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Project Summary

Performance Evaluation of an Industrial Spray Dryer for SO_2 Control

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TRW conducted a continuous monitoring test program at the Amcelle Plant of the Celanese Fibers Company in Cumberland, MD, to evaluate the performance of a dry process flue gas desulfurization system. This system treated flue gas from a coal-fired stoker boiler. Tests involved methods specified by EPA for 30-day compliance testing, which requires a minimum of 22 days of data containing at least 18 hours of data per day and two data points per hour.

Hourly and daily averages of results are presented as well as averages for the entire test period. Operating experience with the spray-dryer/baghouse system is summarized for a 5-month period ending with the completion of testing on September 30, 1980. Brief descriptions of the test site, the flue gas cleaning system, and the continuous monitoring system are included. Manual sampling techniques for data verification are described and the systems for data acquisition, data analysis, and quality assurance, prepared specifically for this program, are presented. Raw process and emissions data are included in the appendices.

Results based on 23 days of data showed the mean SO_2 removal efficiency to be 70 percent over the compliance test when the sulfur content of the coal averaged 2 percent. In general, efficiency was 60-80 percent, except for periods of system upset. Particle removal efficiency was 99.7 percent. Particulate emissions averaged 0.030 g/m^3 (0.013 gr/dscf) during the 2 days these data were taken.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

TRW Inc., under contract to the U.S. EPA, tested the dry SO_2 control system serving the coal-fired (No. 5) boiler at the Amcelle Plant of the Celanese Fibers Company in Cumberland, MD. Celanese ordered the flue gas cleaning system in January 1979. Construction of the system by Rockwell International and Wheelabrator-Frye was completed in October 1979. Boiler installation was not completed, however, until mid-December 1979. Acceptance testing of the FGC system was completed on February 21, 1980.

TRW began collecting data for the demonstration test phase in May 1980. Installation and certification of instrumentation at the site for the performance testing were performed according to provisions for SO_2 compliance testing and began in late April 1980. The objective of the program was to collect 30 days of continuous monitoring data, representing proper operation of the flue gas cleaning system, using compliance test methods. Problems with the boiler, the FGC system, and the continuous monitoring system delayed completion of this test phase until September 30, 1980.

System Description

Celanese Fibers Company installed the coal-fired boiler in 1979 to supplement the existing oil- and gas-fired boilers at their Amcelle Plant. This installation was undertaken to improve the economics of supplying process steam for the production of synthetic fiber. A spray dryer and fabric filter combination was chosen to provide flue gas desulfurization (FGD) on the bases of cost, the lack of available space for ponding wastes from a wet FGD scrubber, and the need to provide good control of particulate emissions.

The flue gas treatment system was purchased as a turnkey installation from Rockwell International and Wheelabrator-Frye, Inc. A flow diagram of the system is presented in Figure 1.

Coal-Fired Boiler

The coal-fired water-tube boiler at the Amcelle Plant is identified as the plant's No. 5 boiler. The boiler is an Erie City spreader-stoker with a traveling grate for continuous ash discharge. This boiler had previously been retired from service at a Celanese plant in Rome, GA. The boiler was retubed when it was reconstructed at the Cumberland, MD, plant. Table 1 specifies design data for this boiler.

The coal-fired boiler is rated at 156 million kJ/hr (148 million Btu/hr) with secondary boiler fuels of gas or No. 6 fuel oil. At the boiler's maximum rating of 68,000 kg steam/hr (150,000 lb/hr) when fired by a combination of coal and oil or gas, the flue gas to be treated by the dry FGD system is 41.4 m^3/s (87,000 acfm) at 216°C (420°F). At the boiler's nominal coal-fired rating of 49,900 kg steam/hr (110,000 lb/hr), the flue gas to be treated is 30.7 m^3/s (65,000 acfm) at 193°C (380°F).

Table 1. *Boiler Data - Amcelle Plant Boiler No. 5*

Boiler Type Fuel	*Erie City Spreader-Stoker Coal and Natural Gas*	
	Coal	*Gas*
Type	*Bituminous*	*Natural Gas*
Fuel Heating Value	*29,056 kJ/kg (12,500 Btu/lb)*	*37.2 MJ/m³ (1,000 Btu/ft³)*
Sulfur Content	*1.0 to 2.0 percent*	*0.0 percent*
Ash Content	*8.0 to 20.0 percent*	*0.0 percent*

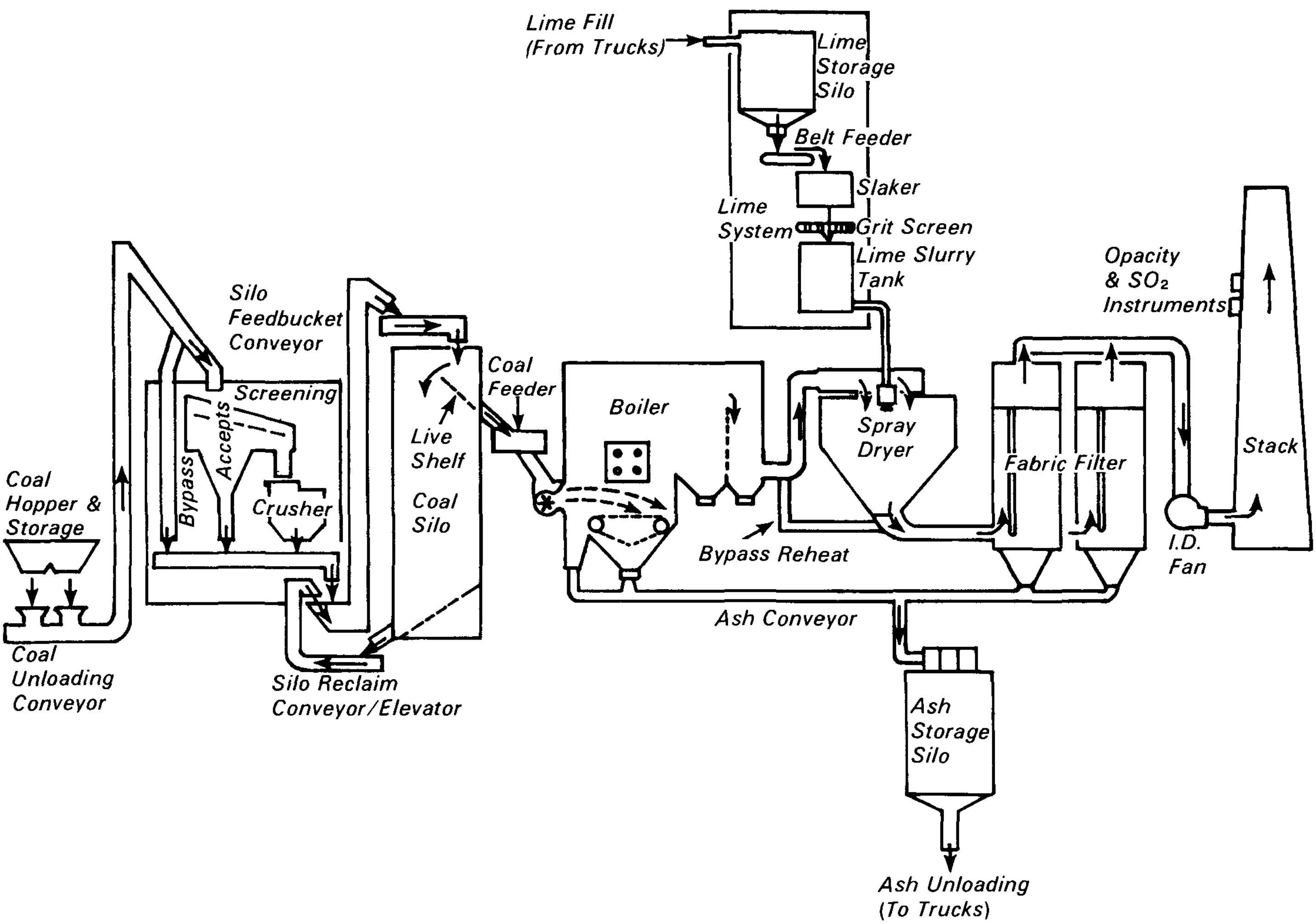


Figure 1. *Celanese boiler and flue gas cleaning system.*

Analyses of randomly selected coal samples are presented in Table 2. The sulfur content of the coals received during the test period was 1.25-2.76 percent, with a mean of 2.02 percent (dry basis).

Table 3 illustrates flue gas design conditions for various coal firings.

Spray Dryer

The gas cleaning system is designed to provide FGD removals of from 70 percent (for 1 percent sulfur coals) to 87 percent (for 2 percent sulfur coals) from half to full boiler load. Most of this SO_2 removal takes place in the spray dryer where the SO_2-laden flue gas is passed through a finely dispersed fog of lime slurry and water.

The spray dryer consists of a single, 6.1-m (20-ft) diameter vessel containing a rotary atomizer (Figure 2). This rotary atomizer (Bowen wheel) is driven at approximately 16,000 rpm. The lime slurry is fed to the wheel at a liquid-to-gas ratio of 0.04 l/m^3 (0.3 gal./1000 acf), where it is centrifugally dispersed into the gas stream. A swirling motion is imparted to the flue gas as it enters the top of the spray dryer through a fixed-vane rotary ring to increase turbulent mixing of the flue gas and the lime slurry.

Approximately 20 percent of the flue gas bypasses the spray dryer, thus providing reheat to raise the gas temperature prior to its entry into the fabric filter. This is necessary for dry operation and compensates for the temperature drop in the fabric filter. The amount of water fed to the spray dryer is automatically adjusted to hold the gas temperature from the spray dryer at a set value.

Lime System

The lime system is depicted in Figure 3. The dry storage silo stores about a 10-day lime supply. High-calcium pebble quicklime is gravity fed into the lime slaker where it is mixed with water to provide a 20 to 30 percent (by weight) slurry. The lime system can provide 125 percent of required capacity when the boiler is fired at its maximum rate with 2 percent sulfur coal and overfired gas or oil. The lime system pumps and piping can be automatically flushed with water to prevent deposits.

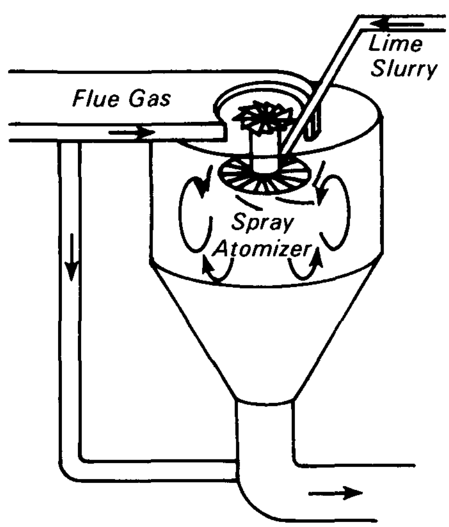


Figure 2. *Spray dryer.*

Table 2. *Selected Coal Analyses*

Sample No.	*Vol* %*	*Ash %*	*Sulfur %*	*HHV kJ/kg*	*HHV Btu/lb*
1 (8-22-80)	*19.9*	*14.95*	*1.58*	*29,860*	*12,846*
2 (8-29-80)	*31.6*	*18.96*	*1.92*	*27,998*	*12,045*
3 (9-12-80)	*17.2*	*13.97*	*1.36*	*30,153*	*12,972*
4 (9-23-80)	*33.14*	*16.81*	*2.24*	*29,411*	*12,653*

**Volatile matter.*

Table 3. *Flue Gas Characteristics - Amcelle Plant Boiler No. 5*

Fuel	*Coal*
Steam Production	*49,900 kg/hr (110,000 lb/hr)*
Flue Gas Temperature	*193°C (380°F)*
Flue Gas Flow Rate	*30.7 m^3/s (65,000 acfm)*
SO_2 Concentration	*800 to 2,500 ppm*
SO_2 Exhaust Rate	*113 to 363 kg/hr (250 to 800 lb/hr)*
Particulate Loading	*8.5 to 11.9 g/m^3 (3.7 to 5.2 gr/dscf)*

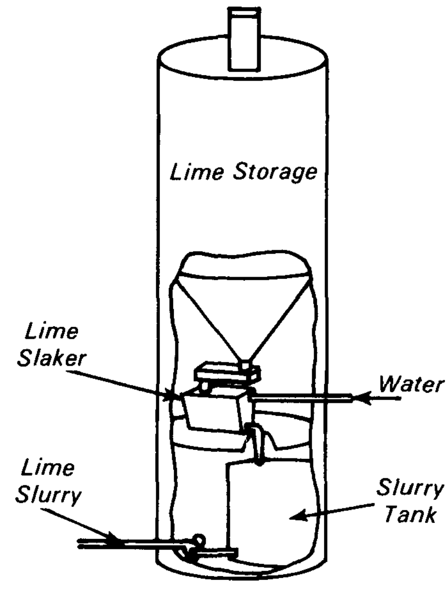


Figure 3. *Lime system.*

Fabric Filter

The fabric filter, a four-compartment pulse-jet baghouse manufactured by Wheelabrator-Frye, Inc., is shown in Figure 4. Each compartment contains 225 bags. The baghouse can operate with three compartments on-line when the boiler is operating at its nominal coal-firing rate to produce 49,896 kg/hr (110,000 lb/hr) of steam.

The air-to-cloth ratio is 2.2 - 6.8 with a design pressure drop of 500 Pa (2.0 in. H_2O). The filter medium is a fiberglass-reinforced felt manufactured by Huyck.

Description of Continuous Monitoring System

Instrumentation

The continuous monitoring system used in the performance evaluation consisted of four major groups: the filter probes and process sample lines, the gaseous analyzers, the data acquisition and recording system, and the remote temperature sensing system. Upon arrival at the test site, these four separate systems were assembled and aligned into one comprehensive system.

Sampling System

Sampling locations are shown in Figure 5. The inlet sample point was in the rectangular duct between the boiler and the spray dryer. The outlet sample point was in the circular cross-section of the stack. The intermediate sample point was not monitored.

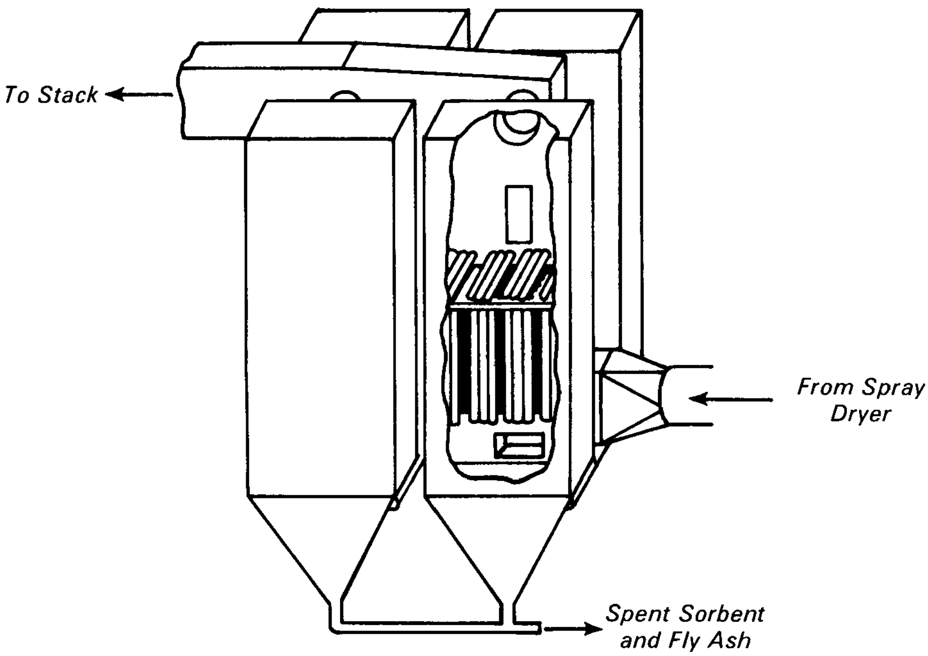


Figure 4. Fabric filter.

The filter probe assemblies utilized stainless steel filters (20-μm mesh) attached to 76-cm (30-in.) long stainless steel tubes with an o.d. of 1.3 cm (0.5 in.) and an i.d. of 0.6 cm (0.2 in.). Connected to this tubing was about 30 m (100 ft) of electrically heat-traced sample line, constructed of 0.6-cm (0.2-in.) Teflon tubing. The sample lines were kept at 121°C (250°F) to prevent condensation from the gas sample.

The gas samples collected at the inlet to the spray dryer and at the outlet of the baghouse were dried with a gas conditioner. This gas conditioner contained two dual stainless steel condenser traps suspended in a medium of ethylene glycol cooled by a Hanke refrigeration unit with copper cooling coils to approximately 3°C (37°F). The sample was pulled through the condenser traps by two Teflon and stainless steel pumps and then delivered to the analyzers. The gas conditioner system was connected to a timer that allowed the condenser traps and heat-traced sample lines to go into the 700 kPa (100 psi) blowback

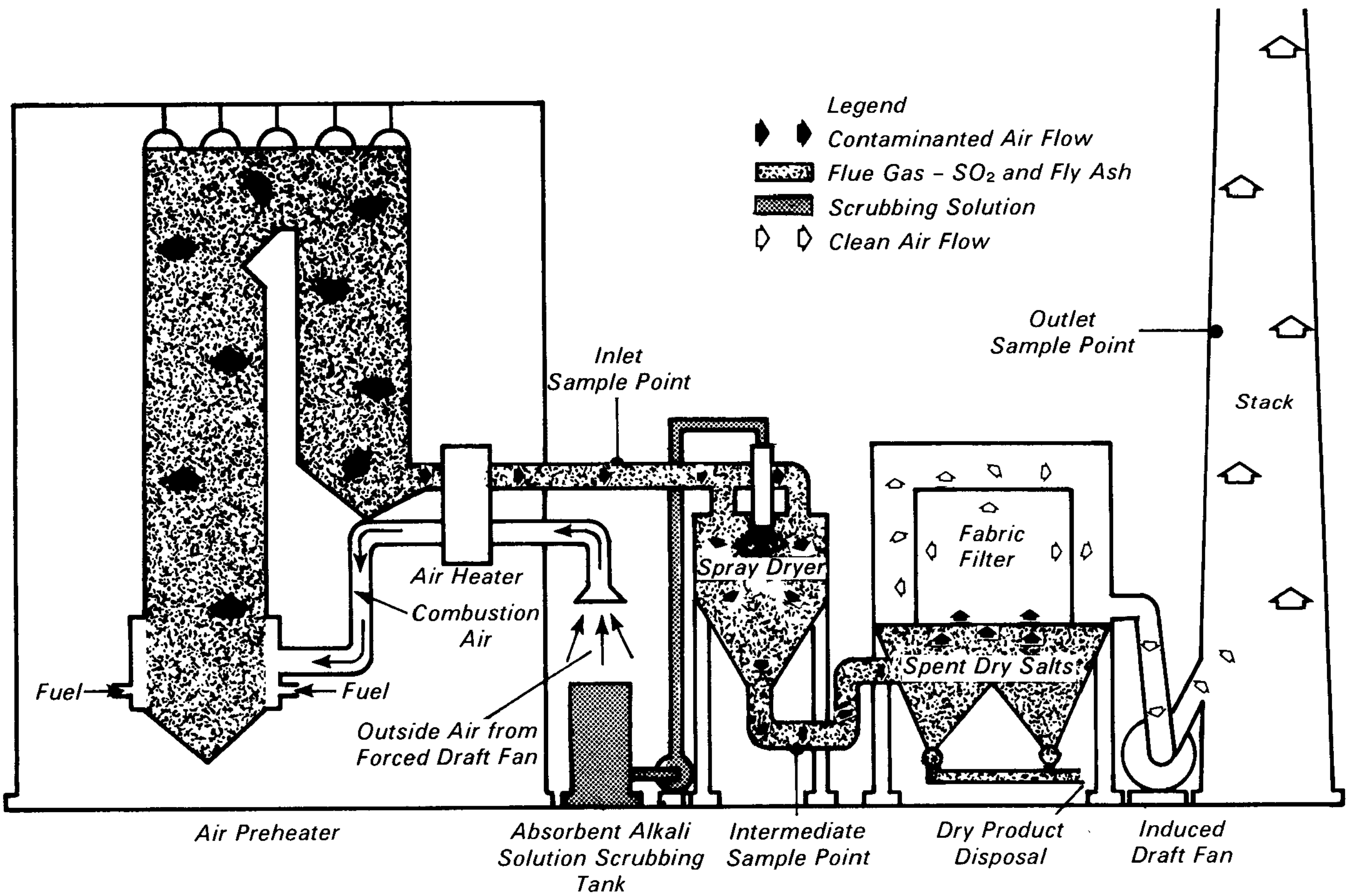


Figure 5. Two-stage dry FGD system with TRW sampling positions indicated.

mode for 3 minutes of every hour. A schematic of this sampling system (Figure 6) shows the path of sample gas from the probe to the analyzers and the path of output data from the analyzers to the data logger.

Flue Gas Analyzers

Flue gas was analysed using a Thermo-Electron Pulsed Fluorescent SO_2 Analyzer, Model 40, and a Beckman Paramagnetic O_2 Analyzer, Model 755. These analyses were conducted continuously for both the inlet of the spray dryer and the outlet of the baghouse. The inlet SO_2 analyzer operated on a 0-5000 ppm full-scale range with a 1-V full-scale output, while the inlet O_2 analyzer operated on a 0-25 percent of total gas volume full-scale range with a 10-mV full-scale output. The outlet SO_2 analyzer operated on a 0-500 or 0-1000 ppm full-scale range, depending on the concentration of SO_2 in the flue gas at the location of the outlet sample probe. The outlet O_2 analyzer operated on the same range as the inlet O_2 analyzer, but with a 1-V full-scale output.

The SO_2 and O_2 analyzers were certified according to procedures outlined in "Performance Specifications 2 and 3 for Continuous Monitors in Stationary Sources" as specified by EPA (44 *Federal Register* 58602, 1979).

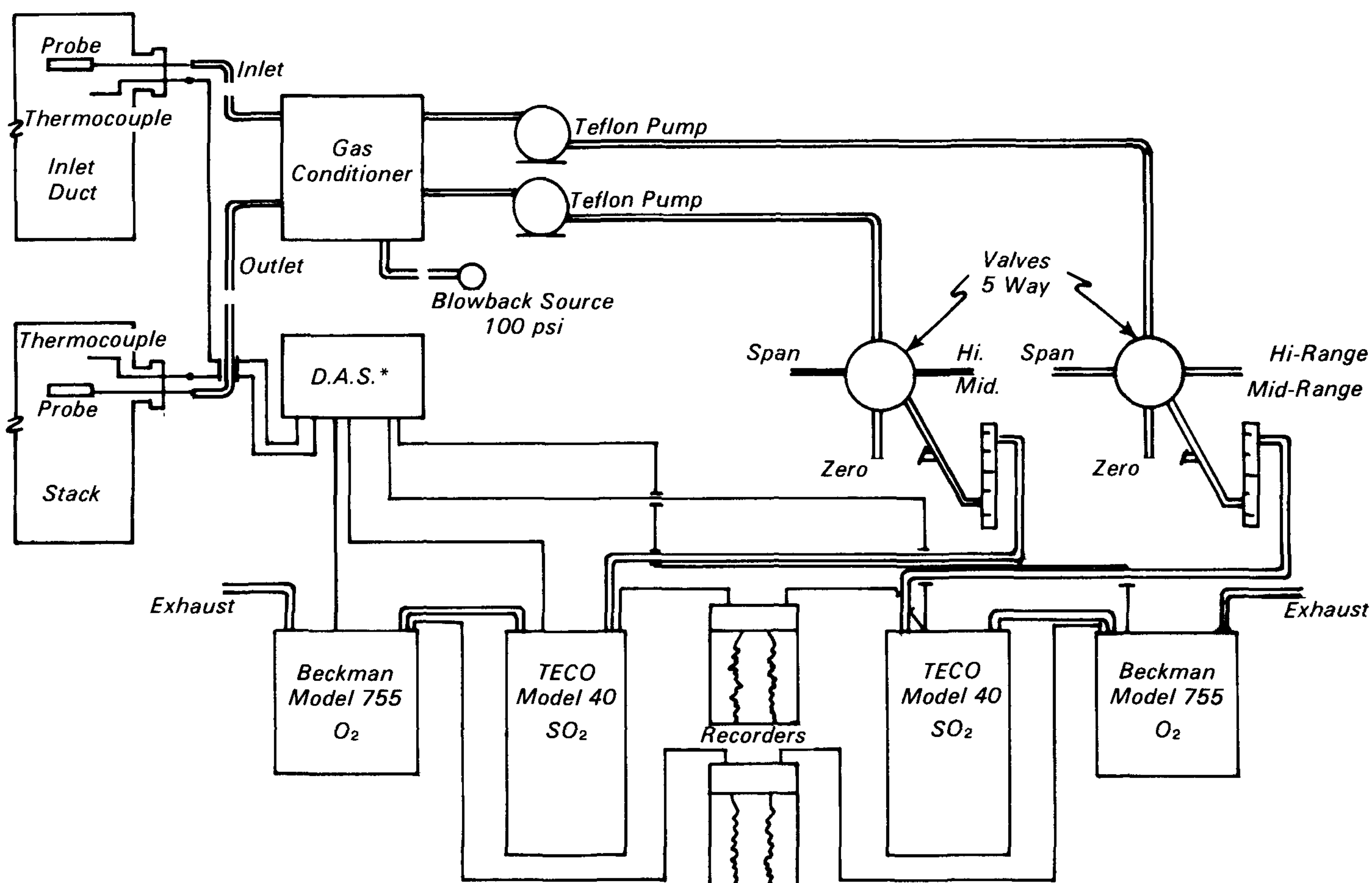
Relative accuracy was determined for the SO_2 analyzers using the average response times for the analyzers obtained during response time tests. These determinations ensured close agreement between the results from the SO_2 analyzers and EPA reference methods (specifically, Reference Method 6 for SO_2).

Calibration errors were also determined for each of the four analyzers. Directly after the daily calibration of the instruments, zero, mid-level, and high-level calibration gases were randomly introduced into the respective analyzer until a set of five points for each concentration (zero, mid-level, and high-level) was obtained.

Both of the SO_2 analyzers and both of the O_2 analyzers passed all of the certification requirements. In addition, all calibration gases used for instrument certification or instrument calibration were either traceable to National Bureau of Standards reference gases or underwent the calibration gas certification. The latter gases were obtained from the EPA repository and were certified by EPA personnel prior to use in the tests at Celanese. The SO_2 and O_2 analyzers were calibrated daily between the hours of 0800 and 1200.

Data Acquisition System

The Data Acquisition System consisted of a Fluke Data Acquisition system, a dual-pen Fisher 5000 Recordall recorder, and a Leeds and Northrop six-channel multipoint recorder.



*Data Acquisition System.

Figure 6. *Flue gas sampling and analysis system.*

Temperature Sensors

Two 60-cm (24-in.) long chromel-alumel thermocouples were mounted parallel to the filter probes. These thermocouples measured flue gas temperatures at the inlet and outlet of the FGD system. They were hard wired into the Fluke Data Acquisition system, using about 30 m (100 ft) of chromel-alumel thermocouple wire.

Results

Data on SO_2 removal that were typical of the fully operating dry FGD system performance and whose relative accuracy was fully documented were collected only during the final month of the tests. This period of "good" data collection ran from August 28 through September 30, 1980. The boiler generally ran at a steady load (about half of the rated value because of seasonal reduction in steam requirements) throughout most of this period, and the FGD system operated almost continuously.

Hourly averages of SO_2 emissions in parts per million were calculated from a minimum of two data points per hour. These hourly averages were then corrected to zero percent oxygen dilution and converted to pounds per million Btu. Calculations of SO_2 removal efficiency were then based on these average hourly SO_2 emission values.

SO_2 emissions in pounds per million Btu were determined using the F-factor technique. An F-factor for dry flue gas from coal of 9820 dscf/10^6 Btu (263.9 m^3/GJ) was used. Heat input to the boiler was calculated from available data. Hourly averages of steam flow were used to derive hourly values of coal feed rate from values of total daily coal consumption.

Typical data for inlet and outlet SO_2 concentrations are shown in Figures 7 and 8. These data are representative of the 23 days when continuous monitoring methods met EPA's compliance criteria, including collection of data for over 18 hours per day with the FGD system treating boiler flue gas. Figure 7 shows that outlet SO_2 concentration, measured in the stack, closely follows the SO_2 concentration at the inlet to the spray dryer. This curve indicates no corrective action being taken to adjust slurry flow rate for varying inlet SO_2 concentration. With the FGD system in automatic control, the outlet SO_2 concentration (see Figure 8) was relatively constant, indicating that the slurry flow was adjusted to accommodate even rapid changes in inlet SO_2 concentration.

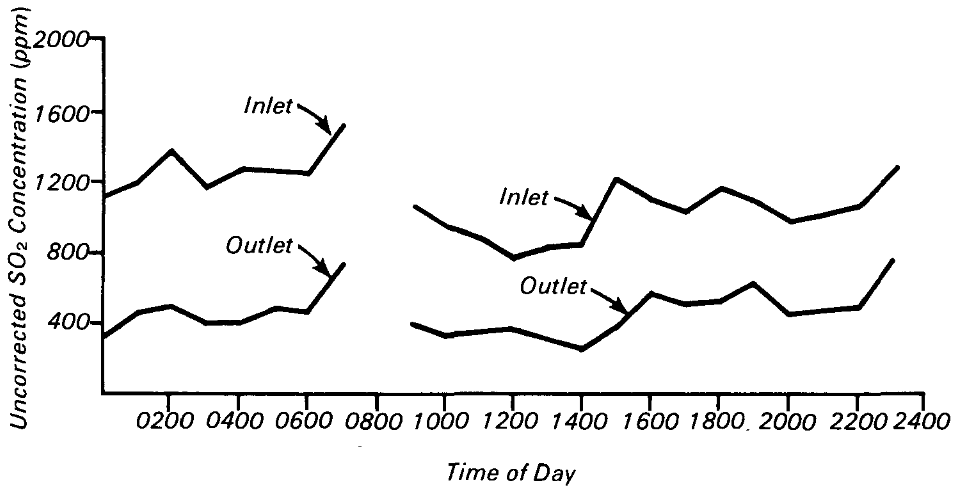


Figure 7. *Average hourly SO_2 concentrations for September 3, 1980, with FGD system controlled manually.*

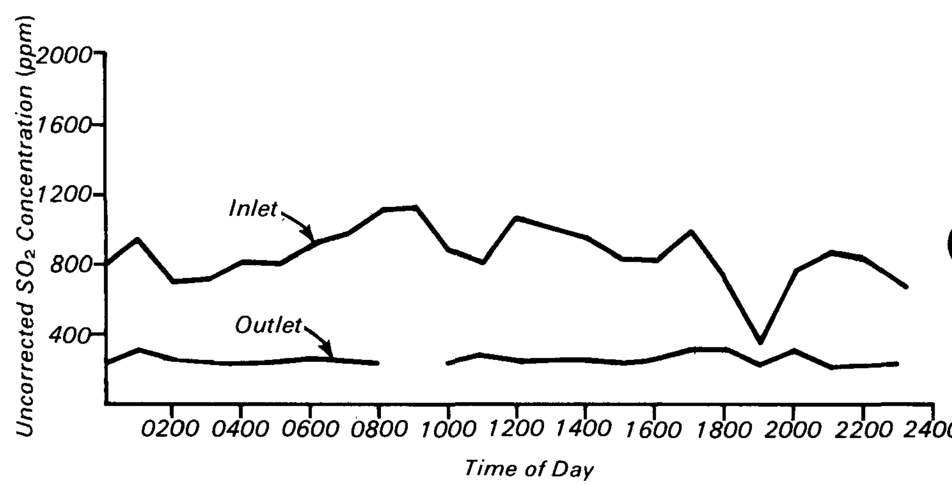


Figure 8. *Average hourly SO_2 concentrations for September 8, 1980, with dry FGD system controlled automatically.*

Although the FGD system was designed to operate automatically, this was not always possible because of malfunctions in the stack SO_2 monitor which provided feedback to the spray dryer control system. Problems with this monitor necessitated extended periods of manual operation. Under manual operation, the slurry flow sometimes became so high that the outlet concentrations were 50 ppm or less. On these occasions, SO_2 removal efficiencies exceeded 90 percent.

The average daily SO_2 removal efficiencies for the continuous monitoring period cited earlier are given in Figure 9. Except for periods of system upset, removal efficiency was 60-80 percent. The only prolonged period of low SO_2 removal occurred between September 3 and 6 and stemmed from inability to maintain steady boiler load and slurry pumping problems. The mean SO_2 removal efficiency for the 23 days of performance data was 70 percent, and the standard deviation from this mean was ±9 percent. However, over the last week of the tests, the

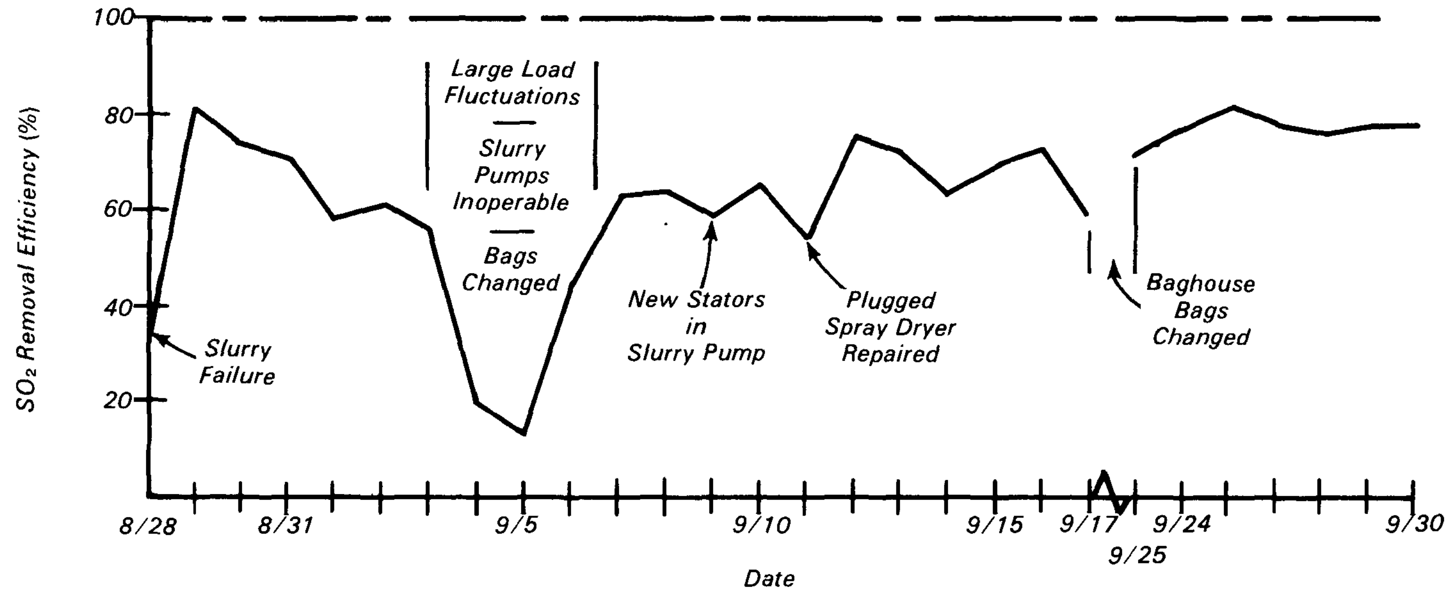


Figure 9. *Average daily SO_2 removal efficiency for dry FGD system.*

average daily SO_2 removal efficiency was 78.5 percent, based on 23 hours of hourly averaged data for each day.

The emission rate and removal efficiency of particulate matter for this FGD system were determined by three isokinetic sampling runs on June 2 and 3, 1980. Testing for particulate matter was conducted according to EPA Method 5 using a RAC Stacksampler sampling train. Results of these tests are summarized in Table 4.

Table 4. *Particulate Emissions Results*

Date / *Run No.*	*6-2-80* / *BI5-1*	*6-2-80* / *BI5-2*	*6-3-80* / *BI5-3*	*Average*
Inlet Concentration				
g/m³ (gr/dscf)	*9.43 (4.12)*	*8.44 (3.69)*	*11.78 (5.15)*	*9.88 (4.32)*
Run No.	*BO5-1*	*BO5-2*	*BO5-3*	
Outlet Concentration				
g/m³ (gr/dscf)	*0.0334 (0.0146)*	*0.0159 (0.00697)*	*0.0400 (0.0175)*	*0.0298 (0.0130)*
Particle Removal Efficiency, %	*99.65*	*99.81*	*99.66*	*99.70*

System Availability and Operating Experience

Table 5 summarizes the availability of the boiler and FGD system during the tests. The boiler went down for refractory repairs on April 20. From then through the end of the program on September 30, the boiler was off-line approximately 12 percent of the time. It was on-line but running abnormally an additional 5 percent. Thus, boiler problems prevented representative characterization of the FGD system for about 17 percent of the time TRW was on site. This amounted to 672 of 3,912 hours in the period.

Table 5. *System Availability*

	Availability, %*		
Component	*Apr-Sep*	*Aug-Sep (720 hr)*	*Sep 25-30 (144 hr)*
Boiler	*82.2*	*93.3*	*100.0*
FGD System	*62.4*	*73.2*	*96.2*
Spray Dryer	*81.8*	*97.8*	*100.0*
Lime Feed System	*83.2*	*76.5*	*96.2*
Fabric Filter	*99.8*	*98.9*	*100.0*

**The percentage of time in the period that the component operated normally.*

The FGD system was off-line (not operating at all) about 23 percent of the time. The FGD system operated abnormally an additional 12 percent of the time. During this time the slurry feed rates were so low or unsteady that *monitoring of any significant SO_2* scrubbing was prevented. Thus, the FGD system was unavailable 35 percent of the time, or a total of 1,354 hours.

Availability of the system was significantly improved in September when most of the continuous monitoring data were collected. During this period the FGD system was off-line less than 19 percent of the time and operated abnormally an additional 8 percent of the time, giving an availability of 73 percent.

Operating problems and their effects on the program were broken down into four system components: the boiler, the *lime feed system, the spray dryer, and* the fabric filter. Problems with each component impact the entire FGD system.

Steam Boiler

A problem which affected the performance of the FGD system was the variability of coal quality. Coal sulfur content varied widely throughout the early part of the program. The quality became less variable near the end of the program, but proximate analyses of daily coal deliveries showed sulfur contents of 1.25 - 2.76 percent. When operating in automatic control to keep the outlet SO_2 concentration at a set value, the FGD system responded to rapid changes in inlet SO_2 concentration so that hourly averages of emissions remained constant. In manual control, the outlet SO_2 concentration followed the inlet concentration in the absence of operator adjustment. With uniform coal quality and automatic control of slurry flow, large fluctuations in inlet SO_2 concentrations were absent and a steady outlet SO_2 concentration was maintained.

Another problem which relates to coal supply involves the amount of fines in the coal. Coal fines, when suddenly dumped into the furnace, cause rapid changes in boiler load and flue gas flow, changes in SO_2 emissions, and increased particulate matter and opacity levels in the stack. Fast changes in flue gas flow and SO_2 concentration made it difficult for the spray dryer to keep SO_2 emissions at a desired level. Such large and rapid load fluctuations occurred on September 5, 6, and 7. Data collected on these days were not included in overall averages.

Lime Feed System

The slurry is fed to the atomizer by progressing cavity pumps; under design conditions, one pump is in use and one is a spare. However, to cope with the higher sulfur coals encountered, the single pump had to be operated at high speeds and this led to rapid pump wear. To alleviate this, the system was modified to use both pumps in parallel. This was the normal mode of operation throughout the latter part of the test period.

Most other problems with the lime feed system related to plugging somewhere in the system because of grit in the lime. Although grit was supposed to have been removed by screens inside the slaker, damaging quantities of it passed through or bypassed the screens into the rest of the system. Failure to remove grit caused excessive wear in the pumps and plugging in the slaker, in the flow lines, in the slurry pump, and in valves. Dual-element screen filters were eventually installed in the feed system, but not enough time elapsed before the end of the program to assess whether they solved the problem.

Spray Dryer

Maldistribution of lime slurry in the atomizer resulted in the wetting of the dryer wall and discharge of damp material from the dryer. It was corrected by redesign.

Other problems encountered with the spray dryer also related to the atomizer. The rotary atomizer was subject to clogging with grit particles if they were not screened sufficiently from the slurry. The spray dryer was shut down for cleaning when this clogging occurred. Another problem was failure of the bearings supporting the shaft of the atomizer wheel caused by an imbalance due to grit plugging the atomizer wheel.

Fabric Filter

The most serious problem with the baghouse was the unexpectedly high pressure drop through the fabric filter. This was apparently caused by moisture on the bags which occurred during an upset and combined with ash and lime to form a coating that increased the resistance to flow. To lower the pressure drop through the baghouse, design and process changes were made, including increasing the pulse-jet air volume by approximately 15 percent. Tests since this modification indicate that this has solved the problem.

Conclusions and Recommendations

The two-stage dry FGD system installed at the Celanese Fibers Company's Amcelle Plant required 28 - 46 hours of maintenance each week and close operating supervision for continuous operation. Some of this maintenance was performed while the system was operating so there was no interruption in SO_2 removal. The average SO_2 removal efficiency demonstrated over a 30-day period, based on 23 days of acceptable data, was 70 percent. This level of performance was achieved while burning coal with an average sulfur content of about 2.0 percent on a dry basis. System guarantees called for 70 percent SO_2 removal for 1 percent sulfur coal and 87 percent SO_2 removal for 2 percent sulfur coal. Compared with these goals, the demonstrated SO_2 removal was low. Over the last 6 days of the tests, after several operational difficulties had been resolved, SO_2 removal efficiency averaged 78.5 percent, a marked improvement over earlier results but still below the stated goal with 2 percent sulfur coal.

Boiler operators operate the FGD system along with their other duties. Modifications made to the system after operating experience had been gained have the potential to make this a more reliable system. As described above, most of the operating problems relate to plugging caused by grit in the slurry and water vapor condensing in the flue gas due to low operating temperatures. Both of these problems can be solved by changes in operation and design. Maintenance needs will also be reduced by these modifications.

Because of problems experienced thus far, redundancy of critical components is recommended. Specifically, three slurry pumps are needed with two on-line at all times and one as a spare. A spare atomizer will limit spray dryer shutdowns due to atomizer failure. Filters should be set up to provide uninterrupted slurry flow to the spray dryer while one filter element is being replaced or cleaned. A means of keeping the outlet SO_2 monitor operating continuously is needed. Since feedback from the outlet SO_2 monitor is used in controlling lime slurry flow to the spray dryer, this will permit a steadier outlet SO_2 level and more consistent FGD system performance via operation in automatic control.

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The complete report, entitled "Performance Evaluation of an Industrial Spray Dryer for SO_2 Control," (Order No. PB 82-110 701; Cost: $21.00, subject to change) will be available only from:

National Technical Information Service
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