifice meter coefficient may be used, subject to the approval of the Administrator.

5.3.3 Acceptable Variation in Calibration. If the dry gas meter coefficient values obtained before and after a test series differ by more than 5 percent, the test series shall either be voided, or calculations for the test series shall be performed using whichever meter coefficient value (i.e., before or after) gives the lower value of total sample volume.

5.4 Probe Heater Calibration. The probe heating system shall be calibrated before its initial use in the field.

[5.4 revised by 50 FR 1165, January 9, 1985]

Use a heat source to generate air heated to selected temperatures that approximate those expected to occur in the sources to be sampled. Pass this air through the probe at a typical simple flow rate while measuring the probe inlet and outlet temperatures at various probe heater settings. For each air temperature generated, construct a graph of probe heating system setting versus probe outlet temperature. The procedure outlined in APTD-0576 can also be used. Probes constructed according to APTD-0581 need not be calibrated if the calibration curves in APTD-0576 are used. Also, probes with outlet temperature monitoring capabilities do not require calibration.

5.5 Temperature Gauges. Use the procedure in Section 4.3 of Method 2 to calibrate in-stack temperature gauges. Dial thermometers, such as are used for the dry gas meter and condenser outlet, shall be calibrated against mercury-in-glass thermometers.

5.6 Leak Check of Metering System Shown in Figure 5-1. That portion of the sampling train from the pump to the orifice meter should be leak checked prior to initial use and after each shipment. Leakage after the pump will result in less volume being recorded than is actually sampled. The following procedure is suggested (see Figure 5-4): Close the main valve on the meter box. Insert a one-hole rubber stopper with rubber tubing attached into the orifice exhaust pipe. Disconnect and vent the low side of the orifice manometer. Close off the low side orifice tap. Pressurize the system to 13 to 18 cm (5 to 7 in.) water column by blowing into the rubber tubing. Pinch off the tubing and observe the manometer for one minute. A loss of pressure on the manometer indicates a leak in the meter box; leaks, if present, must be corrected.

5.7 Barometer. Calibrate against a mercury barometer.

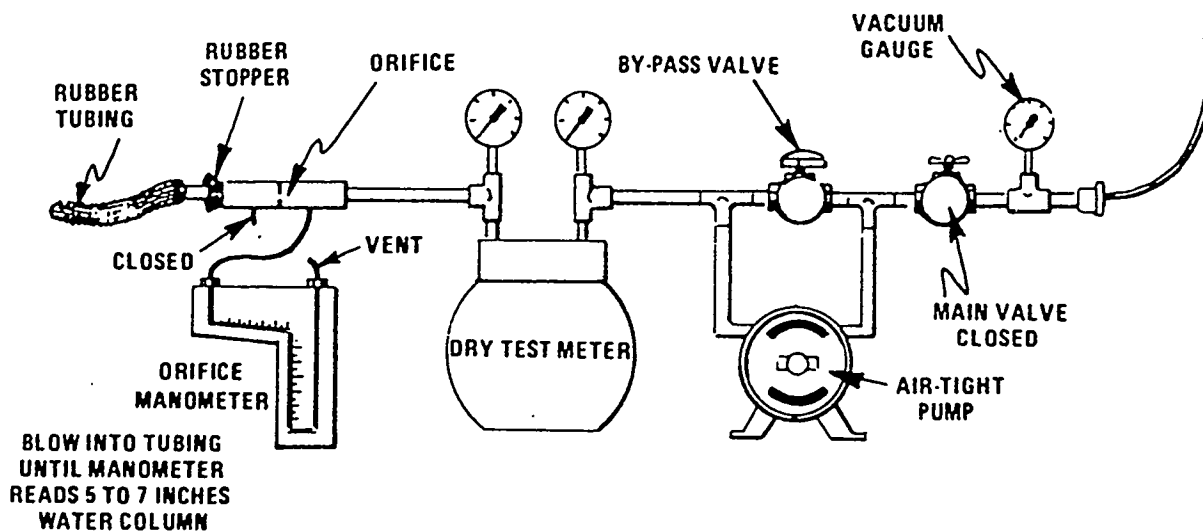


Figure 5-4. Leak check of meter box.

[Appendix A, Method 5]

6. Calculations

Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after the final calculation. Other forms of the equations may be used as long as they give equivalent results.

6.1 Nomenclature

A_n = Cross-sectional area of nozzle, m^2 (ft^2).
 $B_{n,i}$ = Water vapor in the gas stream, proportion by volume.
 C_n = Acetone blank residue concentration, mg/mg.
 c_i = Concentration of particulate matter in stack gas, dry basis, corrected to standard conditions, g/dscm (g/dscf).
 I = Percent of isokinetic sampling.
 L_n = Maximum acceptable leakage rate for either a pretest leak check or for a leak check following a component change: equal to 0.00057 m^3/min (0.02 cfm) or 4 percent of the average sampling rate, whichever is less.
 $L_{n,i}$ = Individual leakage rate observed during the leak check conducted prior to the "ith" component change ($i=1, 2, 3, \dots, n$), m^3/min (cfm).
 $L_{n,p}$ = Leakage rate observed during the post-test leak check, m^3/min (cfm).
 m_n = Total amount of particulate matter collected, mg.
 M_w = Molecular weight of water, 18.0 g/mole (18.0 lb/lb-mole).
 $m_{n,i}$ = Mass of residue of acetone after evaporation, mg.
 P_{bar} = Barometric pressure at the sampling site, mm Hg (in. Hg).
 P_i = Absolute stack gas pressure, mm Hg (in. Hg).
 P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
 R = Ideal gas constant, 0.06236 mm Hg·m³/°K·g-mole (21.85 in. Hg·ft³/°R·lb-mole).
 T_n = Absolute average dry gas meter temperature (see Figure 5-2), °K (°R).
 T_i = Absolute average stack gas temperature (see Figure 5-2), °K (°R).
 T_{std} = Standard absolute temperature, 293° K (528° R).
 V_n = Volume of acetone blank, ml.
 V_{nw} = Volume of acetone used in wash, ml.
 $V_{n,i}$ = Total volume of liquid collected in impingers and silica gel (see Figure 5-3), ml.
 V_n = Volume of gas sample as measured by dry gas meter, dcm (dscf).
 $V_{n,corr}$ = Volume of gas sample measured by the dry gas meter, corrected to standard conditions, dscm (dscf).

$V_{n,corr}$ = Volume of water vapor in the gas sample, corrected to standard conditions, scm (scf).
 v_i = Stack gas velocity, calculated by Method 2, Equation 2-9, using data obtained from Method 5, m/sec (ft/sec).
 W_n = Weight of residue in acetone wash, mg.
 Y = Dry gas meter calibration factor.
 ΔH = Average pressure differential across the orifice meter (see Figure 5-2), mm H₂O (in. H₂O).
 ρ_w = Density of acetone, mg/ml (see label on bottle).
 ρ_w = Density of water, 0.9982 g/ml (0.002201 lb/ml).
 θ = Total sampling time, min.
 θ_i = Sampling time interval, from the beginning of a run until the first component change, min.
 θ_i = Sampling time interval, between two successive component changes, beginning with the interval between the first and second changes, min.
 θ_n = Sampling time interval, from the final (n^{th}) component change until the end of the sampling run, min.
13.6 = Specific gravity of mercury.
60 = Sec/min.
100 = Conversion to percent.

[6.1 amended by 52 FR 34639, September 14, 1987; 55 FR 47472, November 14, 1990]

6.2 Average dry gas meter temperature and average orifice pressure drop. See data sheet (Figure 5-2).

6.3 Dry Gas Volume. Correct the sample volume measured by the dry gas meter to standard conditions (20° C, 760 mm Hg or 68° F, 29.92 in. Hg) by using Equation 5-1.

$$V_{n,corr} = V_n \left(\frac{T_{std}}{T_n} \right) \left[\frac{P_{bar} + \frac{\Delta H}{13.6}}{P_{std}} \right]$$

$$= K_1 V_n Y \frac{P_{bar} + (\Delta H/13.6)}{T_n}$$

Equation 5-1

where:
 $K_1 = 0.3858$ °K/mm Hg for metric units
 $= 17.64$ °R/in. Hg for English units
NOTE.—Equation 5-1 can be used as written unless the leakage rate observed during any of the mandatory leak checks (i.e., the post-test leak check or leak check conducted prior to component changes) exceeds L_n . If L_p or $L_{n,i}$ exceeds L_n , Equation 5-1 must be modified as follows:
(a) Case I. No component changes made during sampling run. In this case, replace V_n in Equation 5-1 with the expression

$$V_n - (L_p - L_n)\theta$$

(b) Case II. One or more component changes made during the sampling run. In this case, replace V_n in Equation 5-1 by the expression:

$$[V_n - (L_1 - L_n)\theta_1 - \sum_{i=2}^n (L_i - L_n)\theta_i - (L_p - L_n)\theta_p]$$

and substitute only for those leakage rates (L_i or L_p) which exceed L_n .

6.4 Volume of water vapor.

Equation 5-2

$$V_{w, std} = V_{1c} \left(\frac{\rho_w}{\rho_{std}} \right) \left(\frac{RT_{std}}{P_{std}} \right) = K_2 V_{1c}$$

where:
 $K_2 = 0.001333$ m³/ml for metric units
 $= 0.04707$ ft³/ml for English units
6.5 Moisture Content.

$$B_{ws} = \frac{V_{w, std}}{V_{m, std} + V_{w, std}}$$

Equation 5-3

NOTE.—In saturated or water droplet-laden gas streams, two calculations of the moisture content of the stack gas shall be made, one from the impinger analysis (Equation 5-3), and a second from the assumption of saturated conditions. The lower of the two values of B_{ws} shall be considered correct. The procedure for determining the moisture content based upon assumption of saturated conditions is given in the Note of Section 1.2 of Method 4. For the purposes of this method, the average stack gas temperature from Figure 5-2 may be used to make this determination, provided that the accuracy of the in-stack temperature sensor is $\pm 1^\circ$ C (2° F).

6.6 Acetone Blank Concentration.

$$C_n = \frac{m_n}{V_n \rho_n}$$

Equation 5-4

6.7 Acetone Wash Blank.

$$W_n = C_n V_{nw} \rho_n$$

Equation 5-5

6.8 Total Particulate Weight. Determine the total particulate catch from the sum of the weights obtained from containers 1 and 2 less the acetone blank (see Figure 5-3).

NOTE: Refer to Section 4.1.5 to assist in calculation of results involving two or more filter assemblies or two or more sampling trains.

6.9 Particulate Concentration.

$$C_i = (0.001 \text{ g/mg}) (m_n / V_{n, corr})$$

Equation 5-6

[Appendix A, Method 5]

6.10 Conversion Factors:

From	To	Multiply by
scf	m ³	0.02832
g/n ³	g/l ³	15.43
g/n ³	lb/n ³	2.205 × 10 ⁻³
g/n ³	g/m ³	35.31
g	mg	0.001

[6.10 table amended by 52 FR 34639, September 14, 1987]

6.11 Isokinetic Variation.

6.11.1 Calculation From Raw Data.

$$I = \frac{100 T_s [K_s V_{ic} \cdot V_{pY} \cdot (P_{bar} + \Delta H/13.6)]}{60 \theta_{r1} P_s A_s}$$

Equation 5-7

where:

$K_s = 0.003454$ mm Hg-m³/ml-°K for metric units.

$= 0.002669$ -in. Hg-ft³/ml-°R for English units.

6.11.2 Calculation From Intermediate Values.

$$I = \frac{T_s V_{m(sid)} P_{sid} 100}{T_{sid} V_s \theta A_s P_s 60 (1 - B_{s,s})}$$

$$= K_s \frac{T_s V_{m(sid)}}{P_s V_s A_s \theta (1 - B_{s,s})}$$

Equation 5-8

where:

$K_s = 4.320$ for metric units

$= 0.09450$ for English units.

6.12 Acceptable Results. If 90 percent $\leq I \leq 110$ percent, the results are acceptable. If the particulate results are low in comparison to the standard, and I is over 110 percent or less than 90 percent, the Administrator may accept the results. Citation 4 in the bibliography section can be used to make acceptability judgments. If I is judged to be unacceptable, reject the particulate results and repeat the test.

[6.12 revised by 50 FR 1165, January 9, 1985]

6.13 Stack Gas Velocity and Volumetric Flow Rate. Calculate the average stack gas velocity and volumetric flow rate, if needed, using data obtained in this method and the equations in Sections 5.2 and 5.3 of Method 2.

[6.13 added by 52 FR 34639, September 14, 1987]

7. Alternative Procedures

[7. added by 48 FR 39011, August 26, 1983]

7.1 Dry Gas Meter as a Calibration Standard. A dry gas meter may be used as a calibration standard for volume measurements in place of the wet test meter specified in Section 5.3, provided that it is calibrated initially and recalibrated periodically as follows:

7.1.1 Standard Dry Gas Meter Calibration.

7.1.1.1 The dry gas meter to be calibrated and used as a secondary reference meter should be of high quality and have an appropriately sized capacity, e.g., 3 liters/rev (0.1 ft³/rev). A spirometer (400 liters or more capacity), or equivalent, may be used for this calibration, although a wet test meter is usually more practical. The wet test meter should have a capacity of 30 liters/rev (1 ft³/rev) and capable of measuring volume to within ± 1.0 percent:

wet test meters should be checked against a spirometer or a liquid displacement meter to ensure the accuracy of the wet test meter. Spirometers or wet test meters of other sizes may be used, provided that the specified accuracies of the procedure are maintained.

7.1.1.2 Set up the components as shown in Figure 5.7. A spirometer, or equivalent, may be used in place of the wet test meter in the system. Run the pump for at least 5 minutes at a flow rate of about 10 liters/min (0.35 cfm) to condition the interior surface of the wet test meter. The pressure drop indicated by the manometer at the inlet side of the dry gas meter should be minimized (no greater than 100 mm H₂O (4 in. H₂O) at a flow rate of 30 liters/min (1 cfm)). This can be accomplished by using large diameter tubing connections and straight pipe fittings.

7.1.1.3 Collect the data as shown in the example data sheet (see Figure 5-8). Make triplicate runs at each of the flow rates and at no less than five different flow rates. The range of flow rates should be between 10 and 34 liters/min (0.35 and 1.2 cfm) or over the expected operating range.

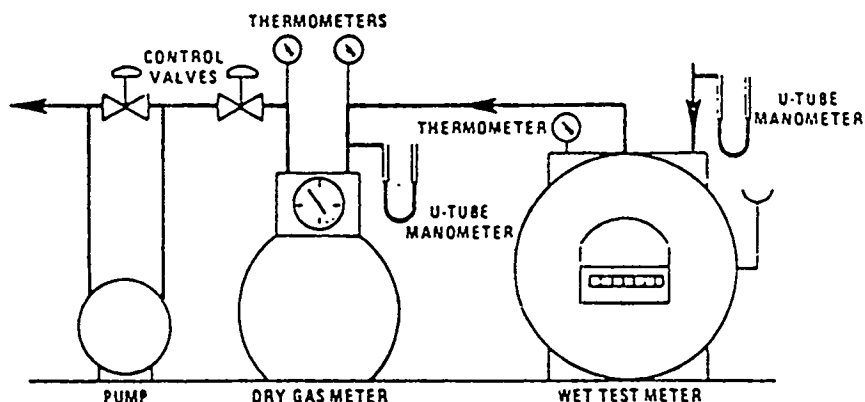


Figure 5.7. Equipment arrangement for dry-gas meter calibration.

[Appendix A, Method 5]

DATE: _____

DRY GAS METER IDENTIFICATION: _____

BAROMETRIC PRESSURE (P_b): _____ in. Hg

APPROXIMATE FLOW RATE ($\bar{Q}$) cfm	SPIROMETER (WET METER) GAS VOLUME (V_s) ft ³	DRY GAS METER VOLUME (V_{dg}) ft ³	TEMPERATURES			DRY GAS METER PRESSURE (Δp) in. H ₂ O	TIME (θ) min.	FLOW RATE (Q) cfm	METER METER COEFFICIENT (Y_{ds})	AVERAGE METER COEFFICIENT ($\bar{Y}_{ds}$)
			SPIROMETER (WET METER) (t_s) °F	INLET (t_i) °F	OUTLET (t_o) °F	AVERAGE ($\bar{t}_d$) °F				
0.40										
0.60										
0.80										
1.00										
1.20										

$$Q = 17.65 \cdot \frac{V_s}{\theta} \cdot \frac{P_b}{(t_s + 460)}$$

$$Y_{ds} = \frac{V_s}{V_{dg}} \cdot \frac{(t_d + 460)}{(t_s + 460)} \cdot \frac{P_b}{(P_b + \frac{\Delta p}{13.6})}$$

Figure 5.8. Example data sheet for calibration of a standard dry gas meter for method 5 sampling equipment (English units).

7.1.1.4 Calculate flow rate, Q , for each run using the wet test meter gas volume, V_s , and the run time, θ . Calculate the dry gas meter coefficient, Y_{ds} , for each run. These calculations are as follows:

$$Q = K_1 \cdot \frac{P_{bar}}{t_s - t_{std}} \cdot \frac{V_s}{\theta}$$

$$Y_{ds} = \frac{V_s}{V_{ds}} \cdot \frac{(t_s + t_{std})}{(t_s - t_{std})} \cdot \frac{P_{bar}}{(P_{bar} + \frac{\Delta p}{13.6})}$$

Where:

$K_1 = 0.3858$ for international system of units (SI); 17.64 for English units.

V_s = Wet test meter volume, liters (ft³).

V_{ds} = Dry gas meter volume, liters (ft³).

t_{std} = Average dry gas meter temperature, °C (°F).

$t_{std} = 273^\circ \text{C}$ for SI units; 460°F for English units.

t_s = Average wet test meter temperature, °C (°F).

P_{bar} = Barometric pressure, mm Hg (in. Hg).
 Δp = Dry gas meter inlet differential pressure, mm H₂O (in. H₂O).
 θ = Run time, min.

7.1.1.5 Compare the three Y_{ds} values at each of the flow rates and determine the maximum and minimum values. The difference between the maximum and minimum values at each flow rate should be no greater than 0.030. Extra sets of triplicate runs may be made in order to complete this requirement. In addition, the meter coefficients should be between 0.95 and 1.05. If these specifications cannot be met in three sets of successive triplicate runs, the meter is not suitable as a calibration standard and should not be used as such. If these specifications are met, average the three Y_{ds} values at each flow rate resulting in five average meter coefficients, $\bar{Y}_{ds}$.

7.1.1.6 Prepare a curve of meter coefficient, Y_{ds} , versus flow rate, Q , for the dry gas meter. This curve shall be used as a reference when the meter is used to calibrate other dry gas meters and to determine whether recalibration is required.

7.1.2 Standard Dry Gas Meter Recalibration.

7.1.2.1 Recalibrate the standard dry gas meter against a wet test meter or spirometer annually or after every 200 hours of operation, whichever comes first. This requirement is valid provided the standard dry gas meter is kept in a laboratory and, if transported, cared for as any other laboratory instrument. Abuse to the standard meter may cause a change in the calibration and will require more frequent recalibrations.

7.1.2.2 As an alternative to full recalibration, a two-point calibration check may be made. Follow the same procedure and equipment arrangement as for a full recalibration, but run the meter at only two flow rates (suggested rates are 14 and 28 liters/min (0.5 and 1.0 cfm)). Calculate the meter coefficients for these two points, and compare the values with the meter calibration curve. If the two coefficients are within ± 1.5 percent of the calibration curve values at the same flow rates, the meter need not be recalibrated until the next date for a recalibration check.

7.2 Critical Orifices As Calibration Standards. Critical orifices may be used as calibration standards in place of the wet test

[Appendix A, Method 5]

meter specified in Section 5.3, provided that they are selected, calibrated, and used as follows:

[7.2 added by 52 FR 9658, March 26, 1987]

7.2.1 Section of Critical Orifices.

7.2.1.1 The procedure that follows describes the use of hypodermic needles or stainless steel needle tubings which have been found suitable for use as critical orifices. Other materials and critical orifice designs may be used provided the orifices act as true critical orifices; i.e., a critical vacuum

can be obtained, as described in Section 7.2.2.2.3. Select five critical orifices that are appropriately sized to cover the range of flow rates between 10 and 34 liters/min or the expected operating range. Two of the critical orifices should bracket the expected operating range.

A minimum of three critical orifices will be needed to calibrate a Method 5 dry gas meter (DGM); the other two critical orifices can serve as spares and provide better selection for bracketing the range of operating flow rates. The needle sizes and tubing lengths shown below give the following approximate flow rates:

Gauge/cm	Flow rate (liters/min)	Gauge/cm	Flow rate (liters/min)
12/7 6	32 58	14/2 5	19 54
12/10 2	30 02	14/5.1	17 27
13/2 5	25 77	14/7 6	16 14
13/5 1	23 50	15/3 2	14 18
13/7 6	22 37	15/7 6	11 61
13/10 2	20 67	15/10 2	10 48

7.2.1.2 These needles can be adapted to a Method 5 type sampling train as follows: Insert a serum bottle stopper, 13- by 20-mm sleeve type, into a 1/2-inch Swagelok quick connect. Insert the needle into the stopper as shown in Figure 5-9.

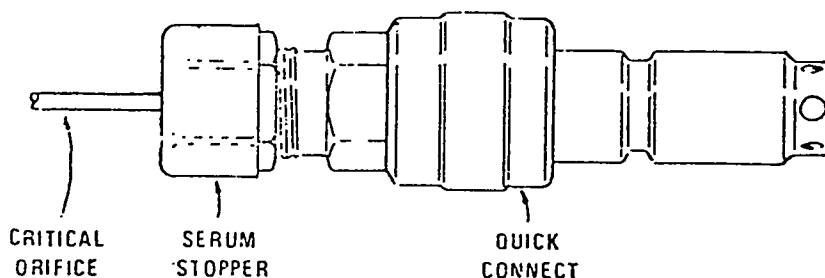


Figure 5-9. Critical orifice adaptation to Method 5 metering system.

7.2.2 Critical Orifice Calibration. The procedure described in this section uses the Method 5 meter box configuration with a DGM as described in Section 2.1.8 to calibrate the critical orifices. Other schemes may be used, subject to the approval of the Administrator.

7.2.2.1 Calibration of Meter Box. The critical orifices must be calibrated in the same configuration as they will be used, i.e., there should be no connections to the inlet of the orifice.

7.2.2.1.1 Before calibrating the meter box, leak check the system as follows: Fully open the coarse adjust valve, and completely close the by-pass valve. Plug the inlet. Then turn on the pump, and determine whether there is any leakage. The leakage rate shall be zero;

i.e., no detectable movement of the DGM dial shall be seen for 1 minute.

7.2.2.1.2 Check also for leakages in that portion of the sampling train between the pump and the orifice meter. See Section 5.6 for the procedure; make any corrections, if necessary. If leakage is detected, check for cracked gaskets, loose fittings, worn O-rings, etc., and make the necessary repairs.

7.2.2.1.3 After determining that the meter box is leakless, calibrate the meter box according to the procedure given in Section 5.3. Make sure that the wet test meter meets the requirements stated in Section 7.1.1.1. Check the water level in the wet test meter. Record the DGM calibration factor, Y.

7.2.2.2 Calibration of Critical Orifices. Set up the apparatus as shown in Figure 5-10.

[Appendix A, Method 5]

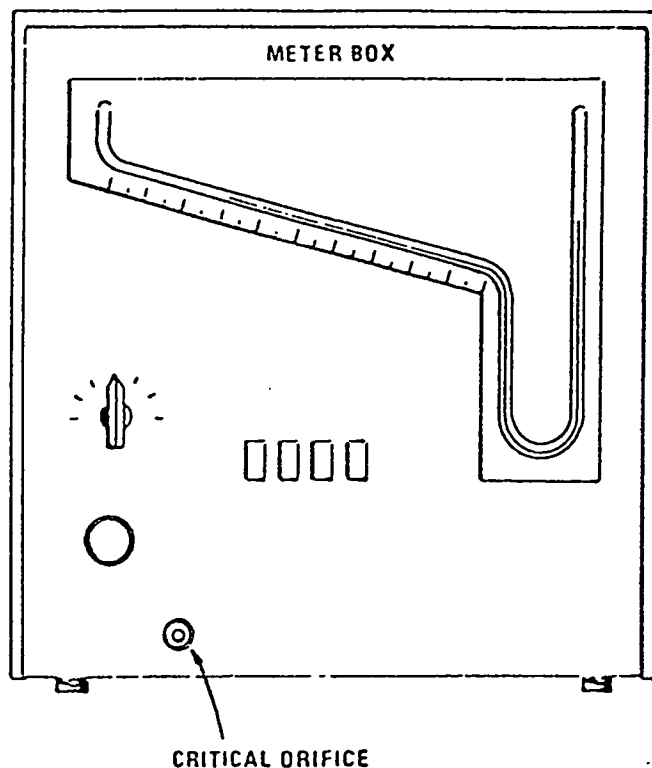


Figure 5-10. Apparatus setup.

7.2.2.2.1 Allow a warm-up time of 15 minutes. This step is important to equilibrate the temperature conditions through the DGM.

7.2.2.2.2 Leak check the system as in Section 7.2.2.1.1. The leakage rate shall be zero.

7.2.2.2.3 Before calibrating the critical orifice, determine its suitability and the appropriate operating vacuum as follows: Turn on the pump, fully open the coarse adjust valve, and adjust the by-pass valve to give a vacuum reading corresponding to about half of atmospheric pressure. Observe the meter box orifice manometer reading, H. Slowly increase the vacuum reading until a stable reading is obtained on the meter box orifice manometer. Record the critical vacuum for each orifice.

Orifices that do not reach a critical value shall not be used.

7.2.2.2.4 Obtain the barometric pressure using a barometer as described in Section

2.1.9. Record the barometric pressure, P_{bar} , in mm Hg (in. Hg).

7.2.2.2.5 Conduct duplicate runs at a vacuum of 25 to 50 mm Hg (1 to 2 in. Hg) above the critical vacuum. The runs shall be at least 5 minutes each. The DGM volume readings shall be in increments of 0.00283 m^3 (0.1 ft^3) or in increments of complete revolutions of the DGM. As a guideline, the

$K' =$ Critical orifice coefficient,

T_{amb} = Absolute ambient temperature, $^{\circ}\text{K}$ ($^{\circ}\text{R}$).

Average the K' values. The individual K' values should not differ by more than ± 0.5

times should not differ by more than 3.0 seconds (this includes allowance for changes in the DGM temperatures) to achieve ± 0.5 percent in K' . Record the information listed in Figure 5-11.

[7.2.2.2.5 corrected by 52 FR 22888, June 16, 1987]

7.2.2.2.6 Calculate K' using Equation 5-9.

where:

$$K' = \frac{K_f V_m Y (P_{bar} + \Delta H/13.6) \sqrt{T_{amb}}}{P_{bar} T_m \Theta} \quad \text{Eq. 5-9}$$

$$\frac{(\text{m}^3)(^{\circ}\text{K})^{1/2}}{(\text{mm. Hg})(\text{min})} \left[\frac{(\text{ft}^3)(^{\circ}\text{R})^{1/2}}{(\text{in. Hg})(\text{min})} \right]$$

percent from the average.

[7.2.2.2.6 corrected by 52 FR 22888, June 16, 1987]

7.2.3 Using the Critical Orifices as Calibration Standards.

[Appendix A, Method 5]

STATIONARY SOURCES

7.2.3.1 Record the barometric pressure.

Date _____ Train ID _____ DGM cal.
factor _____ Critical orifice ID _____

Dry gas meter	Run No.	
	1	2
Final reading	m ³ (ft ³)	
Initial reading	m ³ (ft ³)	
Difference, V _m	m ³ (ft ³)	
Inlet/Outlet temperatures:		
Initial	°C (°F)	/ /
Final	°C (°F)	/ /
Avg.	°C (°F)	
Temperature, t _m		
Time, Θ	min/sec	/ /
min		
Orifice man. rdg., ΔH, H ₂ O	mm (in.)	
Bar. pressure, P _{bar}	mm (in.) Hg	
Ambient	°C (°F)	
temperature, t _{amb}		
Pump vacuum	mm (in.) Hg	
K' factor		
Average		

Figure 5-11. Data sheet for determining K' factor.

7.2.3.2 Calibrate the metering system according to the procedure outlined in Sections 7.2.2.2.1 to 7.2.2.5. Record the information listed in Figure 5-12.

7.2.3.3 Calculate the standard volumes of air passed through the DGM and the critical orifices, and calculate the DGM calibration factor, Y, using the equations below:

$$V_{m(std)} = K_1 V_m \frac{P_{bar} + (\Delta H/13.6)}{T_m} \quad \text{Eq. 5-10}$$

$$V_{cr(std)} = K' \frac{P_{bar} \Theta}{T_{amb}} \quad \text{Eq. 5-11}$$

$$Y = \frac{V_{cr(std)}}{V_{m(std)}} \quad \text{Eq. 5-12}$$

where:

V_{cr(std)} = Volume of gas sample passed through the critical orifice, corrected to standard conditions, dsm³ (dscf).

K₁ = 0.3858 °K/mm Hg for metric units = 17.64 °R/in. Hg for English units.

[7.2.3.3 corrected by 52 FR 22888, June 16, 1987]

7.2.3.4 Average the DGM calibration values for each of the flow rates. The calibration factor, Y, at each of the flow

rates should not differ by more than ±2 percent from the average.

7.2.3.5 To determine the need for recalibrating the critical orifices, compare the DGM Y factors obtained from two adjacent orifices each time a DGM is calibrated; for example, when checking 13/2.5, use orifices 12/10.2 and 13/5.1. If any critical orifice yields a DGM Y factor differing by more than 2 percent from the others, recalibrate the critical orifice according to Section 7.2.2.2.

Date _____ Train ID _____ Critical
orifice ID _____ Critical orifice K' factor _____

Dry gas meter	Run No.	
	1	2
Final reading	m ³ (ft ³)	
Initial reading	m ³ (ft ³)	
Difference, V _m	m ³ (ft ³)	
Inlet/outlet temperatures:		
Initial	°C (°F)	/ /
Final	°C (°F)	/ /
Avg.	°C (°F)	
Temperature, t _m		
Time, Θ	min/sec	/ /
min		
Orifice man. rdg., ΔH, H ₂ O	mm (in.)	
Bar. pressure, P _{bar}	mm (in.) Hg	
Ambient	°C (°F)	
temperature, t _{amb}		
Pump vacuum	mm (in.) Hg	
V _{m(std)}	m ³ (ft ³)	
V _{cr(std)}	m ³ (ft ³)	
DGM cal. factor, Y		

Figure 5-12. Data sheet for determining DGM Y factor.

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[12. added by 52 FR 9658, March 26, 1987]

METHOD 5A—DETERMINATION OF PARTICULATE EMISSIONS FROM THE ASPHALT PROCESSING AND ASPHALT ROOFING INDUSTRY

[Method 5A amended and corrected by 52 FR 34639, September 14, 1987]

1. Applicability and principle.

1.1 *Applicability.* This method applies to the determination of particulate emissions from asphalt roofing industry process saturators, blowing stills, and other sources as specified in the regulations.

1.2 *Principle.* Particulate matter is withdrawn isokinetically from the source and collected on a glass filter fiber maintained at a temperature of 42°±10°C (108°±18°F). The particulate mass, which includes any material that condenses at or above the filtration temperature, is determined gravimetrically after removal of uncombined water.

2. Apparatus.

2.1 Sampling Train. The sampling train configuration is the same as shown in Figure 5-1 of Method 5. The sampling train consists of the following components:

2.1.1 Probe Nozzle, Pitot Tube, Differential Pressure Gauge, Filter Holder, Condenser, Metering System, Barometer, and Gas Density Determination Equipment. Same as Method 5, Sections 2.1.1, 2.1.3 to 2.1.5, and 2.1.7 to 2.1.10, respectively.

2.1.2 Probe Liner. Same as in Method 5, Section 2.1.2, with the note that at high stack gas temperatures (greater than 250°C

[Appendix A, Method 5A]

3. Margeson, J.H., J.E. Knoll, and M.R. Midgett. A Manual Method for TRS Determination. Draft available from the authors. Source Branch, Quality Assurance Division, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

METHOD 17—DETERMINATION OF PARTICULATE EMISSIONS FROM STATIONARY SOURCES (IN-STACK FILTRATION METHOD)

[Method 17 corrected by 52 FR 34639, September 14, 1987]

Introduction

Particulate matter is not an absolute quantity; rather, it is a function of temperature and pressure. Therefore, to prevent variability in particulate matter emission regulations and/or-associated test methods, the temperature and pressure at which particulate matter is to be measured must be carefully defined. Of the two variables (i.e., temperature and pressure), temperature has the greater effect upon the amount of particulate matter in an effluent gas stream; in most stationary source categories, the effect

of pressure appears to be negligible.

In method 5, 250° F is established as a nominal reference temperature. Thus, where Method 5 is specified in an applicable subpart of the standards, particulate matter is defined with respect to temperature. In order to maintain a collection temperature of 250° F, Method 5 employs a heated glass sample probe and a heated filter holder. This equipment is somewhat cumbersome and requires care in its operation. Therefore, where particulate matter concentrations (over the normal range of temperature associated with a specified source category) are known to be independent of temperature, it is desirable to eliminate the glass probe and heating systems, and sample at stack temperature.

This method describes an in-stack sampling system and sampling procedures for use in such cases. It is intended to be used only when specified by an applicable subpart of the standards, and only within the applicable temperature limits (if specified), or when otherwise approved by the Administrator.

1. Principle and Applicability.

1.1 Principle. Particulate matter is withdrawn isokinetically from the source and collected on a glass fiber filter maintained at stack temperature. The particulate mass

is determined gravimetrically after removal of uncombined water.

1.2 Applicability. This method applies to the determination of particulate emissions from stationary sources for determining compliance with new source performance standards, only when specifically provided for in an applicable subpart of the standards. This method is not applicable to stacks that contain liquid droplets or are saturated with water vapor. In addition, this method shall not be used as written if the projected cross-sectional area of the probe extension-filter holder assembly covers more than 5 percent of the stack cross-sectional area (see Section 4.1.2).

2. Apparatus.

2.1 Sampling Train. A schematic of the sampling train used in this method is shown in Figure 17-1. Construction details for many, but not all, of the train components are given in APTD-0581 (Citation 2 in Bibliography; for changes from the APTD-0581 document and for allowable modifications to Figure 17-1, consult with the Administrator.

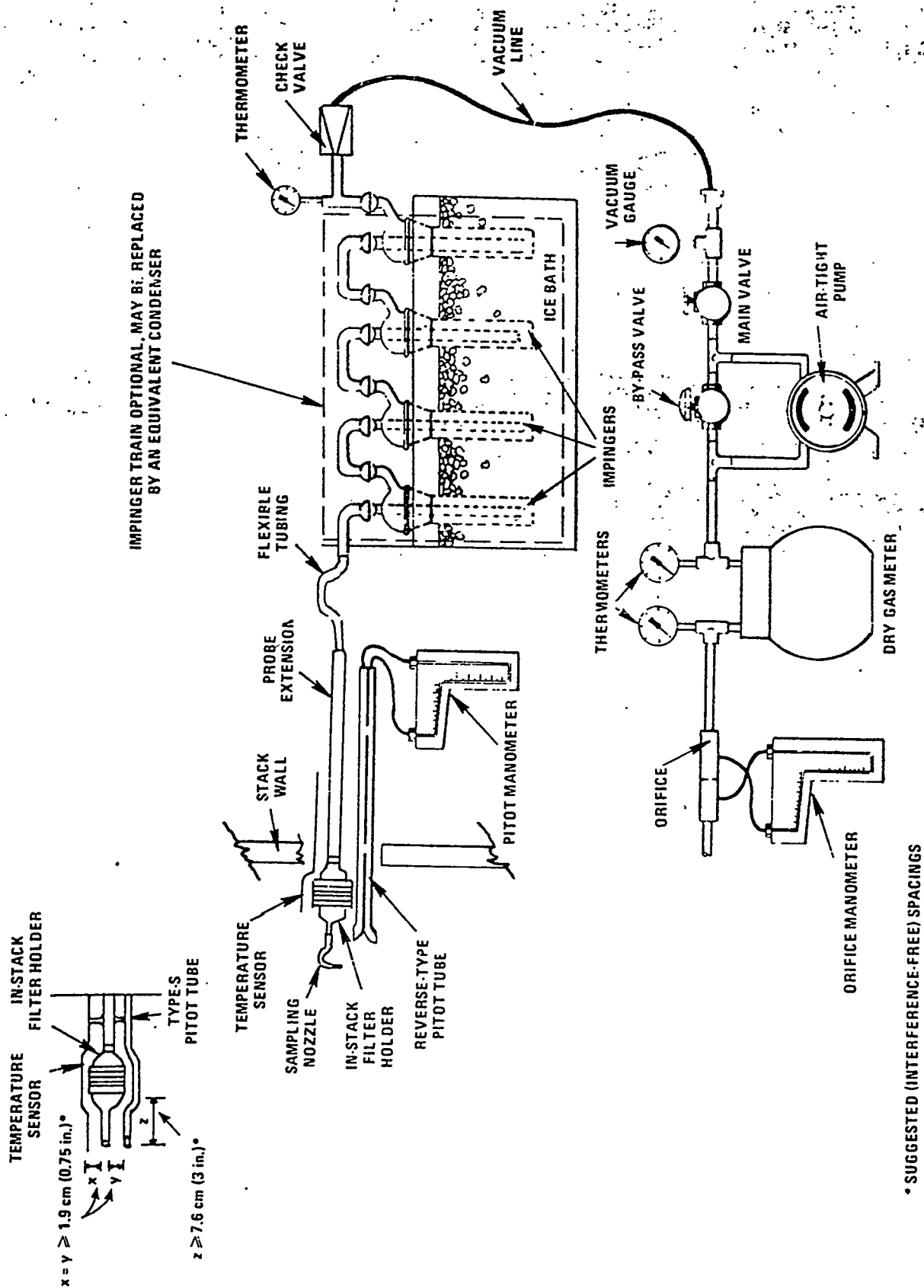


Figure 17-1. Particulate-Sampling Train, Equipped with In-Stack Filter.

[Appendix A, Method 17]

The operating and maintenance procedures for many of the sampling training components are described in APTD-0576 (Citation 3 in Bibliography). Since correct usage is important in obtaining valid results, all users should read the APTD-0576 document and adopt the operating and maintenance procedures outlined in it, unless otherwise specified herein. The sampling train consists of the following components:

[2.1 amended by 55 FR 47472, November 14, 1990]

2.1.1 Probe Nozzle. Stainless steel (316) or glass, with sharp, tapered leading edge. The angle of taper shall be 30° and the taper shall be on the outside to preserve a constant internal diameter. The probe nozzle shall be of the button-hook or elbow design, unless otherwise specified by the Administrator. If made of stainless steel, the nozzle shall be constructed from seamless tubing. Other materials of construction may be used subject to the approval of the Administrator.

A range of sizes suitable for isokinetic sampling should be available, e.g., 0.32 to 1.27 cm ($\frac{1}{8}$ to $\frac{1}{2}$ in)—or larger if higher volume sampling trains are used—inside diameter (ID) nozzles in increments of 0.16 cm ($\frac{1}{16}$ in). Each nozzle shall be calibrated according to the procedures outlined in Section 5.1.

2.1.2 Filter Holder. The in-stack filter holder shall be constructed of borosilicate or quartz glass, or stainless steel; if a gasket is used, it shall be made of silicone rubber, Teflon, or stainless steel. Other holder and gasket materials may be used subject to the approval of the Administrator. The filter holder shall be designed to provide a positive seal against leakage from the outside or around the filter.

2.1.3 Probe Extension. Any suitable rigid probe extension may be used after the filter holder.

2.1.4 Pitot Tube. Type S, as described in Section 2.1 of Method 2, or other device approved by the Administrator; the pitot tube shall be attached to the probe extension to allow constant monitoring of the stack gas velocity (see Figure 17-1). The impact (high pressure) opening plane of the pitot tube shall be even with or above the nozzle entry plane during sampling (see Method 2, Figure 2-6b). It is recommended: (1) that the pitot tube have a known baseline coefficient, determined as outlined in Section 4 of Method 2; and (2) that this known coefficient be preserved by placing the pitot tube in an interference-free arrangement with respect to the sampling nozzle, filter holder, and temperature sensor (see Figure 17-1). Note that the 1.9 cm (0.75 in) free-space between the nozzle and pitot tube shown in Figure 17-1, is based on a 1.3 cm (0.5 in) ID nozzle. If the sampling train is designed for sampling at higher flow rates than that described in APTD-0581, thus necessitating the use of larger sized nozzles, the free-space shall be 1.9 cm (0.75 in) with the largest sized nozzle in place.

Source-sampling assemblies that do not meet the minimum spacing requirements of Figure 17-1 (or the equivalent of these requirements, e.g., Figure 2-7 of Method 2) may be used; however, the pitot tube coefficients of such assemblies shall be determined by calibration, using methods subject to the approval of the Administrator.

2.1.5 Differential Pressure Gauge. Inclined manometer or equivalent device (two), as described in Section 2.2 of Method 2. One manometer shall be used for velocity head (Δp) readings, and the other, for orifice differential pressure readings.

2.1.6 Condenser. It is recommended that the impinger system described in Method 5 be used to determine the moisture content of the stack gas. Alternatively, any system that allows measurement of both the water condensed and the moisture leaving the condenser, each to within 1 ml or 1 g, may be used. The moisture leaving the condenser can be measured either by: (1) monitoring the temperature and pressure at the exit of the condenser and using Dalton's law of partial pressures; or (2) passing the sample gas stream through a silica gel trap with exit gases kept below 20° C (68° F) and determining the weight gain.

Flexible tubing may be used between the probe extension and condenser. If means other than silica gel are used to determine the amount of moisture leaving the condenser, it is recommended that silica gel still be used between the condenser system and pump to prevent moisture condensation in the pump and metering devices and to avoid the need to make corrections for moisture in the metered volume.

2.1.7 Metering System. Vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 3° C (5.4° F), dry gas meter capable of measuring volume to within 2 percent, and related equipment, as shown in Figure 17-1. Other metering systems capable of maintaining sampling rates within 10 percent of isokinetic and of determining sample volumes to within 2 percent may be used, subject to the approval of the Administrator. When the metering system is used in conjunction with a pitot tube, the system shall enable checks of isokinetic rates.

Sampling trains utilizing metering systems designed for higher flow rates than that described in APTD-0581 or APTD-0576 may be used provided that the specifications of this method are met.

2.1.8 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg). In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase or vice versa for elevation decrease.

2.1.9 Gas Density Determination Equipment. Temperature sensor and pressure

gauge, as described in Sections 2.3 and 2.4 of Method 2, and gas analyzer, if necessary, as described in Method 3.

The temperature sensor shall be attached to either the pitot tube or to the probe extension, in a fixed configuration. If the temperature sensor is attached in the field; the sensor shall be placed in an interference-free arrangement with respect to the Type S pitot tube openings (as shown in Figure 17-1 or in Figure 2-7 of Method 2). Alternatively, the temperature sensor need not be attached to either the probe extension or pitot tube during sampling, provided that a difference of not more than 1 percent in the average velocity measurement is introduced. This alternative is subject to the approval of the Administrator.

2.2 Sample Recovery.

2.2.1 Probe Nozzle Brush. Nylon bristle brush with stainless steel wire handle. The brush shall be properly sized and shaped to brush out the probe nozzle.

2.2.2 Wash Bottles—Two. Glass wash bottles are recommended; polyethylene wash bottles may be used at the option of the tester. It is recommended that acetone not be stored in polyethylene bottles for longer than a month.

2.2.3 Glass Sample Storage Containers. Chemically resistant, borosilicate glass bottles, for acetone washes, 500 ml or 1000 ml. Screw cap liners shall either be rubber-backed Teflon or shall be constructed so as to be leak-free and resistant to chemical attack by acetone. (Narrow mouth glass bottles have been found to be less prone to leakage.) Alternatively, polyethylene bottles may be used.

2.2.4 Petri Dishes. For filter samples; glass or polyethylene, unless otherwise specified by the Administrator.

2.2.5 Graduated Cylinder and/or Balance. To measure condensed water to within 1 ml or 1 g. Graduated cylinders shall have subdivisions no greater than 2 ml. Most laboratory balances are capable of weighing to the nearest 0.5 g or less. Any of these balances is suitable for use here and in Section 2.3.4.

2.2.6 Plastic Storage Containers. Air tight containers to store silica gel.

2.2.7 Funnel and Rubber Policeman. To aid in transfer of silica gel to container; not necessary if silica gel is weighed in the field.

2.2.8 Funnel. Glass or polyethylene, to aid in sample recovery.

2.3 Analysis.

2.3.1 Glass Weighing Dishes.

2.3.2 Desiccator.

2.3.3 Analytical Balance. To measure to within 0.1 mg.

2.3.4 Balance. To measure to within 0.5 mg.

2.3.5 Beakers. 250 ml.

2.3.6 Hygrometer. To measure the relative humidity of the laboratory environment.

2.3.7 Temperature Gauge. To measure the temperature of the laboratory environment.

3. Reagents.

3.1 Sampling.

[Appendix A, Method 17]

3.1.1 Filters. The in-stack filters shall be glass mats or thimble fiber filters, without organic binders, and shall exhibit at least 99.95 percent efficiency (0.05 percent penetration) on 0.3 micron dioctyl phthalate smoke particles. The filter efficiency tests shall be conducted in accordance with ASTM Standard Method D2986-71 (Reapproved 1978) (incorporated by reference—see § 60.17). Test data from the supplier's quality control program are sufficient for this purpose.

3.1.2 Silica Gel. Indicating type, 6- to 16-mesh. If previously used, dry at 175° C (350° F) for 2 hours. New silica gel may be used as received. Alternatively, other types of desiccants (equivalent or better) may be used, subject to the approval of the Administrator.

3.1.3 Crushed Ice.

3.1.4 Stopcock Grease. Acetone-insoluble, heat-stable silicone grease. This is not necessary if screw-on connectors with Teflon sleeves, or similar, are used. Alternatively, other types of stopcock grease may be used, subject to the approval of the Administrator.

3.1.5 Water. Same as in Method 5, Section 3.1.3.

[3.1.5 added by 55 FR 474721 November 14, 1990]

3.2 Sample Recovery. Acetone, reagent grade, 0.001 percent residue, in glass bottles. Acetone from metal containers generally has a high residue blank and should not be used. Sometimes, suppliers transfer acetone to glass bottles from metal containers. Thus, acetone blanks shall be run prior to field use and only acetone with low blank values (0.001 percent) shall be used. In no case shall a blank value of greater than 0.001 percent of the weight of acetone used be subtracted from the sample weight.

3.3 Analysis.

3.3.1 Acetone. Same as 3.2.

3.3.2 Desiccant. Anhydrous calcium sulfate, indicating type. Alternatively, other types of desiccants may be used, subject to the approval of the Administrator.

4. Procedure.

4.1 Sampling. The complexity of this method is such that, in order to obtain reliable results, testers should be trained and experienced with the test procedures.

4.1.1 Pretest Preparation. All components shall be maintained and calibrated according to the procedure described in APTD-0576, unless otherwise specified herein.

Weigh several 200 to 300 g portions of silica gel in air-tight containers to the nearest 0.5 g. Record the total weight of the silica gel plus container, on each container. As an alternative, the silica gel need not be preweighed, but may be weighed directly in its impinger or sampling holder just prior to train assembly.

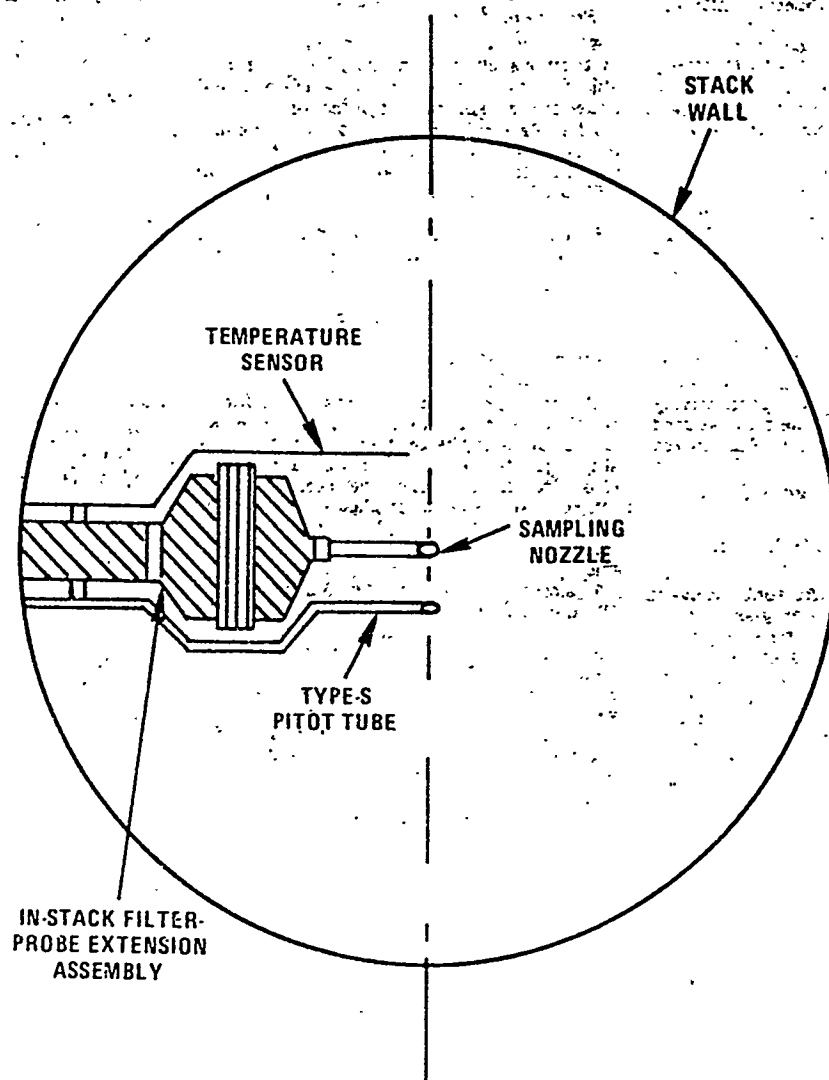
Check filters visually against light for irregularities and flaws or pinhole leaks. Label filters of the proper size on the back side near the edge using numbering machine ink. As an alternative, label the shipping containers (glass or plastic petri dishes) and keep the filters in these containers at all times except during sampling and weighing.

Desiccate the filters at $20 \pm 5.6^\circ \text{C}$ ($68 \pm 10^\circ \text{F}$) and ambient pressure for at least 24 hours and weigh at intervals of at least 6 hours to a constant weight, i.e., 0.5 mg change from previous weighing; record results to the nearest 0.1 mg. During each weighing the filter must not be exposed to the laboratory atmosphere for a period greater than 2 minutes and a relative humidity above 50 percent. Alternatively (unless otherwise specified by the Administrator), the filters may be oven dried at 105°C (220°F) for 2 to 3 hours, desiccated for 2 hours, and weighed. Procedures other than

those described, which account for relative humidity effects, may be used, subject to the approval of the Administrator.

4.1.2 Preliminary Determinations. Select the sampling site and the minimum number of sampling points according to Method 1 or as specified by the Administrator. Make a projected-area model of the probe extension-filter holder assembly, with the pitot tube face openings positioned along the centerline of the stack, as shown in Figure 17-2. Calculate the estimated cross-section blockage, as shown in Figure 17-2. If the blockage exceeds 5 percent of the duct cross sectional area, the tester has the following options: (1) a suitable out-of-stack filtration method may be used instead of in-stack filtration; or (2) a special in-stack arrangement, in which the sampling and velocity measurement sites are separate, may be used; for details concerning this approach, consult with the Administrator (see also Citation 10 in Bibliography 7). Determine the stack pressure, temperature, and the range of velocity heads using Method 2; it is recommended that a leak-check of the pitot lines (see Method 2, Section 3.1) be performed. Determine the moisture content using Approximation Method 4 or its alternatives for the purpose of making isokinetic sampling rate settings. Determine the stack gas dry molecular weight, as described in Method 2, Section 3.6; if integrated Method 3 sampling is used for molecular weight determination, the integrated bag sample shall be taken simultaneously with, and for the same total length of time as, the particular sample run.

[4.1.2 amended by 55 FR 47472, November 14, 1990]



$$\text{ESTIMATED BLOCKAGE (\%)} = \left[\frac{\text{SHADED AREA}}{\text{DUCT AREA}} \right] \times 100$$

Figure 17-2. Projected-area model of cross-section blockage (approximate average for a sample traverse) caused by an in-stack filter holder-probe extension assembly.

[Appendix A, Method 17]

Select a nozzle size based on the range of velocity heads, such that it is not necessary to change the nozzle size in order to maintain isokinetic sampling rates. During the run, do not change the nozzle size. Ensure that the proper differential pressure gauge is chosen for the range of velocity heads encountered (see Section 2.2 of Method 2).

Select a probe extension length such that all traverse points can be sampled. For large stacks, consider sampling from opposite sides of the stack to reduce the length of probes.

Select a total sampling time greater than or equal to the minimum total sampling time specified in the test procedures for the specific industry such that (1) the sampling time per point is not less than 2 minutes (or some greater time interval if specified by the Administrator), and (2) the sample volume taken (corrected to standard conditions) will exceed the required minimum total gas sample volume. The latter is based on an approximate average sampling rate.

It is recommended that the number of minutes sampled at each point be an integer or an integer plus one-half minute, in order to avoid timekeeping errors.

In some circumstances, e.g., batch cycles, it may be necessary to sample for shorter times at the traverse points and to obtain smaller gas sample volumes. In these cases, the Administrator's approval must first be obtained.

4.1.3 Preparation of Collection Train. During preparation and assembly of the sampling train, keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.

If impingers are used to condense stack gas moisture, prepare them as follows: place 100 ml of water in each of the first two impingers, leave the third impinger empty, and transfer approximately 200 to 300 g of preweighed silica gel from its container to the fourth impinger. More silica gel may be used, but care should be taken to ensure that it is not entrained and carried out from the impinger during sampling. Place the container in a clean place for later use in the sample recovery. Alternatively, the weight of the silica gel plus impinger may be determined to the nearest 0.5 g and recorded.

If some means other than impingers is used to condense moisture, prepare the condenser (and, if appropriate, silica gel for condenser outlet) for use.

Using a tweezer or clean disposable surgical gloves, place a labeled (identified) and

weighed filter in the filter holder. Be sure that the filter is properly centered and the gasket properly placed so as not to allow the sample gas stream to circumvent the filter. Check filter for tears after assembly is completed. Mark the probe extension with heat resistant tape or by some other method to denote the proper distance into the stack or duct for each sampling point.

Assemble the train as in Figure 17-1, using a very light coat of silicone grease on all ground glass joints and greasing only the outer portion (see APTD-0576) to avoid possibility of contamination by the silicone grease. Place crushed ice around the impingers.

4.1.4 Leak Check Procedures.

4.1.4.1 Pretest Leak-Check. A pretest leak-check is recommended, but not required. If the tester opts to conduct the pretest leak-check, the following procedure shall be used.

After the sampling train has been assembled, plug the inlet to the probe nozzle with a material that will be able to withstand the stack temperature. Insert the filter holder into the stack and wait approximately 5 minutes (or longer, if necessary) to allow the system to come to equilibrium with the temperature of the stack gas stream. Turn on the pump and draw a vacuum of at least 380 mm Hg (15 in. Hg); note that a lower vacuum may be used, provided that it is not exceeded during the test. Determine the leakage rate. A leakage rate in excess of 4 percent of the average sampling rate or 0.00057 m³/min. (0.02 cfm), whichever is less, is unacceptable.

The following leak-check instructions for the sampling train described in APTD-0576 and APTD-0581 may be helpful. Start the pump with by-pass valve fully open and coarse adjust valve completely closed. Partially open the coarse adjust valve and slowly close the by-pass valve until the desired vacuum is reached. Do not reverse direction of by-pass valve. If the desired vacuum is exceeded, either leak-check at this higher vacuum or end the leak-check as shown below and start over.

When the leak-check is completed, first slowly remove the plug from the inlet to the probe nozzle and immediately turn off the vacuum pump. This prevents water from being forced backward and keeps silica gel from being entrained backward.

4.1.4.2 Leak-Checks During Sample Run. If, during the sampling run, a component (e.g., filter assembly or impinger) change becomes necessary, a leak-check shall be con-

ducted immediately before the change is made. The leak-check shall be done according to the procedure outlined in Section 4.1.4.1 above, except that it shall be done at a vacuum equal to or greater than the maximum value recorded up to that point in the test. If the leakage rate is found to be no greater than 0.00057 m³/min (0.02 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction will need to be applied to the total volume of dry gas metered; if, however, a higher leakage rate is obtained, the tester shall either record the leakage rate and plan to correct the sample volume as shown in Section 6.3 of this method, or shall void the sampling run.

Immediately after component changes, leak-checks are optional; if such leak-checks are done, the procedure outlined in Section 4.1.4.1 above shall be used.

4.1.4.3 Post-Test Leak-Check. A leak-check is mandatory at the conclusion of each sampling run. The leak-check shall be done in accordance with the procedures outlined in Section 4.1.4.1, except that it shall be conducted at a vacuum equal to or greater than the maximum value reached during the sampling run. If the leakage rate is found to be no greater than 0.00057 m³/min (0.02 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction need be applied to the total volume of dry gas metered. If, however, a higher leakage rate is obtained, the tester shall either record the leakage rate and correct the sample volume as shown in Section 6.3 of this method, or shall void the sampling run.

4.1.5 Particulate Train Operation. During the sampling run, maintain a sampling rate such that sampling is within 10 percent of true isokinetic, unless otherwise specified by the Administrator.

For each run, record the data required on the example data sheet shown in Figure 17-3. Be sure to record the initial dry gas meter reading. Record the dry gas meter readings at the beginning and end of each sampling time increment, when changes in flow rates are made, before and after each leak check, and when sampling is halted. Take other readings required by Figure 17-3 at least once at each sample point during each time increment and additional readings when significant changes (20 percent variation in velocity head readings) necessitate additional adjustments in flow rate. Level and zero the manometer. Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse.

Clean the portholes prior to the test run to minimize the chance of sampling the deposited material. To begin sampling, remove the nozzle cap and verify that the pitot tube and probe extension are properly positioned. Position the nozzle at the first traverse point with the tip pointing directly into the gas stream. Immediately start the pump and adjust the flow to isokinetic conditions. Nomographs are available, which aid in the rapid adjustment to the isokinetic sampling rate without excessive computations. These nomographs are designed for use when the Type S pitot tube coefficient is 0.85 ± 0.02 , and the stack gas equivalent density (dry molecular weight) is equal to 29 ± 4 . APTD-0576 details the procedure for using the nomographs. If C_p and M_g are outside the above stated ranges, do not use the nomographs unless appropriate steps (see Citation 7 in Bibliography) are taken to compensate for the deviations.

[4.1.5 amended by 55 FR 47472, November 14, 1990]

When the stack is under significant negative pressure (height of impinger stem), take care to close the coarse adjust valve before inserting the probe extension assembly into the stack to prevent water from being forced backward. If necessary, the pump may be turned on with the coarse adjust valve closed.

When the probe is in position, block off the openings around the probe and porthole to prevent unrepresentative dilution of the gas stream.

Traverse the stack cross section, as required by Method 1 or as specified by the Administrator, being careful not to bump the probe nozzle into the stack walls when sampling near the walls or when removing or inserting the probe extension through the portholes, to minimize chance of extracting deposited material.

During the test run, take appropriate steps (e.g., adding crushed ice to the impinger ice bath) to maintain a temperature of less than 20°C (68°F) at the condenser outlet; this will prevent excessive moisture losses. Also, periodically check the level and zero of the manometer.

If the pressure drop across the filter becomes too high, making isokinetic sampling difficult to maintain, the filter may be replaced in the midst of a sample run. It is recommended that another complete filter holder assembly be used rather than attempting to change the filter itself. Before a new filter holder is installed, conduct a leak check, as outlined in Section 4.1.4.2. The total particulate weight shall include the summation of all filter assembly catches.

A single train shall be used for the entire sample run, except in cases where simultaneous sampling is required in two or more separate ducts or at two or more different locations within the same duct, or, in cases where equipment failure necessitates a change of trains. In all other situations, the use of two or more trains will be subject to the approval of the Administrator. Note that when two or more trains are used, a separate analysis of the collected particulate from each train shall be performed, unless identical nozzle sizes were used on all trains, in which case the particulate catches from the individual trains may be combined and a single analysis performed.

At the end of the sample run, turn off the pump, remove the probe extension assembly from the stack, and record the final dry gas meter reading. Perform a leak-check, as outlined in Section 4.1.4.3. Also, leak-check the

pitot lines as described in Section 3.1 of Method 2; the lines must pass this leak check, in order to validate the velocity head data.

4.1.6 Calculation of Percent Isokinetic. Calculate percent isokinetic (see Section 6.11) to determine whether another test run should be made. If there is difficulty in maintaining isokinetic rates due to source conditions, consult with the Administrator for possible variance on the isokinetic rates.

4.2 Sample Recovery. Proper cleanup procedure begins as soon as the probe extension assembly is removed from the stack at the end of the sampling period. Allow the assembly to cool.

When the assembly can be safely handled, wipe off all external particulate matter near the tip of the probe nozzle and place a cap over it to prevent losing or gaining particulate matter. Do not cap off the probe tip tightly while the sampling train is cooling down as this would create a vacuum in the filter holder, forcing condenser water backward.

Before moving the sample train to the cleanup site, disconnect the filter holder-probe nozzle assembly from the probe extension; cap the open inlet of the probe extension. Be careful not to lose any condensate, if present. Remove the umbilical cord from the condenser outlet and cap the outlet. If a flexible line is used between the first impinger (or condenser) and the probe extension, disconnect the line at the probe extension and let any condensed water or liquid drain into the impingers or condenser. Disconnect the probe extension from the condenser; cap the probe extension outlet. After wiping off the silicone grease, cap off the condenser inlet. Ground glass stoppers, plastic caps, or serum caps (whichever are appropriate) may be used to close these openings.

Transfer both the filter holder-probe nozzle assembly and the condenser to the cleanup area. This area should be clean and protected from the wind so that the chances of contaminating or losing the sample will be minimized.

Save a portion of the acetone used for cleanup as a blank. Take 200 ml of this acetone directly from the wash bottle being used and place it in a glass sample container labeled "acetone blank."

Inspect the train prior to and during disassembly and note any abnormal conditions. Treat the samples as follows:

Container No. 1. Carefully remove the filter from the filter holder and place it in its identified petri dish container. Use a pair of tweezers and/or clean disposable surgical gloves to handle the filter. If it is necessary to fold the filter, do so such that the particulate cake is inside the fold. Carefully transfer to the petri dish any particulate matter and/or filter fibers which adhere to the filter holder gasket, by using a dry Nylon bristle brush and/or a sharp-edged blade. Seal the container.

Container No. 2. Taking care to see that dust on the outside of the probe nozzle or other exterior surfaces does not get into the sample, quantitatively recover particulate matter or any condensate from the probe nozzle, fitting, and front half of the filter holder by washing these components with acetone and placing the wash in a glass container. Distilled water may be used instead of acetone when approved by the Administrator and shall be used when specified by the Administrator; in these cases, save a water blank and follow Administrator's di-

rections on analysis. Perform the acetone rinses as follows:

Carefully remove the probe nozzle and clean the inside surface by rinsing with acetone from a wash bottle and brushing with a Nylon bristle brush. Brush until acetone rinse shows no visible particles, after which make a final rinse of the inside surface with acetone.

Brush and rinse with acetone the inside parts of the fitting in a similar way until no visible particles remain. A funnel (glass or polyethylene) may be used to aid in transferring liquid washes to the container. Rinse the brush with acetone and quantitatively collect these washings in the sample container. Between sampling runs, keep brushes clean and protected from contamination.

After ensuring that all joints are wiped clean of silicone grease (if applicable), clean the inside of the front half of the filter holder by rubbing the surfaces with a Nylon bristle brush and rinsing with acetone. Rinse each surface three times or more if needed to remove visible particulate. Make final rinse of the brush and filter holder. After all acetone washings and particulate matter are collected in the sample container, tighten the lid on the sample container so that acetone will not leak out when it is shipped to the laboratory. Mark the height of the fluid level to determine whether or not leakage occurred during transport. Label the container to clearly identify its contents.

Container No. 3. If silica gel is used in the condenser system for moisture content determination, note the color of the gel to determine if it has been completely spent; make a notation of its condition. Transfer the silica gel back to its original container and seal. A funnel may make it easier to pour the silica gel without spilling, and a rubber policeman may be used as an aid in removing the silica gel. It is not necessary to remove the small amount of dust particles that may adhere to the walls and are difficult to remove. Since the gain in weight is to be used for moisture calculations, do not use any water or other liquids to transfer the silica gel. If a balance is available in the field, follow the procedure for Container No. 3 under "Analysis."

Condenser Water. Treat the condenser or impinger water as follows: make a notation of any color or film in the liquid catch. Measure the liquid volume to within ± 1 ml by using a graduated cylinder or, if a balance is available, determine the liquid weight to within ± 0.5 g. Record the total volume or weight of liquid present. This information is required to calculate the moisture content of the effluent gas. Discard the liquid after measuring and recording the volume or weight.

4.3 Analysis. Record the data required on the example sheet shown in Figure 17-4. Handle each sample container as follows:

Container No. 1. Leave the contents in the shipping container or transfer the filter and any loose particulate from the sample container to a tared glass weighing dish. Desiccate for 24 hours in a desiccator containing anhydrous calcium sulfate. Weigh to a constant weight and report the results to the nearest 0.1 mg. For purposes of this Section, 4.3, the term "constant weight" means a difference of no more than 0.5 mg or 1 percent of total weight less tare weight, whichever is greater, between two consecutive weighings, with no less than 6 hours of desiccation time between weighings.

Alternatively, the sample may be oven dried at the average stack temperature or

[Appendix A, Method 17]

105° C (220° F); whichever is less, for 2 to 3 hours, cooled in the desiccator, and weighed to a constant weight, unless otherwise specified by the Administrator. The tester may also opt to oven dry the sample at the average stack temperature or 105° C (220° F), whichever is less, for 2 to 3 hours, weigh the sample, and use this weight as a final weight.

105° C (220° F); whichever is less, for 2 to 3 hours, weigh the sample, and use this weight as a final weight.

105° C (220° F); whichever is less, for 2 to 3 hours, weigh the sample, and use this weight as a final weight.

Plant _____

Date _____

Run No. _____

Filter No. _____

Amount liquid lost during transport _____

Acetone blank volume, ml _____

Acetone wash volume, ml _____

Acetone blank concentration, mg/mg (equation 17-4) _____

Acetone wash blank, mg (equation 17-5) _____

CONTAINER NUMBER	WEIGHT OF PARTICULATE COLLECTED mg		
	FINAL WEIGHT	TARE WEIGHT	WEIGHT GAIN
1			
2			
TOTAL			
Less acetone blank			
Weight of particulate matter			

	VOLUME OF LIQUID WATER COLLECTED	
	IMPINGER VOLUME ml	SILICA GEL WEIGHT g
FINAL		
INITIAL		
LIQUID COLLECTED		
TOTAL VOLUME COLLECTED		g* ml

* CONVERT WEIGHT OF WATER TO VOLUME BY DIVIDING TOTAL WEIGHT INCREASE BY DENSITY OF WATER (1g/ml).

$$\frac{\text{INCREASE, g}}{1 \text{ g/ml}} = \text{VOLUME WATER, ml}$$

Figure 17-4. Analytical data.

[Appendix A, Method 17]

Container No. 2. Note the level of liquid in the container and confirm on the analysis sheet whether or not leakage occurred during transport. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results. Measure the liquid in this container either volumetrically to ± 1 ml or gravimetrically to ± 0.5 g. Transfer the contents to a tared 250-ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to a constant weight. Report the results to the nearest 0.1 mg.

Container No. 3. This step may be conducted in the field. Weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g using a balance.

"Acetone Blank" Container. Measure acetone in this container either volumetrically or gravimetrically. Transfer the acetone to a tared 250-ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to a constant weight. Report the results to the nearest 0.1 mg.

NOTE.—At the option of the tester, the contents of Container No. 2 as well as the acetone blank container may be evaporated at temperatures higher than ambient. If evaporation is done at an elevated temperature, the temperature must be below the boiling point of the solvent; also, to prevent "bumping," the evaporation process must be closely supervised, and the contents of the beaker must be swirled occasionally to maintain an even temperature. Use extreme care, as acetone is highly flammable and has a low flash point.

5. Calibration. Maintain a laboratory log of all calibrations.

5.1 Probe Nozzle. Probe nozzles shall be calibrated before their initial use in the field. Using a micrometer, measure the inside diameter of the nozzle to the nearest

0.025 mm (0.001 in.). Make three separate measurements using different diameters each time, and obtain the average of the measurements. The difference between the high and low numbers shall not exceed 0.1 mm (0.004 in.). When nozzles become nicked, dented, or corroded, they shall be reshaped, sharpened, and recalibrated before use. Each nozzle shall be permanently and uniquely identified.

5.2 Pitot Tube. If the pitot tube is placed in an interference-free arrangement with respect to the other probe assembly components, its baseline (isolated tube) coefficient shall be determined as outlined in Section 4 of Method 2. If the probe assembly is not interference-free, the pitot tube assembly coefficient shall be determined by calibration, using methods subject to the approval of the Administrator.

5.3 Metering System. Before its initial use in the field, the metering system shall be calibrated according to the procedure outlined in APTD-0576. Instead of physically adjusting the dry gas meter dial readings to correspond to the wet test meter readings, calibration factors may be used to mathematically correct the gas meter dial readings to the proper values.

Before calibrating the metering system, it is suggested that a leak-check be conducted. For metering systems having diaphragm pumps, the normal leak-check procedure will not detect leakages within the pump. For these cases the following leak-check procedure is suggested: make a 10-minute calibration run at $0.00057 \text{ m}^3/\text{min}$ (0.02 cfm); at the end of the run, take the difference of the measured wet test meter and dry gas meter volumes; divide the difference by 10, to get the leak rate. The leak rate should not exceed $0.00057 \text{ m}^3/\text{min}$ (0.02 cfm).

After each field use, the calibration of the metering system shall be checked by performing three calibration runs at a single, intermediate orifice setting (based on the

previous field test), with the vacuum set at the maximum value reached during the test series. To adjust the vacuum, insert a valve between the wet test meter and the inlet of the metering system. Calculate the average value of the calibration factor. If the calibration has changed by more than 5 percent, recalibrate the meter over the full range of orifice settings, as outlined in APTD-0576.

Alternative procedures, e.g., using the orifice meter coefficients, may be used, subject to the approval of the Administrator.

NOTE.—If the dry gas meter coefficient values obtained before and after a test series differ by more than 5 percent, the test series shall either be voided, or calculations for the test series shall be performed using whichever meter coefficient value (i.e., before or after) gives the lower value of total sample volume.

5.4 Temperature Gauges. Use the procedure in Section 4.3 of Method 2 to calibrate in-stack temperature gauges. Dial thermometers, such as are used for the dry gas meter and condenser outlet, shall be calibrated against mercury-in-glass thermometers.

5.5 Leak Check of Metering System Shown in Figure 17-1. That portion of the sampling train from the pump to the orifice meter should be leak checked prior to initial use and after each shipment. Leakage after the pump will result in less volume being recorded than is actually sampled. The following procedure is suggested (see Figure 17-5). Close the main valve on the meter box. Insert a one-hole rubber stopper with rubber tubing attached into the orifice exhaust pipe. Disconnect and vent the low side of the orifice manometer. Close off the low side orifice tap. Pressurize the system to 13 to 18 cm (5 to 7 in.) water column by blowing into the rubber tubing. Pinch off the tubing and observe the manometer for one minute. A loss of pressure on the manometer indicates a leak in the meter box; leaks, if present, must be corrected.

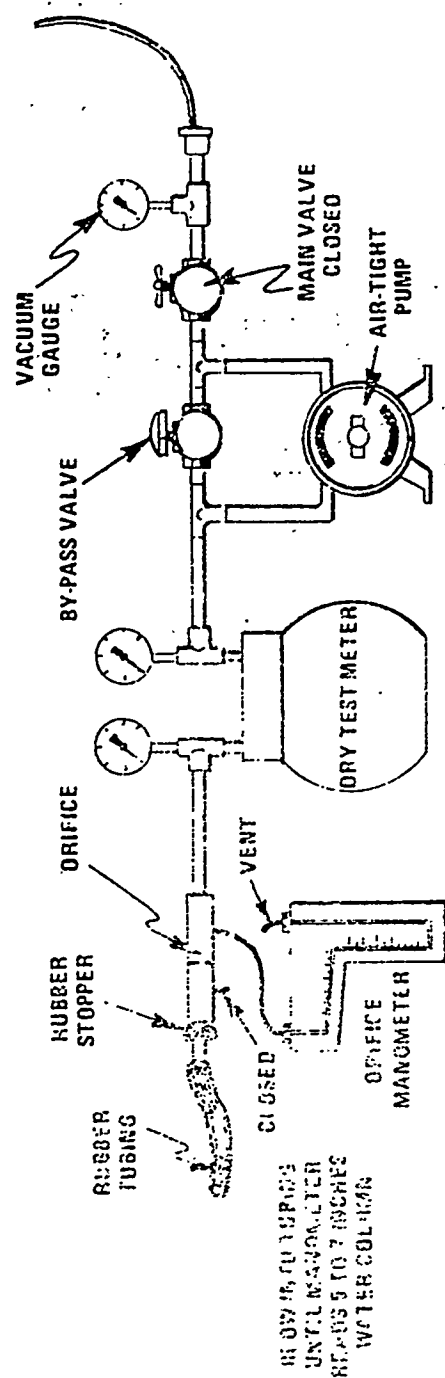


Figure 17 5. Leak check of meter box.

[Appendix A, Method 17]

5.6 Barometer. Calibrate against a mercury barometer.

6 Calculations. Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after the final calculation. Other forms of the equations may be used as long as they give equivalent results.

6.1 Nomenclature.

[6.1 corrected by 52 FR 34639, September 14, 1987; 52 FR 42061, November 2, 1987]

A_n = Cross-sectional area of nozzle, m^2 (ft^2).

B_n = Water vapor in the gas stream, proportion by volume.

C_a = Acetone blank residue concentration, mg/mg .

c_p = Concentration of particulate matter in stack gas, dry basis, corrected to standard conditions, $g/dscm$ ($g/dscf$).

I = Percent of isokinetic sampling.

L_n = Maximum acceptable leakage rate for either a pretest leak check or for a leak check following a component change; equal to 0.00057 m^3/min (0.02 cfm) or 4 percent of the average sampling rate, whichever is less.

L_i = Individual leakage rate observed during the leak check conducted prior to the "ith" component change ($i = 1, 2, 3, \dots, n$), m^3/min (cfm).

L_n = Leakage rate observed during the post-test leak check, m^3/min (cfm).

m_p = Total amount of particulate matter collected, mg .

M_n = Molecular weight of water, 18.0 g/g -mole (18.0 lb/lb -mole).

m_n = Mass of residue of acetone after evaporation, mg .

P_{bar} = Barometric pressure at the sampling site, mm Hg ($in.$ Hg).

P_s = Absolute stack gas pressure, mm Hg ($in.$ Hg).

P_{std} = Standard absolute pressure, 760 mm Hg (29.92 $in.$ Hg).

R = Ideal gas constant, 0.06236 mm Hg- m^3 / $^{\circ}K$ - g mole (21.85 $in.$ Hg- ft^3 / $^{\circ}R$ - lb -mole).

T_r = Absolute average dry gas meter temperature (see Figure 17-3), $^{\circ}K$ ($^{\circ}R$).

T_s = Absolute average stack gas temperature (see Figure 17-3), $^{\circ}K$ ($^{\circ}R$).

T_{std} = Standard absolute temperature, 293 $^{\circ}K$ (528 $^{\circ}R$).

V_a = Volume of acetone blank, ml .

V_n = Volume of acetone used in wash, ml .

V_w = Total volume of liquid collected in impingers and silica gel (see Figure 17-4), ml .

V_m = Volume of gas sample as measured by dry gas meter, dcm ($dscf$).

$V_{m(std)}$ = Volume of gas sample measured by the dry gas meter, corrected to standard conditions, $dscm$ ($dscf$).

V_{water} = Volume of water vapor in the gas sample, corrected to standard conditions, dcm ($dscf$).

v_s = Stack gas velocity, calculated by Method 2, Equation 2-9, using data obtained from Method 17, m/sec (ft/sec).

W_n = Weight of residue in acetone wash, mg .

Y = Dry gas meter calibration coefficient.

ΔH = Average pressure differential across the orifice meter (see Figure 17-3), mm H₂O ($in.$ H₂O).

ρ = Density of acetone, g/ml (see label on bottle).

ρ_w = Density of water, 0.9982 g/ml (0.06... lb/ml).

n = Total sampling time, min .

θ_i = Sampling time interval, from the beginning of a run until the first component change, min .

θ = Sampling time interval, between two successive component changes, beginning with the interval between the first and second changes, min .

θ_i = Sampling time interval, from the final (n^{th}) component change until the end of the sampling run, min .

13.6 = Specific gravity of mercury.

60 = Sec/min.

100 = Conversion to percent.

5.2 Average dry gas meter temperature and average orifice pressure drop. See data sheet (Figure 17-3).

5.3 Dry Gas Volume. Correct the sample volume measured by the dry gas meter to standard conditions (20 $^{\circ}C$, 760 mm Hg or 68 $^{\circ}F$, 29.92 $in.$ Hg) by using Equation 17-1.

$$V_{m(std)} = V_m Y \left(\frac{T_{std}}{T_m} \right) \left[\frac{P_{bar} + \frac{\Delta H}{13.6}}{P_{std}} \right]$$

$$= K_1 V_m Y \frac{P_{bar} + (\Delta H/13.6)}{T_m}$$

Equation 17-1

where:

K_1 = 0.3858 $^{\circ}K/mm$ Hg for metric units; 17.64 $^{\circ}R/in.$ Hg for English units.

NOTE.—Equation 17-1 can be used as written unless the leakage rate observed during any of the mandatory leak checks (i.e., the post-test leak check or leak checks conducted prior to component changes) exceeds L_n . If L_i or L_n exceeds L_n , Equation 17-1 must be modified as follows:

(a) Case I. No component changes made during sampling run. In this case, replace V_m in Equation 17-1 with the expression:

$$[V_m - (L_n - L_i)\theta]$$

(b) Case II. One or more component changes made during the sampling run. In this case, replace V_m in Equation 17-1 by the expression:

$$[V_m - (L_i - L_n)\theta_i - \sum_{i=2}^n (L_i - L_n)\theta_i - (L_n - L_n)\theta_p]$$

and substitute only for those leakage rates (L_i or L_n) which exceed L_n .

5.4 Volume of water vapor.

$$V_{w(std)} = V_{lc} \left(\frac{W}{M} \right) \left(\frac{RT_{std}}{P_{std}} \right) = K_2 V_{lc}$$

Equation 17-2

where:

K_2 = 0.001333 m^3/ml for metric units; 0.04707 ft^3/ml for English units.

6.5 Moisture Content.

$$B_{ws} = \frac{V_{w(std)}}{V_{m(std)} + V_{w(std)}}$$

Equation 17-3

6.6 Acetone Blank Concentration.

$$C_a = \frac{m_a}{V_a \rho_a}$$

Equation 17-4

6.7 Acetone Wash Blank.

$$W_n = C_a V_n \rho_a$$

Equation 17-5

6.8 Total Particulate Weight. Determine the total particulate catch from the sum of the weights obtained from containers 1 and 2 less the acetone blank (see Figure 17-1).

NOTE.—Refer to Section 4.1.5 to assist in calculation of results involving two or more filter assemblies or two or more sampling trains.

6.9 Particulate Concentration.

$$c_p = (0.001 \text{ g/mg}) (m_p / V_{m(std)})$$

Equation 17-6

6.10 Conversion Factors:

From	To	Multiply by
$dscf$	m^3	0.02832
g/ft^3	g/ft^3	15.43
g/ft^3	lb/ft^3	2.205×10^{-3}
g/ft^3	g/m^3	35.31

6.11 Isokinetic Variation.

6.11.1 Calculation from Raw Data.

$$I = \frac{100 \left[T_s \left(K_1 V_{lc} + \frac{V_m Y}{T_m} \right) \left(\frac{P_{bar} + \Delta H/13.6}{P_{std}} \right) - 60 v_s P_s A_n}{60 v_s P_s A_n}$$

Equation 17-7

where:

K_1 = 0.003454 mm Hg- m^3/ml - $^{\circ}K$ for metric units; 0.002669 $in.$ Hg- ft^3/ml - $^{\circ}R$ for English units.

6.11.2 Calculation from Intermediate Values

$$I = \frac{T_s V_{m(std)} P_{std} 100}{T_{std} v_s A_n P_s 60 (1 - B_{ws})}$$

$$= Y \frac{T_s V_{m(std)}}{P_s v_s A_n 60 (1 - B_{ws})}$$

Equation 17-8

where:

K_1 = 4.320 for metric units; 0.09430 for English units.

6.12 Acceptable Results. If 90 percent (0.9) or more of the results are acceptable. If the results are low in comparison to the standard and T is beyond the acceptable range, or, if I is less than 90 percent, the Administrator may opt to accept the results. Use Citation 4 in Bibliography 7 to make judgments. Otherwise, reject the results and repeat the test.

[6.12 amended by 55 FR 47472, November 14, 1990]

7. Bibliography.

[Appendix A, Method 17]

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4. Smith, W. S., R. T. Shigehara, and W. F. Todd, A Method of Interpreting Stack Sampling Data. Paper Presented at the 63rd Annual Meeting of the Air Pollution Control Association, St. Louis, Mo. June 14-19, 1970.

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10. Vollaro, R. F., Recommended Procedure for Sample Traverses in Ducts Smaller than 12 Inches in Diameter. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park, N.C. November, 1976.

METHOD 18 — MEASUREMENT OF GASEOUS ORGANIC COMPOUND EMISSIONS BY GAS CHROMATOGRAPHY

[Method 18 added by 48 FR 48335, October 18, 1983; amended by 49 FR 22606, May 30, 1984; 52 FR 5106, February 19, 1987]

Introduction. [This method should not be attempted by persons unfamiliar with the performance characteristics of gas chromatography, nor by those persons who are unfamiliar with source sampling. Particular care should be exercised in the area of safety concerning choice of equipment and operation in potentially explosive atmospheres.]

1. Applicability and Principle

1.1 Applicability. This method applies to the analysis of approximately 90 percent of the total gaseous organics emitted from an industrial source. It does not include techniques to identify and measure trace amounts of organic compounds, such as

those found in building air and fugitive emission sources.

This method will not determine compounds that (1) are polymeric (high molecular weight), (2) can polymerize before analysis, or (3) have very low vapor pressures at stack or instrument conditions.

1.2 Principle. The major organic components of a gas mixture are separated by gas chromatography (GC) and individually quantified by flame ionization, photoionization, electron capture, or other appropriate detection principles.

[1.2 revised by 52 FR 5106, February 19, 1987]

The retention times of each separated component are compared with those of known compounds under identical conditions. Therefore, the analyst confirms the identity and approximate concentrations of the organic emission components beforehand. With this information, the analyst then prepares or purchases commercially available standard mixtures to calibrate the GC under conditions identical to those of the samples. The analyst also determines the need for sample dilution to avoid detector saturation, gas stream filtration to eliminate particulate matter, and prevention of moisture condensation.

2. Range and Sensitivity

2.1 Range. The range of this method is from about 1 part per million (ppm) to the upper limit governed by GC detector saturation or column overloading. The upper limit can be extended by diluting the stack gases with an inert gas or by using smaller gas sampling loops.

2.2 Sensitivity. The sensitivity limit for a compound is defined as the minimum detectable concentration of that compound, or the concentration that produces a signal-to-noise ratio of three to one. The minimum detectable concentration is determined during the presurvey calibration for each compound.

3. Precision and Accuracy

Gas chromatographic techniques typically provide a precision of 5 to 10 percent relative standard deviation (RSD), but an experienced GC operator with a reliable instrument can readily achieve 5 percent RSD. For this method, the following combined GC/operator values are required.

(a) Precision. Duplicate analyses are within 5 percent of their mean value.

(b) Accuracy. Analysis results of prepared audit samples are within 10 percent of preparation values.

4. Interferences

Resolution interferences that may occur can be eliminated by appropriate GC column and detector choice or by shifting the retention times through changes in the column flow rate and the use of temperature programming.

The analytical system is demonstrated to be essentially free from contaminants by pe-

riodically analyzing blanks that consist of hydrocarbon-free air or nitrogen.

Sample cross-contamination that occurs when high-level and low-level samples or standards are analyzed alternately, is best dealt with by thorough purging of the GC sample loop between samples.

To assure consistent detector response, calibration gases are contained in dry air. To adjust gaseous organic concentrations when water vapor is present in the sample, water vapor concentrations are determined for those samples, and a correction factor is applied.

[4. amended by 52 FR 5106, February 19, 1987]

5. Presurvey and Presurvey Sampling

Perform a presurvey for each source to be tested. Refer to Figure 18-1. Some of the information can be collected from literature surveys and source personnel. Collect gas samples that can be analyzed to confirm the identities and approximate concentrations of the organic emissions.

[5. revised by 52 FR 5106, February 19, 1987]

5.1 Apparatus. This apparatus list also applies to Sections 6 and 7.

[5.1 revised by 52 FR 5106, February 19, 1987]

5.1.1 Teflon Tubing. (Mention of trade names or specific products does not constitute endorsement by the U.S. Environmental Protection Agency.) Diameter and length determined by connection requirements of cylinder regulators and the GC. Additional tubing is necessary to connect the GC sample loop to the sample.

5.1.2 Gas Chromatograph. GC with suitable detector, columns, temperature-controlled sample loop and valve assembly, and temperature programmable oven, if necessary. The GC shall achieve sensitivity requirements for the compounds under study.

5.1.3 Pump. Capable of pumping 100 ml/min. For flushing sample loop.

5.1.4 Flowmeters. To measure flow rates.

[5.1.4 revised by 52 FR 5106, February 19, 1987]

5.1.5 Regulators. Used on gas cylinders for GC and for cylinder standards.

5.1.6 Recorder. Recorder with linear strip chart is minimum acceptable. Integrator (optional) is recommended.

5.1.7 Syringes. 0.5 ml, 1.0- and 10-microliter sizes, calibrated, maximum accuracy (gas tight), for preparing calibration standards. Other appropriate sizes can be used.

[5.1.7 revised by 52 FR 5106, February 19, 1987]

[Appendix A, Method 18]

7.1 Selection of Sampling Site and Sampling Points. Select a measurement site and sampling points using the same criteria that are applicable to tests performed using Method 7.

7.2 Sample Collection. Position the sampling probe at the first measurement point, and begin sampling at the same rate as used during the system calibration drift test. Maintain constant rate sampling (i.e., ± 10 percent) during the entire run. The sampling time per run shall be the same as the total time required to perform a run using Method 7, plus twice the system response time. For each run, use only those measurements obtained after twice the response time of the measurement system has elapsed, to determine the average effluent concentration.

7.3 Zero and Calibration Drift Test. Follow Section 7.4 of Method 6C.

8. Emission Calculation

Follow Section 8 of Method 6C.

9. Bibliography

Same as bibliography of Method 6C.

METHOD 8. DETERMINATION OF SULFURIC ACID MIST AND SULFUR DIOXIDE EMISSIONS FROM STATIONARY SOURCES

[Method 8 amended and corrected by 52 FR 34639, September 14, 1987]

1. Principle and Applicability

1.1 Principle. A gas sample is extracted isokinetically from the stack. The sulfuric acid mist (including sulfur trioxide) and the sulfur dioxide are separated, and both frac-

tions are measured separately by the barium-thorin titration method.

1.2 Applicability. This method is applicable for the determination of sulfuric acid mist (including sulfur trioxide, and in the absence of other particulate matter) and sulfur dioxide emissions from stationary sources. Collaborative tests have shown that the minimum detectable limits of the method are 0.05 milligrams/cubic meter ($0.03 > 10^{-3}$ pounds/cubic foot) for sulfur trioxide and 1.2 mg/m^3 ($0.74 > 10^{-3} \text{ lb/ft}^3$) for sulfur dioxide. No upper limits have been established. Based on theoretical calculations for 200 milliliters of 3 percent hydrogen peroxide solution, the upper concentration limit for sulfur dioxide in a 1.0 m^3 (35.3 ft^3) gas sample is about $12,500 \text{ mg/m}^3$ ($7.7 > 10^{-3} \text{ lb/ft}^3$). The upper limit can be extended by increasing the quantity of peroxide solution in the impingers.

Possible interfering agents of this method are fluorides, free ammonia, and dimethyl aniline. If any of these interfering agents are present (this can be determined by knowledge of the process), alternative methods, subject to the approval of the Administrator, U. S. E. P. A., are required.

Filterable particulate matter may be determined along with SO_2 and SO_3 (subject to the approval of the Administrator) by inserting a heated glass fiber filter between the probe and isopropanol impinger (see Section 2.1 of method 6.) If this option is chosen, particulate analysis is gravimetric only; H_2SO_4 acid mist is not determined separately.

2. Apparatus

2.1 Sampling. A schematic of the sampling train used in this method is shown in Figure 8-1. It is similar to the Method 5 train except that the filter position is different and the filter holder does not have to be heated. Commercial models of this train are available. For those who desire to build their own, however, complete construction details are described in APTD-0581. Changes from the APTD-0581 document and allowable modifications to Figure 8-1 are discussed in the following subsections.

The operating and maintenance procedures for the sampling train are described in APTD-0576. Since correct usage is important in obtaining valid results, all users should read the APTD-0576 document and adopt the operating and maintenance procedures outlined in it, unless otherwise specified herein. Further details and guidelines on operation and maintenance are given in Method 5 and should be read and followed whenever they are applicable.

2.1.1 Probe Nozzle. Same as Method 5, Section 2.1.1.

2.1.2 Probe Liner. Borosilicate or quartz glass, with a heating system to prevent visible condensation during sampling. Do not use metal probe liners.

2.1.3 Pitot Tube. Same as Method 5, Section 2.1.3.

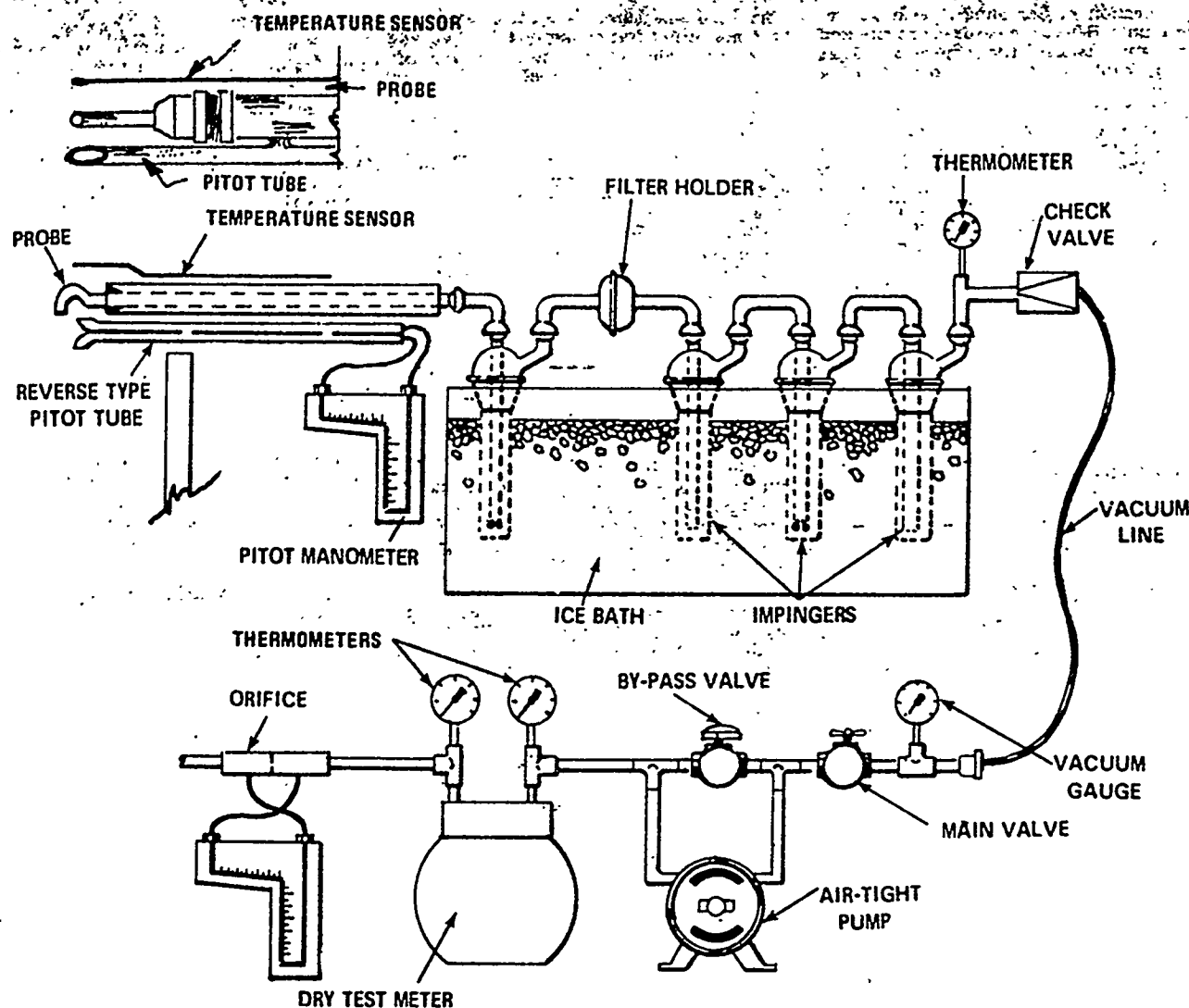


Figure 8-1. Sulfuric acid mist sampling train.

2.1.4 Differential Pressure Gauge. Same as Method 5, Section 2.1.4.

2.1.5 Filter Holder. Borosilicate glass with a glass frit filter support and a silicone rubber gasket. Other gasket materials, e.g., Teflon or Viton, may be used subject to the approval of the Administrator. The holder design shall provide a positive seal against leakage from the outside or around the filter. The filter holder shall be placed between the first and second impingers. Note. Do not heat the filter holder.

2.1.6 Impingers—Four, as shown in

Figure 8-1. The first and third shall be of the Greenburg-Smith design, with standard tips. The second and fourth shall be of the Greenburg-Smith design, modified by replacing the insert with an approximately 13 millimeter (0.5 in.) ID glass tube having an unobstructed tip located 13 mm (0.5 in.) from the bottom of the flask. Similar collection systems which have been approved by the Administrator, may be used.

2.1.7 Metering System. Same as Method 5, Section 2.1.8.

2.1.8 Barometer. Same as Method 5, Section 2.1.9.

2.1.9 Gas Density Determination Equipment. Same as Method 5, Section 2.1.10.

2.1.10 Temperature Gauge. Thermometer, or equivalent, to measure the temperature of the gas leaving the impinger train to within 1 C (2 F).

2.2 Sample Recovery

2.2.1 Wash Bottles. Polyethylene or glass, 500 ml. (two).

2.2.2 Graduated Cylinders, 250 ml. 1 liter. Volumetric flasks may also be used.

2.2.3 Storage Bottles. Leak-free polyethylene bottles, 1000 ml size (two for each sampling run).

2.2.4 Trip Balance. 500-gram capacity, to measure to ± 0.5 g (necessary only if a moisture content analysis is to be done).

2.3 Analysis.

2.3.1 Pipettes. Volumetric 25 ml, 100 ml.

2.3.2 Burette, 50 ml.

2.3.3 Erlenmeyer Flask, 250 ml. (one for each sample blank and standard).

2.3.4 Graduated Cylinder, 100 ml.

2.3.5 Trip Balance 500 g capacity, to measure to ± 0.5 g.

2.3.6 Dropping Bottle To add indicator solution, 125-ml size.

3. Reagents

Unless otherwise indicated, all reagents are to conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Otherwise, use the best available grade.

3.1 Sampling.

3.1.1 Filters. Same as Method 5, Section 3.1.1.

3.1.2 Silica Gel. Same as Method 5, Section 3.1.2.

3.1.3 Water. Deionized, distilled to conform to ASTM Specification D1193-77, Type 3 (incorporated by reference — see §60.17). At the option of the analyst, the KMnO_4 test for oxidizable organic matter may be omitted when high concentrations of organic matter are not expected to be present.

3.1.4 Isopropanol, 80 Percent. Mix 800 ml of isopropanol with 200 ml of deionized, distilled water.

NOTE. Experience has shown that only A.C.S. grade isopropanol is satisfactory. Tests have shown that isopropanol obtained from commercial sources occasionally has peroxide impurities that will cause erroneously high sulfuric acid mist measurement. Use the following test for detecting peroxides in each lot of isopropanol. Shake 10 ml of the isopropanol with 10 ml of freshly prepared 10 percent potassium iodide solution. Prepare a blank by similarly treating 10 ml of distilled water. After 1 minute, read the absorbance on a spectrophotometer at 352

nanometers. If the absorbance exceeds 0.1, the isopropanol shall not be used. Peroxides may be removed from isopropanol by redistilling, or by passage through a column of activated alumina. However, reagent-grade isopropanol with suitably low peroxide levels is readily available from commercial sources; therefore, rejection of contaminated lots may be more efficient than following the peroxide removal procedure.

3.1.5 Hydrogen Peroxide, 3 Percent. Dilute 100 ml of 30 percent hydrogen peroxide to 1 liter with deionized, distilled water. Prepare fresh daily.

3.1.6 Crushed Ice.

3.2 Sample Recovery.

3.2.1 Water. Same as 3.1.3.

3.2.2 Isopropanol, 80 Percent. Same as 3.1.4.

3.3 Analysis.

3.3.1 Water. Same as 3.1.3.

3.3.2 Isopropanol, 100 Percent.

3.3.3 Thorin Indicator, 1-(6-arsenophenylazo)-2-naphthol-3, 6-disulfonic acid, disodium salt, or equivalent. Dissolve 0.20 g in 100 ml of deionized, distilled water.

3.3.4 Barium Perchlorate (0.0100 Normal). Dissolve 1.95 g of barium perchlorate trihydrate ($\text{Ba}(\text{ClO}_4)_3 \cdot 3\text{H}_2\text{O}$) in 200 ml deionized, distilled water, and dilute to 1 liter with isopropanol; 1.22 g of barium chloride dihydrate ($\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$) may be used instead of the barium perchlorate. Standardize with sulfuric acid as in Section 5.2. This solution must be protected against evaporation at all times.

3.3.5 Sulfuric Acid Standard (0.0100 N). Purchase or standardize to ± 0.0002 N against 0.0100 N NaOH that has previously been standardized against primary standard potassium acid phthalate.

3.3.6 Quality Assurance Audit Samples. Same as in Method 6, Section 3.3.6.

[3.3.6 added by 54 FR 46235, November 2, 1989]

4. Procedure

4.1 Sampling.

4.1.1 Pretest Preparation. Follow the procedure outlined in Method 5, Section 4.1.1; filters should be inspected, but need not be desiccated, weighed, or identified. If the effluent gas can be considered dry, i.e., moisture free, the silica gel need not be weighed.

4.1.2 Preliminary Determinations. Follow the procedure outlined in Method 5, Section 4.1.2.

4.1.3 Preparation of Collection Train. Follow the procedure outlined in Method 5,

Section 4.1.3 (except for the second paragraph and other obviously inapplicable parts) and use Figure 8-1 instead of Figure 5-1. Replace the second paragraph with: Place 100 ml of 80 percent isopropanol in the first impinger, 100 ml of 3 percent hydrogen peroxide in both the second and third impingers; retain a portion of each reagent for used as a blank solution. Place about 200g of silica gel in the fourth impinger.

NOTE: If moisture content is to be determined by impinger analysis, weigh each of the first three impingers (plus absorbing solution) to the nearest 0.5 g and record these weights. The weight of the silica gel (or silica gel plus container) must also be determined to the nearest 0.5 g and recorded.

4.1.4 Pretest Leak-Check Procedure. Follow the basic procedure outlined in Method 5, Section 4.1.4.1, noting that the probe heater shall be adjusted to the minimum temperature required to prevent condensation, and also that verbiage such as, "... plugging the inlet to the filter holder ..." shall be replaced by, "... plugging the inlet to the first impinger ..." The pretest leak-check is optional.

4.1.5 Train Operation. Follow the basic procedures outlined in Method 5, Section 4.1.5, in conjunction with the following special instructions. Data shall be recorded on a sheet similar to the one in Figure 8-2. The sampling rate shall not exceed 0.030 m³/min (1.0 cfm) during the run. Periodically during the test, observe the connecting line between the probe and first impinger for signs of condensation. If it does occur, adjust the probe heater setting upward to the minimum temperature required to prevent condensation. If component changes become necessary during a run, a leak-check shall be done immediately before each change, according to the procedure outlined in Section 4.1.4.2 of Method 5 (with appropriate modifications, as mentioned in Section 4.1.4 of this method); record all leak rates. If the leakage rate(s) exceed the specified rate, the tester shall either void the run or shall plan to correct the sample volume as outlined in section 6.3 of Method 5. Immediately after component changes, leak-checks are optional. If these leak-checks are done, the procedure outlined in Section 4.1.4.1 of Method 5 (with appropriate modifications) shall be used.

[Appendix A, Method 8]

[illegible]

Figure 8 2. Field data.

After turning off the pump and recording the final readings at the conclusion of each run, remove the probe from the stack. Conduct a post-test (mandatory) leak-check as in Section 4.1.4.3 of Method 5 (with appropriate modification) and record the leak rate. If the post-test leakage rate exceeds the specified acceptable rate, the tester shall either correct the sample volume, as outlined in Section 6.3 of Method 5, or shall void the run.

Drain the ice bath and, with the probe disconnected, purge the remaining part of the train, by drawing clean ambient air through the system for 15 minutes at the average flow rate used for sampling.

NOTE: Clean ambient air can be provided by passing air through a charcoal filter. At the option of the tester, ambient air (without cleaning) may be used.

4.1.6 Calculation of Percent Isokinetic. Follow the procedure outlined in Method 5, Section 4.1.6.

4.2 Sample Recovery.

4.2.1 Container No. 1. If a moisture content analysis is to be done, weigh the first impinger plus contents to the nearest 0.5 g and record this weight.

Transfer the contents of the first impinger to a 250-ml graduated cylinder. Rinse the probe, first impinger, all connecting glassware before the filter, and the front half of the filter holder with 80 percent isopropanol. Add the rinse solution to the cylinder. Dilute to 250 ml with 80 percent isopropanol. Add the filter to the solution, mix, and transfer to the storage container. Protect the solution against evaporation. Mark the level of liquid on the container and identify the sample container.

4.2.2 Container No. 2. if a moisture content analysis is to be done, weigh the second and third impingers (plus contents) to the nearest 0.5 g and record these weights. Also, weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g.

Transfer the solutions from the second and third impingers to a 1000-ml graduated

cylinder. Rinse all connecting glassware (including back half of filter holder) between the filter and silica gel impinger with deionized, distilled water, and add this rinse water to the cylinder. Dilute to a volume of 1000 ml with deionized, distilled water. Transfer the solution to a storage container. Mark the level of liquid on the container. Seal and identify the sample container.

4.3 Analysis.

Note the level of liquid in containers 1 and 2, and confirm whether or not any sample was lost during shipment; note this on the analytical data sheet. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results.

4.3.1 Container No. 1. Shake the container holding the isopropanol solution and the filter. If the filter breaks up, allow the fragments to settle for and few minutes before removing a sample. Pipette a 100-ml aliquot of this solution into a 250-ml Erlenmeyer

flask, add 2 to 4 drops of thorin indicator, and titrate to a pink endpoint using 0.0100 N barium perchlorate. Repeat the titration with a second aliquot of sample and average the titration values. Replicate titrations must agree within 1 percent or 0.2 ml, whichever is greater.

4.3.2 Container No. 2. Thoroughly mix the solution in the container holding the contents of the second and third impingers. Pipette a 10-ml aliquot of sample into a 250-ml Erlenmeyer flask. Add 40 ml of isopropanol, 2 to 4 drops of thorin indicator, and titrate to a pink endpoint using 0.0100 N barium perchlorate. Repeat the titration with a second aliquot of sample and average the titration values. Replicate titrations must agree within 1 percent or 0.2 ml, whichever is greater.

4.3.3 Blanks. Prepare blanks by adding 2 to 4 drops of thorin indicator to 100 ml of 80 percent isopropanol. Titrate the blanks in the same manner as the samples.

[4.4 and 4.5 added by 54 FR 46235, November 2, 1989]

4.4 Quality Control Procedures. Same as in Method 5, Section 4.4.

4.5 Audit Sample Analysis. Same as in Method 8, Section 4.4.

5. Calibration.

5.1 Calibrate equipment using the procedures specified in the following sections of Method 5: Section 5.3 (metering system); Section 5.5 (temperature gauges); Section 5.7 (barometer). Note that the recommended leak-check of the metering system, described in Section 5.6 of Method 5, also applies to this method.

5.2 Standardize the barium perchlorate solution with 25 ml of standard sulfuric acid, to which 100 ml of 100 percent isopropanol has been added.

6. Calculations

NOTE: Carry out calculations retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation.

6.1 Nomenclature.

A_n = Cross-sectional area of nozzle, m^2 (ft^2).

B_m = Water vapor in the gas stream, proportion by volume.

$C_{H_2SO_4}$ = Sulfuric acid (including SO_3) concentration, g/dscm (lb/dscf).

C_{SO_2} = Sulfur dioxide concentration, g/dscm (lb/dscf).

I = Percent of isokinetic sampling.

N = Normality of barium perchlorate titrant, mcq/ml

P_{bar} = Barometric pressure at the sampling site, mm Hg (in. Hg).

P_s = Absolute stack gas pressure, mm Hg (in. Hg).

P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).

T_m = Average absolute dry gas meter temperature (see Figure 8-2), °K (°R).

T_s = Average absolute stack gas temperature (see Figure 8-2), °K (°R).

T_{std} = Standard absolute temperature, 293°K (528°R).

V_s = Volume of sample aliquot titrated, 100 ml for H_2SO_4 and 10 ml for SO_3 .

V_L = Total volume of liquid collected in impingers and silica gel, ml.

V_m = Volume of gas sample as measured by dry gas meter, dcm (dcf).

$V_{m(std)}$ = Volume of gas sample measured by the dry gas meter corrected to standard conditions, dscm (dscf).

v_s = Average stack gas velocity, calculated by Method 2, Equation 2-9, using data obtained from method 8, m/sec (ft/sec).

V_{soln} = Total volume of solution in which the sulfuric acid or sulfur dioxide sample is contained, 250 ml or 1,000 ml, respectively.

V_t = Volume of barium perchlorate titrant used for the sample, ml.

V_b = Volume of barium perchlorate titrant used for the blank, ml.

Y = Dry gas meter calibration factor.

ΔH = Average pressure drop across orifice meter, mm (in.) H_2O .

θ = Total sampling time, min.

13.6 = Specific gravity of mercury.

60 = sec/min.

100 = Conversion to percent.

[6.1 corrected by 52 FR 34639, September 14, 1987]

6.2 Average dry gas meter temperature and average orifice pressure drop. See data sheet (Figure 8-2).

6.3 Dry Gas Volume. Correct the sample volume measured by the dry gas meter to standard conditions (20° C and 760 mm Hg or 68° F and 29.92 in. Hg) by using Equation 8-1.

$$V_{m(std)} = V_m Y \left(\frac{T_{std}}{T_m} \right) \frac{P_{bar} + \left(\frac{\Delta H}{13.6} \right)}{P_{std}}$$

$$= K_1 V_m Y \frac{P_{bar} + (\Delta H/13.6)}{T_m}$$

Equation 8-1

where:

$K_1 = 0.3858$ °K/mm Hg for metric units.

$= 17.64$ °R/in. Hg for English units.

NOTE: If the leak rate observed during any mandatory leak-checks exceeds the specified acceptable rate, the tester shall either correct the value of V_m in Equation 8-1 (as described in Section 6.3 of Method 5), or shall invalidate the test run.

6.4 Volume of Water Vapor and Moisture Content. Calculate the volume of water vapor using Equation 5-2 of Method 5; the weight of water collected in the impingers and silica gel can be directly converted to milliliters (the specific gravity of water is 1 g/ml). Calculate the moisture content of the stack gas, using Equation 5-3 of Method 5. The "Note" in Section 6.5 of Method 5 also applies to this method. Note that if the effluent gas stream can be considered dry, the volume of water vapor and moisture content need not be calculated.

6.5 Sulfuric acid mist (including SO_3) concentration.

$$C_{H_2SO_4} = K_2 \frac{N(V_t - V_b) \left(\frac{V_{soln}}{V_s} \right)}{V_{m(std)}}$$

Equation 8-2

where:

$K_2 = 0.04904$ g/milliequivalent for metric units.

$= 1.081 \times 10^{-4}$ lb/meq for English units.

6.6 Sulfur dioxide concentration.

$$C_{SO_2} = K_3 \frac{N(V_t - V_b) \left(\frac{V_{soln}}{V_s} \right)}{V_{m(std)}}$$

Equation 8-3

where:

$K_3 = 0.03203$ g/meq for metric units.

$= 7.061 \times 10^{-4}$ lb/meq for English units.

6.7 Isokinetic Variation.

6.7.1 Calculation from raw data.

$$I = \frac{100 T_s [K_4 V_L + (V_{m1} / T_m) P_{bar} + \Delta H / 13.6]}{60 \theta V_s P_s A_n}$$

Equation 8-4

[Appendix A, Method 8]

[6.7.1 equation corrected by 52 FR 34639, September 14, 1987]

where:

$K_s = 0.003464$ mm Hg-m³/ml·K for metric units.

$= 0.002876$ in. Hg-ft³/ml·R for English units.

6.7.2 Calculation from intermediate values.

$$I = \frac{T_s V_m (a_{sid}) P_{sid} 100}{T_{sid} v_s \theta A_s P_s 60 (1 - B_{ss})}$$

$$= K_s \frac{T_s V_m (a_{sid})}{P_s v_s A_s \theta (1 - B_{ss})}$$

Equation 8-5

where:

$K_s = 4.320$ for metric units.

$= 0.09450$ for English units

6.8 Acceptable Results. If 90 percent < I < 110 percent, the results are acceptable. If the results are low in comparison to the standards and I is beyond the acceptable range, the Administrator may opt to accept the results. Use Citation 4 in the Bibliography of Method 5 to make judgments. Otherwise, reject the results and repeat the test.

6.9 Stack Gas Velocity and Volumetric Flow Rate. Calculate the average stack gas velocity and volumetric flow rate, if needed, using data obtained in this method and equations in Sections 5.2 and 5.3 of Method 2.

[6.9 added by 52 FR 34639, September 14, 1987]

6.10 Relative Error (RE) for QA Acid Samples. Same as in Method 6, Section 6.4.

[6.10 added by 54 FR 46235, November 2, 1989]

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METHOD 9—VISUAL DETERMINATION OF THE OPACITY OF EMISSIONS FROM STATIONARY SOURCES

[Method 9 corrected by 52 FR 34639, September 14, 1987]

Many stationary sources discharge visible emissions into the atmosphere; these emissions are usually in the shape of a plume. This method involves the determination of plume opacity by qualified observers. The method includes procedures for the training and certification of observers, and procedures to be used in the field for determination of plume opacity. The appearance of a plume as viewed by an observer depends upon a number of variables, some of which may be controllable and some of which may not be controllable in the field. Variables which can be controlled to an extent to which they no longer exert a significant influence upon plume appearance include: Angle of the observer with respect to the plume; angle of the observer with respect to the sun; point of observation of attached and detached steam plume; and angle of the observer with respect to a plume emitted from a rectangular stack with a large length to width ratio. The method includes specific criteria applicable to these variables.

Other variables which may not be controllable in the field are luminescence and color contrast between the plume and the background against which the plume is viewed. These variables exert an influence upon the appearance of a plume as viewed by an observer, and can affect the ability of the observer to accurately assign opacity values to the observed plume. Studies of the theory of plume opacity and field studies have demonstrated that a plume is most visible and presents the greatest apparent opacity when viewed against a contrasting background. It follows from this, and is confirmed by field trials, that the opacity of a plume, viewed under conditions where a contrasting background is present can be assigned with the greatest degree of accuracy. However, the potential for a positive error is also the greatest when a plume is viewed under such contrasting conditions. Under conditions presenting a less contrasting background, the apparent opacity of a plume is less and approaches zero as the color and luminescence contrast decrease toward zero. As a result, significant negative bias and negative errors can be made when a plume is viewed under less contrasting conditions. A negative bias decreases rather than increases the possibility that a plant operator will be cited for a violation of opacity standards due to observer error.

Studies have been undertaken to determine the magnitude of positive errors which can be made by qualified observers while

reading plumes under contrasting conditions and using the procedures set forth in this method. The results of these studies (field trials) which involve a total of 769 sets of 25 readings each are as follows:

(1) For black plumes (133 sets at a smoke generator), 100 percent of the sets were read with a positive error¹ of less than 7.5 percent opacity; 99 percent were read with a positive error of less than 5 percent opacity.

(2) For white plumes (170 sets at a smoke generator, 168 sets at a coal-fired power plant, 298 sets at a sulfuric acid plant), 99 percent of the sets were read with a positive error of less than 7.5 percent opacity; 95 percent were read with a positive error of less than 5 percent opacity.

The positive observational error associated with an average of twenty-five readings is therefore established. The accuracy of the method must be taken into account when determining possible violations of applicable opacity standards.

1. Principle and applicability.

1.1 Principle. The opacity of emissions from stationary sources is determined visually by a qualified observer.

1.2 Applicability. This method is applicable for the determination of the opacity of emissions from stationary sources pursuant to § 60.11(b) and for qualifying observers for visually determining opacity of emissions.

2. Procedures.

The observer qualified in accordance with Section 3 of this method shall use the following procedures for visually determining the opacity of emissions:

[2. amended by 55 FR 47472, November 14, 1990]

2.1 Position. The qualified observer shall stand at a distance sufficient to provide a clear view of the emissions with the sun oriented in the 140° sector to his back. Consistent with maintaining the above requirement, the observer shall, as much as possible, make his observations from a position such that his line of vision is approximately perpendicular to the plume direction, and when observing opacity of emissions from rectangular outlets (e.g. roof monitors, open baghouses, noncircular stacks), approximately perpendicular to the longer axis of the outlet. The observer's line of sight should not include more than one plume at a time when multiple stacks are involved, and in any case the observer should make his observations with his line of sight perpendicular to the longer axis of such a set of multiple stacks (e.g. stub stacks on baghouses).

2.2 Field records. The observer shall record the name of the plant, emission location, type facility, observer's name and affiliation, a sketch of the observer's position relative to the source, and the date on a field data sheet (Figure 9-1). The time, estimated distance

¹For a set, positive error = average opacity determined by observers' 25 observations—average opacity determined from transmissometer's 25 recordings.

[Appendix A, Method 9]