Construction Materials for Wet Scrubbers

Volume 2

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March 1981

MASTER

Prepared by
Battelle, Columbus Laboratories
Columbus, Ohio

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Construction Materials for Wet Scrubbers
Volume 2

CS-1736, Volume 2
Research Project 982-14

Final Report, March 1981

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ABSTRACT

This report is a comprehensive documentation and analysis of utility experience with materials of construction in full-scale lime and limestone wet fluidized gas desulfurization (FGD) systems on boilers burning eastern or western coals. It is not a guidelines document but rather a summary of materials experience. Information on field performance of construction materials was collected primarily by site visits but also by telephone and letter contacts with FGD system operators and equipment vendors and by literature searches. Information was collected for the following FGD system components: prescrubbers, absorbers, spray nozzles, mist eliminators, reheaters, fans, ducts, expansion joints, dampers, stacks, storage silos, ball mills and slakers, pumps, piping and valves, tanks and thickeners, agitators and rakes, vacuum filters and centrifuges, and pond linings.

Materials documentation and analysis includes successes, failures, reasons for success or failure, failure mechanisms, and relative costs of various materials. Detailed trip reports on each site visit are included in an appendix. The results are designed to be a first step in aiding utilities and FGD equipment suppliers in selecting materials that will perform satisfactorily without unnecessary expense.

Outlet ducts downstream from the outlet dampers and stack linings have a significant history of materials problems and are critical components--failures may require complete boiler shutdown and loss of generating capacity for lengthy periods. Prescrubbers, absorbers, reheaters, outlet ducts upstream of the outlet dampers, dampers, pumps, and piping and valves have a moderate history of materials problems, but failures may not require complete boiler shutdown. Spray nozzles, mist eliminators, fans, inlet and bypass ducts, expansion joints, storage silos, ball mills and slakers, tanks and thickeners, agitators and rakes, vacuum filters and centrifuges, and pond linings have a relatively low history of materials problems and/or are amenable to rapid repair or replacement.

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EPRI PERSPECTIVE

PROJECT DESCRIPTION

This final report under RP982-14 presents the results of a construction materials survey of utility industry experience at full-scale lime and limestone flue gas desulfurization (FGD) installations. The results bridge a gap in the existing data base and are useful in designing new systems. They have also helped direct EPRI's research into corrosion in FGD systems. Other EPRI projects in this area include a laboratory evaluation of corrosion inhibitors under RP982-19 and an evaluation of materials for use in ducts and stacks--the most trouble-prone areas of FGD systems--in RP1871. Future work under RP1871 will include laboratory testing of materials for other FGD problem areas and large-scale field testing of promising materials.

Materials of construction for FGD systems is an area of significant uncertainty. Available materials range from carbon steel to coated materials to exotic alloys. The trick is to select a material which will give satisfactory service at the lowest lifetime cost. Most of the information available comes from lab tests or materials coupons inserted into existing systems. However, there are almost no data on experience at full-scale installations, and these data should be the most applicable for utilities choosing materials for new systems. The results are presented in two volumes: Volume 1 contains a summary by system component (absorber, mist eliminator, reheater, etc.), and Volume 2 contains the trip reports.

PROJECT OBJECTIVES

The major objectives were (1) to collect and summarize the materials of construction data from all existing full-scale utility lime and limestone FGD systems, (2) to identify successful materials, (3) to identify the reasons for failure, and (4) to suggest needed research in this area.

PROJECT RESULTS

Visits were made to all of the existing lime and limestone sites, most of the FGD vendors, and several coatings suppliers.

Three component categories were identified: (1) those with a significant history of materials problems where failure might require lengthy boiler shutdown, (2) those with moderate materials problems where failure may not require boiler shutdown, and (3) those with little history of materials problems. Only two components--ducts downstream of outlet dampers and stack linings--were identified in the first category.

Identification of reasons for successes and failures was very difficult due to insufficient maintenance records. Especially for coatings, it was difficult to tell whether problems were due to faulty application or severe service conditions.

This report should be most useful to utility and other engineers interested in materials selection for lime and limestone FGD systems. As new systems are brought online, this study will be updated on a one- to two-year cycle.

Richard G. Rhudy, Project Manager
Coal Combustion Systems Division

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CONVERSION FACTORS

To Convert from English Units	To Metric Units	Multiply By
acres	hectares	0.4047
British thermal units	kilojoules	1.056
British thermal units per pound	joules per gram	2.328
degrees Fahrenheit-32	degrees Celsius	0.556
feet	meters	0.3048
square feet	square meters	0.0929
cubic feet	cubic meters	0.02832
cubic feet per minute	cubic meters per second	0.0004720
gallons	cubic meters	0.003785
gallons per minute	cubic meters per hour	0.2271
gallons per thousand actual cubic feet (125°F)	liters per normal cubic meter (0°C)	0.1616
grains	grams	0.0648
grains per cubic foot	grams per cubic meter	2.288
horsepower	kilowatts	0.7457
inches	millimeters	25.40
inches of water	pascals (newtons per square meter)	249.1
mils	millimeters	0.02540
miles	kilometers	1.609
pounds	kilograms	0.4536
pounds per million British thermal units	nanograms per joule	429.6
pounds per square inch	pascals	6895
standard cubic feet per minute (70°F)	normal cubic meters per hour(0°C)	1.577
tons	kilograms	907.2
tons per day	kilograms per hour	37.80

APPENDIX A

TRIP REPORTS

LOUISVILLE GAS & ELECTRIC COMPANY (LG&E)
PADDY'S RUN UNIT 6

Trip Report Number: EPRI-CM1

Date of Trip: November 28, 1978

Persons Interviewed: Robert P. Van Ness, Manager of Environmental Affairs, LG&E.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Combustion Engineering (CE) is the process designer and vendor; LG&E supervised the design and is the contractor and consulting engineer; retrofit installation.

2. Boiler Type - Foster Wheeler pulverized coal fired boiler rated at 65 MW but operated at 72 MW at full load; heat rate is 13,000 Btu/kWh.

   a. 25 to 30 percent excess air.

   b. The capacity factor was about 18 percent for 1977 and 10 percent for 1978; the boiler is a peaking unit and is usually either at full load or shut down; however, the unit is sometimes operated at 1/2 load at night.

   c. Stack height is 250 ft.

3. Flue Gas Flow Rate - 360 to 380,000 acfm at 335 F at full load; all the flue gas is scrubbed but any fraction of the gas can be bypassed around the scrubbers by using louver dampers.

4. SO_2 Concentration - 1800-2200 ppm SO_2 in inlet gas; 150-300 ppm SO_2 in outlet gas; have run with different SO_2 concentrations in test runs.

5. Fuel - Bituminous coal mined by Peabody in Kentucky; 3.7 percent sulfur and 14 percent ash; heat content is 11,300 Btu/lb.

6. Scrubber Reactant - Carbide sludge about 25 years old; 50 percent solids as piled on ground; 20-30 percent solids as added to system; a chemical analysis of the carbide lime is:

Solid	Liquid
90-92% $Ca(OH)_2$	Soluble ionic species
3-8% $CaCO_3$	200 ppm NH_3
2-2.5% SiO_2	Trace of C_2H_2
2-2.5% R_2O_3	
0.3% C	
0.03% S	
<0.07% MgO	
Trace Cl	

7. Removal Efficiency - Greater than 85 percent SO_2 removal and greater than 99 percent fly ash removal; 95 percent fly ash removal is accomplished with an electrostatic precipitator.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables -

a. 335 F inlet gas to marble bed (steam soot blower in wet-dry zone used every 3 days).

b. 126 F scrubber outlet temperature.

c. Fly ash inlet loading to scrubber is about 0.10 to 0.15 grains/scf.

d. Scrubbing liquor pH of 8-10 at inlet, 4.8 - 5.7 at overflow pot drains, and 5.8 - 6.4 at sump; the pH at the overflow pot drains is a very critical item - pH at upper marble bed overflow pot drain must be below 6 to prevent sulfite scaling and pH at lower marble bed overflow pot drain must be above 4 to guard against corrosion; main system control is pH meter which controls lime slurry flow through feed valve.

3. Absorber Design -

a. Electrostatic precipitator for fly ash removal.

b. Two marble bed scrubbers with two beds per scrubber for SO_2 removal.

c. The superficial gas velocity is about 10 ft/sec; the split in gas flow between the two scrubbers is about 54 percent and 46 percent.

d. The turndown ratio is 1.2 (5 to 4); when turndown ratio is exceeded, velocity is controlled by recycling gas through the scrubber; can go down to 80 percent load without gas recycling, but liquor flow rate must decrease; at 1/2 load or less, the system can be operated with just one scrubbing module.

4. Liquid-to-Gas Ratio - L/G is 32-40 gal/10^3 ft^3 or 16-20 gal/10^3 ft^3 per bed.

5. Oxidation - Amount of oxidation in system is negligible; have never noticed sulfate formation anywhere in system with carbide lime as the reactant; filter cake appears to be 96-98 percent sulfite based on total sulfur.

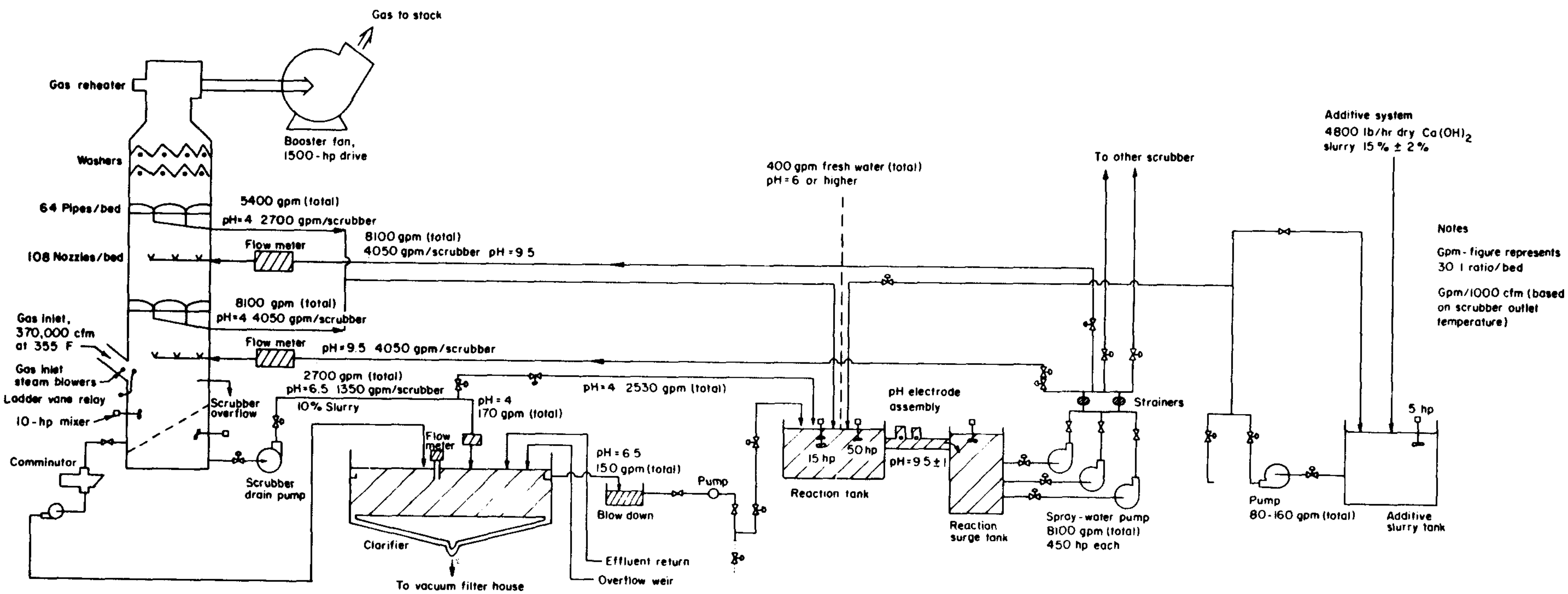

FIGURE 1. AIR QUALITY CONTROL SYSTEM FOR PADDY'S RUN UNIT 6

6. Pressure Drop - Total pressure drop is about 15 in. H_2O from outlet of precipitator to stack; ductwork exceeds 2 in., demisters are less than 1 in., and scrubbers are 5-1/2 in. per bed.

7. Solids Level - Carbide sludge additive to system is 20-30 percent solids; slurry to scrubber is 10 percent solids; thickener bottoms are 23 percent solids; filter cake is 40 percent solids.

8. Reactant Addition - Carbide sludge is added to the reaction tank in a small inner section.

9. Reactant Feed Rate - About 1 mole of calcium per mole of SO_2 removed or about 4800 lb/hr of dry $Ca(OH)_2$ at full load.

10. Slurry Retention Time - 30 minutes retention time in hold tank plus 4 to 6 minutes retention time in scrubber sumps; effluent bisulfite from scrubber and hydroxide from carbide sludge are mixed as quickly as possible in the reaction tank.

   a. Reaction tank is about 48 feet in diameter but contains a small cylindrical compartment about 5 feet in diameter where the scrubber bottoms and carbide sludge are added and rapidly stirred with an agitator in addition to the main tank agitator.

11. Mist Eliminator - Two-stage chevron mist eliminators; washed about 10 to 15 minutes every 8 hours using service water at 80-200 gpm; marble bed may be protecting mist eliminator by producing less mist than other scrubber designs; most of the mist elimination is accomplished by the first stage; about 5 feet of freeboard between marble bed and mist eliminator and 4 feet between mist eliminators.

12. Reheat System - Reheat with natural gas burners located in duct; 2 burners per scrubber or 4 total; 16-18 x 10^6 Btu/hr total to produce 40-50 F of reheat.

13. Waste Disposal - Closed-loop system; the only water leaving the system goes up the stack with the flue gas or out with the filter cake; the filter cake is trucked to a borrow pit where it is bulldozed with fly ash.

14. Fans - One 1500 hp Westinghouse induced draft fan is located after the reheaters; usually runs at 800 hp; 2 induced draft fans for the boiler are located between the precipitator and the scrubbers.

C. RELIABILITY

1. Start-up - April 5, 1973.

2. Availability - The system was operated for 8-1/2 months during 1973 to prove viability; during this period the scrubber operability (hours FGD system was operated divided by boiler operating hours) was about 90 percent considering that the system can be operated with only one scrubber

at reduced loads; since 1973, the operability has been almost 100 percent during the limited time that the boiler has been on.

3. Longest Run - 45 days of continuous operation (B scrubber ran all the time and load was reduced by leaving A scrubber off).

4. Calendar of Operation - The FGD system has accumulated over 22,000 hours of operation since startup counting both modules; however, some of the operation time was with reagents other than carbide lime for testing purposes.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - None used.

2. Absorber - Absorber walls constructed of carbon steel. There is a Flakeline 103 or 151 "flaked glass" liner (glass flakes in polyester resin) from a foot below the inlet duct to about 2 feet above the second stage mist eliminator. The liner was applied at time of construction and total time in service is greater than 22,000 hours. There has been some deterioration requiring repair in localized areas where there has been spray impingement. The lining application was by a subcontractor (unknown to LG&E) arranged for by CE. For liner application, the steel surface was first blasted. The liner was applied in two applications, about 40 mils each. More details on lining application, if available, must be obtained from CE.

The punch plate that supports the marble bed is constructed of Type 316 stainless steel, and the various brackets for this plate also are of this alloy. There is some corrosion at the welds.

3. Spray Nozzles - The spray nozzles are plastic with rubber lining. The plastic spinners inside the nozzles were replaced in April, 1977 because they were beginning to wear. The original nozzles had been used for 4 years at about 1/2 time operation (or 15,000 hours).

4. Mist Eliminators - The mist eliminators are two-stage chevron type constructed of polypropylene. They have never been repaired. Their color has changed but they are otherwise all right.

5. Fans - Induced draft fan located after reheaters. The fan is constructed with carbon steel blades, and no problems of erosion or corrosion have been encountered as yet.

6. Reheater - Reheat is accomplished with cast iron natural gas burners located in the duct, producing 40-50 F of reheat. Each burner is rated at 5 x 10^6 Btu/hr and there are two per module. No problems reported.

7. Pumps - There is one slurry recycle pump for each module and one spare for a total of three. They are Ni-Hard pumps manufactured by Allen-Sherman-Hoff (A-S-H). There have been no problems with these pumps. The scrubber drain pumps are rubber-lined carbon steel and also manufactured by A-S-H. One lining had to be replaced because of damage from tramp metal in the scrubber circuit. Sometimes slurry gets through the packing gland and ruins a bearing. The two thickener underflow pumps are rubber-lined carbon steel. The carbide lime slurry pumps are carbon steel.

8. Tanks - The reaction tank is mild steel with no lining. All other tanks are also unlined mild steel. The only deterioration has been on the outside of some tanks where they are welded to the base platform. There is corrosion at the welds because the steel was not welded properly.

9. Agitators - The agitator in the reaction tank was originally mild steel. About a year after start up the shaft and blades were replaced with mild steel clad with rubber because the agitator showed some signs of wear. Also, CE decided to change the blade design to improve reliability. Rubber coated agitators are also used in the reaction surge tank. The agitators in the bottom of the scrubber are carbon steel.

10. Storage Silos - There is no storage silo. The slaked carbide lime is delivered as a slurry (about 25 percent solids in water).

11. Thickener - The thickener tank is mild steel.

12. Vacuum Filter - The vacuum filter has a carbon steel frame with polypropylene cloth. The cloth has been replaced three times, not because of failure but because of holes punched in it during cleaning.

13. Ducts, Expansion Joints, and Dampers - The ducts are all carbon steel with no lining. Flue gas inlet temperature is about 300 F. At outlet, the temperature is always kept 50 F above the dew point with reheat to avoid condensation. The short bypass duct is carbon steel and connects to the outlet duct. The expansion joints are rubber. Louver dampers are mild steel. No materials problems were described for these components. However, the dampers do not seal well.

14. Piping and Valves - All piping to the scrubber is mild steel. The spray headers and outlet piping are fiberglass. There have been no failures. DeZurik knife gate valves used in the system are Type 316 stainless steel. The valves are used either in the on or off position and do not seal very well.

15. Stack - The stack has a concrete shell with an acid-resistant brick lining (installed about 1952). In the fall of 1972, the stack liner was sand blasted and coated with Pre-Krete G-8 (a product of Pocono Fabricators) by Custodis Construction Company as a precautionary measure. Cracks which have developed in the upper 10 ft section of the stack lining are believed to be the result of freeze-thaw damage. In April, 1975, the stack was repaired with Pennwalt's HES gunite in the top corbel section

(over bricks), Pre-Krete G-8 in the second corbel section (bricks removed), and with HES gunite in the lower three sections. The HES lined sections were replaced about May, 1976, due to poor application. The HES and Pre-Krete zones were in good condition when last inspected in October, 1976. Because of the stack design, there is no annulus to pressurize.

E. COMMENTS

Details regarding materials composition, materials application procedures, and costs could not be obtained from the utility. Consequently, it was not possible to prepare detailed responses to matrices on metallic components, organic lined and plastic components, and ceramic and inorganic linings and components.

LOUISVILLE GAS & ELECTRIC COMPANY (LG&E)
CANE RUN UNIT 4

Trip Report Number: EPRI-CM2

Date of Trip: November 28, 1978

Persons Interviewed: Robert P. Van Ness, Manager of Environmental Affairs, LG&E.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - American Air Filter (AAF) is the process designer and vendor; LG&E is the contractor and consulting engineer; retrofit installation.

2. Boiler Type - Unit 4 is a Foster Wheeler pulverized coal-fired boiler nominally rated at 178 MW with a heat rate of 10,600 Btu/kWh.

   a. Greater than 25 percent excess air to prevent slagging of ash.

   b. Capacity factor is 55 to 60 percent; unit is at full load during the day and reduced load at night.

   c. Stack height is 250 feet.

3. Flue Gas Flow Rate - 730,000 acfm at 310 to 325 F at full load; all the flue gas is scrubbed.

   a. 5 to 6 percent oxygen in the flue gas.

4. SO_2 Concentration - 2,200 to 3,700 ppm SO_2 in inlet gas and 200 to 300 ppm SO_2 in outlet gas.

5. Fuel - Bituminous coal mined by Peabody in Kentucky; 3.87 percent sulfur and 15 percent ash; heat content is 11,300 Btu/lb.

6. Scrubber Reactant - Carbide lime from storage pile across from an Airco plant; transported to Cane Run by barge as a 30 percent slurry; a chemical analysis of the carbide lime is:

Solid	Liquid
90-92% $Ca(OH)_2$	Soluble ionic species
3-8% $CaCO_3$	200 ppm NH_3
2-2.5% SiO_2	Trace of C_2H_2
2-2.5% R_2O_3	
0.3% C	
0.03% S	
<0.07% MgO	
Trace Cl	

7. Removal Efficiency - Higher SO_2 removal efficiency is achieved at reduced boiler load; at close to full load, the SO_2 removal efficiency is 86 to 88 percent; electrostatic precipitator ahead of the scrubber removes 98.6 to 99.1 percent of the fly ash; no data on fly ash removal in the scrubber; scrubber may add particulates to the flue gas.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables -

   a. Flue gas enters the quencher at 320 F and enters the scrubber at 130 to 150 F.

   b. Outlet gas temperature from the scrubber is 130 F.

   c. Fly ash inlet loading to scrubber is 0.06 to 0.08 grains/scf; emission regulation is 0.05 grains/scf.

   d. The scrubbing liquor pH is 8.5 at the inlet and 6.1 to 6.2 at the outlet.

3. Absorber Design -

   a. Two electrostatic precipitators for fly ash removal.

   b. Two American Air Filter mobile bed contactors for SO_2 control; the contactors are compartmented with a partition in each compartment; sponge-like plastic balls, approximately 1-1/2 inches in diameter, are circulated around the partitions by the action of the flue gas.

   c. The gas velocity is 10 to 14 ft/sec to keep the balls moving.

   d. Turn down is achieved by closing dampers at the bottom of on-line scrubber compartments; the closed compartments are continuously alternated; both modules are always on-line when the FGD system is operating.

4. Liquid-to-Gas Ratio - L/G is 5 gal/1000 ft^3 in the quencher and 50 to 60 gal/1000 ft^3 in the mobile bed.

5. Oxidation - The scrubber effluent solids are 95 to 97 percent sulfite and 3 to 5 percent sulfate.

6. Pressure Drop - The total pressure drop at full load appears to be about 12 in. H_2O; the pressure drop is 2 in. H_2O across the quencher, 6 in. H_2O across the mobile bed, 1 to 1.5 in. H_2O across the old mist eliminator and two new chevrons, and 2.5 to 3 in. H_2O in the ductwork.

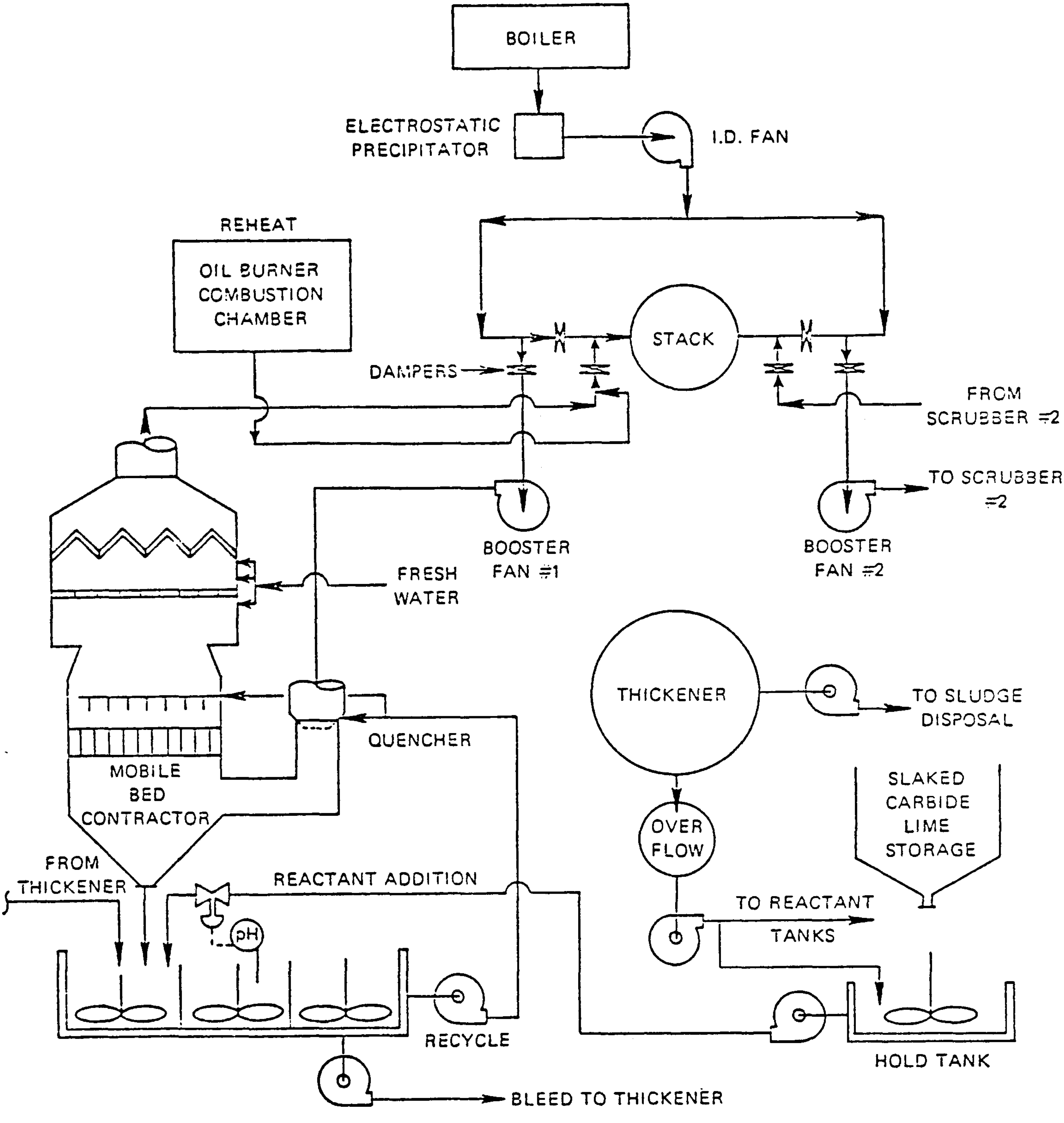

FIGURE 1. FLUE GAS DESULFURIZATION SYSTEM ON CANE RUN UNIT 4

7. Solids Level - 10 percent solids in recirculating scrubber slurry; 22 to 25 percent solids in thickener bottoms using Betz 1100 flocculating agent.

8. Reactant Addition - Carbide lime slurry is added to the hold tank where it is mixed with thickener overflow; the lime slurry can also be added to the reaction tank for fine control of the pH.

9. Reactant Feed Rate - About 1 mole of calcium per mole of SO_2 removed or about 15,000 lb/hr of dry $Ca(OH)_2$ at full load.

10. Slurry Retention Time - About 15 to 17 minutes total in the three chambers of the reaction tank.

11. Mist Eliminator - Two-stage chevron with superficial gas velocity of 10 to 15 ft/sec; first stage is a horizontal chevron with three passes; it is washed intermittently from below and above with fresh water; second stage is a three-pass, A-frame chevron which is washed intermittently from the bottom with fresh water; the mist eliminators are washed sequentially every 16 minutes from 8 sprays with a flow rate of about 20 to 100 gpm depending upon the surface being washed.

12. Reheat System - Reheater fired with No. 2 fuel oil is supposed to provide 50 F of reheat but only gives 25 to 30 F.

13. Waste Disposal - LG&E has a variance to operate the system open-loop; thickener underflow goes to the ash pond; ash pond overflow goes to another pond which overflows the ash sluice water to the Ohio River; LG&E will eventually close the loop by dewatering the sludge.

14. Fans - Two existing induced draft fans and two booster fans ahead of the scrubbers; fans are forced draft with respect to the scrubbers.

C. RELIABILITY

1. Start-up - August 7, 1976.

2. Availability - About 70 to 75 percent operability (hours the FGD system was operated divided by boiler operating hours) during the first year of operation and 90 percent operability from August to December, 1977; the boiler did not operate in early 1978 and came back on line in March; from that time until September, 1978, when the boiler was shut down for 2 months for maintenance, the monthly operabilities have been higher than 90 percent; however, in May, 1978 the operability was only 35 percent because modifications were being made to the dampers.

3. Longest Run - About 30 to 40 days.

4. Calendar of Operation - The FGD system has operated for more than 7,000 hours since startup.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - The quencher wall surface is mild steel coated with Pre-Krete G-8. The flow is deflected by a sheet of Type 316 stainless steel placed at an angle to the wall.

2. Abosrber - The absorber is mild steel coated with Pre-Krete from the quencher to the mist eliminator. During an outage in May 1977, the Pre-Krete G-8 received minor repairs to the walls near the nozzles, and to the floor which was cracked. The grid compartments (cages) for the absorber balls as well as the dampers below each of the 10-bed compartments are constructed from Type 316L stainless steel. The original sponge rubber balls installed in the bed "pruned up" and were replaced by a different type (green coating) supplied by AAF. LG&E feels that (glass) marble bed media used in Paddy's Run Unit 6 has more long-term potential than organic bed media.

3. Spray Nozzles - The spray nozzles were originally plastic (same as Paddy's Run Unit 6) but the spinners of these plastic nozzles were heat-softened in service and extruded from the housing. They were then replaced with ceramic (dense Al_2O_3) nozzles but too much pressure drop resulted. The nozzles on the second (upper) header layer are now Type 316 stainless steel cork screw type. No nozzles are used in the first header -- the lime slurry is sprayed directly out of 1-foot long fiberglass pipe nipples.

4. Mist Eliminators - A centrifugal design originally installed has been replaced with a two-stage plastic chevron. The original material was Type 316 stainless steel but it was replaced because of the high pressure drop, not material failure.

5. Fans - Carbon steel fans.

6. Reheater - The reheat combustion chamber is refractory lined and has cast iron burners; the outlet duct is Type 316 stainless steel.

7. Pumps - The slurry recycle pumps are rubber lined and manufactured by Gardner-Denver. There are three pumps per module and all are in use so there is no spare. Originally there was one spare pump per module but the L/G had to be increased to meet the SO_2 removal efficiency requirements. The bleed pumps, thickener overflow pumps, and hold tank pumps are rubber lined. Rubber debonding failures on the rotors of the recycle pumps have been caused by overloading and too high a speed. The lining pieces end up in the spray nozzles. The pumps have been slowed down and the linings have been replaced. Case lining erosion has also occurred. Overloading may have occurred because the pumps may be overrated by the manufacturers and operating the pumps at or near rated capacity causes lining failures. LG&E prefers Ni-Hard pumps. The thickener underflow pump is Type 316 stainless steel. Pumps installed in pits have been submerged when leaks develop. Above ground locations are preferred to avoid damage and maintenance problems.

8. Tanks - The reaction-recycle tank is concrete. The hold tank for lime slurry is mild steel with no lining.

9. Agitators - The agitator blades in the reaction tank were originally rubber coated cast stainless steel which were prone to mechanical breakage. They were replaced with rubber coated mild steel and are now operating satisfactorily. The agitator in the hold tank is rubber coated mild steel.

10. Storage Silos - There is no storage silo. The slaked carbide lime is delivered as a slurry.

11. Thickener - Mild steel tank with no lining.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The inlet duct is uncoated carbon steel. The outlet duct is carbon steel originally coated with a Carboline coating (type uncertain) to the reheat chamber. This coating blistered after about a half-year of scrubber operation without reheat, and was replaced about May, 1977 with Plasite 4005 (applied in two 20 mil coats to freshly blasted and primed steel). After the system was restarted about June, 1977, it has always been operated with reheat, but this section of the duct is exposed to wet flue gas and has apparently given good service. The outlet duct from the reheaters to the stack and a short section of bypass duct tying into it are carbon steel with Pre-Krete G-8. The lining in the bypass section (worn) and the breaching (cracked) also received minor repairs during the May, 1977 outage, and again in March, 1979. The section of the bypass duct ahead of the dampers is uncoated carbon steel.

The original rubber expansion joints were replaced in July, 1977 during an outage.

Dampers are guillotine-type mild steel set in stainless steel runners. There has been trouble with hang-up of the rack and pinion-driven gate which was solved by providing more clearance.

14. Piping and Valves - All piping to and from the scrubber is fiberglass. Localized erosion near butterfly control valves resulted in wear through of the fiberglass. This was solved by using rubber-lined spool pieces near valves. Valves are stainless steel, butterfly for flow control, and knife gate (DeZurik) for isolation (shutdown to replace pumps, etc.). Problems have been experienced because of packing seal leaks. Recommended solution to valve problem is to eliminate them completely as they compound rather than simplify maintenance.

15. Stack - The 250-ft stack has a concrete shell with 5 corbel sections lined with acid resistant brick. The stack was built in 1962 and the mortar type is unknown, but it washed out after about 9 months of scrubber operation without reheat, and the acidic (pH2) condensate attacked the concrete. The bricks were removed in June, 1977, the concrete was sandblasted, and 2 inches of Pre-Krete G-8 was installed with wire mesh reinforcement anchored to the concrete. It has given satisfactory service with reheat since that time. Because of the stack design, there is no annulus for pressurization.

16. Slaker - None used since the reagent is delivered as a slurry of $Ca(OH)_2$.

17. Pond - A clay-lined pond common to Cane Run 4 and 5 is being used to temporarily dispose of the sludge under a code variance. However, the variance will expire during 1980 after which LG&E will have to install a sludge stabilization process.

E. COMMENTS

LG&E collected data on Cane Run Unit 4 and characterized the maintenance problems from August, 1976 to July, 1978. About 42 percent of the maintenance time was related to problems with the pumps. Piping problems ranked second in maintenance time. Only 3 to 4 percent of the maintenance time was related to pH meters, controls, etc.

LOUISVILLE GAS & ELECTRIC COMPANY (LG&E)
MILL CREEK UNIT 3

Trip Report Number: EPRI-CM3

Date of Trip: November 28, 1978

Persons Interviewed: Robert P. Van Ness, Manager of Environmental Affairs, LG&E.

A. PROCESS DESCRIPTION

Mill Creek Unit 3 is a 425 MW new boiler designed for base load use. It has an American Air Filter FGD system that is the same as the modified Cane Run Unit 4 except that it has four modules instead of two. The same coal and scrubber reactant are used as at Cane Run.

B. PROCESS DESIGN

The process design is the same as at Cane Run Unit 4 including the liquid-to-gas ratio and the pressure drop. The four mobile bed contactors have chevron mist eliminators without the vestiges of the centrifugal mist eliminators that were originally installed on Cane Run Unit 4. The flue gas will be reheated with in-line steam coils constructed of mild steel finned tubes installed in the duct to the stack. The reheat system is not in operation yet because it was not installed on time. The scrubber sludge is sent to an existing ash pond.

C. RELIABILITY

The system started up on July 25, 1978. All of the recycle pumps have not been operated yet. Pump failure has been the major problem with this unit.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - Quencher is carbon steel lined with Pre-Krete G-8.

2. Absorber - Pre-Krete lined mild steel.

3. Spray Nozzles - The scrubbers were constructed with the same nozzles now in use at Cane Run 4. The lower header has only FRP pipe nipples and the upper header has Type 316 stainless steel corkscrew nozzles on FRP pipe.

4. Reheater - Reheat will be provided at the top of the absorber by in-line steam coils using mild steel finned tubes. However, the reheaters are not yet in operation.

5. Pumps - The recycle pumps are rubber-lined manufactured by Ingersoll-Rand. There are two banks of five pumps each. Normally, four pumps should

be operating in each bank (two per module) with one standby. However, no more than three to five pumps out of the ten have been operable at any given time. All of the rubber linings have failed. Other pump shutdowns have been caused by shaft failures, bearing failures, and improper lubrication.

6. Ducts - The inlet duct is unlined carbon steel. The outlet duct is Pre-Krete lined mild steel. The bypass duct was originally lined with Penngard foam glass blocks (adhesive type unknown) and had a water spray section to quench the gas and protect the stack lining. The foam glass blocks fell out after several months of operation and were removed in January, 1979 along with the spray nozzles. The steel duct was badly corroded and was patched with carbon steel plate. The bypass and outlet ducts join before the stack. It is uncertain what materials are used in the breeching duct section.

7. Stack - The 600-foot concrete stack has a steel lining covered with about 80 mils of Ceilcote Flakeline 151. The coating has begun to flake off after one year of operation without reheat, and will not be replaced unless a satisfactory coating is found.

8. Pond - As at Cane Run, Mill Creek 3 temporarily disposes of the sludge in a clay-lined pond under a variance.

E. COMMENTS

The Mill Creek Unit 3 FGD system has not operated long enough to judge materials performance.

LOUISVILLE GAS & ELECTRIC COMPANY (LG&E)
CANE RUN UNIT 5

Trip Report Number: EPRI-CM4

Date of Trip: November 28, 1978

Persons Interviewed: Robert P. Van Ness, Manager of Environmental Affairs, LG&E.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Combustion Engineering (CE) is the process designer and vendor; LG&E is the contractor and consulting engineer; retrofit installation.

2. Boiler Type - Unit 5 is a pulverized coal, front fired, dry bottom boiler nominally rated at 190 MW with a heat rate of 10,600 Btu/kWh.

a. 30 percent excess air.

b. Capacity factor is 62.7 percent; the unit is at full load during the day and at half load at night.

c. Stack height is 250 feet.

3. Flue Gas Flow Rate - 740,000 acfm at 300 F at full load; all the flue gas is scrubbed.

a. 6 percent oxygen in the flue gas.

4. SO_2 Concentration - 2,700 to 2,900 ppm SO_2 in inlet gas and 200 ppm SO_2 in outlet gas.

4. Fuel - Kentucky bituminous coal containing 3.8 percent sulfur and 13.9 percent ash, with a heat content of 11,000 Btu/lb.

6. Scrubber Reactant - Carbide lime as in Cane Run 4 and Paddy's Run 6.

7. Removal Efficiency - Greater than 85 percent SO_2 removal to meet a Jefferson County emission regulation of 1.2 lb $SO_2/10^6$ Btu; electrostatic precipitator ahead of the scrubber removes 98 to 98.5 percent of the fly ash.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables -

a. Flue gas enters the scrubber at 300 F.

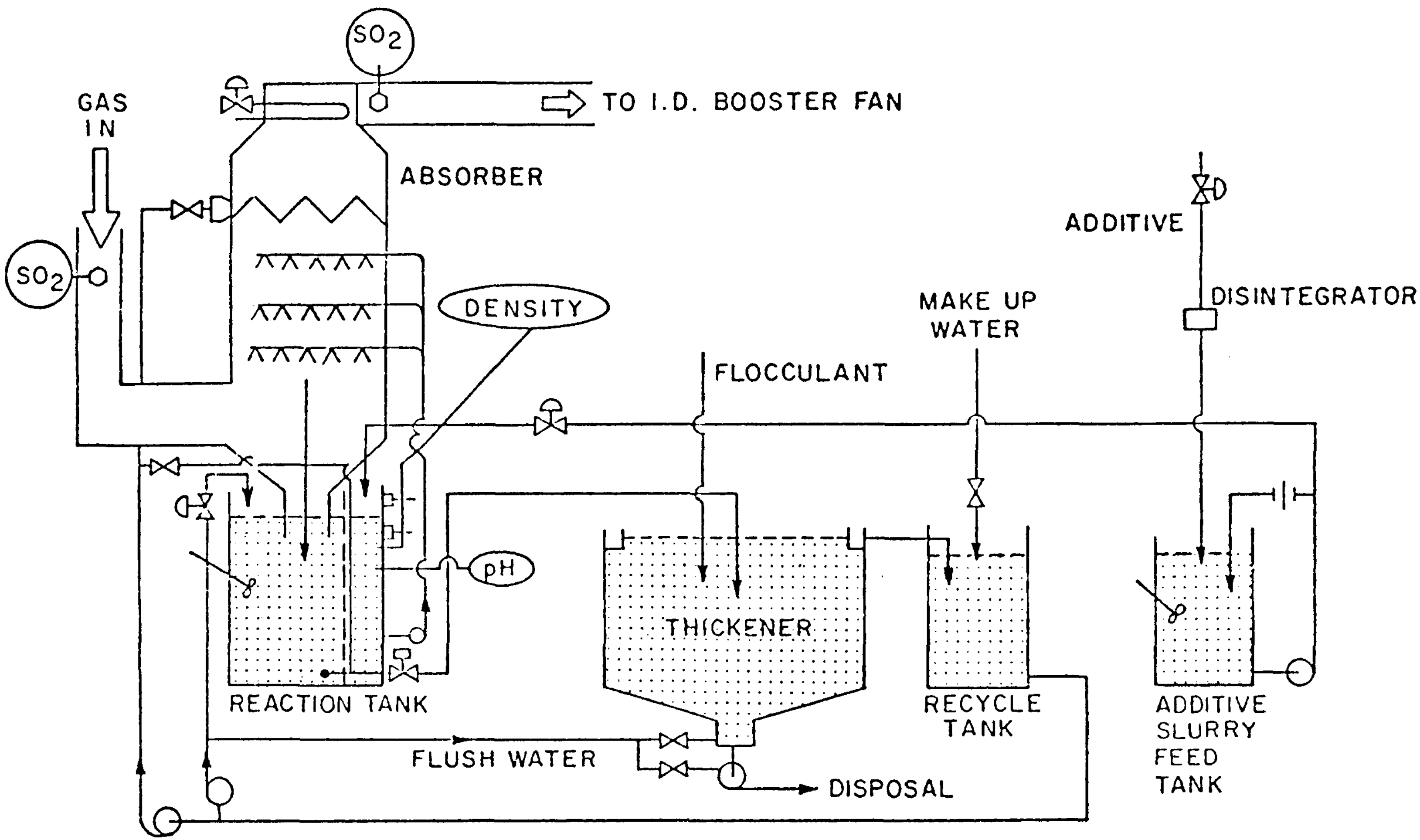

FIGURE 1. AIR QUALITY CONTROL SYSTEM FOR CANE RUN UNIT 5

b. Outlet gas temperature from the scrubber is 130 F.

c. Fly ash inlet loading to scrubber is probably about 0.05 to 0.10 grains/scf.

d. The scrubbing liquor pH is 9 at the inlet and 5.4 to 5.6 at the outlet.

3. Absorber Design -

a. Electrostatic precipitator for fly ash removal.

b. Two spray towers for SO_2 removal with one recycle pump per tower (design converted from marble beds to spray towers by the vendor during the construction period).

c. The superficial gas velocity in the towers is 12 ft/sec at full load.

d. The turndown ratio is very high; the system has been operated from 190 down to 30 MW; both modules are usually operated but a module has to be taken off-line to wash the reheater.

4. Liquid-to-Gas Ratio - L/G is 65 to 70 gal/10^3 ft^3 at full load.

5. Oxidation - The scrubber effluent solids are 90 percent sulfite and 10 percent sulfate; the system operates at about 70 percent saturation with respect to sulfate.

6. Pressure Drop - The total pressure drop is 6 to 7 in. H_2O; the pressure drop is 2 in. H_2O from the boiler I.D. fan to the scrubber, 2 in. H_2O across the scrubber, 1/2 in. H_2O across the mist eliminators, 1/2 in. H_2O across the reheater, and 1 in. H_2O from the reheater to the booster fan.

7. Solids Level - 7 percent solids in recirculating scrubber slurry; 25 percent solids in lime slurry; 25 percent solids in thickener bottoms; 5 ppm of Betz 1100 flocculating agent is used in the thickener.

8. Reactant Addition - Carbide lime slurry is added to the one reaction tank for the two spray towers.

9. Reactant Feed Rate - Appears to be 1.05 moles Ca/mole SO_2 removed not counting a 10 percent loss of gritty material that will be reground in a hydroclone ball mill.

10. Slurry Retention Time - 7 to 8 minutes at full load.

11. Mist Eliminator - Slat-type bulk entrainment separator plus two-stage, A-shape, chevron mist eliminator with three passes per stage; the superficial gas velocity is 12 ft/sec; the mist eliminator is washed once per shift from below the first stage and between the first and second

stages using river water at 200 psi and 80 gpm for the whole area; the washing is done when the reheater is washed.

12. Reheat System - In-line reheat with finned, carbon steel tubes containing steam at 450 F and 200 psi providing about 25 F of reheat; the reheater is equipped with steam soot blowers. The reheater is located about 10 feet beyond the absorber outlet in a horizontal duct rather than in the top of the absorber as shown in Figure 1.

13. Waste Disposal - LG&E has a variance to operate the system open-loop; thickener underflow goes to the existing ash pond; ash pond overflow goes to another pond which overflows the ash sluice water to the Ohio River; overflow from the thickener is returned to the scrubber system; LG&E will eventually close the loop by dewatering and stabilizing the sludge for landfill.

14. Fans - There is an axial I.D. booster fan after each scrubber.

C. RELIABILITY

1. Start-up - December 29, 1977.

2. Availability - The monthly operabilities (hours the FGD system was operated divided by boiler operating hours) for 1978 are as follows:

Month	Scrubber Operability, percent	Boiler Operation, hrs
March	50	182
April	96	669
May	85	432
June	86	685
July	80	632
August	86	540
September	90	609
October	96	530 .

3. Longest Run - Roughly three weeks.

4. Calendar of Operation - The scrubber was operated for 2 days in 1977 to get a tax credit and then was shut down until March, 1978.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - None used.

2. Absorber - The absorber is carbon steel with a Flakeline 252 lining containing glass flakes. There has been some repair of eroded areas with Dudick Protecto-Flake 500 whenever a header or nozzle fails and direct impingement occurs. There are Type 316 stainless steel impingement plates in the area of the three spray headers. The exterior of the absorber is also coated with Flakeline 252 for about 5 feet above the reaction tank.

3. Spray Nozzles - Black ceramic from CE, probably silicon carbide.

4. Mist Eliminators - The mist eliminator is formed plastic supplied by CE. Identification of this plastic and further details regarding construction must be obtained from CE.

5. Fans - Fans are constructed of mild steel.

6. Reheater - The reheater is constructed of mild steel, with finned carbon steel tubes. There are some stainless steel baffle plates on the sides of the duct. The reheaters are located in a horizontal duct about 10 feet from the top of the absorber.

7. Pumps - The recycle pumps are rubber lined Denver with direct drive. The thickener underflow pumps are Robbins & Myers Moyno pumps with a stainless steel rotor and a rubber stator. Slurry additive pumps are centrifugal type made of carbon steel.

8. Tanks - The reaction tank is mild steel with no lining, as are the recycle and additive tanks.

9. Agitators - The agitators in the reaction and slurry feed tanks are Lightnin mixers (four blades). The shaft is mild steel and the blades are mild steel clad with rubber.

10. Storage Silos - None used.

11. Thickener - Mild steel walls with no lining. Concrete formed conical bottom.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - Ducts are mild steel except for a 10 ft section of the outlet duct which is lined with Flakeline 252. Due to erosion of the lining by soot blowers just ahead of the reheaters, Type 316L stainless steel wear plates have been installed for the last 3 feet. As the system is never operated without reheat, there are no linings in the carbon steel ducts in or beyond the reheater section.

Expansion joints were described as the typical rubber type.

The louver dampers are mild steel with Type 316 stainless steel blades.

14. Piping and Valves - Piping is fiberglass reinforced plastic. The only large valves used are two Type 316 stainless steel DeZurik knife gate valves on suction side of recycle pumps. All solids in slurries are ground to less than 200 mesh to curtail abrasion of pipes.

15. Stack - The 250-ft concrete stack was originally constructed about 1966 with acid-resistant brick sitting on 5 corbel sections. In September, 1977 before scrubber start-up, the bricks were removed from the top 50 feet and a Pre-Krete G-8 lining was installed in the entire stack.

16. Slaker - None used as the lime is delivered as a slurry of $Ca(OH)_2$.

17. Pond - The pond common to Cane Run 4 and 5 being used temporarily (under a variance) for sludge disposal is clay-lined.

KENTUCKY UTILITIES COMPANY (KU)
GREEN RIVER UNITS 1 AND 2
(BOILERS 1, 2, AND 3)

Trip Report Number: EPRI-CM5

Date of Trip: November 29, 1978

Persons Interviewed: S. V. Anderson, Assistant Superintendent, Operations, and K. D. Cummins, Assistant Superintendent, Maintenance, Green River Power Station, KU.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - American Air Filter (AAF) is the process designer, vendor, and contractor; retrofit installation.

2. Boiler Type - Babcock and Wilcox pulverized coal-fired boilers; 26 years old; rated at 25 MW but running at 21 MW full load; heat rate is about 10,000 Btu/kWh.

   a. 25 percent excess air.

   b. The capacity factor is about 40 percent; the units are normally operated at full load on weekdays and are shut down on weekends.

   c. The stack height is 165 ft above grade and 78 ft above the scrubber.

3. Flue Gas Flow Rate - 296,300 acfm of flue gas at 116 F; all three boilers are ducted to a single venturi and mobile bed contactor system. However, the gas-handling capacity limits the scrubber to handling only the gases from boilers at reduced load (50 to 52 MW instead of 64 MW). The only bypass is complete bypass to the original stack.

4. SO_2 Concentration - 1,600-2,600 ppm SO_2 in inlet gas; 300-450 ppm SO_2 in outlet gas. Occasionally the process was run on a much lower SO_2 inlet concentration when burning low-sulfur coal.

5. Fuel - Western Kentucky high-sulfur coal, 3.5 to 4 percent sulfur, 12.5 percent ash, 11,200 Btu/lb; principally surface-mined coal.

6. Scrubber Reactant - Virginia or Missouri lime, composition unknown.

7. Removal Efficiency - Approximately 80-90 percent SO_2 removal; particulate removal is estimated at 98 percent.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

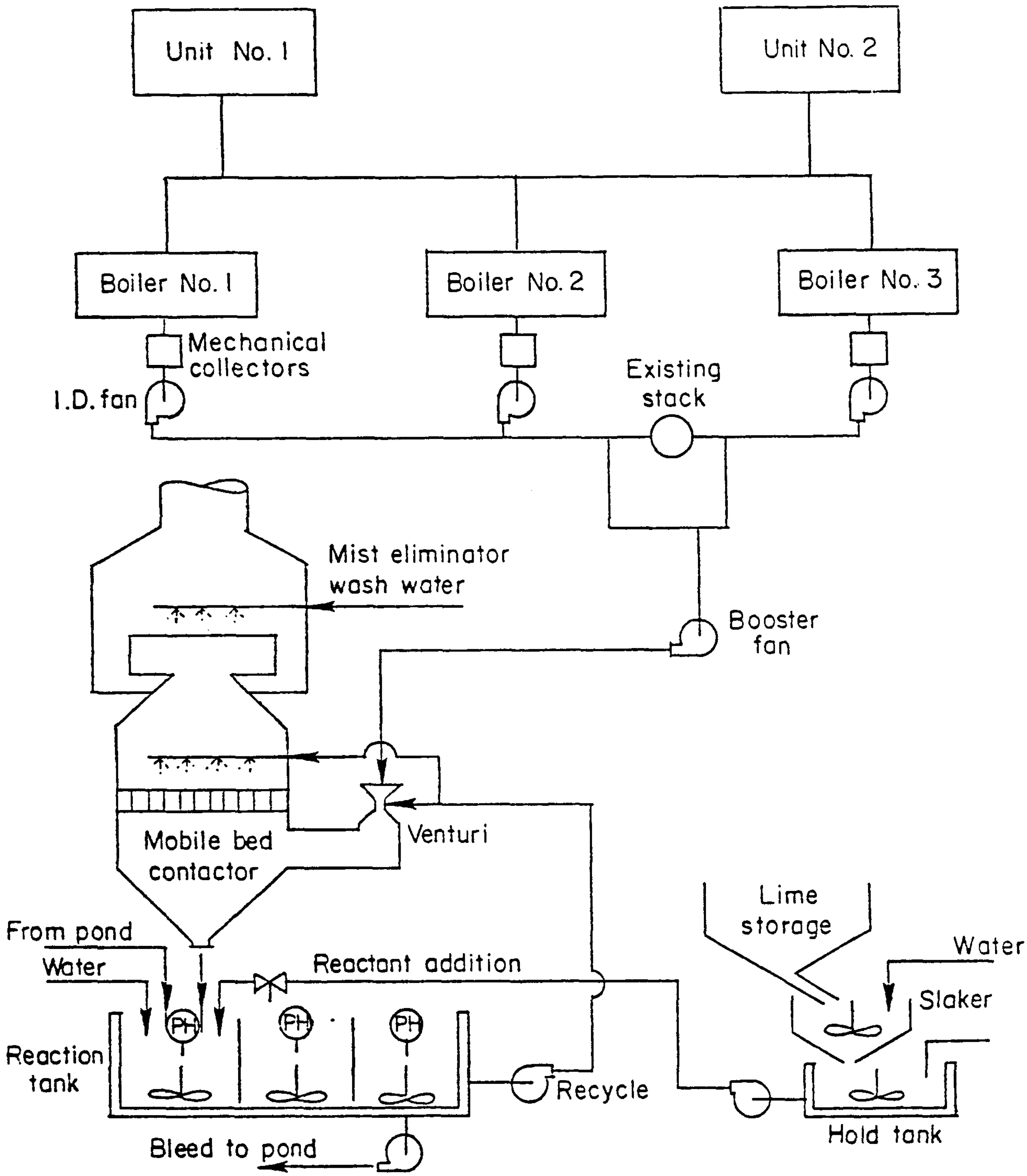

FIGURE 1. FLUE GAS DESULFURIZATION SYSTEM ON GREEN RIVER UNITS 1, 2, AND 3

2. Process Variables -

   a. Gas inlet temperature is 300 F.

   b. Gas outlet temperature is 116 F; no reheat currently, but reheat is being added to raise the outlet temperature by 50 F.

   c. The fly ash loading to the scrubber is 2.68 grains/dry scf.

   d. Scrubbing liquor pH is 8.5-9.0 at the inlet and 5.5-6.0 at the outlet.

3. Absorber Design -

   a. An adjustable throat venturi with tangential spray and flooded elbow for particulate removal; also functions to cool and saturate the gas.

   b. A mobile bed contactor for SO_2 removal consisting of ten compartments with a partition installed in each compartment; sponge-like plastic balls, approximately 1-1/2 inches in diameter, are circulated around the partitions by the action of the flue gas. The lime-based scrubbing slurry is sprayed overhead into both sides of the partitions. The spent slurry drains from the bottom of the scrubber along with the mist eliminator wash spray into the three-stage reaction tank.

   c. The superficial gas velocity is 11-12 ft/sec through the mobile bed contactor.

   d. Turndown is accomplished by closing dampers, located at the bottom of each compartment, and redirecting the flue gas into the remaining open compartments. AAF recommends that no more than two of the ten compartments be closed at any one time, thus enabling a 20-percent turndown to 80 percent of maximum flow. To prevent plugging of the closed compartments AAF also recommends that each compartment be closed for no longer than 5 minutes and that the various compartments be alternately opened and closed to achieve the net turndown effect. During turndown operation, the scrubbing slurry spray is maintained in all compartments.

4. Liquid-to-Gas Ratio - 35 gal/1000 acf.

5. Oxidation - Not specified.

6. Pressure Drop - 6.4 to 9.0 inches of water through the venturi and 2.8 to 3.2 inches of water through the mobile bed contactor.

7. Solids Level - Approximately 10 percent in recycle and discharge slurry and 20 percent in makeup lime slurry.

8. Reactant Addition - Into the spent slurry return section of the reaction tank.

9. Reactant Feed Rate - Approximately 120 lb of lime per ton of coal (3.5 percent sulfur) burned, or 1.1 to 1.2 moles lime/mole SO_2 removed.

10. Slurry Retention Time - 27 to 30 minutes in the reaction tank.

11. Mist Eliminator - Centrifugal mist eliminator with stationary spin vanes; the vanes and sidewalls are washed with makeup water at the rate of 45 gpm.

12. Reheat System - There are currently no provisions for reheat, but indirect hot air reheat is being added.

13. Waste Disposal - The waste disposal system is closed loop; the scrubber effluent is sent to a 9 acre, 25 ft deep pond with an estimated storage life of 12 years at full load.

14. Fans - Single 1500 hp booster fan ahead of the scrubber.

C. RELIABILITY

1. Start-up - September 10, 1975.

2. Availability - The system operability (hours the FGD system was operated divided by boiler operating hours) was 79 percent in 1976, 87 percent in 1977, and 48 percent in 1978 through July.

3. Longest Run - About 30 days.

4. Calendar of Operation - The FGD system has operated for about 21,000 hours since startup.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - a two-stage particulate removal (mechanical collectors and a venturi) system is used. The variable throat venturi scrubber is carbon steel to inlet, then Type 316 stainless steel to throat. Following the throat it is carbon steel lined with Pre-Krete G-8. The Pre-Krete was gunned (sprayed) over an expanded metal mesh to a 3/4 inch thickness. Erosive wear has required a reline in this area. The bottom of the venturi is also mild steel with a "flooded elbow" lined with 2 inches of red shale acid resistant brick (G-8 mortar) overcoated with 3/4 inch of Pre-Krete. Localized erosive wear on the upper inside surfaces of the elbow has required a reline. There are 12 Stellite spray nozzles in the venturi.

2. Absorber - The bottom of the absorber (up to the mobile bed area) module is Pre-Krete G-8 coated mild steel. The zone from the bed area to the top of the mist eliminator is Type 316 stainless steel. The mild steel

part of the module above the mist eliminator (including the mild steel stack) originally had a Carboline coating which blistered and failed and has since been replaced with Pre-Krete.

There is a Type 316 stainless steel anti-spin vane at the bottom of the stack. If the gas were allowed to spin up the stack, sway would result.

The Pre-Krete lining (except in stack) has been in place since 1975 (about 21,000 hours operation). The original stack lining was replaced after 13,000 hours of operation.

3. Spray Nozzles - The original nozzles above the bed were a mixture of plastic and stainless steel but they all plugged. Six different types were then tried but best success was had when the nozzles were removed and only the FRP pipe nipples used. Below the bed, ceramic (Refrax) nozzles originally used "spun off" the pipe when they became clogged and have since been replaced with Stellite nozzles. The spray headers are fiberglass by Fibercast Co.

4. Mist Eliminator - The centrifugal vane mist eliminator is Type 316 stainless steel. It consists of stationary vanes to spin the air and throw out water droplets. The build up of solids on the vanes and module side walls require cyclic washing. Eight manifolds with stainless steel spray nozzles are used to wash the vanes with fresh water. An additional four manifolds with stainless nozzles spray the vessel walls with fresh water.

5. Fans - The booster fan precedes the scrubber and is plain carbon steel. It has been recoated by flame spraying mild steel rods two or three times to replace metal worn away by fly ash erosion. A poured refractory lining is used to help prevent casing erosion.

6. Reheater - None currently used, but will install indirect hot air reheat in future to provide reheat from 115 to 165 F.

7. Pumps - The recycle pumps are Ingersoll-Rand with Schabauer (French-made) rubber linings which have been replaced twice. Housing linings tear loose and impeller linings erode from slurry wear and insufficient curing. Ni-Hard impellers are now successfully used without a lining. There are three recycle pumps (two in use and one spare). These have caused many of the problems in operating the scrubber to date.

The bleed pumps are also rubber lined. Linings and impellers are believed to have been replaced once.

The pond return pumps are carbon steel and are replacements for rubber-lined pumps which failed because the bearing water supply froze during cold weather.

Reactant pumps are rubber-lined, fitted with rubber-lined impellers. Frequent impeller failures are attributable to gravel being carried in with slaked lime.

8. Tanks - The three section reaction tank is concrete. The lime slaker tank and hold tank are both unlined mild steel.

9. Agitators - The agitators have a cold-rolled carbon steel shaft and a cast carbon steel impeller, all rubber clad. There have been some problems thus far, primarily with hub breakage and with the gear box to shift couplings. These problems have been solved by redesign.

10. Storage Silos. Lime storage silo is unlined mild steel.

11. Thickener - None used. Spent slurry pumped to an unlined natural clay pond.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The inlet ducts are mild steel. The outlet duct is mild steel with a Pre-Krete lining. Original fabric (Viton®) expansion joints tore loose and have been replaced with stainless steel bellows. The dampers are guillotine type.

14. Piping and Valves - The pipe from the reaction tank to the hold tank is Type 316 stainless steel. Rubber lined mild steel pipe is used from reaction tank to scrubber and to pond and back. The spray headers and the lines from the scrubber to the reaction tank are fiberglass. The slurry valves are knift gate DeZurick. The modulating valves have a stainless steel body and a rubber-lined plug.

15. Stack - Stack is mild steel and is directly above the scrubber. Gas temperature in stack is 116 F. It was originally lined with a Carboline material (details and specifications unknown). The lining failed after about 13,000 hours causing corrosion of the stack. New plates were welded over about half to two-thirds of the outer surface of the stack. The stack was then blasted and lined with Pre-Krete. Wire mesh was first attached to the stack interior to anchor the Pre-Krete, and the Pre-Krete was gun applied about 3/4 inch thick. Service time for the Pre-Krete lining in the stack is about 8000 hours, all without reheat.

INDIANAPOLIS POWER & LIGHT COMPANY (IPL)
PETERSBURG UNIT 3

Trip Report Number: EPRI-CM6

Date of Trip: November 30, 1978

Persons Interviewed: Steve Moore, Construction Engineer, and Rex Hoppes, Plant Engineer, Petersburg Generating Station, IPL.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Universal Oil Products (UOP) is the process designer and vendor; Gibbs and Hill is the consulting engineer; new installation.

2. Boiler Type - Unit 3 at Petersburg is nominally rated at 515 MW with a heat rate of about 10,000 Btu/kWh. The boiler is manufactured by Combustion Engineering and is pulverized-coal fired with a rating of 4,150,000 lb steam/hr.

a. Design is 25 percent excess air.

b. Base load unit: full load during the day and 300 MW from midnight to 5:00 a.m.

c. Stack height is 616 feet.

3. Flue Gas Flow Rate - 1,950,000 acfm at 286 F at full load; a portion of the flue gas is bypassed for reheat and operating flexibility.

a. 5 percent oxygen in the flue gas.

4. SO_2 Concentration - About 2600 ppm SO_2 in inlet gas and about 400 - 500 ppm SO_2 in outlet gas.

5. Fuel - Bituminous Indiana strip mine, high-sulfur coal (3 -4.5 percent S); ash content is 8 - 10 percent; moisture content is 10.5 - 16.5 percent; heat content is about 10,750 Btu/lb.

6. Scrubber Reactant - Limestone from Orleans, Indiana.

Specifications:	$CaCO_3$	94.6 - 97.8 percent	(avg. 95.9 percent)
	$MgCO_3$	0.6 - 6.6 percent	(avg. 2.9 percent)
	R_2O_3	0.2 - 0.8 percent	(avg. 0.5 percent)

7. Removal Efficiency - SO_2 removal efficiency in excess of 80 percent has been obtained during recent emission testing where the required emission rate of 1.2 lb/10^6 Btu input was met. NO_x testing to date has

been less than the 0.7 $lb/10^6$ Btu required emission limit. Electrostatic precipitators ahead of scrubbers are designed to remove about 99 percent of particulate matter; stack testing has substantiated that particulate emission meets 0.1 $lb/10^6$ Btu input.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables -

   a. Flue gas enters the scrubber at about 280 to 286 F.

   b. Outlet gas temperature from the scrubber is about 118 to 125 F before reheat.

   c. Fly ash inlet loading to scrubber is normally about 0.03 grains/acf; design allows for this loading to be as high as 0.09 $lb/10^6$ Btu.

   d. The scrubbing liquor pH is about 5.6 to 5.9.

3. Absorber Design -

   a. Two Research-Cottrell cold-side electrostatic precipitators are used for particulate removal (99.3 percent efficiency).

   b. Four modules of turbulent contact absorbers (TCA) are used for SO_2 removal; each module has three stages of mobile bed packing; the first two stages are packed with rubber spheres (about 1.5 inches in diameter) in adjacent compartments; the top stage has no compartmental division and is filled with plastic ping pong type balls.

   c. Superficial gas velocity is about 14.5 ft/sec to keep all the balls and spheres moving.

   d. As the boiler load changes, scrubber modules can be put on or off line via a set of guillotine dampers in the gas line.

4. Liquid-to-Gas Ratio - 60 gal/1000 ft^3.

5. Oxidation - Preliminary tests indicate 12 percent oxidation.

6. Pressure Drop - Absorber pressure drop is about 8.5 inches of H_2O; total pressure drop through the system is estimated at less than 17 in. of H_2O.

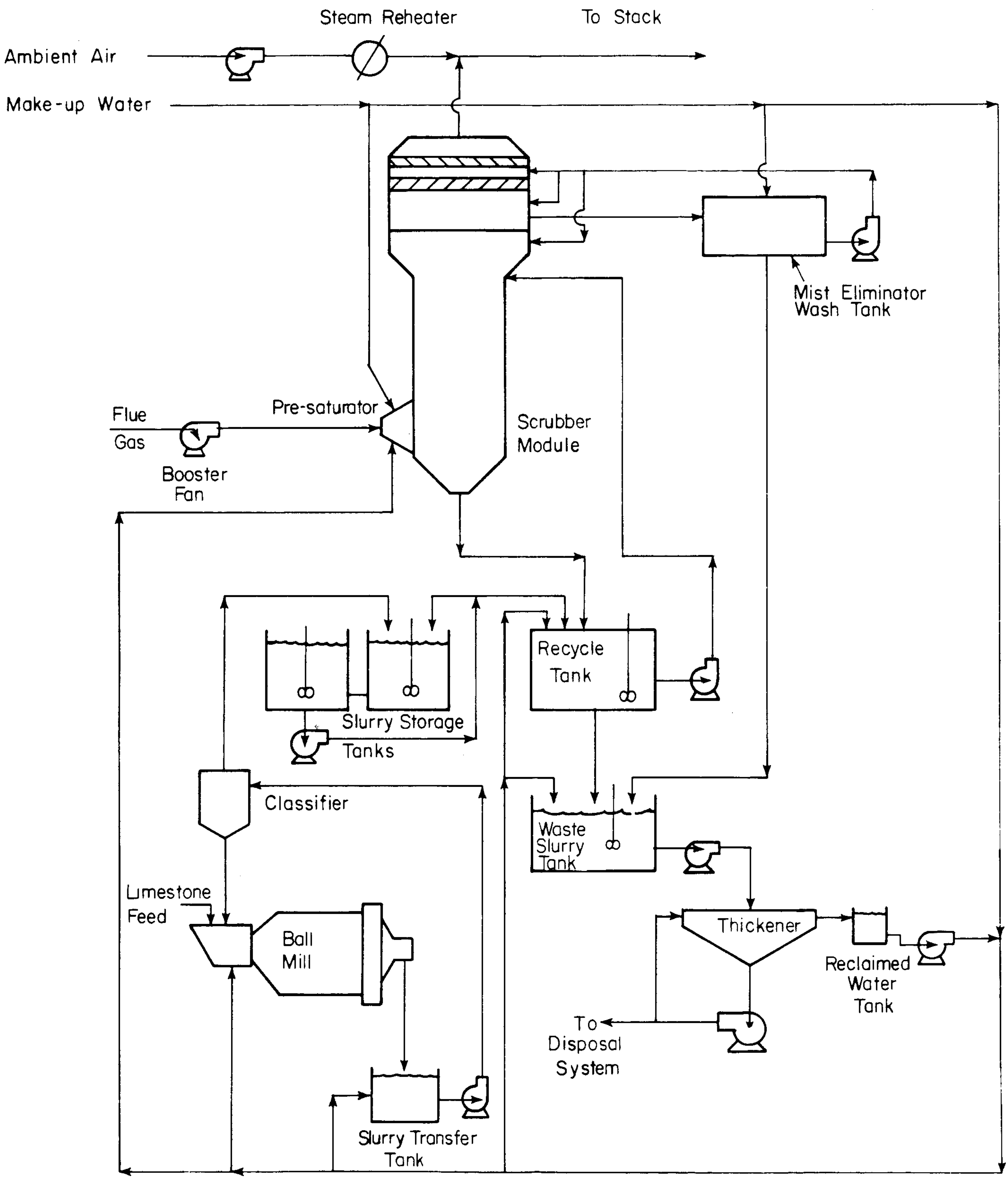

FIGURE 1. FLUE GAS DESULFURIZATION SYSTEM ON PETERSBURG UNIT 3

7. Solids Level - 7 to 15 percent solids in recirculating slurry; 35 percent solids in limestone feed; 30 percent solids in thickener underflow and 55 percent in filter cake.

8. Reactant Addition - Fresh limestone slurry is added to the slurry tanks and pumped to the recycle tank.

9. Reactant Feed Rate - Design is about 1.2 moles of limestone per mole of SO_2 removed.

10. Slurry Retention Time - About 10 minutes.

11. Mist Eliminator - A trap out tray and two stages of horizontal chevron mist eliminators located in an expanded section of the scrubbers; the first and second stages have three passes each; there is an upward wash spray below the trap out tray and below the first stage; there is a downward wash spray above the first stage; the wash water is a mixture of recycle water and makeup water; all the makeup water goes to the mist eliminator wash.

12. Reheat System - Stack gas reheat is provided by heating ambient air with steam tube bundles located outside the gas ducts; this indirect reheat raises the flue gas temperature up about 30 F (118 to 148 F).

13. Waste Disposal - Closed-loop system; about 150 tons/hour of thickener underflow (30 to 35 percent solids) is discharged to an IUCS sludge stabilization system for chemical fixation; stabilized sludge is hauled by trucks to a disposal area on site.

14. Fans - Two forced draft fans (one per two modules) located ahead of the scrubbers boost the gas through the FGD system.

C. RELIABILITY

1. Start-up - December, 1977.

2. Availability - The scrubber has been in operation only about 2 months since start-up.

3. Longest Run - 5 to 6 days for all four modules and 2 to 3 weeks for two modules.

4. Calendar of Operation - Original start was simply a 2-day trial (December 23 and 24, 1977); between then and September, 1978, unit operated only about six days; since September, 1978, operation has been about 2 out of 3 months, with two out of the four modules.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - The horizontal presaturator duct is carbon steel lined with 1-in. thick Pre-Krete G-8. Recycled water is sprayed into the gas stream through Carpenter 20 stainless steel nozzles. The gas enters the scrubbers through a perforated mild steel plate. Struts inside the duct are Pre-Krete coated steel, which has some corrosion or erosion. The Pre-Krete G-8 lining on the side walls of the duct also shows some erosion.

2. Absorber - The absorber module is rubber lined mild steel except for the outlet duct, which is "flake lined" mild steel. The "flake" lining in the outlet duct is holding up very well. It was applied by Corrosioneering.

The cages in the absorber are as follows: side grates are Fibergrate Type D (fiberglass reinforced orange vinyl ester) while top and bottom grids are Goodyear LS 575 neoprene rubber clad (by a subcontractor for UOP) mild steel.

Ping pong like balls are used in the top of three absorber sections; sponge rubber like balls are used in the two lower sections.

3. Spray Nozzles - The absorber slurry nozzles are silicon carbide. The mist eliminator wash and saturator nozzles are Carpenter 20 stainless steel.

4. Mist Eliminator - The slats are FRP with Hetron® 197 resin.

5. Fans - All carbon steel.

6. Reheater - Indirect steam type with mild steel tubes.

7. Pumps - The recycle pumps (Denver), slurry transfer pumps (Galigher), and slurry makeup pumps (Worthington) are all rubber-lined. The reclaim water and demister wash pumps (Goulds) are stainless steel but the casings are a different material than the impellers. The pumps to the thickener and the thickener underflow pump (Worthington) are rubber-lined.

8. Tanks - The recycle tank is "flake lined" mild steel (lining applied by Corrosioneering). Slurry hold and mill discharge tanks are carbon steel. The reclaim water tank is carbon steel lined with Carbomastic 14 (coal tar epoxy by Carboline). The mist eliminator wash tank is FRP and the waste slurry tank is concrete.

9. Agitators - All agitators are rubber coated mild steel except for a stainless steel shaft on a small Lightnin mixer in the slurry transfer tank.

10. Storage Silos - Limestone storage silo is mild steel.

11. Thickener - The thickener has carbon steel walls and a concrete base, all lined with Carbomastic 14.

12. Vacuum Filter - Mild steel parts with Carbomastic coating. The filter cloth is polypropylene.

13. Ducts, Expansion Joints, and Dampers - The outlet duct to the bypass duct is carbon steel with a Resista-Flake 1150AR lining. Steps in applications included blasting, priming, and two coats of "flake glass" to about 60 mils thickness. This lining was replaced with the same material in April, 1979, as it was wearing thin. The bypass duct is carbon steel with a Rigiflake 4850 lining after the junction with the outlet duct. This lining began coming off in the Fall of 1978 and is due to be replaced in the Fall of 1979. There is no quench section in this duct. Inlet ducts are unlined mild steel, with a 1-inch thick Pre-Krete coating starting in the saturator. The dampers are carbon steel guillotine-type with Carpenter 20 seals. The expansion joints are rubber.

14. Piping and Valves - The slurry lines are rubber lined carbon steel. Fiberglass is used for the reclaimed water lines. There were problems with the fiberglass piping system in the scrubber area for the smaller sized (6 in. and below) piping. This piping system was replaced with Kelolite polypropylene-lined carbon steel. The mist eliminator wash lines are fiberglass.

The valves are mostly Hilton knife gate type with stainless steel blades and body. Seals are Teflon impregnated asbestos. Leakage around the valve seats and stems required all valves to be reworked by the manufacturer. Reliable valve operation is still a problem to be resolved. Mist eliminator wash valves are DeZurik eccentric plug cast steel valves. There are a few rubber lined butterfly valves in the system.

15. Stack - The stack is concrete with a carbon steel lining protected with Rigiflake 4850. The lining was applied by Rigiline Division of Dart Industries, Avon, Ohio. The base coat was hand troweled 30 to 40 mils thick and then highly rolled. The top coat was spray applied 15 to 20 mils thick, and blistered badly under bypass conditions. In April, 1979, the entire lining was replaced with two troweled coats. Although the system is never operated without reheat, acid condensation is noted in the drain at the base of the stack. Future construction will consider acid-resistant brick lining for stacks.

TENNESSEE VALLEY AUTHORITY (TVA)
WIDOWS CREEK UNIT 8

Trip Report Number: EPRI-CM7

Date of Trip: December 7, 1978

Persons Interviewed: Environmental Research Dept: W. L. Wells, Projects Manager; George Munson, Research Chemist; Russell F. Robards, Engineer; Power Production Dept: J. H. Buckner, Power Plant Operations Specialist; Joe Barkley, Engineer; Dave Goetcheus, Metallurgist.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - TVA provided all the engineering services required for this effort, from preliminary research studies to design and construction of the facility. This is a retrofit application for the scrubber system.

2. Boiler Type - The boiler is a Combustion Engineering pulverized coal-fired dry-bottom unit which began commercial operation in 1965. It is designed for a 2400-psi operation, but due to tube failures, pressures until recently had been reduced to 1800 psi. Thus the boiler was derated to about 300 MW from a nameplate rating of 550 MW to avoid further tube failures. A six-week outage has permitted extensive boiler repairs and the unit was running at near maximum output in September, 1977. However, at the time of this visit it was again at half load.

   a. The boiler operates with excess air in the range of 15 to 18 percent.

   b. The load factor varies widely, but is generally in the range of 40 to 60 percent.

   c. The stack height is 500 feet.

3. Flue Gas Flow Rate - Approximately 5,240,000 lb/hr of flue gas at full load is involved, all of which passes through the four scrubber modules operated in parallel. Volumetric rate through each module is 405,000 acfm at 280 F.

   a. Oxygen content in flue gas ranges from 2.8 to 3.6 percent.

4. SO_2 Concentration - It is assumed that 92 percent of the sulfur in the coal is emitted as SO_2. Design SO_2 inlet concentration is about 3740 ppm (dry basis); outlet concentration was expected to be about 750 ppm (dry basis). Actual current levels at a reduced boiler load are about 2800 ppm inlet, 250 ppm outlet.

5. Fuel - The coal for Widows Creek comes from a number of sources. It is generally bituminous and probably averages about 10,000 Btu/lb, 10 percent moisture, 20 percent ash, and 4 percent sulfur. The average chlorine content is 0.07 percent.

6. Scrubber Reactant - Limestone, ground to 90 percent minus 200 mesh, is the reactant. Specifications on the stone are a minimum of 90 percent $CaCO_3$ and maximum of 5 percent for $MgCO_3$, 5 percent for moisture, 5 percent for silica, and 1 percent for alkali.

7. Removal Efficiency - The system is designed for an overall SO_2 removal efficiency of 80 percent. About 80 percent of the ash is emitted as fly ash, and 50 percent of this is removed in the electrostatic precipitators. Overall particulate removal is expected to be 98 to 99 percent. Particulates at scrubber exit are expected to be about 0.026 grains/scf (dry).

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1. Innovative design concepts include the avoidance of valves in the slurry lines, elimination of a thickener, and use of a fully automated limestone grinding system.

2. Process Variables -

a. Flue gas inlet design temperature is 280 F (250-260 F are actual values).

b. Outlet design temperature is 125 F before reheat air is added (160 F is a recent actual value after reheat air is added).

c. Design fly ash inlet loading to the scrubber is 5.6 grains/scf (dry).

d. Scrubber pH at the inlet is designed to be in the range of 5.8-6.0. A value of 5.7 is currently thought best by operators. The pH at outlet is not monitored.

3. Absorber Design -

a. Koppers ESP's remove about 50 percent of the fly ash; about 90 percent of the balance is removed in the venturi, and the remainder in the grid towers.

b. Each of the four scrubbing trains has a TVA-designed scrubber module consisting of one venturi, one grid-type absorber, two reaction tanks, and two reaction tank drains. In the venturi, two damper blades extend the length of the throat opening, one on each side of the center pipe. Each blade

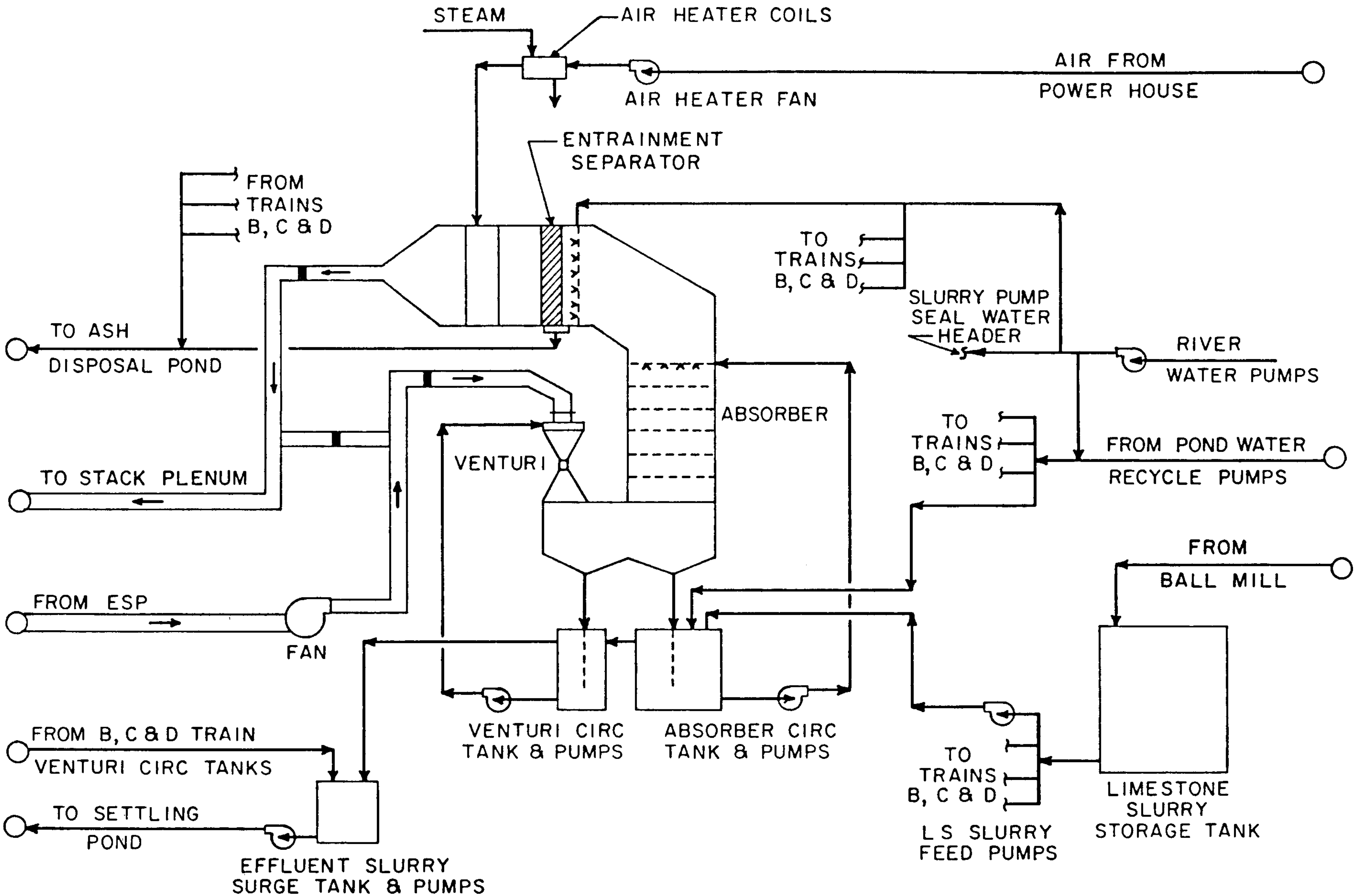

FIGURE 1. SCRUBBER SYSTEM FLOW DIAGRAM FOR WIDOWS CREEK UNIT 8

pivots on a shaft powered by a Limitorque pneumatic actuator to control pressure drop through the throat at a value between about 5 and 15 inches of water. The absorber consists of five grid assemblies (65-70 percent open area) consisting of 1-1/2 inch square openings. In November, 1978, sponge nitrile foam elastomer balls were added to the lower three grids. Unfortunately, these were ignited accidentally and burned before they could be tried. The system is designed to remove about 10 percent of the SO_2 in the venturi and 70 percent in the grid tower.

c. Design superficial velocities in the absorbers are about 12 ft/sec; current values run about 7-8 ft/sec.

d. The turndown ratio is practically unlimited. Liquid flow can be maintained relatively constant, but gas flow can be reduced to essentially zero without upsetting the system.

4. Liquid-to-Gas Ratio - The system is designed for an L/G ratio of 50 gal/1000 scf for each absorber at full load. An additional 10 gal/1000 scf is used in each venturi.

5. Oxidation - The amount of sulfate in the system is currently about 30 percent, but it is highly variable and may not yet have reached a steady-state value.

6. Pressure Drop - Total pressure drop through the system should be less than approximately 18-20 inches of water before operational problems develop. A clean system will probably show about a 12-16-inch pressure drop.

7. Solids Level - The solids content of the circulating venturi slurry is about 15 percent, while the absorber slurry is about 10 percent solids.

8. Reactant Addition - Ground stone is added to the absorber circulation tank as a 40-percent slurry in response to pH control.

9. Reactant Feed Rate - The design stoichiometry was 1.5 moles of $CaCO_3$ per mole of inlet SO_2. Actual values have been higher, primarily because of reduced boiler load and inability to control proper fresh limestone feed to the scrubbers because of feed pump problems.

10. Slurry Retention Time - The absorber tank at a full liquor flow rate has a seven-minute retention time. The venturi tank has a twelve-minute retention time under the same conditions.

11. Mist Eliminator - The mist eliminators are four-pass chevron-type vertically mounted in a horizontal shell. The vanes are 20-gauge Type 316 stainless steel. The velocity through the mist eliminators is about 9 ft/sec. The face of the vanes is washed continuously on the upstream side (equivalent to "below" washing in horizontal units) with about 1 gpm of river water

per square foot of mist eliminator cross sectional area. The drains from the mist eliminators in each scrubber train are piped to a central wash hold tank, which can be recycled to the absorber hold tanks or may overflow to the ash pond.

12. Reheat System - Scrubbed flue gas leaving the entrainment separator is heated about 50 F by the addition of ambient air heated to 400 F. This added air is taken from the powerhouse by an induced draft fan and heated via a steam coil heat exchanger.

13. Waste Disposal - Ponding was chosen as the most feasible method of disposing of the waste byproduct solids from the Widows Creek scrubbing facility. The byproducts, consisting of fly ash, hydrates of calcium sulfite, and sulfate, and unreacted limestone, are diluted and pumped about 1/4 mile as a 5-percent solids slurry. The volume of the pond is 4,500,000 cubic yards, which is estimated to provide a five-year pond life. The supernate flows around a deflector dike, and then back to the scrubbers through a pond recycle water-pumping station. The waste disposal is designed to be closed-loop, but because of the large pond size, the chemistry may not have yet reached steady state.

14. Fans - The flue gas forced-draft fans for each scrubber module are manufactured by the Green Fuel Economizer Company, Model 1264, type RGT 6821 BDE. They operate at 890 rpm and 3500 hp and deliver 460,000 cfm to 32 inches of water. The fans are double width, double inlet, and radial tip blade design. The fans are located between the precipitators and the scrubbers, where it was hoped erosion/corrosion would be minimal. This area, however, has turned out to be a major maintenance problem because of the high velocity tip speed of the fan rotors and the high fly ash loading.

C. RELIABILITY

1. Start-up - The A train came on-stream on May 16, 1977.

2. Availability - The monthly average operabilities (hours the FGD system was operated divided by boiler operating hours) for all four modules are as follows:

Month	Scrubber Operability, percent	Boiler Operation, hrs
May, 1977	3	427
June	17	462
July	28	653
August	30	651
September	71	609
October	Scheduled boiler outage	
November	88	413
December, 1977	97	426
January, 1978	96	618
February	69	586
March	66	644
April, 1978	83	540

3. Longest Run - About 20 days.

4. Calendar of Operation - The scrubber modules have accumulated an average of about 6150 hours of operation through November, 1978.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - The four venturis are rectangular (about 23 ft long and 8 in. wide) vessels with two pneumatic operated variable throat openings having fired alumina brick linings and 40 nozzles on a central spray header pipe. The converging and diverging sections of the venturis are constructed of Type 316L stainless steel. The venturi/absorber hoppers were originally rubber-lined (Goodyear LS575R neoprene) Cor-Ten steel. The lining was applied by Bittner Industries, Mobile, Alabama in the winter of 1976-1977. This has debonded and was patched several times in each module during the summer of 1977. In the winter of 1977-78, debonding of the rubber lining on the bottom (sloping surfaces) of the hopper was again encountered, at which time the rubber lining was replaced with a Type 316L stainless steel plate lining. After some 4000 hours of service, some corrosion has been encountered in the welds joining these plates and is attributed to the use of improper (Type 309L) welding electrodes at the inner surface.

Returning to the upper part of the venturi, the convergent section wall is lined with 2 inches of an abrasion resistant castable refractory (referred to as Carborundum's Fraxcast ES) in a hexagonal stainless steel honeycomb grid. Examination revealed no significant material erosion, but the exposed aggregate appeared to be silicon carbide instead of the calcined kaolin which Fraxcast ES should contain. Carborundum's Carbofrax (which contains silicon carbide) mav have been installed instead, as a 1973 TVA report mentions the use of a "silicon carbide castable" for this area. The impinged side of the venturi throat blades and the throat center pipe support are lined with fired alumina brick. The venturi divergent section and throat are not lined.

The major problems with the venturi were with the throat control drive mechanisms and pluggage of the central header spray nozzles, but primarily erosive/abrasive wear of the stainless steel header pipe feeding 25 percent of the slurry flow to the top of the convergent section (no erosion problems reported for the central spray pipe carrying 75 percent of the slurry feed).

2. Absorber - The entire absorber vessel below the slurry spray nozzle level is constructed of rubber-lined Cor-Ten steel, but the outlet elbow and mist eliminator duct is unlined Type 316L stainless steel. The Goodyear LS575R neoprene rubber lining was installed by Bittner Industries, and had lap joints pointing up (rather than down with liquid flow) to prevent eddying. After 3000 hours of operation, the vertical side walls have given no problem, but the tapered hopper bottom had debonded and was replaced with a Type 316L stainless steel liner. As with the venturi hopper

lining, some joints between the stainless steel plates were inadvertently welded with Type 309L weld rod. These weldments have undergone rapid corrosion and stress corrosion cracking. Slight erosion of the Type 316L weldments had also been observed.

There are five gratings or grids in the absorber which alternate between Type 316L stainless steel and FRP (product not identified). The original installation specified FRP as the top grating. This arrangement might have been successful if the nozzles above the absorber had had better spray distribution. The blasts from the failed nozzles resulted in localized erosion of the FRP grid. Nozzle cones have now been replaced and the grid arrangement has been changed to a top steel grid. Some erosion of this grating has also been observed.

3. Spray Nozzles - Stainless steel (Type 316L) slurry spray nozzles are used in the absorber tower and venturi throat. The absorber nozzles have a conical deflector originally connected with three 1/4-inch rods which failed by fatigue and were replaced with plates. Erosion of the nozzles has been observed and they require frequent replacement. TVA is considering nozzles which have curved inserts to swirl the slurry. Stainless steel with Stellite inserts and all ceramic nozzles are being considered.

Mist eliminator wash nozzles are Type 316L stainless steel and some plugging problems have been encountered. Erosion of the nozzles has also been observed and they are frequently replaced.

4. Mist Eliminators - The mist eliminators are a 4-pass vertical chevron design fabricated entirely from Type 316L stainless steel (vessel, vanes, nozzles, and headers). Mud deposit build-up on the upstream spray headers and on the downstream vertical vanes is a major maintenance problem, as chloride corrosion of the metal is accelerated in the low pH environment which develops in the deposits. Pitting of the vanes has been observed in low velocity areas, and pitting and crevice attack of the vessel has been observed under scale build-up. At one time, the mist eliminator on train D scaled and plugged so badly that it had to be dismantled. TVA staff pointed out that if the mist eliminator had been made of FRP, it would not have survived the cleaning operation. Plugging occurred when the mist eliminator was washed with pond return water. No plugging or scaling has occurred with fresh water.

5. Fans - Induced draft fans are located between the electrostatic precipitators and the scrubbers. The fan casings are constructed of A-242 carbon steel and the blades have chromium carbide wear plates. Abrasion failures of the blades occur in 8 to 13 weeks. Abrasion of the housing is also observed. These failures are thought to result from the high fly ash load (5 to 6 grains/scf) in the flue gas. On the average, one of the four rotors must be replaced every 10 weeks at a replacement cost of $40,000 each.

6. Reheater - There are four reheat systems, one for each scrubber train. A single pass steam coil heat exchanger is used to heat ambient air which is then mixed with the flue gas. Each reheat system is an assembly of 20 coil banks that are arranged four banks deep, five banks high, and one bank wide. Aerofin Corporation is the manufacturer of the copper-finned 1-inch carbon steel tube banks, model CHH. The housing is constructed of Cor-Ten steel.

7. Pumps - The pumps are rubber-lined cast iron and contain rubber-coated ductile iron impellers. The pumps were manufactured by Allen-Sherman-Hoff (A-S-H) and, after 7000 hours, the performance is still satisfactory.

8. Tanks - The process slurry tanks are carbon steel with a 1/4 in. neoprene lining. The heating coil drain tank is unlined carbon steel. The limestone slurry storage tank is rubber-lined carbon steel.

9. Agitators - The agitators in the venturi circulation tank, absorber circulation tank, effluent tank, and mist eliminator wash tank are constructed of Type 316L stainless steel. The agitators in the limestone product storage tank, mill slurry sump tank, and limestone slurry surge tank are constructed of carbon steel. No problems have been observed.

10. Storage Silos - The limestone storage silo is of poured concrete construction.

11. Thickener - None used.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The ductwork is constructed of unlined Cor-Ten steel. Corrosion of the ducts has been observed immediately downstream of the reheater. The attack is most severe on the duct floor. The ductwork in this area is Type 316L stainless steel. It was while a welder was cutting out samples of the wall in the steam soot blower area for metallographic examination on November 28, 1978, that sparks caused a fire in the A train absorber.

Bottom entry guillotine type dampers were installed for the gas inlet, gas outlet and bypass ducts. The damper blades are constructed of Cor-Ten steel and the seals were constructed of Type 316L stainless steel. The Type 316L stainless steel seals underwent rapid corrosion and stress corrosion cracking necessitating replacement with Inconel 625 seals. The Inconel 625 seals have performed satisfactorily. No corrosion problems with the blades were reported. However, jamming of the drive mechanism with particulates has rendered all of the dampers inoperative.

14. Piping and Valves - All slurry pipes are rubber-lined. The elbow where two 10 inch header pipes join the 20 inch slurry distribution pipe has been the site of several debondings which have propagated from the area of the sharp tee joint. The piping in the pond return system is

coated with Kelolite, a polyethylene copolymer. The internal spray headers are constructed of Type 316L stainless steel. The headers on all four venturi units failed by erosion and were temporarily replaced with Type 304L stainless steel headers.

Knife-type gate valves are used for the slurry feed. They are constructed of Type 316L stainless steel. No corrosion or erosion problems have been experienced. One valve housing cracked as a result of a pressure surge when the valve hesitated upon closing. A rubber O-ring failed quickly but the slurry does not leak through the gate in the closed position so that no corrective action is planned.

15. Stack - The 500 foot stack is a concrete shell with a 8-12 inch thick free-standing brick inner liner for the first 180 feet, and nine 37 foot corbel supported brick sections for the upper portion. There is a 2 or 3 inch gap between the upper brick lining and the concrete shell. Flat cast-iron bands encircle the free standing liner about every 5 feet. The 4-inch wide gap between the free-standing liner and the first corbel supported portion is sealed with a laminated fabric (asbestos, Inconel, and Viton) expansion joint. The "bricks" are ASTM C279 Type H (low strength, high porosity) red fireclay tiles, and the mortar is a portland cement - fly ash - sand mix with some raw fireclay added for workability. The stack has been in service about 12 years at temperatures of 300-350 F before the scrubber was installed, at which time the mortar, bricks, and cast iron bands were still sound. After 14 months of scrubber operation at temperatures in the 140-175 F range, no deterioration has been noted.

Although the stack has given satisfactory service, TVA has stacks on other units which will be retrofitted with scrubbers in the future. In anticipation of selecting future lining materials, and becoming familiar with their installation/performance, TVA is starting to use the scrubber outlet duct and the stack for test purposes (organics in duct, inorganics in stack).

Five inorganic lining materials (Saueriesen No. 33 and No. 72, Pennwalt SDX, and Pullman Swindell Swindress Bond 210 and 200) have been applied to the brick inner lining of the stack for test purposes. In addition, monolithic mortar test blocks (two portland cement mortars plus Saueriesen No. 65, and Swindress Bond 100) have been installed in the upper portion of the stack for periodic testing. In the scrubber outlet duct, two organic (Conchem Fibercrete AR and Wisconsin Protective Coatings Plasite 4005) and one inorganic (Pennwalt's Pennguard borosilicate foam glass block made by Pittsburgh Corning) test linings have been installed. Future plans also call for exposure of metallic test specimens (Cor-Ten, Type 316L stainless steel, mild steel, and cast iron) in the stack. The exact composition of many of these lining materials is proprietary. However, the critical element in their survival is the coefficient of expansion, relative impermeability, and bonding properties.

16. Ball Mill - The ball mill is completely lined with 1-1/2 inches of rubber. Occasionally, small pieces of rubber lining are removed during milling so that the walls had to be completely relined after 4000 hours of service. Lifter bars in the mill are also rubber coated and these fail often. Mill design is by Kennedy Van Saun Corp. and the rubber is a Skega neoprene.

E. COMMENTS

Metallic components are used throughout the FGD system at the Widows Creek Steam Plant. Type 316L stainless steel and Cor-Ten steel are used extensively whereas some Type 304L stainless steel is used for temporary repair purposes. The stainless steels are used in the uncoated condition whereas the Cor-Ten steel is generally rubber-lined.

No protective organic coatings are used in the FGD system at Widows Creek. However, rubber and plastic linings and FRP gratings are used for several applications. As a general comment, Widows Creek personnel are dissatisfied with the poor performance of rubber linings for several reasons: 1) failure of a rubber lining requires shutdown for long periods of time whereas failure of metal may require only a one hour shutdown for spot weld repair; 2) neoprene sheet is not an "off the shelf" item and generally requires the presence of the original installer and/or contractor; and 3) the performance of a field "patch" is poorer then that of the original installation because the patch cure is dependent upon a "fast chemical reaction" whereas the original installation can be cured slowly with steam. All failures observed with rubber linings resulted from loss of the adhesive bond at a butt joint (average width of neoprene sheets is 4 feet) which then propagated into large debond areas.

RESEARCH-COTTRELL
UTILITY DIVISION
SOMERVILLE, NEW JERSEY

Trip Report Number: EPRI-CM8

Date of Trip: December 19, 1978

Persons Interviewed: Dr. Raymond L. Kent, Manager, Process Engineering and Product Development, SO_2 Operations; Dr. George T. Paul, Materials Specialist, SO_2 Operations; Richard Rao, Manager, Product Planning, Flue Gas Desulfurization, Research-Cottrell.

A. BACKGROUND

Table 1 summarizes Research-Cottrell's experience with flue gas desulfurization (FGD) systems on utility boilers. Their philosophy on construction materials for FGD systems is to use Type 316L stainless steels for most applications but use materials containing higher molybdenum, chromium and nickel contents for those areas where more severe conditions are encountered. According to Research-Cottrell personnel this philosophy results in a higher initial cost than systems utilizing coated mild steel, but the overall cost over a 20-30 year life is less due to lower maintenance costs.

Research-Cottrell's first limestone scrubber was installed in the Arizona Public Service Cholla Power Plant, Unit 1. This unit was started up in December, 1973. Since they have the largest amount of materials information on the Cholla Power Plant, the discussion was focused on materials problems encountered with this unit. Following this discussion, materials which are currently preferred were discussed.

B. MATERIALS OF CONSTRUCTION
(Cholla Unit 1)

The FGD system at the Cholla Power Plant consists of two modules. The modules are identical except that the absorption tower in Module B contains no packing and has no slurry flow to reduce acidity of the gas. Materials applications and associated problems for this system are detailed below. Most problems have occurred in the B module of the scrubber system.

1. Prescrubber - The prescrubber is a flooded disc type with a variable orifice area. The vessel and conical-shaped deflector were constructed of Type 316L stainless steel. Severe erosion of the venturi throat was observed. Either Hastelloy C or Inconel 625 were recommended for replacement of the throat region. Stress corrosion cracking of the conical-shaped deflector was also observed. It is postulated that the stress-corrosion failure was the result of the high temperature, 175 F, and high Cl^- concentration which exist at the wet/dry interface. The design of the deflector was changed and it was again fabricated of Type 316L stainless steel. Research-Cottrell has recommended that Incoloy 825 be used.

TABLE 1. RESEARCH-COTTRELL LIMESTONE FGD SYSTEM ON COAL-FIRED UTILITY BOILERS

Client	Power Station	Size, MW	Sulfur in Coal, Wt Percent	Scheduled Startup Date
Arizona Electric Power Coop	Apache 2	200	0.5-0.8	September, 1978
Arizona Electric Power Coop	Apache 3	200	0.5-0.8	April, 1979
Arizona Public Service	Cholla 1	115	0.55	October, 1973
Arizona Public Service	Cholla 2	250	0.5	June, 1978
Arizona Public Service	Cholla 4	350	0.44-1.0	June, 1980
Basin Electric Power Coop	Laramie River 1	570	0.8	April, 1980
Basin Electric Power Coop	Laramie River 2	570	0.8	October, 1980
Indianapolis Power & Light	Petersburg 4	530	3.5	April, 1982
Springfield Water, Light, & Power	Dallman 3	190	3.0-4.3	July, 1980
Texas Utilities	Martin Lake 1	793	1.0	August, 1977
Texas Utilities	Martin Lake 2	793	1.0	May, 1978
Texas Utilities	Martin Lake 3	793	1.0	December, 1978
Texas Utilities	Martin Lake 4	793	1.0	November, 1982

The type 316L stainless steel spider supports, located beneath the deflector, have undergone severe erosion. Coating or more resistant alloys such as Hastelloy C are being considered.

Serious materials problems have also been observed in the wet well of the scrubber where the Cl^- concentration is high (2000 ppm) and the pH is low (the Cl^- concentration and pH are not monitored). A collar constructed of CF-8M (cast alloy equivalent to Type 316L stainless steel) underwent severe pitting and crevice corrosion. The floor and walls of the wet well have also undergone pitting with some perforations. The attack is most severe in areas where mild steel supports were welded to the external surface of the vessel. The pits are repaired by welding during scheduled outages. Some pitted areas of the scrubber wet well and outlet duct were repaired by coating with an epoxy coating (Coroline 505AR). This lining failed because of erosion and loss of adhesion (it is difficult to obtain an anchor pattern on stainless steel by blasting). A brick (ceramic) lining was installed. The bricks were originally bonded with a portland cement-based mortar. This mortar was severly attacked and numerous bricks were washed into the slurry tank. The brick lining has since been replaced with an acid-resistant inorganic cement (type unknown) which so far has proven to be satisfactory.

2. Absorber - The SO_2 absorber is a tower containing rigid, wetted-film polypropylene packing which is replaced about once a year. The slurry is removed from the gas stream entering the absorber by means of a centrifugal plate separator containing a conical hat. This unit is located in the bottom of the absorber tower. The absorber vessel is constructed of Type 316L stainless steel. Areas wetted by the scrubber slurry (lower part of absorber) have undergone pitting and crevice corrosion which is approximately equal in severity to that observed in the scrubber. Areas in the bottom of the tower were repaired with an epoxy (Coroline 505AR) and have exhibited debonding and erosion. In contrast, areas wetted by the absorber slurry (upper part of absorber) have undergone much less severe attack although significant buildup of solids is observed. The better performance of the Type 316L stainless steel in the latter application is thought to be the results of the lower Cl^- concentration and higher pH (about 4.5) found in the absorber slurry.

3. Spray Nozzles - The headers and nozzles are constructed of Type 316L stainless steel. Some erosion damage has been observed but, in general, these components have performed satisfactorily.

4. Mist Eliminators - Two mist eliminators are found in each FGD unit; a cyclonic mist eliminator located between the scrubber and the absorber, and an impingement mist eliminator located at the top of the absorber tower. The cyclonic mist eliminator is constructed of Type 316L stainless steel and is exposed to the scrubber slurry. Materials problems encountered were the same as those encountered with the wet well of the scrubber.

An impingement mist eliminator is located above the absorber packing. It consists of two stages, each of which contain polypropylene slats. The unit is contained in the Type 316L stainless steel absorber vessel. Few materials problems have been encountered. One case of weld attack of the stainless steel was observed when the slag located over a weld was not removed. It was speculated that HF was generated as a result of the reaction of fluoride in the slag with moist vapors. The slag may also have acted as a crevice and caused some concentration of chloride ions there.

5. Fans - Booster fans are located between the mechanical dust collectors and the scrubbers. They are constructed of carbon steel. The performance record of these units was not known.

6. Reheater - A direct contact steam reheater is used. The vertical heat exchanger tubes and the vessel are constructed of Type 316L stainless steel. Some flanges on the vessel door on Module B were inadvertently fabricated of Type 304L stainless steel. These flanges suffered severe pitting and general attack and were replaced with ones constructed of Type 316L stainless steel. Pitting of the vessel and the deposit covered tubes has also been observed. Repair of the vessel is easily accomplished by welding, but most of the tubes are inaccessible and require replacement. Tubes fabricated of Incoloy 825 have been recommended as replacements.

7. Pumps - Most of the slurry-recycle pumps are constructed of rubber-lined, cast iron. However, some CD-4MCu cast pumps are used. The latter pumps suffer from corrosion and erosion and are inferior to the rubber-lined pumps for slurry recycle lines.

8. Tanks - The tanks are fabricated of mild steel coated with an organic lining (thought to be a Ceilcote material). No problems were reported.

9. Agitators - The agitators are constructed of both rubber-coated steel and Type 316L stainless steel. No problems have been encountered with either type of construction.

10. Storage Silo - The limestone storage silo is constructed of carbon steel. No materials problems have been encountered.

11. Thickener - None used.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The ductwork ahead of the scrubber is fabricated of unlined carbon steel. No problems were reported. The ductwork between the absorber and the reheater is mild steel coated with Ceilcote's Flakeline 151. No failures have been reported on the A module (unit in which SO_2 is removed) whereas perforations of the lining have occurred on the B module (unit in which only particulates are removed). It is speculated that the high concentration of H_2SO_4 in the vapors on the B side is responsible for the failures. A Plasite (number not known) coating was used to repair the B module in 1975.

The expansion joints are fabricated of Viton® reinforced with canvas. Some failures have been observed. In addition, flanges fabricated of Cor-Ten steel have undergone rapid corrosion failures.

The dampers are a guillotine design and are constructed of Type 316L stainless steel. No problem with the dampers were reported. The type of seal material and its performance were not known.

14. Piping and Valves - Type 316L stainless steel, fiberglass-reinforced plastic (FRP) and some rubber-lined carbon steel are used for the slurry piping. The FRP piping was frequently used outside. In areas of high Cl^- concentrations, a high molybdenum grade of Type 316L stainless steel is used. No problems have been encountered with the stainless steel piping. Elbows on the FRP piping have undergone erosion. Blisters in the rubber lining of the carbon steel piping have been observed.

Rubber-lined, steel butterfly valves are used for most applications in the slurry lines. They perform satisfactorily. In one case a flow restriction valve, constructed of cast CD-4MCu was used in a slurry recirculation line. This unit had a carbon steel orifice plate with a Stellite insert. Severe erosion of the casting was observed. The Stellite insert also cracked and exposed the carbon steel to the slurry, resulting in rapid general corrosion of the orifice plate. An alumina orifice plate has satisfactorily solved this problem.

15. Stack - The stack is of a brick lined design. No problems have been encountered.

16. Grinding Mill - None used as limestone is purchased in powdered form.

(Current Materials Preferences)

Following the discussion of the Cholla Unit 1 FGD system, Research-Cottrell personnel discussed their current recommendations on materials of construction for the major components of the scrubbers. These recommendations are not fully consistent with their philosophy on usage of corrosion-resistant materials rather than coatings, because of the necessity of the company to bid competitively on scrubber installations, at the expense of building what they consider to be the most cost-effective unit over the life of the power plant.

1. Prescrubber - The use of high alloyed materials such as Uddeholm 904L, Jessop JS-700 or JS-777 is recommended for vessel fabrication. Hastelloy G, Inconel 625 or Hastelloy C are recommended for fabrication at the wet-dry interface region.

2. Absorber - The absorbers are currently being fabricated of mild steel lined with glass-reinforced epoxy (e.g., Coroline 505AR) except where corrosion-resistant alloys are requested by the utilities. Type 316L

stainless steel containing a minimum of 2.75 Mo is used under these circumstances.

3. Spray Nozzles - Type 316L stainless steel is recommended for use in spray nozzles and headers, although some erosion-corrosion can be expected.

4. Mist Eliminators - Polypropylene slats are recommended for fabrication of the mist eliminators.

5. Fans - Carbon steel fans located ahead of the scrubber are recommended. If design necessitates the use of fans located down-stream of the scrubber, then corrosion-resistant alloys are recommended. Hastelloy C or Inconel 625 are recommended for moving parts, whereas Haynes Alloy 20 (or equivalent) is recommended for the stationary parts.

6. Reheaters - A pitting-resistant alloy such as Hastelloy G is recommended for use in fabrication of in-line reheater tubes.

7. Pumps - Rubber-lined carbon steel pumps are recommended. Pumps that are used by the mining industry rather than the chemical industry are recommended.

8. Tanks - Lined mild steel tanks are recommended.

9. Agitators - Rubber-coated mild steel agitators are recommended.

10. Storage Silos - Not discussed.

11. Thickener - Lined mild steel is recommended for thickener vessel fabrication. A rubber-coated mild steel rake is recommended. The use of cathodic protection of the vessel and rake is presently being studied by Research-Cottrell. Ceilcrete 2500AR coated concrete is recommended for fabrication of the floor.

12. Vacuum Filters - Not discussed.

13. Ducts, Expansion Joints, and Dampers - A pitting-resistant alloy such as Type 317LM stainless steel is recommended for fabrication of ducts located ahead of the reheater, whereas Type 316L stainless steel is recommended for use between the reheater and the stack. Carbon steel is recommended for fabrication of ducts located ahead of the scrubber.

Viton®-impregnated asbestos joints are preferred as problems have been encountered with multiple layer (unbonded) joint materials.

The guillotine damper design is recommended. Carbon steel is recommended for fabrication of dampers exposed to the entering gas, whereas a material which is resistant to the chloride level present is recommended for fabrication of dampers located down-stream of the wet scrubber. Hastelloy C or Inconel 625 is recommended for fabrication of all seals.

14. Piping and Valves - Type 316L stainless steel is generally recommended for fabrication of the internal piping. However, higher alloyed materials may be necessary in the more aggressive environments. An alloy which is one grade better than the piping is recommended for fabrication of valves.

15. Stacks - Not discussed.

CHEMICO
AIR POLLUTION CONTROL CORPORATION
NEW YORK, NEW YORK

Trip Report Number: EPRI-CM9

Date of Trip: December 20, 1978

Persons Interviewed: Dr. Abdus Saleem, Vice President-Process Engineering; Robert L. Benoit, Principal Engineer; and Rex Helfant, Product Manager-Utility Systems, Chemico.

A. BACKGROUND

Table 1 summarizes Chemico's worldwide experience with scrubbers. Discussion was limited to the six operational full-scale U. S. units (3 venturi and 3 spray tower systems) listed in the table which use lime or limestone as the scrubbing agent. Phillips and Elrama have single-stage venturi systems but are constructed of similar materials as the two-stage venturi system at Bruce Mansfield. The Monticello, Huntington, and Hunter systems have spray tower absorbers. The Bruce Mansfield unit was selected for discussing construction materials for venturi systems and the Huntington unit was discussed as being representative of Chemico's newer spray tower designs. Chemico has over 60 organic lined scrubber vessels in service, and has obtained a 7-year life in the Holtwood unit at a pH of 2.

Chemico's design philosophy with regard to materials of construction is reflected in the following points:

(1) utilize lined mild steel as much as possible

(2) avoid combustible materials (specifically rubber linings)

(3) design the system to avoid scaling (as organic linings must be cleaned only with high pressure water)

(4) design the system to avoid erosion problems (use liquid pool below venturis, and brick, stainless steel or abrasion resistant organic linings at critical areas)

(5) utilize proven materials and vendors from good past experience (such as lining and pump vendors)

(6) design to insure that organic linings used in hot gas quench areas are kept cool by a continuous film of spray water.

TABLE 1. CHEMICO AIR POLLUTION CONTROL UTILITY SCRUBBING SYSTEMS

Client	Power Station	Fuel	Percent Sulfur	MW	Inlet Gas Volume, 10^3 acfm	Scrubbing Agent	Scope of Work	Components Removed	Required SO_2 Removal Efficiency, percent	Operational Date
U. S.										
1. Pennsylvania Power & Light Co.	Holtwood	Coal		80	400	Water	Turnkey	Partcl.	-	May '70
2. Arizona Public Service Co.	Four Corners 1-3	Coal	.75	575	2,650	Water	Turnkey	Partcl.	-	Dec. '71
3. Pacific Power & Light Co.	Dave Johnston 4	Coal	.4	360	1,600	Water	Turnkey	Partcl.	-	Jan. '72
4. Potomac Electric Power Co.	Dickerson 1-2	Coal	1.5-3.5	190	650	Water	Engr., Equip.	Partcl.	-	Nov. '78
1. TVA	Shawnee No. 10B	Coal		10	50	Lime/Limestone (Pilot)	Equip.	Partcl./SO		Apr. '72
2. Duquesne Light Co.	Phillips No. 1-6	Coal	2.3	410	2,200	Lime	Engr., Equip.	Partcl./SO_2		Jul. '73
3. Potomac Electric Power Co.	Dickerson No. 3	Coal	1.5	95	300	MgO (Demo.)	Engr., Equip.	Partcl./SO_2	90	Sept. '73
4. Duquesne Light Co.	Elrama No. 1-5	Coal	2.3	510	2,200	Lime	Engr., Equip.	Partcl./SO_2		Oct. '75
5. CAPCO/Pennsylvania Power Co.	Bruce Mansfield 1-2	Coal	4.3	1,650	6,400	Thiosorbic Lime	Engr., Equip.	Partcl./SO_2	92	Jan. '76
6. Texas Utilities Services	Monticello No.3	Coal	1.5	750	3,400	Limestone	Engr., Equip.	Partcl./SO_2	72	Jun. '78
1. Boston Edison Co.	Mystic No. 6	Oil	2.5	150	450	MgO (Demo.)	Turnkey	SO_2	90	Apr. '72
2. Utah Power & Light Co.	Huntington No. 1	Coal	.5	415	1,750	Lime	Engr., Equip.	SO_2	89	June. '78
3. Utah Power & Light Co.	Hunter No. 1	Coal	.5	400	1,700	Lime	Engr., Equip.	SO_2	89	Sept. '78
4. Central Illinois Public Service	Newton No. 1	Coal	4.0	575	2,200	Double Alkali	Engr., Equip.	SO_2	90	Nov. '79
5. Wisconsin Power & Light Co.	Columbia No. 2	Coal	1.0	527	2,050	Fly Ash/Lime	Turnkey	SO_2	50	Jan. '80
6. Utah Power & Light Co.	Hunter No. 2	Coal	.5	400	1,700	Lime	Engr., Equip.	SO_2	89	Jun. '80
International										
1. Mitsui Aluminum	Omuta No. 1	Coal	2.3	155	400	Carbide Sludge	Engr.	Partcl./SO_2	90	Apr. '72
2. Idemitsu Kosan Co.	Chiba Refinery	Oil		225	600	MgO	Engr.	Partcl./SO_2	95	Oct. '74
3. Electric Power Development Co.	Takasago No. 1	Coal	1.8	250	650	Limestone	Engr.	Partcl./SO_2	98	Dec. '74
4. Mitsui Aluminum	Omuta No. 2	Coal	2.3	175	450	Limestone	Engr.	Partcl./SO_2	90	Apr. '75
5. Electric Power Development Co.	Takasago No. 2	Coal	1.8	250	650	Limestone	Engr.	Partcl./SO_2	90	Apr. '76
6. Electric Power Development Co.	Isogo No. 1 & 2	Coal	.45	530	1,600	Limestone	Engr.	Partcl./SO_2	90	Apr. '76
7. Electric Power Development Co.	Matsushima No. 1	Coal	.3-3.0	500	1,300	Limestone	Engr.	Particl./SO_2	95	Jun. '80
8. Steag	Bergkamen No. 1	Coal	1.3	410	1,169	Lime	Engr.	Partcl./SO_2	80	Sept. '80

Totals, MW

U.S. Particulate Removal	1,205
U.S. Particulate SO_2 Removal	3,425
U.S. SO_2 Removal	2,467
International SO_2 Removal	2,495
Worldwide Scrubbing Experience	9,592

B. MATERIALS OF CONSTRUCTION
(Bruce Mansfield Venturi System)

1. Prescrubber - Particulates are primarily removed in the first-stage variable-throat venturi. The inlet duct to this vessel is unlined carbon steel except for the few feet extending into the top of the vessel, which is Type 316L stainless steel. Beginning at the inlet duct, the rest of the vessel (including outlet duct to the fan) is coated with a flake glass/polyester lining (similar to Ceilcote's Flakeline 103 but thought to have been applied by another vendor) which has an installed cost of about $\$6/ft^2$. This lining has held up well for over 2 years, except for erosion below the mist eliminator sprays and on the top of the conical plumb bob, where localized erosion has occurred and a more erosion resistant material (Ceilcote's Coroline 505AR, about $\$8/ft^2$) has been installed. The mist eliminator sprays have since been eliminated to avoid additional problems, permitting a similar material to be used for repairs. At areas where erosive wear was anticipated, wear plates originally installed above the flake glass/polyester lining have proved satisfactory (Type 316 stainless steel band on edge of cylindrical plumb bob and ASTM C279 Type L acid resistant bricks on ID of throat just below plumb bob).

2. Absorber - The second-stage venturi vessel is a fixed-throat design and provides only SO_2 removal. It is also flake glass/polyester (similar to Flakeline 103) lined, except for the throat area, which contains Type 316 stainless steel annulus rings and throat liner plates. In other systems, acid resistant brick has been used instead of Type 316 stainless steel to line the throat area. The inlet and outlet ducts of this vessel are also lined with a flake glass/polyester lining. No major problems were reported.

3. Spray Nozzles - Bull (low velocity) nozzles and headers in the second-stage venturi are Type 316L stainless steel. No problems have been encountered. No spray nozzles are used in the first-stage venturi. The slurry is injected tangentially at the top of the converging section to form a cooling film.

4. Mist Eliminators - Mist eliminators in both venturi vessels are fiberglass reinforced polypropylene (with fire retardant added) with a curved blade design.

5. Fans - The wet fan between the two venturis has required considerable maintenance due to impingement of loose duct deposits which damage the rubber-lined fan housing. These deposits are carried over from the prescrubber when there are excessively high gas flow rates. This condition occurs when too few scrubbers are operating. The Inconel 625 fan rotor has performed satisfactorily, so the utility lined the housing with Inconel 625 in 1977. Sprays have been installed in both the inlet duct and the fan housing itself to minimize deposit build-up in this area. This problem has not occurred at other sites in which the wet fan is used.

6. Reheaters - Direct-fired reheat chambers installed at Bruce Mansfield have caused considerable problems due to instability of the oil-fired, refractory-burner-block combustion system provided by Chemico's vendor, Train Thermal. Although the exact nature of the burner problem was not described, the original refractory lining (Sauereisen No. 72) in at least two of the four chambers was damaged and was replaced with a conventional castable (from Resco Products) refractory. The burner instability problems apparently were not solved, causing the utility to abandon the reheat system, and operate without it. As a result, the fire-resistant polyester linings on two of the four carbon steel stack flues have failed by debonding, and the utility is now considering relining these flues with Inconel 625. Chemico did not design or provide the stack lining which failed, but they did design and provide the flake glass-lined steel ducting between the reheater and the stack which has apparently operated satisfactorily.

7. Pumps - All major pumps are rubber-lined carbon steel. No major problems were reported.

8. Tanks - Tanks are flake glass/polyester lined carbon steel, except for the reactant tank, which is unlined carbon steel.

9. Agitators - Rubber-coated carbon steel is used for agitator shafts and blades.

10. Storage Silos - No information obtained.

11. Thickener - Flake glass/polyester-lined steel with rubber covered rake.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - Ducts are flake glass/ polyester-lined steel. Expansion joints used at Bruce Mansfield were not specifically identified. However, expansion joints must not be deformed to make up tolerances. The following information was given on expansion joint materials:

(a) 250 F or below - can use neoprene with asbestos fiber reinforcement

(b) 300 F or below - can use chlorobutyl rubber with asbestos

(c) 400 F or below - can use Viton® with asbestos

(d) above 400 F - must use a layered asbestos approach.

Vulcanized types are preferred over laminated cloth construction as flow liner shields are not required and fatigue resistance is better. Slip collars are now just tack welded in place by the fabricator shop so that the collars can be moved during assembly to align ducts with a minimum of joint distortion.

The dampers are a louver design. Dampers exposed to the hot dry gases are fabricated of carbon steel and dampers exposed to the scrubber environment are fabricated of Type 316L stainless steel. Inconel 625 seals are used for both applications. Pitting of the Type 316L stainless steel was observed. No problems with the seals were reported.

14. Piping and Valves - Rubber-lined piping is used for most major lines except the thickener return, which is FRP. Water hammer problems have required some of the FRP field cemented joints to be replaced; Chemico now prefers to use shop-fabricated joints and/or flanges to avoid problems with field cemented joints. Industry has had problems in joining FRP pipe. The joining is typically done by pipe fitters who are not experienced with FRP.

Valves (guillotine) are used for isolation only. Chemico has used some rubber pinch valves for control purposes but finds that they must be properly sized such that they are at least 50 percent open. Plug valves are less desirable.

15. Stack - Chemico did not design the stack or stack lining at Bruce Mansfield where lining failures have been encountered.

(Huntington Spray Tower System)

The Huntinton unit is the first of a vertical spray tower design provided by Chemico.

1. Prescrubber - None used; particulates are removed from the flue gas by an ESP before passing into the lower portion of the spray tower.

2. Absorber - Three different lining materials are used to line the carbon steel tower. Pre-Krete G-8 is used in both the inlet duct and on a Type 316L stainless steel deflector shield extending part way into the scrubber vessel. There are stainless steel stops where the Pre-Krete ends to prevent peeling at the edges of the lining. The Type 316L stainless steel deflector shield is used to direct the incoming gas down against a pool of reactant in the bottom of the tower. The reactant pool section is entirely lined with Ceilcote's Flakeline 103, with an asphalt membrane/ acid resistant brick overlay on the floor of the tower (applied over the Flakeline). From the inlet duct area to the mist eliminator, the tower is lined with a 1/4-inch thick layer of Ceilcote's Ceilcrete 2500AR (abrasion resistant) to resist the erosive environment in this spray nozzle area. Above the mist eliminator, Flakeline 103 is again used.

3. Spray Nozzles - Spraco's off-center bottom-ramp silicon carbide (Carborundum' Refrax) spray nozzles are used. The centrifugal motion imparted by this design results in a hollow conical spray pattern.

4. Mist Eliminators - Fiberglass reinforced polypropylene.

5. Fans - Not discussed.

6. Reheater - Indirect steam reheat system; materials not discussed.

7. Pumps - Rubber-lined steel (specific vendors are preferred).

8. Tanks - Not discussed.

9. Agitators - Rubber-coated steel.

10. Storage Silos - Not discussed.

11. Thickener - Not discussed.

12. Vacuum Filter - Not discussed.

13. Ducts, Expansion Joints, and Dampers - Ducts are Flakeline 103 coated carbon steel. Specific joint and damper materials not identified.

14. Piping and Valves - Rubber-lined steel pipes and valves are used based on past experiences. However, Chemico would now consider the use of ABCO's (Atlantic Bridge Company) AA-150 or A-150 chlorinated vinyl ester FRP pipes.

15. Stack - Not discussed.

COMBUSTION EQUIPMENT ASSOCIATES, INC. (CEA)
ENVIRONMENTAL SYSTEMS DIVISION
NEW YORK, NEW YORK

Trip Report Number: EPRI-CM10

Date of Trip: December 21, 1978

Persons Interviewed: Minesh J. Kinkhbwala, Manager, Market Research; Robert G. Davis, Senior Staff Engineer; Vito Nuzzi, Mechanical Supervisor; Charles S. White, CEA.

A. BACKGROUND

Under an exclusive technology agreement, CEA and Arthur D. Little, Inc. (ADL) work together developing innovative technology in two areas, one of which is the control of gaseous emissions from stationary sources. Table 1 lists major CEA/ADL flue gas desulfurization projects. Two systems are in operation utilizing lime/alkaline fly ash scrubbing (Colstrip and Milton Young) and one system under construction will utilize lime scrubbing (Spurlock). Colstrip has a venturi scrubber and Milton Young and Spurlock have spray towers.

The design philosophy of CEA is to use lined carbon steel for scrubber vessels except in special areas where abrasion is a problem or temperatures are high. However, CEA also constructs absorbers of stainless steel if specified by the utility.

CEA has had good experience with the lined absorbers thus far, with little maintenance required on the linings. The linings problems experienced thus far have been (1) in the top of the vessel where temperature is higher and (2) where spray strikes the sides of the vessel (abrasion). Repair has been with the same lining material. CEA has placed test panels of various steels and linings in the high abrasion area near the spray nozzles. Results of these tests may affect future selection of materials for the high abrasion areas.

B. MATERIALS OF CONSTRUCTION
(Colstrip)

1. Prescrubber - At Colstrip, a single vessel houses a venturi section, a spray section, and a Koch tray.

2. Absorber - The vessel is a carbon steel shell lined with flake glass/polyester. An acid-resistant brick lining with acid-resistant mortar has been used to line the throat area of the venturi. The bottom part of the plumb bob, which is in a high abrasion area, is Type 316L stainless steel. These materials were reported to give excellent service. The downcomer is polyester-lined carbon steel on both sides. The Koch tray is Type 316L stainless steel. The bottom of the vessel is lined with a Heil polyester/glass laminate reinforced with fabric. A high temperature excursion caused a lot of damage in one module.

TABLE 1. MAJOR CEA/ADL EMISSION CONTROL PROJECTS

	Nevada Power Company	Montana Power Company	Southern Company (Gulf Power)	Louisville Gas & Electric	Kerr McGee Chemical Corp.	Square Butte Electric Cooperative	Eastern Kentucky Power Cooperative
Station	Reid Gardner Units #1,2,3,4	Colstrip-Units #1,2 #3 and #4 planned	Scholz 1	Cane Run 6	Kerr McGee Trona, California	Milton R. Young Unit #2	Spurlock Unit #2
Consultant	Bechtel Power Corp. Units #1,2 Stearns, Roger, #3,4	Bechtel Power Corp.	Southern Services	Louisville Gas & Electric	Ralph M. Parsons Co.	Sanderson & Porter	Black & Veatch
Capacity, MW	4 x 125 MW	2 x 360 MW 2 x 720 MW in Design	20 MW	280 MW	2 x 80 MW	450 MW	500 MW
Scope	Turnkey, including Engineering, Material Erection, Startup, and Sludge Disposal System for Particulate and SO_2 Control	Turnkey, including Engineering, Material, Erection and Startup. Particulate and SO_2 Control	Turnkey, including Engineering, Materials Erection, Startup and Sludge Disposal. SO_2 and Particulate Control	Engineering, Material, Startup and Sludge Preparation. SO_2 Control	Engineering, Material, Startup, and Erection Supervision SO_2 and Particulate Control (Precipitator)	Turnkey, including Engineering, Material Erection, Startup and Sludge Preparation. SO_2 Control	Turnkey, including Engineering, Material Erection and Startup. SO_2 Control
Site Considerations	1. Close to impure soda ash raw material 2. Large scale ponding possible 3. Desert location (High evaporation rate)	1. Mine mouth coal 2. High alkalinity fly ash 3. Poor evaporation rate	1. Extremely high sulfur coal 2. Poor natural evaporation rate	1. High sulfur coal 2. No large scale ponding possible	1. Multi-fueled plant with wide range of sulfur contents 2. Onsite liquor disposal available	1. Mine mouth coal 2. High alkalinity fly ash 3. Poor evaporation rate 4. Filter cake 5. Mist eliminator wash tray	1. Landfill Available 2. High Sulfur Coal 3. High Magnesium Lime 4. High Chloride Coal
Fuel	Coal	Coal	Coal	Coal	Petroleum Coke, Coal and Oil	Lignite	Coal
Sulfur, percent	0.7	0.8 - 1.0	2.0 - 4.5	3.5 - 4.0	0.5 - 5.0	0.4 - 1.3	3.5
Removal Efficiency, percent	90	60	97	95+	97	75 with reheat 90 without reheat	90 without Reheat
Process	Soda Ash/Trona	Lime/Fly Ash	Dual Alkali	Dual Alkali	Sodium Solution (Waste Brines)	Lime/Fly Ash	Lime
Scrubber Type	Venturi/Tray Tower	Venturi/Spray/Tray	Venturi/Tray	Tray-SO_2	Precipitator-Particulate Tray-SO_2	Spray Tower	Spray Tower
Sludge Disposal Method	Solar Evaporation Ponds	Scrubber Water Recycled to/from Onsite Pond	Dry Filter Cake to Landfill	Dry Filter Cake to Landfill	Ponding	Solid Waste to exhausted Mine Pits	
Reliability	Over 90 percent Units #1 and 2 Started up 3/74 #3 Started up 7/76 Unit #4 in design	#1-Started up 10/75 nearly 100 percent Availibility #2-Started up 6/76 Units #3 and 4-in design	Over 90 percent Started up 2/75 g operating periods	Started up 2/79	Over 90 percent Started up 12/77	Over 90 percent Started up 10/77	Scheduled Startup 1/81

3. Spray Nozzles - The main spray nozzles are silicon carbide and the mist eliminator wash nozzles are Type 316 stainless steel.

4. Mist Eliminator - The chevron mist eliminator is Noryl (plastic made by General Electric).

5. Fan - The induced draft fan located after the reheater has a carbon steel rotor and a rubber-lined housing.

6. Reheater - The reheater is a plate coil type located in the duct. The upstream row is constructed of Inconel 625 and the downstream row is constructed of Hastelloy G.

7. Pumps - Most pumps are rubber-lined. The lime slurry pumps are plain cast iron.

8. Tanks - All tanks are flake glass/polyester-lined carbon steel except for the lime tank which is unlined carbon steel. There have been no problems with the linings.

9. Agitators - The shafts and blades of the bottom entry agitators of the recycle tanks are stainless steel with rubber-lined tips.

10. Storage Silo - The lime storage silo is unlined carbon steel.

11. Thickener - None used.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The duct in the area of the reheater is Type 316L stainless steel. Before and after the reheater, the duct is flake glass/polyester-lined carbon steel. Inlet ducts are unlined carbon steel up to section where emergency spray nozzles are installed at the venturi inlet. This duct is Type 316L stainless steel and then flake glass/polyester-lined carbon steel. Diesel driven pumps are provided for the emergency sprays. The linings cannot withstand temperatures above 180 F.

The expansion joints are Viton®-asbestos type.

Hot side dampers are carbon steel, and those on the outlet side are Type 316L stainless steel. Inconel seals are used on the wet side. Louver-type dampers are preferred by CEA.

14. Piping and Valves - Large slurry lines are rubber-lined carbon steel. Smaller lines, less than 3 inches in diameter, are Type 316 stainless steel.

The large valves are rubber-lined and the small valves are Type 316 stainless steel. Rubber pinch valves are better for slurry service.

15. Stack - The stack is not within the scope of the CEA contract.

16. Slaker - The lime slaker is carbon steel.

(Milton R. Young)

1. Prescrubber - None used.

2. Absorber - The vessel is flake glass/polyester-lined carbon steel. An aluminum oxide-filled lining is applied over the polyester where the hot gas enters the scrubber. The inlet duct protrudes into the scrubber.

3. Spray Nozzles - The slurry spray nozzles are Refrax with Type 316 stainless steel headers. The mist eliminator wash nozzles are Type 316 stainless steel, including the headers.

4. Mist Eliminator - The mist eliminator has Noryl chevrons. The wash tray is Type 316 stainless steel.

5. Fans - The hot side axial fans are carbon steel.

6. Reheater - The reheater is a bustle-type arrangement wherein a jacket surrounds the exhaust duct. Bypass gas is fed into the jacket (bustle) to heat the exhaust gas before it enters the stack. The hot area of the wet duct near and within the bustle area is Type 316 stainless steel. The outer chamber (bypass gas) is carbon steel.

7. Pumps - The slurry pumps are rubber-lined and have held up well with the fly ash slurry.

8. Tanks - The recycle tank is an integral part of the absorber vessel and is flake glass/polyester-lined carbon steel. The lime and fly ash slurry tanks are plain carbon steel.

9. Agitators - The recycle tank agitator is rubber-coated and supported by a tunnel through the middle of the absorber vessel. The agitators in the lime and fly ash slurry tanks are plain carbon steel.

10. Storage Silos - The lime and fly ash storage silos are plain carbon steel.

11. Thickener - The thickener bottom is concrete with a cloth reinforced polyester lining by Dudick. The sides are carbon steel with a Dudick polyester lining. The rake which is rubber-coated, broke because of misoperation of the thickener.

There was a lining problem on the concrete. The concrete had crazed, and this crazing extended through the lining. However, CEA personnel thought that there would have been no problem if the concrete had been properly cured before the lining was applied. The tank was patched and relined with no problem reported, thus far.

12. Vacuum Filter - The vacuum filter is rubber-lined carbon steel with some stainless steel and some FRP parts. The filters have polypropylene cloth.

13. Ducts, Expansion Joints, and Dampers - The inlet (hot side) duct is plain carbon steel except for the section near the absorber. There is an emergency spray area at the absorber inlet. The duct in this area is Type 316L stainless steel, as are the emergency spray nozzles.

The exit (wet side) duct is flake glass/polyester-lined carbon steel except for the hot section near the bustle reheater which is Type 316L stainless steel.

The expansion joints are fabric type. Dampers are the same as at Colstrip.

14. Piping and Valves - The piping is rubber-lined carbon steel. Large pinch valves are used on the headers. Other large valves are rubber-lined and small valves are Type 316 stainless steel.

15. Stack - Not discussed.

16. Slaker - The lime slaker is carbon steel.

(Spurlock)

The Spurlock scrubber is a straight lime system on high sulfur eastern coal. Differences in materials used in this system from the previously described systems were because of customer preference. This system employs substantial usage of stainless steel rather than lined carbon steel.

An electrostatic precipitator precedes the spray tower absorber. The upper portion of the absorber (mist eliminator area) is Type 316L stainless steel. There is no wash tray. The center portion (spray area) is Type 317L stainless steel. The lower portion including the sides of the recycle tank is polyester-lined carbon steel, except for the bottom of the tank which has a fabric-reinforced, polyester lining. The recycle tank agitators enter from the top via shoulders to avoid bottom entry (Colstrip), side entry, or a tunnel (Milton R. Young). The spray headers and external piping are FRP.

The main source of reheat is hot flue gas from an old boiler, but there is also bypass reheat from the boiler having the scrubber. There are four small bustles per module and one large bustle for the common header. All outlet ductwork is Type 316L stainless steel. The stack has a carbon steel flue with a polyester lining.

The lime slurry system has a rubber-lined pump, agitator, and piping because of customer preference.

COLUMBUS & SOUTHERN OHIO ELECTRIC COMPANY (C&SOE)
CONESVILLE UNITS 5 AND 6

Trip Report Number: EPRI-CM11

Date of Trip: January 11, 1979

Persons Interviewed: Dan L. Boston, Chemical Engineer, C&SOE.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Universal Oil Products is the process designer and vendor; Union Boiler of Nitro, West Virginia, is the contractor; the consultant is Black and Veatch; Units 5 and 6 are new boilers.

2. Boiler Type - Each unit is a nominal 410-MW Combustion Engineering, pulverized coal fired boiler; the heat rate is 8,880 Btu/kWh.

a. Typical excess air is 25 percent.

b. The units were intended to go off line every night and on weekends (peaking units) because of the high cost of scrubber operation; however, the units generally operate at half load at night and on weekends; the intended capacity factor was 49 percent but the units probably operate at a capacity factor of 60 percent.

c. An 800-ft common stack is utilized for Units 5 and 6.

3. Flue Gas Flow Rate - The flue gas flow rate at various boiler load factors is

Load Factor, percent	ACFM @ 286 F
25	365,000
60	731,000
100	1,265,000
maximum	1,394,000

a. Oxygen in the flue gas ranges from 5.0 to 5.5 percent.

4. SO_2 Concentration - The inlet SO_2 concentration is approximately 3000 ppm (dry basis); the outlet concentration is about 240 ppm.

5. Fuel - Ohio coal with a typical sulfur content of 4.5 percent, an ash content of 14.9 percent, and an average heating value of 10,800 Btu/lb.

6. Scrubber Reactant - Dravo's thiosorbic lime from Maysville, Kentucky. The calcined pelletized lime has a nominal particle diameter of 1-3/4 inch, an MgO content of 3 to 8 percent, and CaO content of 90-95 percent.

7. Removal Efficiency - The SO_2 removal efficiency is about 92 percent; the electrostatic precipitator (supplied by Research Cottrell) has a fly ash removal efficiency of 99.65 percent.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables -

a. The flue gas inlet temperature to the scrubber is 286 F.

b. The flue gas outlet temperature from the scrubber is 125 F.

c. The design value for the inlet fly ash loading to the scrubber is 0.025 grains/scf (dry).

d. The pH of the recirculating scrubbing slurry is 7 to 7.5; the pH of the effluent from the trap out tray is 5.5 to 6.3.

3. Absorber Design -

a. An electrostatic precipitator for particulate control. The scrubber does provide for some particulate removal, but the extent of its contribution has not been determined.

b. Two TCA (turbulent contact absorbers) per unit for SO_2 control with one stage of sponge rubber balls one-foot deep; the stage is compartmented to give uniform ball distribution; a spray chamber at the bottom of the scrubber installed within the gas inlet cools and saturates the gas.

c. The superficial design gas velocities through the scrubber range from a minimum of 6.5 ft/sec at 25 percent boiler load to a maximum of 13.1 ft/sec at 60 percent boiler load.

d. Each scrubber module is designed to accommodate 25 to 60 percent of the flue gas flow rate at full boiler load. Below 25 percent boiler load, there is insufficient gas flow to induce turbulence in the balls. When the boiler is operating above 60 percent, both scrubbing modules are utilized; at below 60 percent load, only one scrubber is utilized. The system is equipped with a 100 percent bypass.

4. Liquid-to-Gas Ratio - Three constant flow recycle pumps operate continuously with two pumps on standby per module. As the liquid flow rate is constant, the L/G is exclusively a function of the gas flow rate or boiler loading. The L/G for each module is designed to range from a maximum of 90 gal/1000 acfm at 25 percent boiler load to 45 gal/1000 acfm at 60 percent boiler load.

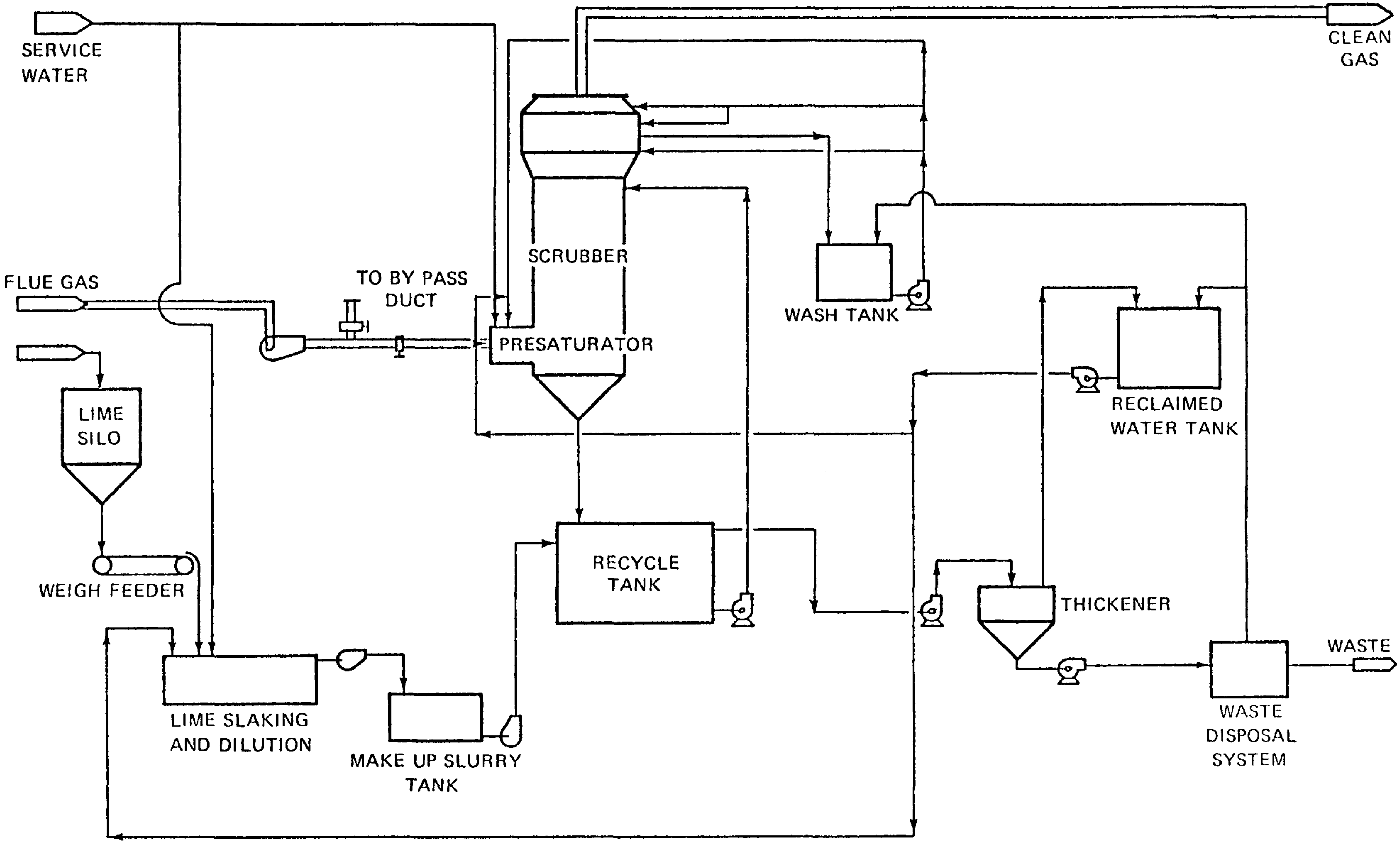

FIGURE 1. FLOW SHEET FOR LIME SCRUBBING AT CONESVILLE UNITS 5 AND 6

5. Oxidation - In the scrubber, 15-20 percent oxidation of sulfite to sulfate occurs.

6. Pressure Drop - The pressure drop through the system is 6 to 8 inches of water.

7. Solids Level - The scrubbing liquor contains about 7 to 12 percent solids; the thickener underflow contains 30 percent solids; the IUCS thickener is not increasing the solids content of the sludge; the filter cake contains 50 percent solids.

8. Reactant Addition - The thiosorbic lime is added to the top of the recycle tank.

9. Reactant Feed Rate - The system is designed for 1.10 moles of thiosorbic lime per mole of SO_2 removed or about 31,560 lb/hr of lime per boiler at full load.

10. Slurry Retention Time - 7 to 8 minutes in recycle tank; retention time can be changed by varying the liquid level in the tank.

11. Mist Eliminator - A trap out tray and two horizontal banks of chevron-type mist eliminators, the lower bank three pass and the upper bank four pass; no provisions are made for washing the upper mist eliminator; the lower mist eliminator is washed continuously from top and bottom, and the bottom of the trap out tray is washed intermittently; the recycled water supplies all of the washing water; the mist eliminator section of the scrubber is expanded by 2 ft per side so that the superficial gas velocity ranges from 4.9 to 9.8 ft/sec, depending upon boiler load.

12. Reheat System - No provisions have been made for stack gas reheat.

13. Waste Disposal - Closed-loop system; C&SOE has contracted with IUCS (International Utilities Conversion Systems) to fixate and landfill the sludge. The terms of the contract provide for C&SOE to pay IUCS a fixed monthly fee for their services with an option to purchase the sludge treatment plant from IUCS in the future. The fixation process takes the thickener underflow, tries to further thicken it, filters it in a vacuum filter and mixes it with a blend of dry fly ash and lime to form a 62 percent solids substance trade named Poz-O-Tec. The fixated sludge is landfilled in a diked disposal area of about 80 acres to a height of 50 feet.

14. Fans - Two forced draft fans with respect to the scrubber; fans are centrifugal, air foil type; fans supply a minifold which supplies either the scrubber or the bypass.

C. RELIABILITY

1. Start-up - Module 5B started up in January, 1977, and 5A in November, 1977; Modules 6A and 6B both started up in April, 1978.

2. Availability - Module 5B had an availability (hours the FGD is available for operation divided by hours in period) of 45 percent in 1977; in 1978 the availabilities were 52 percent for 5A, 47 percent for 5B, 69 percent for 6A, and 57 percent for 6B.

3. Longest Run - 8 days for Module 5A and 7 days for the other modules.

4. Calendar of Operation - Module 5B has accumulated over 4,000 hours of operation since startup, but was shut down in July and August, 1977, for modifications and repairs; Module 5A operated for only two weeks in 1977; in 1977, there were a number of reasons for down time, primarily replacement of FRP piping with rubber-lined piping because of leaks at joints in the high pressure lines and plugging of units; during 1978, operating problems rather than materials failures have been the cause of downtime; there was a major boiler outage from December, 1977, to March, 1978, to reline the stack.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - There is a presaturator made of Carpenter 20 steel at the entrance to the absorber. It has a guillotine damper at the inlet. The spool piece between the damper and the presaturator is Cor-Ten steel. Corrosion has occured in this area and it has been patched.

2. Absorber - The absorber is carbon steel with a 1/4 in. neoprene rubber lining. Except for a fire in the Module 5A absorber, the only problem with the rubber lining was in one of the modules where the rubber had been improperly lapped (upper layer under lower layer). It was reapplied with the lap reversed (upper layer lapped over the lower layer) and has given no problems. The rubber lining was steam cured (Reco was the applicator company). The rubber lining extends up to the mist eliminator. Above the mist eliminator a Corrosioneering flake glass lining is used.

The cage support rods are carbon steel with a rubber coating. The only problem has been tearing of the rubber where the coating is thin. The vertical dividers are fiberglass. The balls are sponge rubber (nitrile). They are still in use after nine months. The original balls were hollow plastic (like ping pong balls). They expanded and became thin walled, possibly because of a thermal excursion.

3. Spray Nozzles - The recycle nozzles are silicon carbide and the mist eliminator wash nozzles are Type 316 stainless steel. The presaturator nozzles are either Carpenter 20 or Type 316 stainless steel. The only problem with nozzles has been plugging due to solids in the reclaim water.

4. Mist Eliminator - The trap out tray and the chevrons are fiberglass. The only materials problem has been breakage during cleaning, caused by striking with a hammer.

5. Fans - The fans are forced-draft type, all on the hot side of the scrubber. They are made of A 514-517 carbon steel.

6. Reheater - None used.

7. Pumps - The reclaim water (thickener overflow) and mist eliminator wash pumps (Goulds) are Type 316 stainless steel. Slurry transfer, recycle, slurry makeup, slurry draw-off, and thickener underflow pumps are all rubber-lined. Two linings have been lost from recycle pumps. These linings were damaged by pieces of fiberglass from pH sample troughs in the absorber which fell down and got into the pumps. A lining was also lost from one of the thickener underflow pumps because of cavitation during a period of operation without flow. The recycle pumps were made by Allen-Sherman-Hoff, and the remaining pumps are Galigher except for the IUCS thickener underflow pump which is a rubber-lined, helical screw Moyno pump from Robbins & Myers. The pumps have been highly satisfactory thus far.

8. Tanks - The recycle tanks are carbon steel with a Corrosioneering polyester/flake glass lining. A small area needed repair because of damage when a sample trough fell against the lining and chipped it. The reclaim water and slurry storage tanks are both carbon steel. The mist eliminator wash tank and the slurry transfer tank are fiberglass.

9. Agitators - Shafts and blades of agitators are rubber-coated carbon steel.

10. Storage Silos - The lime silo is concrete with an A-36 steel bottom.

11. Thickener - The thickener has carbon steel sides and a concrete bottom. The bottom is lined (believed to be epoxy). There is a problem where the steel and concrete join, and a proper seal is still being sought. The IUCS thickener tank is carbon steel with a clay bottom covered with a plastic film (type unknown).

12. Vacuum Filter - The vacuum filters are carbon steel with a polypropylene filter cloth. The pH is kept neutral.

13. Ducts, Expansion Joints, and Dampers - The inlet and bypass ducts are Cor-Ten steel. There is corrosion in the inlet duct just ahead of the quencher sprays and Uddeholm 904L is being considered as a replacement; coatings of any type are not considered acceptable. The outlet duct to the scrubber outlet damper is Cor-Ten steel lined with Resista-Flake 1150 which is still intact in both units. Beyond the outlet dampers, the lining was Flakeline 151 which failed during bypass of flue gas at high temperature (330 F) and was replaced on both units with a 1.5 inch layer of Sauereisen No. 54 gunned onto a steel grid. The Sauereisen was cured as follows: 60 hours at 70-80 F, 24 hours at 150 F, 12 hours at 200 F, and 12 hours at 250 F. This lining has not been inspected since installation. A 6 inch unlined outlet spool piece on Unit 6 is due to be replaced with Uddeholm 904L. There have never been any quench sprays in the bypass duct to protect the original stack liner coating.

The expansion joints are Teflon® /asbestos by Raybestos-Manhattan and have given no problem.

The inlet dampers are carbon steel and have given no problems, but the Type 316 stainless steel seals corroded rapidly and were replaced with Inconel 625. The bypass and outlet dampers are entirely Inconel 625. The materials are fine but the screw drive mechanisms do not work. C&SOE would prefer chain drive mechanisms.

14. Piping and Valves - The slurry recycle lines are rubber-lined carbon steel. The lime slurry, scrubber slurry bleed, and mist eliminator wash lines are all FRP, as well as the spray headers inside the absorber. The reclaim water lines were FRP but are now rubber-lined carbon steel because high pressure pulled the FRP joints apart. The FRP line from the thickener to the IUCS waste disposal system broke. The line had a 45 degree uphill slope and was replaced with FRP on elevated pipe supports to give a more gentle slope. The big recycle valves are rubber-lined DeZurik eccentric plug type. Other valves are either rubber-lined or rubber diaphram. The only problems have been of a mechanical nature (not materials related); the torque settings need to be increased on closure.

15. Stack - The stack was originally a Cor-Ten liner in a concrete shell. The Cor-Ten was lined with two coats of Flakeline 151; the bottom coat was troweled (40 mils) and the top coat was sprayed (20 mils). The Ceilcote lining failed because of bypassing flue gas at a maximum temperature of 330 F. Six or seven other linings were tried and none worked. The steel liner was removed and the stack was then relined with acid resistant brick (Kellogg ASTM C 279) with Sauereisen No. 65 mortar. The annulus is pressurized. The relining started in December, 1977, and was completed in April, 1978, at a contract cost of $\$4.3 \times 10^6$ ($\$48/ft^2$ based on an average diameter of 35 ft). Only the outside of the brick lining has been checked thus far.

16. Slaker - The lime slaker is carbon steel.

BABCOCK & WILCOX
FOSSIL POWER GENERATION DIVISION
BARBERTON, OHIO

Trip Report Number: EPRI-CM12

Date of Trip: January 26, 1979

Persons Interviewed: H. M. Majdeski, Carl Hamilton, William DePriest, and Gregory Bielawski, Air Pollution Control, Babcock & Wilcox (B&W).

A. BACKGROUND

Table 1 summarizes B&W's experience with wet lime/limestone scrubber systems in the United States. B&W's first full-scale flue gas desulfurization (FGD) system at Will County was started up in February, 1972. This system was plagued with many mechanical problems because it was a difficult retrofit installation. Nevertheless, much was learned about materials, and the good experience with rubber linings at Will County has been a factor in B&W preference for their use in other installations. However, B&W designs its systems to meet customer preference as was the case with the La Cygne Station discussed below. La Cygne represents an extreme condition for SO_2 and particulate removal so that many of the construction materials used in this installation would not be used in other installations. A discussion of B&W's current materials preferences follows the La Cygne discussion.

B. MATERIALS OF CONSTRUCTION (La Cygne Unit 1)

The La Cygne FGD system consists of eight modules. First firing was on December 26, 1972, and commercial operation began in June, 1973. The extensive use of Type 316L stainless steel in this system was governed in part by the inability to bypass the scrubber. There was concern that the relatively high temperatures that can develop when the scrubber is not operational could damage rubber linings or organic coatings.

1. Prescrubber - The venturi prescrubber and sump are constructed of Type 316L stainless steel with a minimum of 2.75 percent molybdenum. There is a Kaocrete HS lining for abrasion resistance over a plastic undercoating in the venturi, the sump floor, and the sump walls under the venturi. The Kaocrete was gun applied to a thickness of two inches over two-prong anchors. The plastic undercoating is Plasite 7122, an epoxy-phenolic coating from Wisconsin Protective Coatings Corporation. The venturi throat is lined with movable Refrax (silicon carbide) blocks manufactured by B&W under a license agreement with Carborundum.

2. Absorber - The absorber is unlined Type 316L stainless steel with a minimum of 2.75 percent molybdenum from the common sump drain to the top of the mist eliminator section. All internal supports and trays are

TABLE 1. B&W FGD SYSTEMS IN THE UNITED STATES

Client	Power Station	Size, MW	Sulfur in Coal, wt, percent	Reagent	Startup Date
Commonwealth Edison	Will County 1	176	0.3-4.0	Limestone	February, 1972
Kansas City Power & Light	La Cygne 1	848	5.0	Limestone	December, 1972
South Carolina Public Service	Winyah 2	140	1.0	Limestone	July, 1977
Southern Illinois Power Coop	Marion 4	184	3.0	Limestone	April, 1979
Allegheny Power	Pleasants 1	626	4.5	Lime	March, 1979
Allegheny Power	Pleasants 2	626	4.5	Lime	October, 1979
San Miguel Electric Coop	San Miguel 1	400	1.67	Limestone	June, 1980
South Carolina Public Service	Winyah 3	280	1.7	Limestone	June, 1980
Cincinnati Gas & Electric	East Bend 2	650	-	Lime	August, 1980
Sikeston Board of Municipal Utilities	Sikeston	235	2.8	Limestone	May, 1980
Lakeland Utilities	McIntosh	364	2.6	Limestone	November, 1981

also Type 316L stainless steel except for a few Type 304 stainless steel trays which were added at a later date because of availability of the material. The Type 304 stainless steel trays have not been examined for performance, but the chloride content is low at this point in the system so they may be suitable. There are two absorber trays and one prewash tray in each absorber vessel.

3. Spray Nozzles - The venturi spray nozzles are fabricated of Type 316L stainless steel with Coors alumina inserts. The absorber and mist eliminator wash nozzles are Type 316 stainless steel without ceramic inserts because they are not high pressure nozzles. In early operation, scale would plug some nozzles and other nozzles would wear because of the increased flow rate and pressure drop. However, the process chemistry is now under control and the nozzles are not wearing. All the spray headers are Type 316 stainless steel.

4. Mist Eliminators - The mist eliminators are two stage, three pass chevrons. The early design failed prematurely because of embrittlement. They were thought to have been constructed of clay-filled acrylic resin and designed for cooling tower use, but were used for the scrubbers because they were readily available. The new mist eliminators are a proprietary B&W fiberglass reinforced plastic formulation and are in satisfactory condition after 4 to 5 years of service.

5. Fans - The fans are located downstream from the absorbers and are constructed of carbon steel with a Plasite 4030 lining. This is a vinyl ester type lining which uses Dow's Derakane resin and has special fillers for abrasion resistance. The lining is replaced about every 7 months. The leading edges of the blades have Type 316 stainless steel wear plates tacked on for abrasion resistance.

6. Reheater - The reheater housing is carbon steel sheathed with 16 gauge Type 316L stainless steel. The original steam tubes were constructed of Type 304 stainless steel. These tubes failed by stress corrosion caused by moisture when the tubes were out of service. The tube bundles were replaced with Type 316L stainless steel tubes with a minimum of 2.75 percent molybdenum. These tubes last about three years before replacement becomes necessary because of pitting attack. The tubes must be kept hot, but steam is not available when the boiler is down. The reheater in the last module has tubes with thicker walls and larger outside diameters and seems to be doing better.

7. Pumps - The slurry recycle pumps are rubber-lined, manufactured by A-S-H. There has been wear at the entrance throat because of the abrasive action of the ash-laden slurry. Also, when a pump plugged, the liner was pulled off. However, the rubber liners can be replaced in the field and this is not considered to be a major maintenance problem. The limestone slurry pumps are also rubber-lined and are manufactured by Denver Equipment Company. The pond return pumps and the mist eliminator wash pumps have brass impellers in carbon steel bodies. These pumps have not had any problems.

8. Tanks - The recycle tanks and the limestone slurry tank are carbon steel lined with soft natural rubber.

9. Agitators - The agitators are all rubber coated carbon steel. Only one coating failed and had to be replaced.

10. Storage Silo - The limestone storage silo is carbon steel.

11. Thickener - None used.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The inlet ducts are unlined carbon steel. Originally, the outlet ducts were also unlined carbon steel. B&W engineers think that a heavy deposit of calcium sulfate protected the outlet ducts. Later, the deposition problems were solved and corrosion became a problem. The outlet ducts including the plenum were lined with Plasite 4005 (vinyl ester by Wisconsin Protective Coatings) in 1975.

The expansion joints were originally standard rubber with a temperature rating of 250 F. These joints failed because the temperature limit was sometimes reached, and were replaced with Viton® which is performing satisfactorily. The supports for the expansion joints were mild steel and corroded rapidly. A change was made from internal to external bolting and supports. The main problem is at the discharge of the ID fans.

The inlet dampers are louver type and are made of carbon steel. The outlet dampers are also carbon steel louver type, but with Type 316 stainless steel seals. The outlet dampers have required extensive work. The dampers on the suction side of the ID fans are all stainless steel louver type. Cold air seepage through the damper blade seals causes acid condensation and corrosion of the shafts; pieces have fallen into the fans. The packing in the bearings has been improved to minimize air seepage.

14. Piping and Valves - All slurry piping is carbon steel with a 3/16-inch rubber lining. Problems encountered have related to curing of the rubber. The carbon steel piping is connected to the Type 316 stainless steel spray headers by means of bolted flanges. The piping for the mist eliminator wash system was originally 8-inch diameter rubber-lined carbon steel, but it has been replaced with 1-1/2- to 2-inch diameter stainless steel because there is now a continuous wash instead of an intermittent deluge.

Originally, the system was equipped mainly with rubber-lined butterfly valves but they did not hold up well in slurry service with a high fly ash loading. They have been replaced with Type 316 stainless steel knife-gate valves which work well. Most of the control valve problems were solved by eliminating their function. Butterfly valves cannot be used to control flow because of the high torque. However, butterfly valves are still used in low pressure water service (less than 1 percent solids) for isolation but globe valves are used for control. For pipe diameters of 2 inches and less, ball valves are used without any problems.

15. Stack - The 700 ft. stack (not supplied by B&W) is concrete with a steel liner. Originally, the steel liner was protected with a flake glass polyester lining (Heil Rigiflake). This lining debonded and was replaced about 1-1/2 to 2 years ago with a 4000 series Plasite lining. There is no report on the condition of the latter lining.

16. Ball Mill - The ball mill is carbon steel and has metal wear plates. There is a cyclone separator between the venturi recycle pump and spray nozzles to keep the nozzles from plugging. The major body is rubber-lined carbon steel and the cone sections are ceramic lined over an epoxy coating.

17. Pond - The pond is not lined.

(Current Materials Preferences)

1. Prescrubber - Elimination of the venturi prescrubber by the use of an electrostatic precipitator is recommended. A fixed throat quencher with a pressure drop of 1 to 1.5 inches of H_2O is used. The quencher has a carbon steel shell with an overlay of organic lining (type not specified) topped with a refractory concrete similar to Kaocrete HS. Silicon carbide blocks are not required in this type of system.

2. Absorber - A carbon steel absorber with a rubber lining extending to the outlet is preferred. The lap joints for the lining are feathered down. The internal supports are also rubber-lined carbon steel. One tray of Type 316 stainless steel with a minimum of 2.75 percent molybdenum is recommended. However, a mist eliminator prewash tray may be needed to meet particulate emission requirements.

3. Spray Nozzles - Refrax silicon carbide is recommended for the absorber spray nozzles where the pressure drop is high. The quencher spray nozzles are Type 316L stainless steel with alumina inserts, and the mist eliminator wash nozzles are Type 316 stainless steel.

4. Mist Eliminator - The preferred mist eliminator is a chevron type constructed of B&W's proprietary fiberglass reinforced plastic.

5. Fans - One fan located between the electrostatic precipitator and the scrubber is preferred for drafting the boiler and pressurizing the scrubber. The fan can be constructed of carbon steel.

6. Reheaters - Indirect hot air reheat using carbon steel steam coils is preferred. The mixing chamber is a very critical area and B&W currently recommends refractory linings. Plasite 4030 was used by

United Engineers & Constructors at Pleasants Station and failed after one month of bypass operation. Perhaps refractory linings would be suitable, but some parts are difficult to coat.

7. Pumps - The recommended construction materials for pumps are the same as used at La Cygne.

8. Tanks - Same as at La Cygne except in the reagent preparation area where the tanks can be unlined mild steel.

9. Agitators - Rubber-coated mild steel is recommended.

10. Storage Silos - Carbon steel is recommended.

11. Thickener - When a thickener is used, it can be constructed of mild steel walls and a concrete bottom. A coal tar epoxy lining is usually used.

12. Vacuum Filter - In B&W scope, but designed and manufactured by others.

13. Ducts, Expansion Joints, and Dampers - The inlet duct can be unlined carbon steel and the outlet duct can be carbon steel lined with a Plasite or Ceilcote lining. The recommended expansion joints are Viton® serviceable from the outside except when they are high above the ground. Double louver dampers with seal air between them are recommended. The inlet dampers can be carbon steel and the outlet dampers can also be carbon steel but with a lining of flakeglass filled polyester.

14. Piping and Valves - Rubber lined carbon steel piping is preferred for sizes above 2 inches and stainless steel can be used for 2 inches and below. Knife gate valves are preferred in slurry service for isolation and control. Butterfly valves can be used for isolation in slurry service on lines 3 inches and up, and ball valves on lines 2 inches and below. Globe valves are used for control in high pressure water service.

15. Stacks - Not supplied by B&W.

SAUEREISEN CEMENTS COMPANY
PITTSBURGH, PENNSYLVANIA

Trip Report Number: EPRI-CM13

Date of Trip: February 14, 1979*

Persons Interviewed: George W. Read, Jr., Vice President.

A. BACKGROUND

The Sauereisen Cements Company is one of the leading manufacturers of specialty cements and industrial bonding compounds. The Sauereisen corrosion resistant monolithic linings and mortars have been in service in chimneys, ducts, and breechings for more than 38 years, and more recently in scrubbers, precipitators, and other equipment related to pollution control. Sauereisen's chimney product line includes three monolithics and four mortars, all inorganic but one. Sauereisen products can provide protection over a wide pH range, as well as resistance to temperatures up to 2000 F, and to moisture, sulfation, blooming, and efflorescence.

B. DESCRIPTION OF APPLICABLE MATERIALS

Sauereisen Acid-Alk No. 33-Mortar Grade is the original one-part, chemical-setting, inorganic, modified-silicate base cement. Supplied in powder form, No. 33-Mortar Grade is mixed with potable water as used. No. 33-Mortar Grade is formulated to be used as a mortar in acid-brick construction or as a castable in monolithic applications. No. 33-Mortar Grade resists most acids (except hydrofluoric and acid fluoride salts), as well as most alkalies, from pH 0.0 to 9.0. It also resists water, steam and weather when completely set, without any special after-treatment or acid washing.

No. 33-Mortar Grade cures with an internal chemical-setting action developing a final set in 36 to 48 hours at 70 F. It does not have the fast initial set characteristic of most chemical-setting cements and permits economical, efficient construction. No. 33-Mortar Grade develops an extremely strong bond to concrete, steel, or brick, without requiring special surface preparation, and also bonds to itself.

Sauereisen Acidproof Concrete No. 54 is the original acid-resistant material for gunite or cast construction of monolithic floors, chimney and tank linings - all areas where corrosive acids are present. No. 54 is a two-component material consisting of a Filler powder and a Binder liquid which are mixed together as used on the job. For flue gas system linings, gunited No. 54 provides economical, quickly installed protection for new or acid-attacked concrete, steel or brick substrates.

Sauereisen Corrosion-Resisting Mortar No. 65 is a completely inorganic potassium silicate base mortar for bonding acidproof brick or tile used in the construction of industrial chimneys, stacks, tanks, kilns,

*Telephone contact rather than office visit.

and other installations. No. 65 is a two-component material, consisting of a Filler powder and a Binder liquid which are mixed together as used on the job. No. 65 is applied by troweling in the same manner as ordinary bricklaying.

No. 65 is particularly recommended for installations handling strong oxidizing acids such as nitric and chromic as well as sulfuric acid in all concentrations. The mortar is highly resistant to sulfation which may develop in other types of silicate base cements when brickwork is subjected to alternate wetting and drying, fluctuating dewpoints, or acid mist conditions.

No. 65 is preferred as a mortar for bonding brick linings in large industrial chimneys handling combustion gases from sulfur-bearing fuel. With the trend towards lower operating temperatures in these chimneys, there is considerably stronger acid condensation and increasingly higher moisture present in the gases. As a consequence, moisture can be as great a problem as acids, and it is extremely important that the materials used to line the chimneys are both acid- and moisture-proof.

Wet scrubber systems, water sprays, and hosing greatly accelerate chimney lining damage and deterioration since water may increase corrosive-erosive action and thermal shock. When fully cured, No. 65 is resistant to water and acids (except hydrofluoric) throughout the complete width of the joint. Linings laid with No. 65 do not require any special acid treatment for protection from the weather.

Sauereisen No. 72-Gunite Grade is a lightweight, thermal insulating chemical-resistant refractory for use as a monolithic lining in chimneys, stacks, ducts, breechings, scrubbers, precipitators, tanks, process vessels, and other equipment. It is recommended for new installations and also for repairing and restoring existing linings. Since it is considerably lighter in weight than most other corrosion resisting linings, No. 72-Gunite Grade reduces the dead load and provides high insulating value and exceptional strength at low initial cost.

No. 72-Gunite Grade resists most acids (except hydrofluoric and acid fluoride salts), as well as most alkalies, within a pH range of 0.0 to 9.0. It resists water, steam, and weather without requiring any special after-treatment or acid washing.

No. 72-Gunite Grade is supplied as an inorganic, modified-silicate base powder to be mixed with potable water when used - no special binders or additives are required. It is formulated for guniting and hardens by an internal chemical setting action with final set in 24 hours at 70 F. A strong bond is developed to steel, concrete, and brick without any special surface preparation.

The following scrubber installations have stack linings of acid proof brick and Sauereisen Corrosion Resisting Mortar No. 65:

Columbus & Southern Ohio Electric, Conesville, Ohio
Duquesne Light Co., Elrama Station
Duquesne Light Co., Phillips Station
South Mississippi Electric, R. D. Morrow 1 and 2
Southwest Public Service Co., Harrington 1
Texas Utilities, Martin Lake 1, 2 and 3.

In addition, Sauereisen Chemical Resistant Refractory No. 72 is used as a 1-1/2 in. thick lining in the breeching at Kansas Power & Light Co., Jeffrey Unit 4, St. Marys, Kansas, and Sauereisen Acid Proof Concrete No. 54 is used as a 1-1/2 in. thick lining in the ducts at the same station.

Columbus & Southern Ohio Electric, Conesville, Ohio has a 1-1/2 in. thick lining of Sauereisen Acid Proof Concrete No. 54 in the ducts and breeching. And, Kansas Power & Light, Lawrence has 1-1/2 in. lining of Sauereisen Acid-Alk Cement No. 33 Gunite Grade in the new steel stack which was installed in 1976 when when the scrubber was rebuilt on Unit 4.

POCONO FABRICATORS
EAST STROUDSBURG, PENNSYLVANIA

Trip Report Number: EPRI-CM14

Date of Trip: February 20, 1979*

Persons Interviewed: Dick Zerwey

A. BACKGROUND

Pocono Fabricators was contacted by telephone on February 20, 1979, regarding the use of Formula G-8 Pre-Krete in utility power plants. Information on the generic nature of the material is considered proprietary by the company. Pre-Krete is field installed with pneumatic gunning equipment and is generally applied 1-1/2 inches thick. First, a suitable anchoring system is installed, and then wire mesh is attached to the anchors so that it is embedded in the middle of the Pre-Krete lining at the completion of the installation. Curing is accomplished by spraying on a resin based, membrane curing compound such as Pre-Kure. A list of Pre-Krete installations in power plants is shown in Table 1.

B. DESCRIPTION OF APPLICABLE LININGS

Formula G-8 Pre-Krete - An aluminous cement lining designed for use with many mild acids, various chemicals, acidic condensation, etc. G-8 is good for service temperatures to 1000 F and has approximately the same coefficient of expansion as medium steel. Formula G-8 Pre-Krete is an inorganic coating which is completely non-toxic.

Formula G-8 Pre-Krete, an acid-resistant mortar lining, protects stacks in coal- and oil-burning power plants from the corrosive effects of condensing gases. Pre-Krete protects both masonry and steel stacks from the damaging effects caused when exhaust gas containing SO_2 and/or SO_3 reaches its dewpoint and condenses, forming dilute sulfurous and/or sulfuric acid. Formula G-8 Pre-Krete has extremely good mechanical characteristics, with 3 to 4 times the strength of ordinary concrete.

The interior surfaces of breechings, flues and ducts connected to power plant stacks can be protected from corrosion with Formula G-8 Pre-Krete. Application techniques, including thickness and anchoring systems, vary and depend on the size and shape of the equipment to be lined. Sometimes a wire mesh system is used with a gunned application of Pre-Krete. Other times an expanded metal system along with a hand trowelled application works best.

Certain types of scrubbers and cyclones can also be Pre-Krete lined, depending on the specific service conditions. Sometimes testing a patch of Pre-Krete may be recommended to evaluate the effect of the service conditions on the Pre-Krete.

*Telephone contact rather than office visit.

TABLE 1. PRE-KRETE INSTALLATIONS IN POWER PLANTS AS OF JUNE 1977

Alabama Power Co. (Demopolis, AL) -- Formula G-8 Pre-Krete was used to line I.D. fan housings which were approximately 24 ft diameter x 12 ft wide. They are part of an electrostatic precipitator scrubbing system at this coal burning plant.

Arizona Public Service (Four Corners, NM) -- this is a coal burning plant. They used G-8 for lining a breeching and a stack. G-8 was also used to construct a 1200 ft long flume used for fly ash disposal. Pre-Krete installed in 1971.

Baltimore Gas & Electric (Sellers Point, MD) -- Formula G-8 Pre-Krete was used in 1976 for lining three stacks, 4-1/2 ft diameter x 60 ft high. All three were free standing stacks. This plant burns oil.

Boston Edison (Everett, MA) -- lined breechings in 1971 from an existing electrostatic precipitator to a new scrubber installed for the removal of sulfur dioxide. Also lined the breeching from the scrubber to the stack. This is an oil burning plant.

Central Electric Power (Chamois, MO) -- they have a free-standing steel stack, 6-1/2 ft diameter x 178 ft high. It was previously lined with a lumnite mixture. The top several feet failed. The lumnite was removed, wire mesh was installed and the lining was repaired, using Formula G-8 Pre-Krete.

Central Illinois Public Service (Newton Power Station, Newton, IL) -- Formula G-8 Pre-Krete was used for lining the top 450 ft of a 1200 ft high stack 22 ft diameter. Job finished May, 1977. 4160 bags of G-8 were used. Bottom of the stack is protected by a water seal.

Central Maine Power (Yarmouth, ME) -- used Formula G-8 Pre-Krete in 1971 for lining a stack and a breeching. This is an oil burning plant.

Commonwealth Edison (Hammond, IN) -- at the coal burning plant, G-8 Pre-Krete was gunned into a steel stack with a brick liner. Stack was 14 ft diameter x 250 ft high. Brick was studded and wire meshed -- then 1-1/2 in. Pre-Krete gunned in.

Dairyland Power Cooperative (Genoa, WI) - used Formula G-8 Pre-Krete for lining a stack and a breeching. The stack was 8 ft diameter x 60 ft high. One inch of Pre-Krete was gunned into place in May, 1973 over wire mesh. This plant burns heavy oil.

TABLE 1 (Continued)

Dayton Power & Light Co. (Dayton, OH) -- this was the first Pre-Krete application in an electric generating station. G-8 was used in 1966 for lining a breeching and part of a stack at this coal burning station.

Indiana Power & Light (Petersburg, IN) -- used Formula G-8 Pre-Krete for lining 3 presaturator ducts which lead to the scrubber. Ducts are 10 ft high, 8 ft long, 26 ft wide. The gas from the boiler is wetted down and cooled in the ducts before entering the scrubbers.

Kentucky Utilities (Central City, KE) -- at this coal burning plant, Formula G-8 Pre-Krete was used for lining scrubbers 20 ft diameter x 37 ft high made by American Air Filter Corp. These scrubbers are located right underneath the stacks. Also lined were crossover sections and elbows leading to the scrubber. In 1977, a 20 ft diameter x 60 ft high steel stack was lined with 1 in. of Formula G-8 Pre-Krete gunned into place over wire mesh. Previous lining failed due to high temperature.

Louisville Gas & Electric (Louisville, KY) -- in 1975 as part of a test program they lined a 250 ft high stack with HES at the top 50 ft, Formula G-8 over the next 50 ft and HES below the Pre-Krete. This was Chimney 6 at the Paddy's Run Generating Station. The stack was constructed of concrete with a brick liner. Anchors were drilled in the masonry joints. Then wire mesh was installed. The lining was then gunned on 2-1/2 in. thick. After one year of operation, the HES failed. It has been removed and Formula G-8 Pre-Krete was gunned into place over wire mesh. Also at the Cane Run Station, Formula G-8 Pre-Krete was used for lining the duct leading from the SO_2 scrubber to the stack. Duct 15 ft high, 12 ft wide x 30 ft long. Over 3000 bags of Pre-Krete used. Also at Cane Run a 250 ft high stack 20 ft diameter was lined with Formula G-8 Pre-Krete. These plants burn high sulphur coal from western Kentucky.

Nebraska Public Service (Sheldon Station, Hallam, NE) -- 500 bags of Formula G-8 Pre-Krete was used for lining a duct from the air heater to the stack. The air heater removes heat from the exhaust gas and that heat is then used for preheating air to the boiler to aid in combustion.

New Orleans Public Service -- this is a coal burning plant. Formula G-8 Pre-Krete was used for lining a stack in 1974.

Niagara Mohawk Power (Dunkirk, NY) -- lined a breeching in 1974 leading to the stack. Breeching was 12 ft x 16 ft x 40 ft long. This plant burns high sulphur coal.

TABLE 1 (Continued)

Philadelphia Electric Co. (Philadelphia, PA) -- a concrete waste condensate trench was lined with Formula G-8. Sonocrete was used to bond Pre-Krete to the old concrete. This trench runs from 1 ft to 4 ft deep by 200 ft long. October, 1975.

Public Service Co. of New Hampshire (Shiller Station) -- used G-8 for lining bottom of 3 stacks each 165 ft high with diameters ranging from 6 ft to 12 ft. These stacks are off a Foster Wheeler boiler burning Bunker C oil. Used 1 in. of G-8 over wire mesh. Job completed May, 1972.

Springfield Utilities Co. (Springfield, MO) -- 2 presaturator ducts from a UOP scrubber were lined with G-8 in May, 1976. G-8 was gunned on 1 in. thick over a wire mesh system.

Texas Utilities (Monticello Steam Plant, Winfield, TX) -- this job involves the lining of some of the largest rectangular breechings ever lined with Formula G-8 Pre-Krete. The stack breeching inlet is 150 ft long x 14 ft wide x 56 ft high at the stack entrance. It widens to 33 ft in the center of its length and narrows to a 28 ft square rectangle at the inlet duct from the 3 scrubbers. 24,000 sq ft of surface was lined with Pre-Krete. The inlet duct was also lined. It is a 28 ft diameter pipe 256 ft long. There are 3 outlet and 3 inlet ducts to this breeching. The total square feet of surface area lined was 29,799. This is a lignite burning plant rated at 750 MW.

Wisconsin Electric Power Co. -- in February, 1976, 1300 bags of Formula G-8 Pre-Krete were used for lining 10,000 sq ft of boiler breechings and ducts. In July, 1977 Formula G-8 Pre-Krete was used for lining a stack at the Columbia Generating Station Unit No. 2. Stack was 650 ft high, 21 ft diameter. 5800 bags of G-8 were used.

Utah Power & Light (Huntington, UT) -- at this coal burning plant, Formula G-8 Pre-Krete was specified for ducts from four SO_2 scrubbers to four stacks. Inlet plenums are 60 ft long, 8 ft x 12 ft at the scrubber end and 16 ft x 54 ft high at the stack.

PENNSYLVANIA POWER COMPANY
BRUCE MANSFIELD UNITS 1 AND 2

Trip Report Number: EPRI-CM15

Date of Trip: February 21, 1979

Persons Interviewed: Daniel Bodor, Plant Superintendent; R. C. Forsythe, Engineer; T. O. Flora, Associate Engineer; D. R. Billheimer, Production Engineer; Don Thomas, Asst. Superintendent, Bruce Mansfield Station, Pennsylvania Power Company.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Chemico designed the venturi scrubbing system; the consulting engineers were Commonwealth Associates; new installation.

2. Boiler Type - Foster Wheeler once-through supercritical boiler designed to produce 6,415,000 lb/hr steam at 3785 psig and 1005 F, burning pulverized coal; it is an opposed wall firing boiler; each unit is designed to have a net capability of 825 MW; the heat rate is about 9,000 Btu/kWh, corresponding to 37.9 percent efficiency.

   a. The boiler was designed to operate with 18 percent excess air.

   b. The units are designed to be base loaded; during 1978, the capacity factors were 50 percent and 34 percent for Units 1 and 2, respectively.

   c. A common 950-foot stack is used for Units 1 and 2.

3. Flue Gas Flow Rate - 3,350,000 acfm per boiler.

   a. Approximately 4 percent oxygen in the flue gas.

4. SO_2 Concentration - Approximately 2000 to 3000 ppm SO_2 in inlet flue gas.

5. Fuel - Mostly deep-mined southern Ohio coal with 2 to 5 percent sulfur, 8 to 15 percent ash, and about 12,000 Btu/lb.

6. Scrubber Reactant - Thiosorbic lime produced near Maysville, Ky., by the Dravo Company; 1-3/4 in. x 0 pebble lime with 90 percent minimum CaO, 2 to 6 percent MgO, and 4 percent maximum acid insolubles.

7. Removal Efficiency - The FGD system was designed to remove 92.1 percent of the SO_2 and 99.8 percent of the particulates; the system was not designed to remove NO_x.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables -

a. Inlet gas temperature to scrubber is 285 F.

b. Outlet gas temperature from scrubber is 128 F.

c. Fly ash inlet loading to scrubber is 7.75 grains/dry scf.

d. Scrubbers are maintained to a pH of 7.0 to 8.0 measured at the header to the sprays.

3. Absorber Design -

a. Two-stage Chemico venturi scrubbing system with six trains per unit; the first stage has a variable venturi throat used to maintain sufficient pressure drop to remove particulates.

b. The second stage is a fixed-throat venturi scrubber used to remove the remaining SO_2 to meet the required 92 percent removal efficiency; pilot plant tests indicated 70 percent SO_2 removal in the first stage; lime is added to both stages for SO_2 removal.

c. The venturi throat velocities were not specified.

d. The FGD system is designed to follow the expected boiler swings by varying the number of scrubbing trains sharing the total gas flow; the adjustable throat venturi is used to achieve a fixed pressure drop of 20 in. H_2O in the first stage. They try to operate seven days per week at full load. Full load is approximately 137 MW for each of 6 trains, 822 MW total. The practice is to reduce load by dropping trains to a minimum of 3 trains, even below half load. Servicing of the trains is done on weekends. During shutdown all liquids are kept circulating, except during extended periods.

4. Liquid-to-Gas Ratio - The system is designed for an L/G of 40 gal/1000 scf per stage.

5. Oxidation - The amount of oxidation is not known.

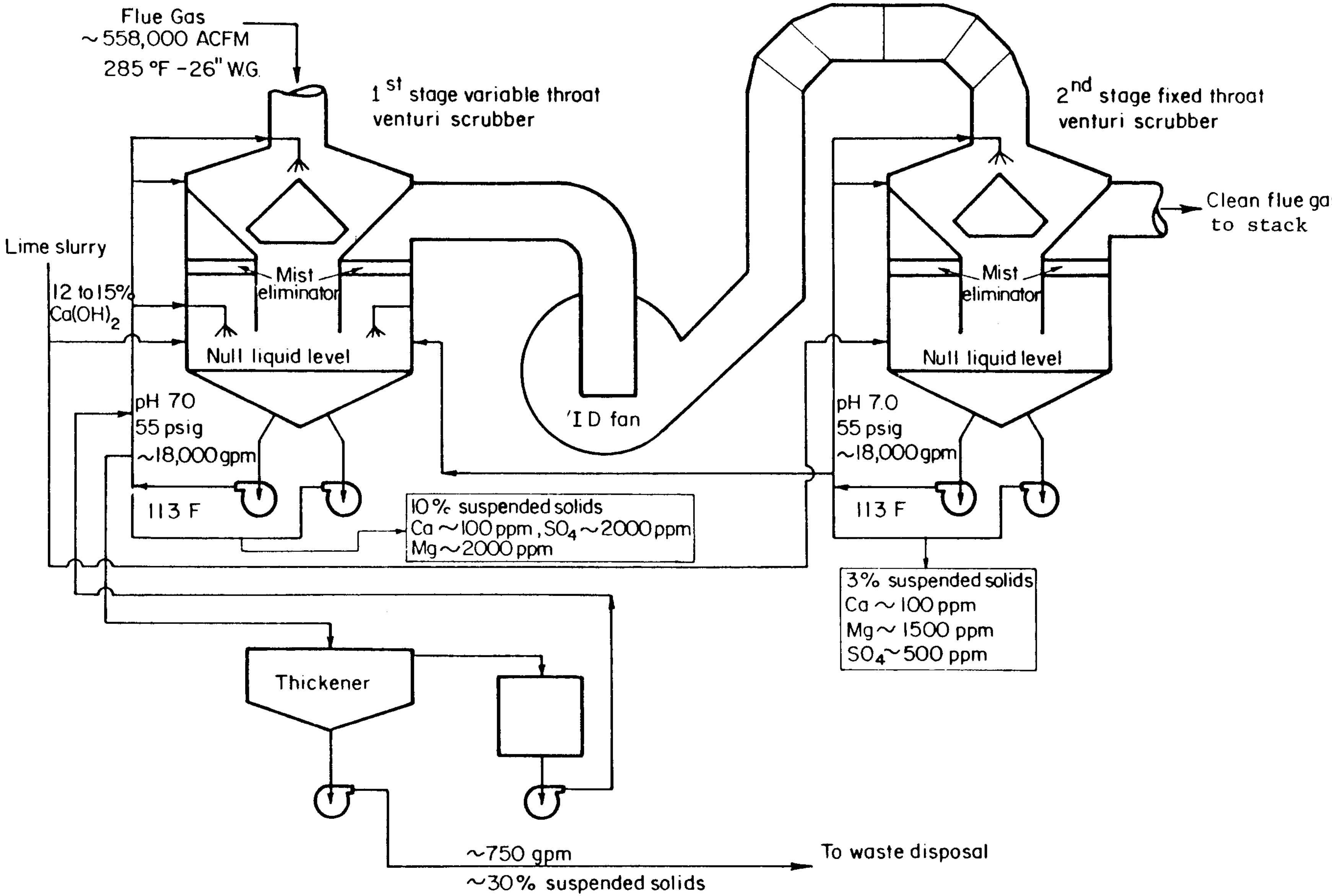

FIGURE 1. SIMPLIFIED SCHEMATIC OF CHEMICO TWO-STAGE VENTURI SCRUBBER SYSTEM AT THE BRUCE MANSFIELD PLANT

6. Pressure Drop - Total pressure drop through the FGD system is about 26 in. H_2O with 20 in. through the first stage and 6 in. or less through the second-stage scrubber.

7. Solids Level - 10 percent solids and 3 percent solids in first- and second-stage recirculating slurry, respectively.

8. Reactant Addition - Lime slurry is added to the bottom of each scrubber vessel below the liquid level and above the liquid level in each absorber vessel; the system uses about 144 lb lime per ton of coal burned.

9. Reactant Feed Rate - 1.1 to 1.2 moles of lime per inlet mole of SO_2.

10. Slurry Retention Time - About 30 seconds in each scrubber vessel.

11. Mist Eliminator - Each scrubbing vessel has chevron type, open vane, four pass, horizontal mist eliminators (vertical gas flow); the superficial gas velocity is 10 to 11 ft/sec; the mist eliminators are washed intermittently with overflow water from the thickener. Sprays below the demisters are operated on a rotating basis of about one per minute and sprays above are operated manually for a short duration about twice per 8-hour shift. If scale starts to build up, fresh water is used in the sprays.

12. Reheat System - The system was designed for 40 F reheat using direct oil-fired burners, but the burners have not operated properly even when modified by the manufacturer; Pennsylvania Power would like to continue to operate without reheat.

13. Waste Disposal - Thickener underflow containing 30 percent solids is mixed with Dravo's Calcilox additive (the maximum addition of Calcilox is 10 percent based on dry solids) in tanks which provide a 40-minute residence time. The material is then pumped seven miles to an impoundment area and the supernate will eventually be returned to the scrubber system. There is no return flow at present because an excess of fresh water is used in the scrubbers. The system has four 1,000-hp sludge pumps and two 285,000-gal flush tanks to flush the sludge lines. The pipeline can be cleaned with a dumb pig.

The impoundment area is 1,300 to 1,400 acres with a 420-ft-high earth and rock dam with an impervious core. The dam has a crest length of 2,200 ft and measures 1,300 ft thick at the base. The present dam (Blue Run) will impound an estimated 200 x 10^6 tons of sludge which is the estimated output of two units for a 20 to 25-year period. A floating pipeline is located on the reservoir area for sludge discharge. A separate set of pumps discharges water to the Ohio River when the former meets water quality standards.

14. Fans - The induced draft fans are wet fans manufactured by Green Fuel Economizer Company; there is one 9000-hp I.D. fan located between the first and second scrubber stages of each train (a total of six fans for each unit).

C. RELIABILITY

1. Start-up - Unit 1 was started up and synchronized for the first time on December 11, 1975; the unit was up and down several times working out the various problems until the unit went commercial on April 5, 1976; Unit 2 was started up in July, 1977 and went commercial in October, 1977.

2. Availability - Monthly availabilities (hours the FGD system is available for operation divided by hours in period) by individual modules for Units 1 and 2 are shown in Tables 1 and 2, respectively. Since there is no bypass of the scrubbers, availability of the FGD modules has a direct affect on the generating capacity of the units.

3. Longest Run - 68 days for Unit 1 and 42 days for Unit 2.

4. Calendar of Operation - Each module on Unit 1 has operated from 10,800 to 12,400 hours between startup and the end of June, 1978. Modules A, B, and C on Unit 2 have operated from 3,900 to 4,700 hours and modules D, E, and F from 2,600 to 2,900 hours between startup and the end of June, 1978.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - Particulates are primarily removed in the first-stage variable-throat, venturi-type scrubber. The inlet duct to this vessel is unlined carbon steel, except for the few feet extending into the top of the vessel. Beginning at the inlet duct, most of the rest of the vessel (including outlet duct to the fan) is coated with a flake glass/polyester lining (Rigiflake 4850, Rigiline Corporation).

Part of the plumb bob forming the variable throat was stainless steel (section at venturi throat). There was failure in the lining at the carbon steel/stainless steel junction. Stainless steel wear plates were therefore extended upward on the surface of the plumb bob. An acceptable life for these plates is considered to be four years. There is an acid-resistant brick lining on the wall within the area of the venturi throat.

TABLE 1. AVAILABILITY OF BRUCE MANSFIELD UNIT 1 SCRUBBERS*

		Availability[a] of Each FGD Module, Percent					
	Month	A	B	C	D	E	F
1976[b]	May	35	100	99	83	100	83
	June	99	94	97	94	98	80
	July	80	88	90	95	98	98
	August	95	88	93	76	71	95
	September	98	86	96	97	83	64
	October	98	86	96	97	83	64
	November	97	100	100	41	57	89
	December	81	100	95	60	86	87
1977	January	95	92	77	95	92	91
	February	77	69	77	86	92	81
	March	99	100	58	95	97	80
	April[c]	--	--	--	--	--	--
	May[d]	0	0	0	100	100	47
	June[d]	0	0	0	94	95	90
	July[d]	0	0	0	99	99	100
	August	58	54	31	96	95	88
	September	87	82	81	53	50	43
	October[e]	93	98	87	0	0	0
	November[e]	95	99	91	0	0	0
	December[e]	100	93	99	0	0	0
1978	January[e]	100	0	100	0	0	0
	February[e]	79	61	82	0	0	0
	March	43	91	90	65	50	60
	April	74	88	49	87	97	94
	May	98	0	98	91	92	92
	June[f]	--	--	--	--	--	--

*See footnotes on next page.

(a) Hours the FGD system is available for operation (whether operated or not) divided by hours in period.
(b) Data for 1976 are operability (hours the FGD system was operated divided by boiler operating hours) rather than availability.
(c) Unit shut down for turbine overhaul.
(d) Modules A, B, and C not operated due to stack lining repairs on one of two flues.
(e) Modules D, E, and F not operated due to stack lining reparis on one of two flues.
(f) Unit shut down for boiler inspection and generator repairs.

TABLE 2. AVAILABILITY OF BRUCE MANSFIELD UNIT 2 SCRUBBERS

		Availability[(a)] of Each FGD Module, percent					
	Month	A	B	C	D	E	F
1977	October	94	97	98	63	66	61
	November	100	96	88	47	55	47
	December	74	99	98	100	89	99
1978	January	95	100	96	94	99	99
	February	84	87	89	97	99	78
	March	100	93	13	95	95	97
	April	100	100	59	15	14	13
	May[(b)]	100	100	100	0	0	0
	June[(b)]	70	69	66	0	0	0

(a) Hours the FGD system is available for operation (whether operated or not) divided by hours in period.

(b) Modules D, E, and F were not operated due to stack lining repairs on one of two flues.

A stainless steel inverted cap has been installed at the scrubber sump to control flow into the inlet pipe to the recycle pump. This cap diverts flow so as to prevent cavitation of pumps. The plates used previously had lost their lining (Rigiflake 4850, Rigiline Corporation).

Part of the scrubber lining has held up well for over two years, except for erosion below the mist eliminator sprays and on the top of the conical plumb bob, where localized erosion has occurred. A more erosion-resistant material (Ceilcote's Ceilcrete 2500AR-1) has been installed on the plumb bob. The mist eliminator spray angles were shifted to avoid wall erosion. At areas where erosive wear was anticipated, wear plates originally installed above the flake glass/polyester lining have proved satisfactory (Type 316 stainless steel band on edge of cylindrical plumb bob and ASTM C279, Type L acid-resistant bricks on ID of throat just below plumb bob. The bricks are standing up well.).

2. Absorber - The second-stage venturi vessel is a fixed-throat design and provides only SO_2 removal. It is also flake glass/polyester (Rigiflake 4850) lined, except for the throat area, which contains Type 316 stainless steel annulus rings and throat liner plates. Originally, there was an epoxy-glass fiber mat lining over the stainless steel because of fear of chloride attack. Chloride concentration ranges from 300 to 3000 ppm. The lining failed and was not replaced because there was no problem with chloride attack. Loose sheets of broken mat lining plugged the pumps. The inlet and outlet ducts of this vessel are also lined with a flake glass/polyester lining. No major problems were reported. Originally, full load was carried by five trains, but this caused excessive mist carryover, so six are now used.

3. Spray Nozzles - Bull (low velocity) nozzles and headers in the second-stage venturi are Type 316L stainless steel. The nozzles were originally lined with an epoxy on a glass fiber mat (Rigiflake 413GS) because of the belief that chlorides might corrode the stainless steel. After three attempts, Heil was unable to achieve a reliable bond to the stainless steel nozzle surface, so that the idea of a protective lining was abandoned. No problems have been encountered with the nozzles. No spray nozzles are used in the first-stage venturi. The slurry is injected tangentially at the top of the converging section to form a cooling film.

4. Mist Eliminators - Mist eliminators in both venturi vessels are fiberglass reinforced polypropylene (with fire-retardant added) with a curved blade design. There were plugging problems originally, but they were solved by control of operation to avoid carryover caused by excessive scrubber velocity. Another problem has been breakage during manual cleaning. Cleaning spray water at 2,500 psig must be used with great care to avoid blade damage.

5. Fans - The wet fan between the two venturis has required considerable maintenance due to impingement of loosened duct deposits which damage the rubber-lined fan housing. These deposits are carried over from the scrubber when there are excessively high gas flow rates. This

condition occurs when too few scrubbers are operating. The Inconel 625 fan rotor has performed satisfactorily so the housing was lined with 3/16-inch Incoloy 825 in 1977. The Incoloy lining was welded to the steel. This kind of lining costs more than rebuilding the housing. Now, new housings are being fabricated of 3/8-inch Incoloy 825.

Maintenance cost on rubber linings for the first two years was estimated at about $800,000/year. Cost to replace eleven fan housings is about $7,000,000.

6. Reheaters - The direct-fired reheat chambers have caused considerable problems due to instability of the oil-fired, refractory-burner-block combustion system. The original refractory lining (Sauereisen No. 72) in three of the four chambers was damaged and was replaced with a conventional castable (from Resco Products) refractory. The burner instability problems apparently were not solved, causing abandonment of the reheat system. It was pointed out that the stack lining deterioration probably would have occurred even if reheat had been satisfactory.

7. Pumps - All major pumps are rubber-lined carbon steel. No major problems were reported. At first, there was a vortex at the scrubber bottom that led to pump cavitation. This was solved by inserting a Type 316L stainless steel cone at the bottom of the vessel over the pump suctions. Before the cone was applied, rubber coated plates were installed to divert the flow, but they were wrecked by the violent turbulence.

The piston-poppet-valve type sludge pumps by Ingersoll-Rand had been expected to last 3000 hours, but the valves wear out rapidly because of coarse grit. Larger size ball valves with tungsten carbide seats will be tried.

A separate problem with the sludge pumps was that their heat exchangers leaked when cooled by untreated river water.

8. Tanks - Tanks are flake glass/polyester (Rigiflake 4850) lined carbon steel, except for the reactant tank which is unlined carbon steel. There have been some problems with failure of the lining for the Calcilox addition tank which required patching. The lime mixing tank is rubber lined, although that probably was unnecessary.

9. Agitators - Rubber-coated carbon steel is used for agitator shafts and blades.

10. Storage Silos - No information obtained.

11. Thickener - Flake glass/polyester-lined steel with rubber covered rake. This has not been a problem area.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The inlet duct is uncoated carbon steel. The outlet duct to the inoperable reheater is carbon steel plus Rigiflake 4850, and the section from the reheater is carbon steel plus Rigiflake 4855 (a fire retardant variety of 4850 containing Sb_2O_3). No duct problems have occured.

The expansion joints were thought to be neoprene rubber with asbestos filler. No problems were reported.

The inlet dampers for dry flue gas are butterfly type, constructed of Type 316L stainless steel. They seal well. Outlet dampers are louver-type designed for 15 percent leakage. Dampers exposed to wet flue gas are Type 316L stainless Steel.

14. Piping and Valves - Rubber-lined piping is used for most major lines except the thickener return which is FRP. The FRP slurry pipe lines gave much trouble because of joint failure by cracking from water hammer and mechanical shock, and have been replaced with unlined carbon steel.

The valves in the slurry lines are knife-gate type. Some were originally installed backwards and they are designed to seal only in one direction. Plug valves are used at the inlet and outlet of all pumps. They must be kept right side up so that the plug rotates to the top of the valve when it opens. This keeps slurry from building up in the valve seat and causing the plug to stick. The valves in the bottom of the storage silo cannot be opened because of the weight on the valves.

15. Stack - The 950-foot concrete stack contains 4 carbon steel flues, 2 for each unit. All were originally lined with Rigiflake 4855 (fire retardant version of 4850 applied as 2 trowel coats, total 80-100 mils thick) in the lower 50 feet, and Rigiflake 489 (2 spray coats, total 40 mils thick) in the top 800 feet. The flues do not extend down to the bottom 100 feet of the stack shell. The linings in all four flues have deteriorated after 1-1/2 years of service. The 1A flue itself was badly corroded and required major patching with steel plates (applied on the inside). It was relined entirely with Rigiflake 4850 (2 trowel coats, 60-80 mils) about August, 1977 and as of June, 1979 was beginning to exhibit blistering of the top coat. The original lining in the other 3 flues was removed before extensive corrosion damage occured and has been replaced with 30-40 mils of CXL-2000 (1B 3/78, 2B 8/78, and 2A 3/79) selected on the basis of stack tests conducted in 1977.

Materials tests in one of the flues before selecting CXL-2000 included the following results:

Poor Results	Good Results
Pyroflex	Rigiflake 4850 (troweled)
Splashzone (troweled epoxy)	Flakeline 103
Furan	CXL-2000
Glass Block	Plasite 4004-5
Pre-Krete G8 } gunite mixes	Plasite 4005
Swindress Bond } gunite mixes	

CXL-2000 is a very expensive material and difficult to apply. It must be preceded by a sandblast and a primer. It costs $27 per square foot, raw, and $60-70 applied.

There is a lot of condensation in the stacks, as the gas temperature is about 130 F.

Consideration is now being given to the use of Inconel 625 for the stacks. It has been calculated that the high initial cost is justified because of the excessive costs of shut-down and relining of stacks.

DUQUESNE LIGHT COMPANY
PHILLIPS STATION

Trip Report Number: EPRI-CM16

Date of Trip: February 22, 1979

Persons Interviewed: John M. Malone, Jr., Senior Engineer, Power Stations Department, Duquesne Light Company

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Chemico is the process designer and vendor, and Gibbs & Hill is the architect-engineer; retrofit installation.

2. Boiler Type - Six Foster Wheeler pulverized coal-fired boilers; Units 1 and 2 are rated at 500,000 lb steam/hr each; Units 3, 4, and 5 are rated at 700,000 lb/hr each and Unit 6 is rated at 1,060,000 lb/hr; there are four steam turbines; steam supply for the first three, rated at 74, 83, and 82 MW, respectively, is obtained from a header system fed by Boiler Units 1 through 5; the fourth turbine rated at 148 MW is driven by steam generated in Boiler Unit 6; the total generating capacity is 387 MW and the plant heat rate is about 11,800 Btu/kWh.

   a. Excess air is 100 percent.

   b. Capacity factor was about 52 percent in 1975 and about 40 percent over the past two years.

   c. New, common stack for scrubbed flue gas is 340 ft high.

3. Flue Gas Flow Rate - 2,220,000 acfm at 362 F; all flue gas goes to the scrubbing system through a manifold; the scrubber can be bypassed, but shutdown of the boilers is necessary in order to divert the flow.

   a. Oxygen content of the flue gas was not specified.

4. SO_2 Concentration - About 1000 ppm SO_2 in inlet gas and about 170 ppm SO_2 in outlet gas under present operating conditions.

5. Fuel - System is designed for Pennsylvania bituminous coal containing 2.3 percent sulfur, 21 percent ash, and 7 percent moisture; heat content is 11,000 Btu/lb; actual sulfur content of coal is about 2 percent.

6. Scrubber Reactant - Ordinary lime 1-1/2 in. by 1/2 in. containing 95 percent CaO and 5 percent inerts was used, but the system switched to thiosorbic lime in 1977; thiosorbic lime contains 85 to 90 percent CaO, 6 to 10 percent MgO, and 5 percent inerts, and is delivered as 1-1/2 in. x 0 pebbles.

7. Removal Efficiency - System was designed for 80 percent SO_2 removal with ordinary lime in a two-stage venturi; 50 percent SO_2 removal was achieved in a single-stage scrubber; 83 percent SO_2 removal is now being obtained with thiosorbic lime and one-stage; 99.3 percent fly ash removal is required to meet local emission regulations.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables -

   a. Inlet gas temperature to scrubber is about 362 F.

   b. Outlet gas temperature from scrubber is about 125 F.

   c. Fly ash inlet loading to scrubber is about 2 to 3 grains/dry scf.

   d. pH of recirculating scrubber slurry is about 5.

3. Absorber Design -

   a. Existing mechanical cyclones and electrostatic precipitators are still used for particulate control but have an efficiency of about 80 percent; the remainder of the particulate removal is accomplished in a single-stage, variable-throat venturi.

   b. The single-stage venturi is also used for SO_2 control; the throat diameter is varied with pie-shaped louvers.

   c. Throat velocity was not specified.

   d. Turndown is achieved by taking trains off-line to a minimum of two trains on-line to assure redundancy; there are four scrubber trains, each designed for a gas flow rate of 550,000 acfm at 362 F; one scrubber train has two venturies in series, but all four trains are now operated as single-stage scrubbers.

4. Liquid-to-Gas Ratio - About 30 to 40 gal/10^3 scf.

5. Oxidation - The thickener underflow was analyzed at Battelle in September, 1976, and the oxidation of sulfur values to sulfate was found to be about 90 percent; however, the amount of oxidation occurring with thiosorbic lime may be less than with ordinary lime.

6. Pressure Drop - About 8 in. H_2O across venturi scrubber.

7. Solids Level - About 5 percent solids in recirculating slurry.

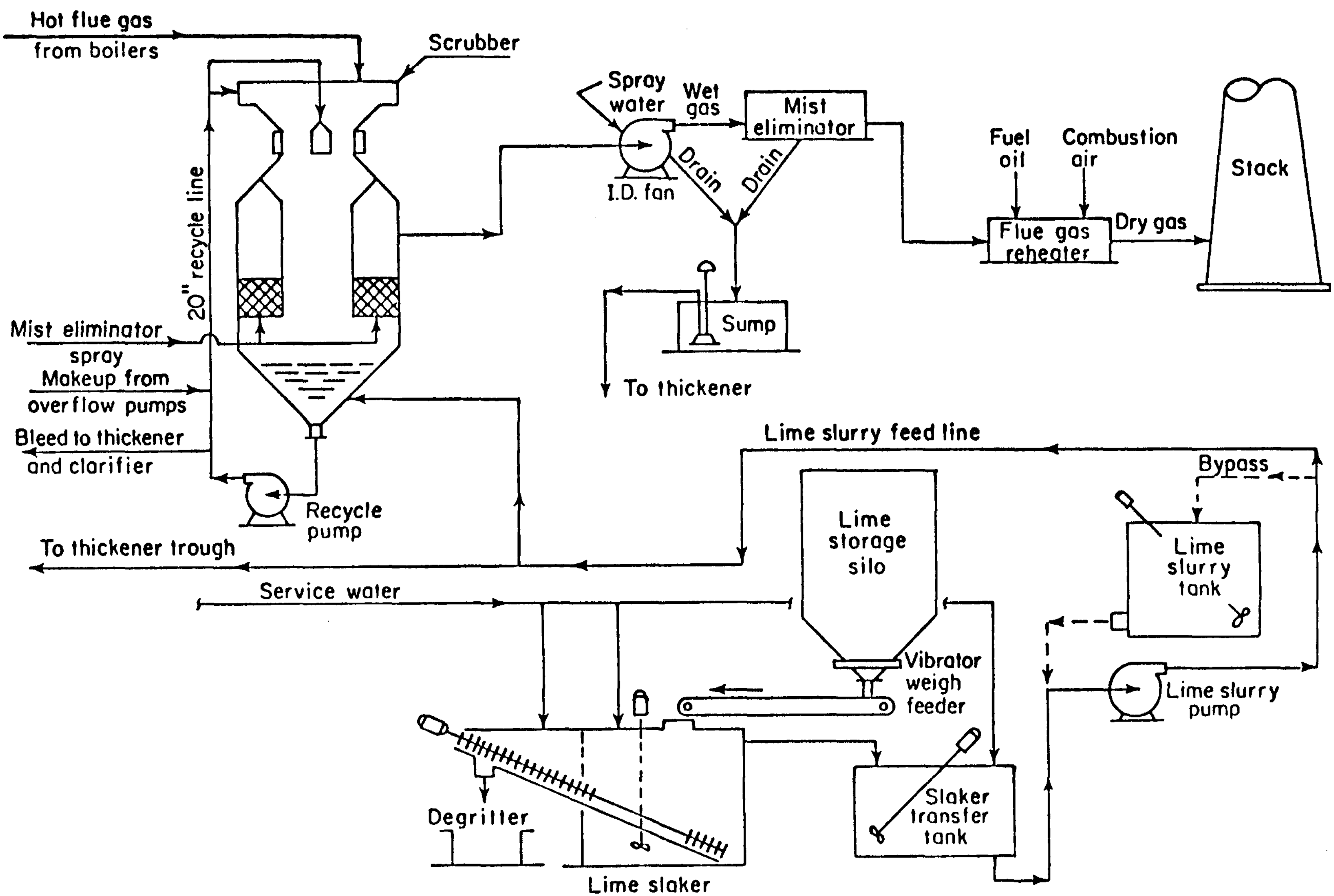

FIGURE 1. SCHEMATIC FLOW DIAGRAM OF ONE SCRUBBER TRAIN AT PHILLIPS

8. Reactant Addition - Lime slurry is added to the scrubber vessel bottom cone.

9. Reactant Feed Rate - 130 tons per day.

10. Slurry Retention Time - Less than 1 minute residence time in the bottom of the scrubber vessel; there is no hold tank.

11. Mist Eliminator - Two single-stage, horizontal chevron mist eliminators; one mist eliminator is located inside the scrubber vessel and the other is located in a separate vessel after the induced draft fan; the internal mist eliminator is washed sequentially from the bottom in an automatic spray mode and manually from the top using fresh makeup water; the external mist eliminator is washed manually from the top with fresh makeup water; the manual oversprays are performed 1 hour per week.

12. Reheat System - The reheat system consisted of oil-fired burners capable of providing 23 F of reheat with a heat output of 12.5 x 10^6 Btu/hr; the burners had a turndown ratio of 8:1 and were mounted on the duct; the reheater was used only briefly and corrosion occurred when they were not in use; the gas mixing was not effective, causing a nonuniform temperature distribution in the downstream ductwork; the reheaters have been removed and a study is under way to determine whether they are needed or whether mist eliminator modifications would suffice.

13. Waste Disposal - The waste disposal system is open-loop since there is blowdown of excess liquor in the winter; the sludge is stabilized with fly ash and lime using the IUCS process; the stabilized sludge is truck hauled to a landfill site where it is mixed with bottom ash and compacted.

14. Fans - Wet induced draft fans located between scrubber vessels and second mist eliminator vessels; fans are sprayed with fresh water and sumps are drained to the thickeners.

C. RELIABILITY

1. Start-Up - System started up serving two boilers on July 8, 1973. Rapid corrosion from operation without lime required repairs; system restarted in March, 1974 on three boilers. In March, 1975, all six boilers were connected.

2. Availability - No detailed availability figures because only 3 of 4 scrubber trains are required and these are constantly alternated. Overall availability (hours the FGD system is available for operation divided by hours in period) is approximately 65 to 70 percent; sometimes the boiler load has to be cut back because of scrubber problems.

3. Longest Run - The system ran continuously from March, 1974, to June 1976, except for a one-day outage; however, the longest continuous run for a given scrubber vessel is about 58 days between cleanings.

4. Calendar of Operation - Intermittent operation from start-up through October, 1973; shut down for modifications from October, 1973, to March, 1974; continuous operation from March, 1974, to June, 1976; shut down in June and July, 1976; continuous operation from July, 1976, to May, 1977 when FGD system was shut down for inspection; thiosorbic lime tests began in late May, 1977, but lasted only about one week; continuous operation from late May, 1977, to February, 1978, except for one weekend in November; shut down in February and March, 1978 because of coal shortage; continuous operation from late March through September, 1978; the FGD system has accumulated approximately 24,000 hours of operation on each of the four modules as of August 1, 1978.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - Prescrubbers are not used.

2. Absorber - Four single-stage scrubber units are now in operation. They are identical in design. However, one of the four units is part of a two-stage scrubber/absorber train. This was operated experimentally from about July, 1973 until late in 1975. It is now used as a single stage.

The absorbers are constructed mainly from mild steel. Originally, they were lined with Flakeline 103 (flakeglass-filled polyester). This lining gave good service until a change was made from high calcium lime to high magnesium lime, at which time problems began to develop with the Flakeline 103 lining. It is postulated that the high calcium lime produced a deposit scale over the surfaces of the absorber, which protected the lining. With high magnesium lime, the scale disappeared, and lining erosion was observed. The top of the cone which is impinged by the slurry from the simple, open bull nozzle was severely perforated. There was also serious damage to the adjustable throat dampers, and to large portions of the walls near the tangent slurry nozzles above the throat.

The perforated plates were replaced and relined, but this time with Coroline 505AR. This is a glass cloth, reinforced lining of the amine-cured epoxy type. It was selected because an area of the inverted cone directly under the bull nozzle had been lined in 1974 with Coroline 505AR, and it is still in excellent condition. This lining replaced the original Type 316L stainless steel, which had eroded away after only three months.

The upper surface of the incline which forms the top of the demister area is a high-abrasion area. The slurry from the bull nozzle and the tangential nozzles flows over this surface. It is covered with acid-resistant bricks. There has been no problem with this brick lining.

At the joint where this brick lining contacts the sidewall, which is now lined with Coroline 505AR, there was a 1/4-inch Type 316 stainless steel skirt plate. This eroded badly and holes formed in the adjacent wall.

The bottom cone is also protected by Coroline 505 AR, but some loss of metal occurs right at the cone outlet.

3. Spray Nozzles - Spray nozzles are Type 316 stainless steel. They have not been a problem.

4. Mist Eliminators - The mist eliminators are chevron-type, constructed of fiberglass-reinforced plastic. They withstand the chemical environment, but can be damaged by impact during manual cleaning of scale. Because the velocities are above design capacity, there is carry over which causes buildup of scale in the vanes. Consequently, they are washed on a continuous cycle with fresh water. This has minimized scale build-up; hence manual cleaning is infrequent.

5. Fans - The fans operate wet. The rotors are made of Carpenter 20 steel with Inconel welds. There are wear plates at the tips of the rotors which must be replaced after approximately 23,000 to 25,000 hours of operation.

The housing is constructed of mild steel with a rubber lining. Trouble with the rubber lining started after about 20,000 hours. Total is now 28,000 hours. They anticipate replacement of parts of the steel housing with Inconel at the curved section near the fan outlet where erosion is worst.

6. Reheaters - The flue gas is not reheated. Originally, there were oil-fired reheaters outside the exhaust duct, but on test, they produced hot spots, and were unused. Then wet corrosion ruined the reheat burners so they are now sealed off. In summer, the exhaust is 130 F. In winter, it is 90 F, producing a very white vapor plume.

7. Pumps - The slurry recycle pumps made by Ingersoll-Rand, operate under a head of 125 ft (54 psig). Originally, the impellers and the housing were Carpenter 20 steel (no lining). There was rapid wear from slurry erosion. The impeller design was changed (in 1974-75) from 6 vane to 5 vane, in the hope of decreasing velocities at the impeller tips. This did not help. Hard facing on the impellers lasted 200 hours. Numerous other changes have been tried, including installation of wear rings in the sides of the casings. Many materials were tried as wear rings and impellers (1975-1977), including the following: Carpenter 20 steel, Type 317L stainless steel, titanium, 20 percent chrome-iron, and CD-4MCu, a stainless alloy developed at Ohio State. The impellers would last about 2500 to 3500 hours and could not be rebuilt.

Recently, cast silicon carbide wear rings have been used to line the casings. They are lower priced than the metal wear rings, although they must be diamond ground. They have now operated in excess of 9,000 hours and appear to be in good condition. Moreover, the housing can be weld-repaired without removing these refractory rings.

Segmented silicon carbide wear plates have also been developed for the housing, and have been in service for 4200 hours without evident wear. They are epoxy-bonded to the steel.

Silicon carbide is now being tried for impellers and look excellent after 2000 hours. However, when the pump ran dry and then was hit by a slug of water from sudden opening of a valve, the impeller shattered. Most recently, a pump was built with a silicon carbide impeller, which has a metal sleeve, and a silicon-carbide-lined housing. New impellers and pumps were supplied by Sturm Machine Company, Barboursville, West Virginia, because the original manufacturer could not help.

The pumps used for slurry underflow are rubber-lined, made by Allen-Sherman-Hoff (A-S-H). They have given good service.

The fan sump pumps are by Crane-Deming, operating at a head of 70 ft (30 psig). They are constructed of Carpenter 20 steel. There have been lots of corrosion problems from the high sulfate and chloride environment. Replacement parts are expensive, and long lead times are required. Consequently, a Goulds FRP pump has been installed. There has been some wear after 6-7 months, but it is still operating satisfactory. The FRP pump has cut costs substantially.

The pump used for the return from the thickener was originally by Buffalo Forge, and was constructed of cast iron. The impeller failed in one week because at first the system was operated without lime. A change was made to a Warren Type 316 stainless steel pump. There were mechanical problems which necessitated maintenance. A Goulds Type 316 stainless steel pump is now used successfully.

The lime slurry pumps were originally Goulds (probably cast iron). A change was made to a Morris Ni-Hard pump, which is operating satisfactorily.

8. Tanks - The thickener overflow tank is an open, mild steel vessel lined with Flakeline 103. The lining has given no problems.

The lime slurry tank is concrete, lined with a special Ceilcote lining designed for use on concrete.

9. Agitators - The agitator in the lime slurry tank is rubber-lined. There is no agitator in the overflow tank.

10. Storage Silo - The lime storage silo is unlined carbon steel.

11. Thickener - The thickener has a concrete floor and steel sidewalls. The steel walls are lined with Ceilcote Flakeline 103. The floor has a Ceilcote lining designed for use on concrete. (John Malone surmised it is Ceilcote Hot Mastic 195 - bituminous.) The rake is rubber-coated

steel. The coating has need of some patching. Sludge disposal is contracted with IUCS, and details are not available on their equipment.

12. Vacuum Filter - By IUCS.

13. Ducts, Expansion Joints and Dampers - The inlet ducts are carbon steel. Outlet ducts are carbon steel lined with Flakeline 103. There has been one problem area in the outlet ducts where the reheater had been located. The Type 316 stainless steel in this area corroded. Flakeline 103 was applied in February, 1978. Previously, there had been several shutdowns because of leaks in this section. Thus far, there has been no problem since the Flakeline 103 was applied. The main area of duct wall corrosion was near the floor where slurry accumulated with corrosion occurring under the deposit.

The original expansion joints in the main wet gas outlet (to stack) were Type 405 stainless steel. They failed from corrosion in about six months. They were replaced with asbestos-reinforced butyl rubber, which has provided good service. At the fan inlet and discharge areas, the rubber expansion joints have been replaced because of cracks in the rubber. The original ones gave 23,000 to 24,000 hours of service.

The dampers at the fan inlet are louver type. The dampers and frames are clad with Type 316L stainless steel. They did not last, and were severely pitted and corroded after three months. The stainless steel cladding was removed, and in the fall of 1973, Ceilcote Flakeline 103 was applied to the frames, and Coroline 505 was applied to the louvers. Erosion has occurred in the frames, which has required periodic touch-up since then. The new ones to be installed will have Coroline 505 lining on all carbon steel surfaces. Adhesion of the coating to stainless steel has been found difficult. Local cement finishers are employed for the application.

There are isolation dampers at the inlet and outlet to each scrubber. The louver type inlet dampers are Type 316 stainless steel, and corrosion has been minimal. These dampers operate either wide open or completely closed.

Inlet isolation is obtained from a 16-foot butterfly damper. The entire damper and sealing angle were constructed of mild steel, and designed for two percent leakage. When a scrubber was out of service for capacity reduction, flue gas (acidic) was pulled back through the unit because all ducts fed into a common manifold. This caused a gap to develop in the seal of the butterfly valve because of corrosion. Holes developed in the damper frame. The entire problem areas near the valve were overlaid with segments of Type 316 stainless steel, and a new Type 316 stainless steel sealing angle and shaft seal were installed. This was done in the spring of 1978 and appears to have solved the corrosion problem.

14. Piping and Valves - In the original installation, all piping within the scrubber system was rubber-lined steel. In the underflow piping, a plastic-lined (Kelolite) section of piping was used as a test, but it eroded and the lining has been modified and in some places the piping was changed to FRP. Also, some stainless steel is used where the piping enters the thickeners. The FRP has given good service (two years thus far). The lime slurry piping is carbon steel. The bull nozzle section of piping within the scrubber is Type 316 stainless steel.

Valves in the bleed lines from the scrubber to the thickener were originally DeZurik plug valves. There was considerable wear problem, so a change was made to rubber pinch valves. The liners need to be changed periodically. For pump isolation, DeZurik plug valves are used and again there is a wear problem. The seats and plugs wear and need to be replaced periodically.

A number of manually operated, rubber pinch valves are used in the system. They have given minimal problems. However, the rubber-lined pinch valves on the lime slurry system have given considerable problems (believed to be a design problem, rather than materials related). The Duquesne engineering and operating staff believe that no valves should be used in the lime slurry lines because of rapid wear.

15. Stack - The stack is lined with acid-resistant brick, ASTM C279L (with acid-resistant Saureisen No. 65 Mortar). A lead sheathing extends upwards from the base for about 12 inches because of the accumulation of condensation at the base. Faulty sealing of the lead sheets required repair. There has been a problem from seepage of the corrosive media through the brick stack liner, which has caused some failures in the stack liner support bands which are located at 6-foot intervals. Both mild steel and Type 304 stainless steel were used for the support bands. Both have failed. The surface of the brick lining or inner stack (side towards concrete) was sand blasted to remove buildup so that the bands could be replaced. The new bands are Type 316 stainless steel.

16. Slaker - The slaker is carbon steel and it has given no problems.

DUQUESNE LIGHT COMPANY
ELRAMA STATION

Trip Report Number: EPRI-CM17

Date of Trip: February 22, 1979

Persons Interviewed: John M. Malone, Jr., Senior Engineer, Power Stations Department, Duquesne Light Company

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Chemico was the FGD process designer and vendor, and Gibbs & Hill was the architect-engineer; retrofit installation.

2. Boiler Type - Four Babcock & Wilcox pulverized coal, dry bottom boilers; Units 1 and 2 operate at about 100 MW each, Unit 3 at 115 MW and Unit 4 at 175 MW; each boiler has its own turbine-generator and total plant capacity is 494 MW; plant heat rate is about 10,500 Btu/kWh.

   a. Excess air is 25 percent.

   b. Capacity factor is about 70 percent; capacity factor drops to 40 percent at night.

   c. Stack height is 400 ft.

3. Flue Gas Flow Rate - About 2,060,000 acfm at 300 F; the gases from the four boilers can flow to five scrubbers, although each scrubber can be bypassed as needed; each scrubber is designed for a gas flow rate of 550,000 acfm at 300 F.

   a. Oxygen content of the flue gas was not specified.

4. SO_2 Concentration - 1500 ppm SO_2 in inlet gas and 200 ppm SO_2 in outlet gas under present operating conditions.

5. Fuel - Pennsylvania bituminous coal containing about 2 percent sulfur and 15 to 20 percent ash; heat content is 11,700 Btu/lb.

6. Scrubber Reactant - Ordinary lime was used originally, but the system was switched to thiosorbic lime in 1977. Thiosorbic lime contains 85 to 90 percent CaO, 6 to 10 percent MgO, and 5 percent inerts, and is delivered as 1-1/2 in x 0 pebbles. Experience at Elrama and Phillips indicate that the MgO content must be at least 8 or 9 percent to achieve satisfactory SO_2 removal.

7. Removal Efficiency - 83 percent SO_2 removal is obtained with thiosorbic lime; 99.3 percent fly ash removal is required to meet emission regulations of 0.1 lb/10^6 Btu. A test in October, 1976, resulted in an

emission of 0.04 lb/10^6 Btu when two boilers were feeding five scrubbers. On July 19-21, 1978, the particulate emission tests averaged less than 0.1 lb/10^6 Btu.

B. PROCESS DESIGN

1. Process Flow Sheet - Figure 1 shows the Elrama scrubber train.

2. Process Variables -

   a. Inlet gas temperature to scrubbers is about 275 F; gas temperature leaving boiler is about 300 F.

   b. Outlet gas temperature from scrubbers is about 120 F.

   c. Fly ash inlet loading to scrubbers is 2.2 grains/scf.

   d. pH of recirculating scrubber slurry is maintained at about 8, but this has not yet been automatically controlled because of control sensing problems.

3. Absorber Design -

   a. Existing mechanical cyclones and electrostatic precipitators are still used for particulate control, but have an efficiency of about 90 percent; the remainder of the particulate removal is accomplished in 5 single-stage, variable-throat venturi scrubbers.

   b. The single-stage venturis are also used for SO_2 control; the throat diameter is varied with pie-shaped louvers.

   c. Throat velocity was not specified.

   d. The variable throat allows a turndown ratio of 50 percent; each of the five scrubber trains are designed for a gas flow rate of 550,000 acfm at 300 F (refer to Figure 2).

4. Liquid-to-Gas Ratio - About 30 gal/10^3 ft^3; each set of two venturi recycle pumps has a combined capacity of 17,000 gpm.

5. Oxidation - It is estimated that the oxidation of sulfur values to sulfate is about 20 percent with thiosorbic lime; the use of an antioxidant is being considered; the spent scrubbing liquor was analyzed at Battelle in September, 1976, when ordinary lime was used as the reagent, and the oxidation was found to be about 60 percent.

6. Pressure Drop - Designed for 6 in. H_2O through the scrubber system, but actually operated at 8 in.

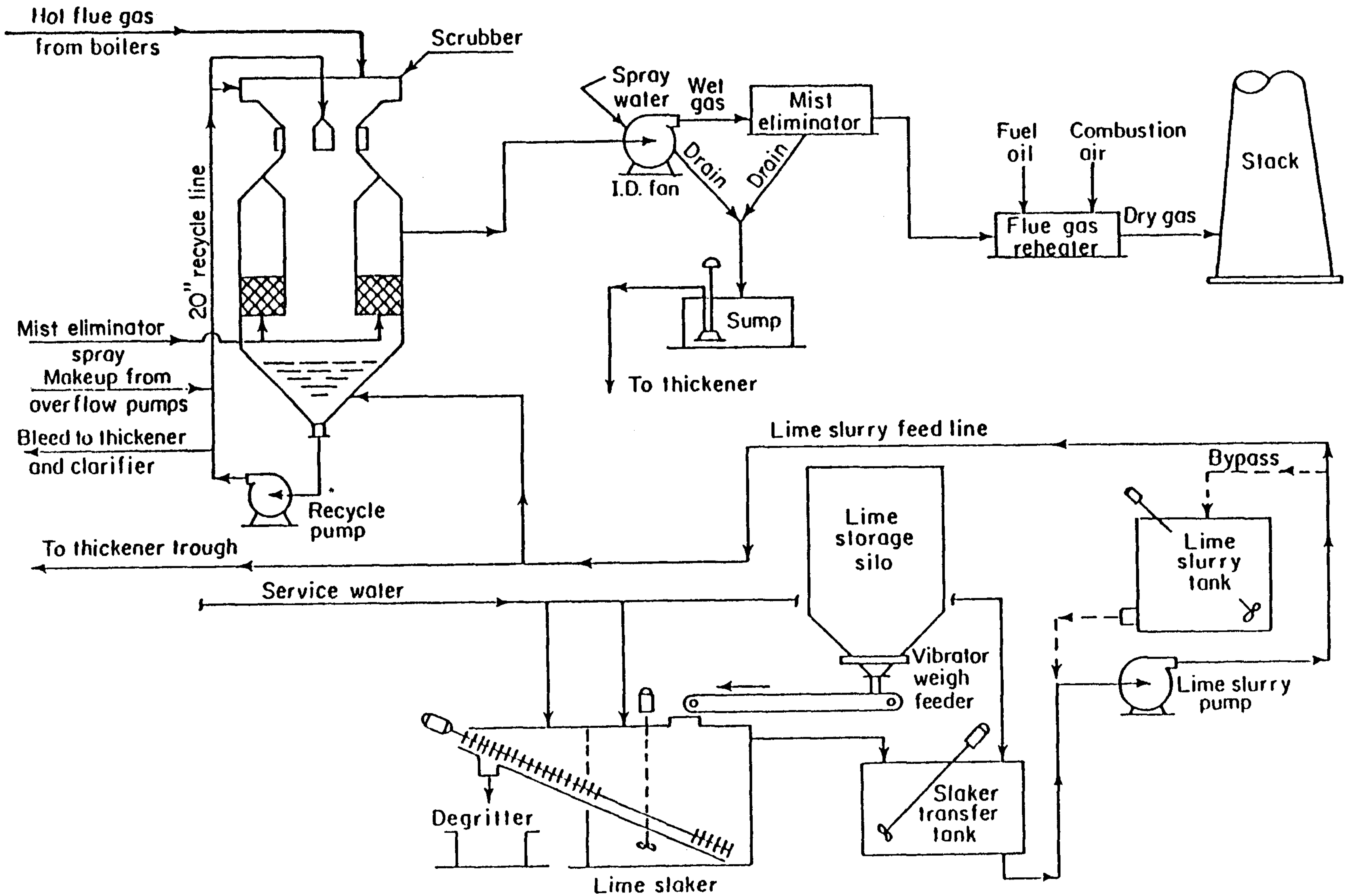

FIGURE 1. SCHEMATIC FLOW DIAGRAM OF ONE SCRUBBER TRAIN AT ELRAMA

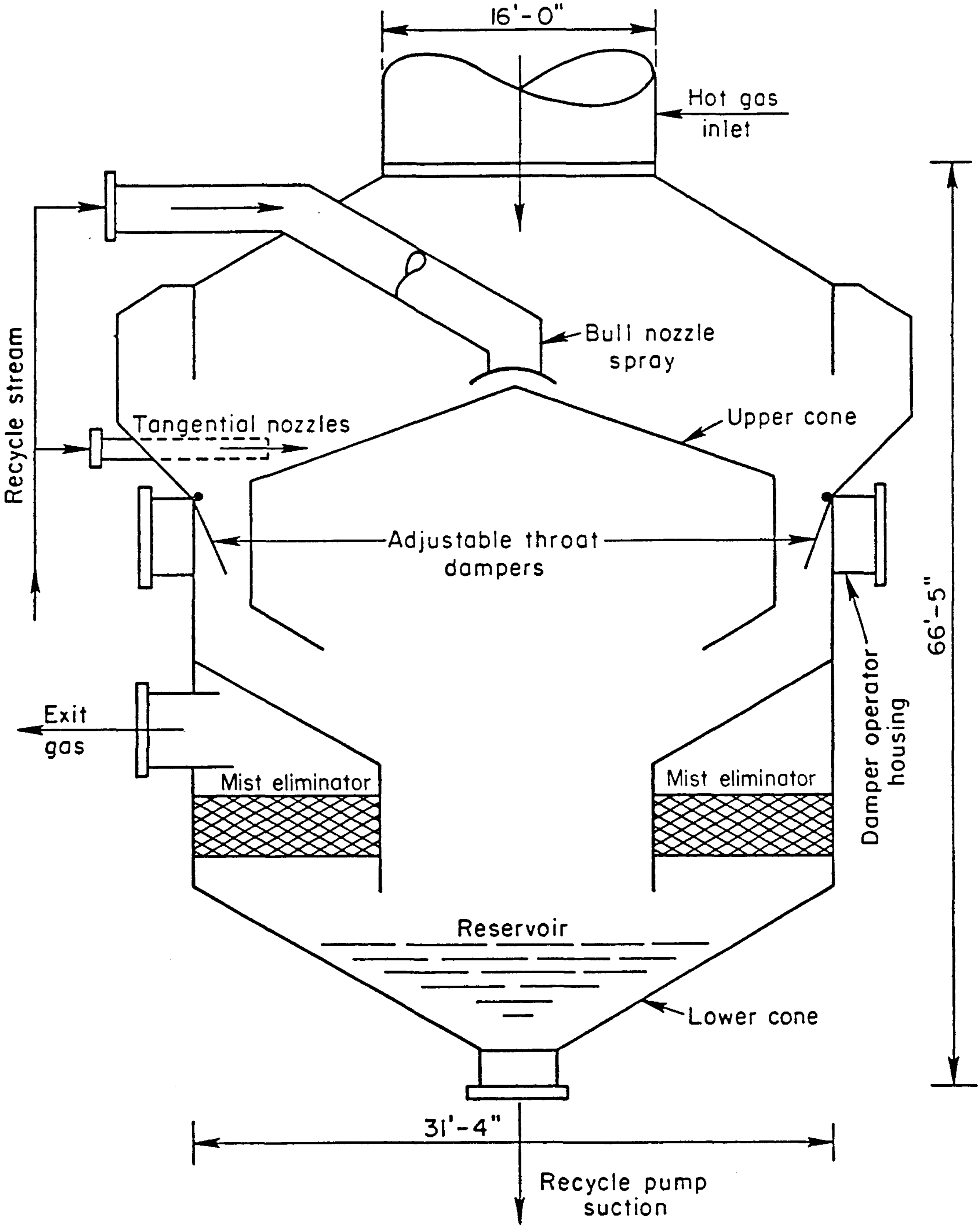

FIGURE 2. DETAILS OF CHEMICO VENTURI SCRUBBER AT ELRAMA STATION

7. Solids Level - About 5 percent solids in recirculating slurry.

8. Reactant Addition - Lime slurry was added initially to the bottom of the scrubber vessel; modifications were made later to add thiosorbic lime right above the water line.

9. Reactant Feed Rate - 30 lb per minute of quicklime per boiler.

10. Slurry Retention Time - About 1.5 minutes residence time in the bottom of the scrubber vessel; there is no hold tank.

11. Mist Eliminator - Two single-stage, horizontal fiberglass chevron mist eliminators; one mist eliminator is located inside the scrubber vessel and the other is located in a separate vessel after the induced draft fan; the internal mist eliminator is washed sequentially from the bottom in an automatic spray mode and manually from the top using fresh makeup water; the external mist eliminator is washed manually from the top using fresh makeup water; the manual oversprays are performed 1 hour per week. Tests are planned to determine flow patterns, velocities and pressure in an effort to devise improved design. No change in material is contemplated.

12. Reheat System - The original reheat system consisted of oil-fired burners external to the ductwork, but is not in use due to corrosion of burner parts as well as poor thermal mixing causing hot spots in the downstream ductwork; firing was internal using outside air for combustion; the system was to provide 25 F of reheat.

13. Waste Disposal - The system operates open loop; the thickener overflow is partly diverted to the ash pond which subsequently overflows to the Monongahela River. IUCS has a contract to apply its Poz-O-Tec system for waste disposal; thickener underflow containing 35 to 40 percent solids is sent to the IUCS facility where a vacuum filter increases the solids content to 50 to 60 percent; dry fly ash and lime are added to stabilize the sludge which is trucked to a nearby site for landfill.

14. Fans - Wet induced draft fans located between scrubber vessels and second mist eliminator vessels; rubber-lined casing, Alloy 20 blades, and Inconel welds; fans are sprayed with fresh water and sumps are drained to thickeners.

C. RELIABILITY

1. Start-up - Unit 2 was connected to the scrubber system on October 26, 1975, and Unit 1 was connected on February 4, 1976; Unit 4 was connected in March, 1978, and Unit 3 in May, 1978.

2. Availability - Initial availability was high, partly because four scrubber trains were in use for only two boilers. Current availability (hours the FGD system is available for operation divided by hours in period) is greater than 90 percent.

3. Longest Run - About two months per module; cleaning time is 3 weeks per module.

4. Calendar of Operation - From January through September, 1976, the total scrubber operating times were as follows:

Scrubbing Train Operation, days[a]

	101			201			301			401			501[b]		
	On	Recycle	Off	On	Recycle	Off	On	Recycle	Off	On	Recycle	Off	On	Recycle	Off
January	30	0	1	31	0	0	0	0	31	1	0	31	0	0	31
February	0	10	19	13	16	0	26	0	5	21	0	8	0	0	29
March	31	0	0	5	0	26	14	12	5	13	18	0	0	0	31
April	1	0	29	10	0	20	30	0	0	20	10	0	0	0	30
May	0	0	31	31	0	0	31	0	0	0	31	0	0	0	31
June	30	0	0	30	0	0	0	0	30	0	30	0	0	0	30
July	26	0	5	7	24	0	4	0	27	25	6	0	0	0	31
August	30	0	1	0	1	30	29	0	2	1	30	0	2	0	29
September[c]	17	11	1	12	0	17	22	7	0	0	19	10	7	0	22

(a) Recycle means slurry is circulating without gas flow.

(b) Train No. 501 was out of service from January 10 to June 21 to install rubber-lined recycle pumps.

(c) Through September 29.

In late 1976, the fifth scrubber was operational and from then on all five scrubbers have usually served two boilers except when some scrubbers were down for pump or fan repairs.

In late 1977, and early 1978, the scrubber operating times were:

Scrubber	101	201	301	401	501
November,hrs	0	84	672	162	426
December,hrs	--	--	--	--	--
January,hrs	700	673	38	121	26
February,hrs	204	277	0	107	121
March, hrs	0	0	0	0	0

Beginning on February 11, 1978, and through March, the entire plant was down owing to a coal chortage.

Operational times since March, 1978, are not available, but availability has continued to be high, with the fifth scrubber generally available

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - Prescrubbers are not used.

2. Absorber - Five single-stage absorber-scrubber units are now connected. They are identical in design to the ones at Duquesne's Phillips plant.

The absorbers are constructed mainly from mild steel. Originally, they were lined with Flakeline 103 (flakeglass-filled polyester). This lining gave good service until a change was made from high calcium lime to high magnesium lime, at which time problems began to develop with the Flakeline 103 lining. As at Phillips, it is postulated that the high calcium lime produced a deposit scale over the surfaces of the absorber, which protected the lining. With high magnesium lime, the scale disappeared, and there was erosion of the lining. The top of the cone which is impinged by the slurry from the simple, open bull nozzle was perforated.

The eroded lining was replaced with Coroline 505AR. This is a glass cloth, reinforced lining of the amine-cured epoxy type. It was selected because an area of the inverted cone directly under the bull nozzle had been lined in 1974 with Coroline 505AR, and it is still in excellent condition. This lining replaced the original Type 316L stainless steel.

The upper surface of the incline which forms the top of the mist eliminator area, is a high-abrasion area. The slurry from the bull nozzle and the tangential nozzles flows over this surface. It is covered with acid-resistant bricks, applied over the Flakeline 103. There has been no problem with this brick lining.

The bottom cone is also protected by Coroline 505AR, but some loss of metal occurs right at the cone outlet.

3. Spray Nozzles - Spray nozzles are Type 316 stainless steel. They have not been a problem.

4. Mist Eliminators - The mist eliminators are chevron-type, constructed of fiberglass-reinforced plastic. They withstand the chemical environment, but can be damaged by impact during manual cleaning of scale. Because the gas flow is above design capacity, there is carryover which causes build-up of scale in the demisters. Consequently, they are washed on a continuous cycle with fresh water. This has minimized scale build-up, hence manual cleaning is infrequent.

5. Fans - The fans operate wet. The rotors are made of Carpenter 20 steel. There are wear plates at the tips of the rotors which must be replaced after approximately 23,000 to 25,000 hours of operation.

The housing is constructed of mild steel with rubber lining. At Phillips, trouble with the rubber lining started after about 20,000 hours of operation. The lining at both plants has generally required replacement in about that time period. They anticipate replacement of the curved portion of the steel housing with Inconel at some time in the future.

6. Reheaters - The flue gas is not reheated. Originally, there were oil-fired reheaters outside the exhaust duct, but on test, they produced hot spots, and were unused. In summer, the exhaust is 130 F. In winter, it is 90 F, producing a very white vapor plume.

7. Pumps - The slurry recycle pumps made by Ingersoll-Rand, operate under a head of 125 ft (54 psig). Originally, the impellers and the housing were Carpenter 20 steel (no lining). There was rapid wear from slurry erosion. Hard facing on the impellers lasted 200 hours. Numerous changes have been tried, including installation of wear rings in the sides of the casings. Many materials were tried as wear rings and impellers (1975-1977), including the following: Carpenter steel, Type 317L stainless steel, titanium, 20 percent chrome-iron, and CD-4MCu. The impellers would last about 2500 to 3500 hours and could not be rebuilt.

A Warren rubber-lined pump has been used at Elrama and looks good with minimal wear after nearly 8000 hours. The impeller is Ni-hard. If it is still good after further use, a change may be made to try all rubber-lined pumps. They are aiming for a pump life of one year.

The pumps used for slurry underflow are rubber-lined, made by Allen-Sherman-Hoff (A-S-H). They have given good service.

8. Tanks - The thickener overflow tank is an open, mild steel vessel lined with Flakeline 103. The lining has given no problems. The lime slurry tank is concrete, lined with a special Ceilcote lining designed for use on concrete.

9. Agitators - The agitator in the lime slurry tank is rubber-lined. There is no agitator in the overflow tank.

10. Storage Silo - The lime storage silo is unlined carbon steel.

11. Thickener - The thickener tank has a concrete floor and steel sidewalls. The steel walls are lined with Ceilcote Flakeline 103. The floor has a Ceilcote lining designed for use on concrete. (John Malone surmised it is Ceilcote Hot Mastic 195.)

The rake is rubber-lined, carbon steel. (The lining on the rake has been patched in a few places, but the rubber linings are otherwise satisfactory.)

Sludge disposal is contracted with IUCS, and details are not available on their equipment.

12. Vacuum Filter - By IUCS.

13. Ducts, Expansion Joints and Dampers - The inlet ducts are carbon steel. Outlet ducts are carbon steel, lined with Flakeline 103.

The expansion joints in the main wet gas outlet (to stack) are asbestos-reinforced butyl rubber, which has provided good service.

The dampers at the fan inlet are louver type with a Coroline 505 lining on all carbon steel surfaces. Adhesion of the coating to stainless steel has been found difficult. Local cement finishers are employed for the application.

There are isolation dampers at the inlet and outlet to each scrubber. The louver type inlet dampers are Type 316 stainless steel, and corrosion has been minimal. These dampers operate either wide open or completely closed.

Inlet isolation is obtained from a 16-foot butterfly damper. The entire damper and sealing angle were constructed of mild steel. The areas of the vanes were overlaid with segments of Type 316 stainless steel, and a new, Type 316 stainless steel sealing angle and shaft seal were installed.

14. Piping and Valves - In the original installation, all piping within the scrubber system was rubber-lined steel. In some places the piping was changed to FRP. Also, some stainless steel is used where the piping enters the thickeners. The FRP has given good service.

The lime slurry piping is carbon steel. The bull nozzle section of piping within the scrubber is Type 316L stainless steel.

Valves in the bleed lines from the scrubber to the thickener are rubber pinch valves. The liners need to be changed periodically. For pump isolation, DeZurik plug valves are used and again there is a wear problem. The seals and plugs wear and need to be replaced periodically.

15. Stack - The 400-ft stack is lined with acid-resistant brick (ASTM C279 Type AL, with acid-resistant Saureisen No. 65 mortar). A lead sheathing extends upwards from the base for about 12 inches because of the accumulation of condensation at the base.

Some of the stainless-steel liner support bands have corroded and required replacement.

16. Slaker - The slaker is carbon steel and it has given no problems.

E. COMMENTS

Scrubber construction at both the Elrama and Phillips stations started in December, 1971. The Phillips scrubbers were ready to operate in June, 1973, but construction at Elrama was stopped for one year during 1974 because of problems encountered at Phillips with the wet induced draft fans and rapid erosion of scrubber recycle pumps. The fan problems consisted of some stress corrosion cracking of the weld metal and some pitting attack on all fan blades, as well as mechanical stresses. The scrubber recycle pumps were replaced by various types of impeller and casing materials. The five Elrama scrubbers were not placed in service until many of the problems at Phillips were resolved and the necessary modifications were made at both stations. Boiler No. 2 was connected to the scrubbers on

October 26, 1975, and Boiler No. 1 was connected on February 4, 1976. Boiler No. 4 was connected to the FGD system in March, 1978, and No. 3 in May, 1978. However, the predominant operating mode is for two boilers to feed into five scrubbers.

In general, the Elrama system has operated with much less difficulty partly because of lessons incorporated from the Phillips experience, but also because Elrama operates with much lower excess air, causing much less oxidation.

DUDICK CORROSION-PROOF INC.
MACEDONIA, OHIO

Trip Report Number: EPRI-CM18

Date of Trip: March 5, 1979

Persons Interviewed: Thomas M. Dudick, President

A. BACKGROUND

Dudick's line of corrosion resistant coatings and linings includes materials designed for use in flue gas scrubber systems. Dudick also supplies the trained crew for applying the linings, and a specialist to oversee application and maintain quality control. Quality control includes blasting (white metal and surface profile), lining thickness, and lack of porosity (spark testing). Usual guarantee for linings is 18 months from application, or 12 months from scrubber start up (materials and labor to repair or replace).

B. DESCRIPTION OF APPLICABLE LININGS

Dudick's linings for scrubber use fall into a few major classifications. Several different resin binders are used. The linings produced by Dudick are described below.

1. Flakeglass-Filled Materials Applied in Two Coats by Troweling to Produce a Nominal Thickness of 80 Mils -

   a. With a polyester resin binder (Atlac resin by Atlas Chemical) - Protecto-Flake 500. The "work horse" of scrubber systems; 250 F top temperature.

   b. With a chlorinated polyester resin binder (Hetron resin by Ashland Chemical) - Protecto-Flake 550. Mr. Dudick feels that this is the best lining for stacks. This is based on good experience in stacks for industrial scrubbers. Dudick has not done a large stack for a power plant. The lining in one industrial stack is still good after 5 years.

   c. With a vinyl ester resin binder (such as Derakane 411 or 470 by Dow Chemical) - Protecto-Flake 400. Mr. Dudick believes this lining gives about equal performance to Protecto-Flake 550. His company has replaced vinyl ester linings (competitors) in two stacks (not utilities) with chlorinated polyesters. Thus, the polyesters can be formulated to better match the expansion coeffecient of steel. He draws the line at 300 F for vinyl esters.

   d. With an epoxy resin binder - Protecto-Flake E. This lining is not recommended by Dudick for SO_2 scrubber systems because it has a much lower heat distortion temperature than the vinyl ester or polyester linings.

2. Mica-Filled, Roller-, Spray-, or Brush-Applied Linings with Nominal Thickness of 20 Mils per Coat -

   a. With a polyester resin binder - Protecto-Flake 600.

   b. With a chlorinated polyester resin binder - Protecto-Flake 650. These are lower priced than the trowel-applied, flake-glass filled linings. Mr. Dudick does not recommend these for scrubbers. However, his company has recommended a chlorinated polyester system (Protecto-Flake 750) wherein the base coat is flakeglass filled, and is applied by trowel. The topcoat is mica filled and generally applied by spray. It provides an ASTM E 84 tunnel test rating of 30. Temperature limit is 300 F. A similar vinyl ester-type system is also supplied, Protecto-Flake 850.

3. Glass Cloth (Woven Roving) Reinforced, Silica-Filled Linings Applied by Trowel in Two Coats to Nominal Thickness of 1/8 Inch -

   a. With a polyester resin binder - Protecto-Coat 600.

   b. With a chlorinated polyester resin binder - Protecto-Coat 650. Aluminum oxide filler can be added to the topcoat for increased resistance to abrasion, in which case "AR" is added to the lining designation.

   c. With an epoxy resin binder - Protecto-Line 100/200. Recommended for use in thickeners and clarifiers, over both concrete and steel (with proper primer in each case).

C. COMMENTS

Tom Dudick discussed experiences with his company's linings, as well as some similar linings installed by competitors. He feels that a lot of the "black eye" given to linings has come about because of the use of mica flake. The use of mica lowers costs, but it also provides much less barrier properties than glass flake. Glass flake costs $1.08/pound while mica costs 9 cents per pound. Moreover, the mica-filled linings are applied by roller, brush, or spray, which further lowers the cost. He gave the following "ball park" comparisons in the installed costs:

a. Troweled glass flake-filled (80 mils) system about $\$6/ft^2$.

b. One troweled coat of glass flake and one spray coat of mica-filled material (60 mils) about $\$5/ft^2$.

c. Two spray coats of mica-filled material (40 mils) about $\$4.25/ft^2$.

The comparative performance is reported to be:

a. Five years maintenance free

b. Two years maintenance free

c. One year maintenance free.

Mr. Dudick mentioned that a competitor's lining used in the stack at the Conesville plant of Columbus and Southern Ohio Electric Company had a mica-filled topcoat. The stacks at Bruce Mansfield (Pennsylvania Power Company) were lined with two coats of mica-filled material (Heil lining). He rates this as a lining designed for mild immersion conditions. In both cases he indicated that these were poor choices in linings for stacks. On the other hand, he does not rule out the use of mica-filled topcoat over glass flake-filled base coat for some parts of scrubber systems. However, severity of exposure conditions must be thoroughly understood, and the customer should recognize that he can expect more maintenance in the long run than for a trowel-applied, flakeglass-filled lining.

Some of Dudick's linings installations are as follows:

Minnkota Power Cooperative, Center, North Dakota - About one year.

U.S. Bureau of Mines, Bruceton, Pennsylvania - Seven or eight years.

Louisville Gas and Electric, Louisville, Kentucky - CEA double alkali system; not on stream.

Louisville Gas and Electric, Louisville, Kentucky - Cane Run Unit 5; 13 or 14 months.

South Mississippi Electric Power Association, Hattiesburg, Mississippi - Dudick lined absorber and another company lined ducts.

Public Service of New Mexico, Farmington, New Mexico - Wellman-Lord system; all ducts were lined two years ago, but scrubber has been operating only a year.

Dudick's poor experiences included a failure in Protecto-Flake 500 lining in an industrial installation where temperature reached 750 F before sensors turned on a cold water spray. There was also an abrasion problem in a venturi section of a Chemico experimental unit at Dickerson, Maryland (PEPCO). The lining performed satisfactorily for a year before the throat area was decreased in size by one half. This caused a lining problem because of abrasion. There was also a fire in the unit; the plastic trays burned.

For abrasion resistance, aluminum oxide can be added to Dudick lining materials, as mentioned earlier. However, Dudick does this only when customers insist. Dudick recommends the use of wear plates or brick linings in high abrasion areas.

THE CEILCOTE COMPANY
BEREA, OHIO

Trip Report Number: EPRI-CM19

Date of Trip: March 5, 1979

Persons Interviewed: W. R. Slama, Technical Director, Corrosion Control Division

A. BACKGROUND

Ceilcote produces (along with other product lines) special linings for use in SO_2 scrubber components. They also apply these lining materials with their specially trained labor crews. On those large jobs where labor unions require the use of local applicators, Ceilcote trys to supply at least half of the labor force (from their own trained applicators). A skilled Ceilcote supervisor directs the operations and monitors the quality control. Quality control includes examination of steel surface condition (white blast), profile, coating thickness, and porosity (spark testing). Moreover, lining application is not allowed under humidity/temperature conditions that can cause condensation on the metal surface. Where the customer requires the use of Ceilcote material and chooses to use a local contractor, Ceilcote will not guarantee the installation. However, even if an outside contractor is used, Ceilcote prefers that their specialist be present to direct the application and monitor the quality control procedures. The usual guarantee for linings covers one year from start-up of scrubber, or 18 months from the date lining was applied. It provides for repair or replacement of the lining (materials and labor). Each of the linings described below is applied over a special, thin-film primer, which is designed for use on steel or concrete.

B. DESCRIPTION OF APPLICABLE LININGS

Linings used in scrubbers fall into a few major classifications, each with several different resin binders. The linings produced by Ceilcote are listed below.

1. Flakeglass-Filled Materials Applied in Two Coats by Troweling to Produce a Nominal Thickness of 80 Mils -

   a. With a polyester resin binder-Flakeline 103. This is the "work horse" in absorbers, wet ducts, and on thickener tank side walls. Temperature limitations are 180 F wet and 250 F dry.

   b. With a chlorinated polyester resin binder - Flakeline 164. Ceilcote recommends use of Flakeline 103 instead. Chlorinated polyester systems were originally developed for strong oxidizing environments, and with the incorporation of antimony oxide they provide fire retardancy. However, the antimony oxide can reduce the performance of flake-filled polyester linings in chemical environments.

c. With a vinyl ester resin binder - Flakeline 180. Ceilcote technical people believe that there are no good reasons to use this in preference to Flakeline 103. The vinyl ester linings do provide solvent resistance where needed, but this is not pertinent to scrubber use. In dry conditions they may stand slightly higher temperatures than the 103. Ceilcote has found some vinyl resins difficult to work with in the field because of short shelf life and poor intercoated adhesion related to ultraviolet sensitivity. These problems are not inherent in the Flakeline 103 type system.

d. With an epoxy resin binder - Ceilcote has an experimental one - Flakeline E. However, Ceilcote sees no advantage in the use of epoxy resin in the flakeglass lining.

2. Mica-Filled, Roller-, Spray-, or Brush-Applied Linings with Nominal Thickness of 20 Mils per Coat -

   a. With a polyester resin binder - Flakeline 252.

   b. With a chlorinated polyester resin binder - Flakeline 262.

   c. With a vinyl ester resin binder - Flakeline 242 or 232.

These are lower priced linings than glass flake-filled ones because of the thickness and application method; they are spray-applied in thin coats. Mr. Slama feels that these are marginal linings and should not be used in scrubber systems. Temperature limitation is 130 F (wet). Where these kinds of linings have been used in SO_2 scrubbers, maintenance has been too high.

3. Glass Cloth (Woven Roving) Reinforced, Silica-Filled* Linings Applied by Trowel in Two Coats to Nominal Thickness of 1/8 Inch -

   a. With a polyester resin binder - Ceilcrete 2500S. Recommended for use in concrete slurry tanks over a special primer.

   b. With an epoxy resin binder - Coroline 505. This lining is recommended for use anywhere in the scrubber where there is need for some abrasion resistance. A special grade* is recommended for severely abrasive conditions.

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* The topcoats of these systems can be filled with hard mineral fillers for high abrasion resistance. The lining than takes the designation AR as a suffix.

C. COMMENTS

Ceilcote linings have been used in a substantial number of flue gas desulfurization systems. A listing of these installations is shown in Table 1.

Mr. Slama offered the following comments about linings for SO_2 scrubber systems.

At Duquesne's Elrama Station a switch has been made to Coroline 505AR so that water blasting can be used to remove the sludge cake. Flakeline 103 will not stand the abrasion from water blasting.

Ceilcote does not recommend 40 mil thick spray-type linings for scrubbers or wet ducts. It doesn't matter whether the liner is polyester, vinyl ester, epoxy, or anything else. This type lining does not have adequate thickness and permeation resistance to take these conditions reliably and for long periods of time. Moreover, Ceilcote does not think 40 mil spray-type linings will take the conditions in stacks. The concentration of acid in dry stacks is very high. The higher the dew point becomes, the higher the percentages of acid in the condensate. For example, at 250 F the concentration of sulfuric acid in the condensate is about 80 percent. This increases as the temperature increases until the acid becomes essentially concentrated. However, in scrubbers, the pH typically does not go below 2.

When problems were encountered in unscrubbed flue gas in stacks, samples of the lining were brought back to Ceilcote for analysis. An outside laboratory used an electron probe to measure sulfur at various levels in the lining to give an indication of the depth of penetration of sulfuric acid. Ceilcote also continues to test new lining materials in their own laboratory for potential in scrubber systems.

Ceilcote has also examined the fluoroelastomer linings. The fluoroelastomer will withstand strong acid. However, Ceilcote tests show lack of barrier properties for the fluoroelastomer. They conclude that the fluoropolymers might be satisfactory in dry stacks if conditions remain above the sulfuric acid dew point.

Mr. Slama mentioned $\$58/ft^2$ as the cost of fluoropolymer linings. Ceilcote's approach (still under development) is to use a barrier coat underneath the fluoropolymer topcoat. They have not yet determined if it will find a market.

TABLE 1. FLUE GAS DESULFURIZATION INSTALLATION LIST FOR CEILCOTE LININGS

Site	Vendor and Area	Component	Year and Lining
Youngstown Sheet & Tube East Chicago, Indiana	Chemico 84,000 sq.ft.	Scrubbers/Duct	1968 Flakeline 103
Kennecott Copper Magna, Utah	Peabody 14,000 sq.ft.	Scrubbers	1967 Flakeline 103
Penna. Power & Light Holtwood Station, Pa.	Chemico 14,000 sq.ft.	Scrubber	1970 Flakeline 103
Baltimore Gas & Electric Chase, Maryland	Wellman-Lord 2,000 sq.ft.	Scrubber	1970 Flakeline 103
Minnesota Power & Light Cohassett, Minn.	Combustion Eng. 15,000 sq.ft.	Ductwork	1972 Flakeline 103
Kansas City Power & Light Lawrence Station, Kan.	Combustion Eng. 40,000 sq.ft.	Scrubbers	1972 Flakeline 200
Kansas City Power & Light Hawthorn Station, Kan.	Combustion Eng. 40,000 sq.ft.	Scrubbers	1972 Flakeline 200
Duquesne Power & Light Phillips Station, Pa.	Chemico 160,000 sq.ft.	Scrubbers/Tanks/Duct	1973 Flakeline 103
Duquesne Power & Light Elrama Station, Pa.	Chemico 180,000 sq.ft.	Scrubbers/Tanks/Duct	1973 Flakeline 103
Arizona Public Service Four Corners, N. M.	Chemico 150,000 sq.ft.	Scrubbers/Tanks/Duct	1972 Flakeline 103
Potomac Electric Power Chalk Point Sta., Md.	Combustion Eng. 40,000 sq.ft.	Ductwork	1974 Flakeline 103
Potomac Electric Power Chalk Point Sta., Md.	Peabody Eng. 4,000 sq.ft.	Scrubbers	1974 Flakeline 103
Northern States Power Sherburne Sta. No. 1, Minn.	Combustion Eng. 70,000 sq.ft.	12 Scrubbers	1975 FLakeline 151

TABLE 1 (Continued)

Site	Vendor and Area	Component	Year and Lining
Bethlehem Steel	Chemico		1974
Sparrows Point, Md.	30,000 sq.ft.	Scrubbers	Flakeline 103
Texas Utilities	Research Cottrell		1977
Martin Lake No. 1	75,000 sq.ft.	5 Scrubbers	Flakeline 103
Tatum, Texas	46,000 sq.ft.	Tanks	Coroline 505AR
Texas Utilities	Research Cottrell		1977
Martin Lake No. 2	75,000 sq.ft.	5 Scrubbers	Flakeline 103
Tatum, Texas	46,000 sq.ft.	Tanks	Coroline 505AR
Texas Utilities	Research Cottrell		1978
Martin Lake No. 3	72,000 sq.ft.	6 Scrubbers	FLakeline 103
Tatum, Texas	46,000 sq.ft.	Tanks	Coroline 505AR
Texas Utilities	Chemico		1977
Monticello No. 3	73,000 sq.ft.	3 Scrubbers	Flakeline 103
Mount Pleasant, Texas			Coroline 505AR
Utah Power & Light	Chemico		1977
Huntington Sta. No. 1	45,000 sq.ft.	4 Scrubbers	Flakeline 103
Huntington, Utah	7,000 sq.ft.	Tanks	Coroline 505AR
Duquesne Power & Light	Chemico		1977
Elrama Station, Pa.	35,000 sq.ft.	Clarifier Tanks	Flakeline 151
		Clarifier Tanks	Coroline 505AR
Arizona Public Service	Research Cottrell		1977
Cholla Unit No. 2	72,000 sq.ft.	4 Scrubbers	Flakeline 103
Joseph City, Arizona	62,000 sq.ft.	Duct	FLakeline 103
	24,000 sq.ft.	Tanks	Coroline 505AR

RIGILINE CORPORATION
BRUNSWICK. OHIO

Trip Report Number: EPRI-CM20

Date of Trip: March 6, 1979

Persons Interviewed: Charles F. Overbeck, Vice President Sales

A. BACKGROUND

Rigiline Corporation manufactures and installs protective coatings, thermosetting lining systems, and monolithic floor toppings. Included in the product line are materials for protecting components of flue gas scrubbing systems. In this application, Rigiline prefers to apply materials with their own applicators under the direction of their technical supervisor. The Rigiline supervisor's responsibility is to make sure that the job is done right according to Rigiline specifications. This includes following specified quality control procedures which monitor blasting to white metal, profile, lining thickness, and spark testing to assure lack of porosity. The usual guarantee is for 18 months from application or 12 months from start-up (when linings are used under normal operating conditions).

B. DESCRIPTION OF APPLICABLE LININGS

Rigiline's linings for scrubber use fall into the major categories indicated below. Several different resin binders are used. The linings produced by Rigiline are as follows.

1. Flakeglass-Filled Materials Applied in Two Coats by Troweling to Produce a Nominal Thickness of About 80 Mils -

   a. With a polyester resin binder (Atlac Resin) - Rigiflake 4850. The "work horse" of scrubber systems. Up to 250 F dry or 180 F wet.

   b. With a chlorinated polyester resin binder - Rigiflake 4835 (Hetron 72) or Rigiflake 4837 (Hetron 197).

   c. With a vinyl ester resin binder (Derakane 4030) - Rigiflake 4860. This lining has not been used extensively in scrubbers. Recommended where resistance to sodium hypochlorite is necessary (paper mills, etc).

2. Mica-Filled, Roller-, Spray-, or Brush-Applied Linings with Nominal Thickness of 20 Mils per Coat -

   a. With a polyester resin binder - Rigiline 485.

   b. With a chlorinated polyester resin binder - Rigiline 487.

c. With vinyl ester resin binder - Rigiline 486. Rigiline does not recommend the mica-filled linings for flue gas scrubber systems even though they have been used at times in the past.

3. Glass Fiber (Cloth or Mat) Reinforced, Silica-Filled Linings Applied by Trowel in Two Coats to Nominal Thickness of 1/8 Inch -

   a. With a polyester resin binder - Rigiline 484-4850G. Used in slurry tanks, absorbers, and outlet ducts.

   b. With a chlorinated polyester resin binder - Rigiline 484-4835G, or 484-4837G.

   c. With a vinyl ester resin binder - Rigiline 484-4860G. For high abrasion resistance aluminum oxide filler is used in the topping. In this case, the letter A follows the product number.

   d. With an epoxy resin binder - Rigiline 413G. For use in absorbers, tanks, etc.

C. COMMENTS

Mr. Overbeck indicated that where outlet ducts feed into a common header and bypass gases can enter this common header, he does not recommend using any of the available linings. No linings have been proven for this kind of service. At best, linings are marginal because temperatures can go too high. His solution to the problem is to control the gas flow so that it will be either hot and dry or cool (below 180 F) and wet. At 400 F, the condensate will be concentrated sulfuric acid. He feels that the vinyl esters are also a gamble for this use.

The following cost comparisons were given: Type 316L stainless steel is \$36.40/ft^2, and carbon steel with a lining is \$18.20 + \$6.00 = \$24.20/ft^2. A fluoroelastomer lining costs even more than stainless steel.

Rigiline does not have a fluoroelastomer lining material. The consensus is that they offer only a 50 percent success factor, and costs are too high.

Mr. Overbeck stressed the problem which exists in making the engineering firms and power companies (customers) understand the importance of using quality linings. For example, about $200,000 was saved in costs of lining the stack at Bruce Mansfield by using the thin-film, mica-filled lining (against Rigiline's recommendation). This resulted in an early failure. By comparison, shut down of Units 1 and 2 results in a daily loss of $500,000. The lining in one flue was replaced (about 1-1/2 years ago) with Rigiflake 4850. Mr. Overbeck has received no report of failure of this lining. He did mention that there is evidence of high chloride in the flue gas. The gas temperature is 128 F.

Rigiflake 4850 was reported to have been used in scrubbers, absorbers, and ducts at Bruce Mansfield. Some Rigiline 413G was used in the bottoms of the units.

Rigiflake 4850 was used in the scrubbers and ducts of Montana Power's Colstrip Unit. This unit operated at 275 F for about 2-3/4 hours before discovery. It was then shocked with cooling water. The lining was damaged and required replacement.

At Southwest Public Service, Amarillo, Texas, Rigiline material was used in the scrubber only. Rigiline 484-4850G was used in bottom because of abrasion. There have been no problems.

CORROSIONEERING, INC.
GRAFTON, OHIO

Trip Report Number: EPRI-CM21

Date of Trip: March 6, 1979

Persons Interviewed: Dennis Newton, Linings Specialist

A. BACKGROUND

Corrosioneering, Inc., manufactures corrosion resistant linings and coatings for a number of uses, including components of flue gas scrubbers. They also provide installation services. The labor force and supervision is specially trained to apply the materials according to rigid specifications developed by Corrosioneering. Blasting of the surface to white metal and surface profile obtained must meet specifications as determined by Corrosioneering's job supervisor. He is also responsible for seeing that the specifications for lining thickness, and absence of porosity (spark testing) are met. The usual guarantee offered is for 18 months from installation or one year from start-up.

B. DESCRIPTION OF APPLICABLE LININGS

The linings produced by Corrosioneering for use in scrubber components are described below.

1. Flakeglass-Filled Materials Applied in Two Coats by Troweling to Produce a Nominal Thickness of 80 Mils -

   a. With a polyester resin binder - Resista-Flake 1103. The "work horse" lining for scrubber components.

   b. With a chlorinated polyester resin binder - Resista-Flake 1105.

   c. With a vinyl ester resin binder - Resista-Flake 1101. Requires a more exacting control of application and cure than 1103 to avoid intercoat adhesion problems.

   d. With an epoxy resin binder - Resista-Flake 1109. Has not been used in scrubber systems.

Corrosioneering also produces a series of linings where both coats are flakeglass-filled but the top coat is designed for application by spray, brush, or roller (1150 series). Normal thickness is 60 mils. The designations are as follows:

Polyester binder - Resista-Flake 1151
Chlorinated polyester binder - Resista-Flake 1161
Vinyl ester binder - Resista-Flake 1171.

2. Mica-Filled, Roller-, Spray-, or Brush-Applied Linings with Nominal Thickness of 20 Mils per Coat -

   a. With a polyester resin binder - Resista-Flake 1251.

   b. With a chlorinated polyester resin binder - Resista-Flake 1261.

   c. With a vinyl ester resin binder - Resista-Flake 1271.

   d. With an epoxy resin binder - Resista-Flake 1291. This lining has not been used in scrubber systems.

3. Glass Fiber (Cloth or Mat) Reinforced, Silica-Filled Linings Applied by Trowel in Two Coats to Nominal Thickness of 1/8 Inch -

   a. With a polyester resin binder - Resista-Crete 3250.

   b. With a chlorinated polyester resin binder - Resista-Crete 3640. For fire retardance.

   c. With a vinyl ester resin binder - Resista-Crete 3650. Not often used.

   d. With an epoxy resin binder - Resista-Line 2505M. Corrosioneering generally does not use this lining in scrubbers.

For maximum resistance to abrasion, the above systems are filled with aluminum oxide. The letters AR added as a suffix to the above numbers are indicative of the abrasion-resistant grade.

C. COMMENTS

Corrosioneering's scrubber linings experience began in scrubbers for steel plants. They line the three basic parts of the system-scrubber, outlet ducts, and tanks. The most commonly used lining has been the flakeglass-filled polyester. They have also installed vinyl ester types in a number of scrubber systems.

The company avoids lining jobs where bypass conditions might occur. They will supply linings if there is assurance that conditions will be either continuously wet or continuously dry. Not enough is known regarding effects of cycling conditions between wet and dry.

Spray towers are less abrasive than other kinds of scrubbers and cause no special problems in lining. However, spray nozzles which operate above 2500 psi cause concern. Corrosioneering has worked with Peabody to use bands of natural rubber lining in high abrasion areas.

Corrosioneering's procedure is to obtain as much information as possible from the customer. They then suggest the linings and alternate materials to be used in the various areas.

The 1100 series of linings is recommended for the majority of scrubber systems. The lining may be provided with special treatments where necessary; e.g., for resistance to high chlorides, a seal (gel) coat might be applied over the topcoat for additional barrier effect.

In recycle tanks where erosion is high, the 1100 series might be used. However, the Resista-Crete series is generally recommended. If abrasion is unusually high because of larger particles in the slurry, an aluminum oxide-filled topcoat will be recommended. The type of agitation in the tank may also be a factor in lining selection.

The Resista-Crete linings are used either on steel or concrete (with appropriate primer). Resista-Flake is used only on steel.

Lining choices in scrubbers are based on a number of factors - type of scrubbing media (lime or limestone), placement of baffles, placement of nozzles, etc. It is not unusual to see Resista-Flake on sidewalls, and Resista-Crete on the bottom.

The 1150 series is used only in ducts. The sprayed topcoat cuts linings cost in this area.

Lining costs ("ball-park") were given at $\$7/ft^2$ for two coats of troweled, flakeglass filled materials but exact price depends on location of the job. Resista-Crete may be as low as \$5.00 and as high as $\$9.00/ft^2$. The lower price is where lining is very easy to install; e.g., in open areas of tanks. Generally the costs divide as follows - 2/3 for installation and 1/3 for materials. Rubber linings are twice as expensive as other organic linings.

Some of the Corrosioneering linings installations are listed below.

Square Butte Electric, Square Butte, Montana (CEA pilot plant). Spray tower and tanks. The experience has been good except in some high-abrasion areas.

Potomac Electric, Chalk Point, Maryland (Peabody). The lower section of this "umbrella" or inverted cap type of scrubber is rubber lined and the upper part has a flakeglass lining.

Columbus and Southern Ohio Electric, Conesville, Ohio (B&W). Units 5 and 6 have rubber to outlet of absorber but Resista-Flake 1103 in recycle tanks, and 1151 in outlet ducts. The experience has been good.

South Carolina Public Service, Georgetown, South Carolina (B&W). Good experience with Corrosioneering lining in ducts of Unit 2, except in a small area.

Southern Illinois Power Coop., Marion, Illinois (B&W). Resista-Flake 1103 installed about a year ago in absorber, ducts, recycle tank, and sump pit.

Alabama Electric Power Coop., Jackson, Alabama (Peabody). An 80 mil, Resista-Flake 1101 lining is good after a year even though there was a temperature excursion.

A small power plant for a paper company (Pentec Paper in Johnsonburg, Pa.) had Corrosioneering lining installed about a year ago.

Jobs under construction include Brazos Electric Coop., Jourdanton, Texas (B&W); Colorado-Ute, Steamboat Springs, Colorado (Peabody); Central Illinois Power, Newton, Illinois (Envirotech; scrubber 80 mils and duct 45 to 60 mil linings); Indianapolis Power & Light, Petersburg, Indiana (UOP; duct and tank linings).

UOP INC.
AIR CORRECTION DIVISION
DARIEN, CONNECTICUT

Trip Report Number: EPRI-CM22

Date of Trip: March 16, 1979

Persons Interviewed: Paul S. Nolan, Manager of Product Development, and Paul Wood, Senior Mechanical Engineer, Air Correction Division; Steven A. Bradley, Group Leader, Materials Science Research, Corporate Research Center, UOP.

A. BACKGROUND

Table 1 summarizes UOP's experience with lime/limestone scrubber systems on utility boilers. The installation at Valmont is a two-module particulate scrubber where one module was operated for a short period to remove SO_2 in addition to fly ash. The installation at Mohave was a one-module demonstration unit that operated for 9 months on a 790 MW boiler. The Conesville, Southwest, and Petersburg installations are currently in operation, while the Powerton FGD system is under construction.

Most of the materials problems at the three operating installations have been related to chlorides in the recirculating slurry. The chloride contents of the coals at Springfield, Conesville, and Petersburg are 0.16, 0.05, and 0.06 percent, respectively. The corresponding chloride contents of the recirculating slurries are 4650, 1100, and 1560 ppm, respectively. Practically all of the chloride must be coming from the coal because, in each case, the makeup water has only 10 to 20 ppm of chloride (except at Petersburg where the chloride content of the makeup water is not known). At Springfield, the chlorides level exceeded 4650 ppm when the coal supply was salted during the winter.

From a materials standpoint, dampers are the biggest problem in all UOP scrubbers. Failure has occurred both by pitting attack and intergranular corrosion. On the other hand, there have been no materials failures in any pumps at UOP scrubber installations. The materials of construction at the three operating installations are discussed below.

B. MATERIALS OF CONSTRUCTION
(Southwest Unit 1)

1. Prescrubber - The presaturator was originally lined with Pre-Krete over carbon steel. Complete deterioration of the Pre-Krete occurred by disintegration, cracking, and falling off. The Pre-Krete was replaced with a lining of Uddeholm 904L which is still in good condition after two years of service.

TABLE 1. UOP LIME/LIMESTONE FGD INSTALLATIONS

Client	Power Station	Size, MW	Sulfur in Coal, wt. percent	Reagent	Startup Date
Public Service Company of Colorado	Valmont 5	45	0.7	Limestone	October, 1974[a]
Southern California Edison	Mohave 1	170	0.4	Limestone	October, 1974[b]
Columbus & Southern Ohio Electric	Conesville 5	410	4.5	Thiosorbic lime	January, 1977[c]
Columbus & Southern Ohio Electric	Conesville 6	410	4.5	Thiosorbic lime	April, 1978
Springfield City Utilities	Southwest 1	194	3.8	Limestone	April. 1977
Indianapolis Power & Light	Petersburg 3	515	3.0-4.5	Limestone	December, 1977
Commonwealth Edison	Powerton 51	425	3.6	Limestone	March, 1979
Southwestern Electric Power	Perkey 1	720	0.8	Limestone	February, 1984

(a) Operated for 5 months as an SO_2 absorber
(b) Operated only during 9 month test program
(c) Module 5B started up in January, 1977, and Module 5A started up in November, 1977.

2. Absorber - The absorber is a three-stage TCA with a carbon steel shell lined with 1/4-inch of Goodyear LS-576 neoprene. The white polyethylene balls in the TCA were replaced with black nitrile foam balls.

3. Spray Nozzles - The slurry spray nozzles are Refrax (silicon carbide) and the mist eliminator wash spray nozzles are Carpenter 20. No problems have occurred with the nozzles.

4. Mist Eliminator - The mist eliminator is a chevron type constructed of fiberglass reinforced plastic. There is no problem with the material except that the original design could not support a man walking on it for cleaning. There is now a more durable design.

5. Fans - The fans are located between the electrostatic precipitator and the absorber and are constructed of carbon steel. There have been no problems. The fans are in the same location for all UOP scrubber systems.

6. Reheater - Bypass reheat is used and the mixing chamber is a junction joint between the bypass and outlet ducts.

7. Pumps - Rubber-lined slurry pumps by Worthington and A-S-H have not experienced any problems or failures. The clear water service pumps are of alloy construction and have also operated satisfactorily.

8. Tanks - The recycle tanks are flake-lined carbon steel and flake-lined concrete. The lining is 40 mils of Heil Rigiflake 4850 over 40 mils of Heil P-2 primer. Minor cracks appeared in the concrete and were repaired with mastic and flake lining. The slurry sump and slurry storage tanks are concrete and flake-lined carbon steel. The slurry drawoff sump is flake-lined concrete and the mist eliminator wash tank is flake-lined carbon steel. There have been no problems with the tanks.

9. Agitators - The slurry transfer agitator was constructed of Type 316 stainless steel because of the long delivery time for rubber-covered carbon steel. The agitator wore from abrasion and was replaced by rubber-covered carbon steel. Generally, neoprene is used to cover all agitators and there have been no problems.

10. Storage Silo - The limestone silo is carbon steel and the lower portion of the cone is lined with 10 gauge Type 304 stainless steel. The stainless steel lining provides a low coefficient of friction rather than corrosion resistance.

11. Thickener - Not supplied by UOP.

12. Vacuum Filter - Not supplied by UOP.

13. Ducts, Expansion Joints, and Dampers - The inlet duct is unlined carbon steel and the outlet and bypass ducts were carbon steel lined with Heil Rigiflake 4850 over P-2 primer. Bad quality control on the surface

preparation and installation of the linings resulted in multiple repairs being required. Springfield City Utilities replaced one lining with a different material.

The expansion joints were originally Cor-Ten steel; one joint experienced dew point corrosion during shut downs and one joint was corroded because of poor lagging. The joints were replaced with Viton® expansion joints which have performed satisfactorily.

The fan inlet dampers are carbon steel with Type 301 stainless steel seals. The scrubber inlet dampers were originally constructed of the same material but the seals failed because of corrosion. The seals were replaced with a combination of Inconel 625 and Incoloy 825 with Hastelloy C fasteners. Some seal corrosion is still occurring. The outlet dampers were originally Type 316L stainless steel, and pitting corrosion occurred on the stack side only. The replacement materials were a Uddeholm 904L frame, Inconel 625 seals, and Hastelloy C fasteners. The replacement is satisfactory after one year of service. The bypass dampers were originally carbon steel with Type 301 stainless steel seals. Corrosion led to replacement of seals, first with Type 316 stainless steel and finally with Inconel 625 which is performing satisfactorily. The frame and blades are still carbon steel.

14. Piping and Valves - The piping is FRP by Fibercast Company. There were problems with broken socket joints that were solved by overwrapping the joints.

The limestone slurry service valves are DeZurik plug valves with all wetted parts having neoprene linings. There has been peeling of the linings. The water service valves are diaphragm type with cast iron bodies and Saran-lined Hypalon diaphragms. The diaphragms of two valves have failed and have been replaced with the same material.

15. Stack - Acid resistant brick not supplied by UOP.

16. Ball Mill - The ball mill has rubber linings which are replaced periodically for normal wear.

(Conesville Units 5 and 6)

1. Prescrubber - The quench section is constructed of Carpenter 20 alloy and has performed satisfactorily.

2. Absorber - The absorber shell is constructed of carbon steel lined with 1/4-inch of Goodyear LS-576 neoprene. Poor application in one module required repair of the lining. The module grids are rubber-covered carbon steel. The grids corroded because of uneven covering so that they had to be replaced.

3. Spray Nozzles - The slurry spray nozzles are Refrax and the wash spray nozzles are Carpenter 20. No problems have occurred.

4. Mist Eliminator - Chevron type constructed of fiberglass reinforced plastic.

5. Fans - Not supplied by UOP.

6. Reheater - None used.

7. Pumps - The slurry service pumps are rubber-lined and the clear water service pumps are alloy construction.

8. Tanks - The recycle tanks are carbon steel lined with Resista-Flake 1100. The reclaimed water and slurry storage tanks are carbon steel coated with a zinc oxide primer. The mist eliminator wash tanks and the slurry transfer tank are FRP. Abrasion in the bottom of the latter tank led to the installation of a stainless steel wear plate.

9. Agitators - All agitators are rubber-covered carbon steel. An Inconel stuffing box with a graphite rope seal was added to the roof seal on the recycle tank agitator to solve the problem of shaft corrosion. The tank is pressurized with flue gas.

10. Storage Silo - The lime silo (not supplied by UOP) is concrete.

11. Thickener - The thickener has carbon steel walls coated with a zinc oxide primer and no topcoat (decision made by Columbus & Southern Ohio Electric). The thickener bottom is concrete lined with a coal tar epoxy coating. Some rust has been observed on the walls. The rake is carbon steel with a 1/8-inch corrosion allowance. The rake is coated with DuPont 373-785 zinc chromate primer and Rustoleum R-9 topcoat. There have been no problems with these coatings.

12. Vacuum Filter - Not supplied by UOP.

13. Ducts, Expansion Joints, and Dampers - The inlet duct and inlet spool are Cor-Ten steel. There has been corrosion of the spool and Uddeholm 904L is being considered as a replacement. The Cor-Ten steel outlet spool on Unit 6 will be replaced by Uddeholm 904L because of corrosion. The outlet duct is Cor-Ten steel and is lined from the scrubber to the dampers with 45 to 60 mils of Resista-Flake 1150. The outlet breeching (duct from the dampers to the stack) was lined with Flakeline 151 by Columbus & Southern Ohio Electric which failed by delamination after a brief period in service at a maximum temperature of 320 F and was replaced with Sauereisen No. 54.

The expansion joints are Viton® and asbestos, and have not been a problem.

The I.D. fan discharge and scrubber inlet dampers are carbon steel with Type 316L stainless steel seals. The seals on the latter dampers corroded and were replaced with Inconel 625. The outlet isolation dampers have Incoloy 825 frames and blades and Inconel 625 seals. The bypass control damper is carbon steel. They have not presented any materials problems.

14. Piping and Valves - The slurry and clear water lines were rubber-lined carbon steel. Slurry erosion in the reducer led to replacement with plastic lined carbon steel which is still under evaluation. The relcaimed water piping was originally FRP, but water hammer led to replacement with rubber-lined carbon steel.

Neoprene-lined plug valves are used for lime slurry service and neoprene-lined diaphragm valves with a Hypalon diaphragm are used for water service. Liner erosion in the latter valves was solved by reducing the flow velocity.

15. Stack - The stack (not supplied by UOP) was originally lined with Flakeline 151 over a steel liner. The lining delaminated and the steel liner was replaced by acid resistant brick.

16. Slaker - The lime slaker is carbon steel with Ni-hard alloy paddles.

(Petersburg Unit 3)

1. Prescrubber - The presaturator is carbon steel with a Pre-Krete G-8 lining. There is no barrier layer underneath the Pre-Krete. The top and bottom linings are good, but erosion and cracking is occurring on the sidewalls. A design change is under study.

2. Absorber - The absorber shell is carbon steel lined with 1/4-inch of LS-576 neoprene.

3. Spray Nozzles - The slurry spray nozzles are Refrax and the wash spray nozzles are Carpenter 20.

4. Mist Eliminator - Chevron type constructed of FRP.

5. Fans - Carbon steel located upstream from absorber.

6. Reheater - Carbon steel steam coils used to heat ambient air.

7. Pumps - Pumps for slurry service are rubber-lined cast iron by Worthington.

8. Tanks - The recycle and waste slurry tanks have a carbon steel wall and a concrete bottom. The walls are lined with 80 mils of Resista-Flake 1100 and the bottoms are lined with 1/8 to 3/16-inch of Resista-crete 3000AR. The slurry storage and transfer tanks are carbon steel coated with 2 mils of zinc chromate primer and 4.5 mils of epoxy ester topcoat. The reclaim water tank is carbon steel with a zinc silicate primer and an epoxy coal tar finish coat. The mist eliminator wash tank is FRP.

9. Agitators - All agitators are rubber-covered carbon steel.

10. Storage Silo - The limestone silo is carbon steel.

11. Thickener - The thickener has a carbon steel wall and a concrete bottom. The walls are coated with 3 mils of Carbozinc 11 (zinc silicate from Carboline Co.) and the bottom is coated with 8 mils of Carbomastic 14 (epoxy coal tar from Carboline Co.) The rake is carbon steel coated with 2 mils of Carbozinc 11 primer and 1.5 mils of Carbomastic 14 topcoat.

12. Vacuum Filter - Not supplied by UOP.

13. Ducts, Expansion Joints, and Dampers - The inlet duct is unlined carbon steel and the outlet duct and plenum are carbon steel lined with 60 mils of Resista-Flake 1100AR.

The expansion joints are nonmetallic.

The booster fan inlet and outlet dampers, the scrubber inlet damper, and the reheater outlet damper are carbon steel guillotine type with Type 316 stainless steel seals. The scrubber outlet dampers have Incoloy 825 frames, alloy blades, and Inconel 625 seals.

14. Piping and Valves - The spray wash headers were FRP but the press molded fittings ruptured so that the FRP was replaced by plastic-coated carbon steel pipe.

Modulating valves for slurry service are pinch type with a cast iron body and pure gum rubber sleeve. Modulating valves for clear water service are eccentric plug type with a bronze body and a neoprene plug. There have been no problems with the modulating valves. Knife gate valves constructed of Type 316 stainless steel were used for shut off valves in all service. These valves exhibited leaking and seizing so that the slurry valves were remanufactured and the clear water valves were replaced with a different type design. However, there may be a galling problem due to the design.

15. Stack - Not supplied by UOP.

16. Ball Mill - Rubber-lined carbon steel.

PEABODY PROCESS SYSTEMS
STAMFORD, CONNECTICUT

Trip Report Number: EPRI-CM23

Date of Trip: March 16, 1979

Persons Interviewed: Carlton A. Johnson and Alex Kirschner, Peabody Process Systems.

A. BACKGROUND

Table 1 summarizes Peabody's experience with lime/limestone scrubber systems on utility boilers. Prior to the development of flue gas scrubber systems for power generating stations, Peabody had developed experience in SO_2 scrubbing at industrial installations. The largest experience was with tail gas from sulfuric acid plants (U. S. Steel Agricultural and Chemicals Division, Fort Mead and Bartow, Florida). The installation went from contract to start up in just 14 months. A rectangular scrubber tower was built. Flakeglass (Heil) linings were used in the whole vessel. Piping was rubber lined, and headers were FRP with a rubber lining. The exterior abrasion on the headers inside the scrubber was worse than the interior wear. The outside was not rubber protected, so piping lasted only about six months. Spray impinging on the walls of the scrubber abraded away the lining. The silicon carbide nozzles were intact after 4 or 5 years and will probably last a long time. There were no threaded connections as everything was flanged.

The recycle tank was concrete lined with a glass roving reinforced polyester. Linings have performed well here, and in the scrubber, except in high abrasion areas.

The mist eliminator wash tray was Type 316 stainless steel. The mist eliminator itself was a Heil chevron type made of plastic (unsure of type). The ducts have the same lining used in the scrubber. The lining is satisfactory after 5 years.

The erosion problems were solved by design modifications and/or additional use of rubber linings. This experience is reflected in materials selection for two utility scrubber systems (St. Clair and Tombigbee) discussed below.

B. MATERIALS OF CONSTRUCTION
(St. Clair Unit 6)

The St. Clair scrubber system is shown in Figure 1. The mechanical collectors and electrostatic precipitators were followed by two parallel wet scrubbing trains, with bypass, each treating 246,700 acfm (270 F) of flue gas. The scrubbing trains utilized a Lurgi variable-throat venturi scrubber for particulate control followed by a six-bank

TABLE 1. PEABODY FGD SYSTEMS ON UTILITY BOILERS

Client	Power Station	Size, MW	Sulfur in Coal, wt. percent	Reagent	Startup Date
Detroit Edison	St. Clair 6	175	1.5-3.0	Limestone	June, 1975
Alabama Electric Coop	Tombigbee 2	255	1.75	Limestone	September, 1978
Alabama Electric Coop	Tombigbee 3	255	1.75	Limestone	June, 1979
Colorado Ute Electric Assn	Yampa 1	450	0.8	Limestone	1979
Colorado Ute Electric Assn	Yampa 2	450	0.8	Limestone	1979
Minnesota Power & Light	Clay Boswell 4	500	0.8	Lime/alkaline fly ash	1980

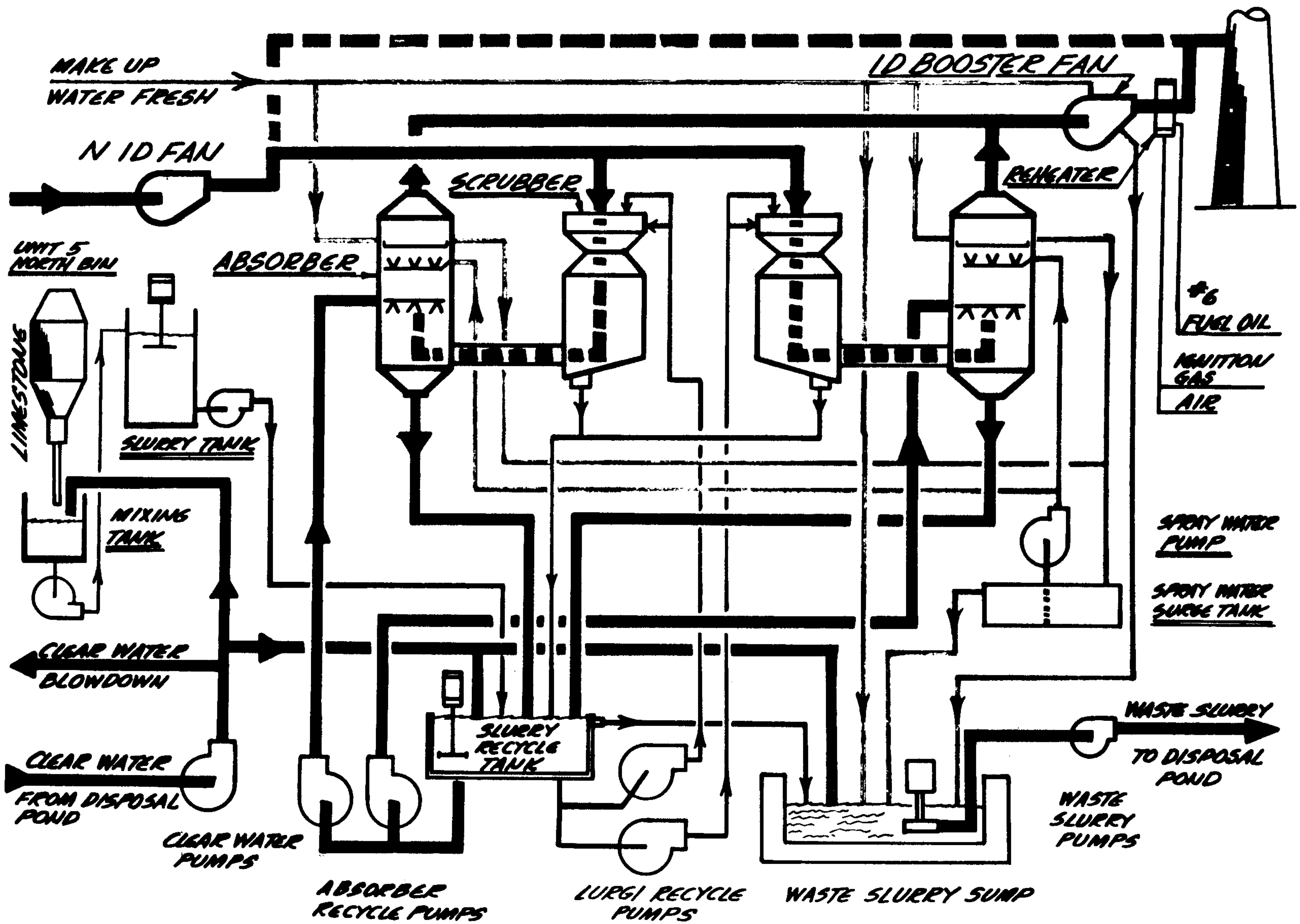


FIGURE 1. PROCESS FLOW DIAGRAM FOR FGD SYSTEM AT ST. CLAIR STATION

spray tower, an impingement wash tray, and a radial spin vane mist eliminator for SO_2 control. Reheat was accomplished by mixing the cleaned gas with air heated with No. 6 fuel oil.

The St. Clair plant was switched to low sulfur Decker coal to meet the SO_2 emission standards. The SO_2 removal system was shut down and the scrubber was then operated for particulate control only, using limestone to control pH.

1. Prescrubber - The venturi scrubber is rubber lined. There are two disposable wear rings of rubber coated steel at the highest abrasion areas. The rubber lining is satisfactory.

2. Absorber - The absorber is Type 316L stainless steel, but the system was never operated with a high chloride concentration to test this material.

3. Spray Nozzles - The spray nozzles are Refrax (silicon carbide). Peabody has had excellent experience with these kinds of nozzles in their scrubber systems. They have, however, converted from threaded to flanged designs.

4. Mist Eliminator - The mist eliminator consists of a Type 316L stainless steel wash tray and a Type 316L stainless steel radial spin vane.

5. Fans - The fan is in the wet side of the system. It is thought to be constructed of Inconel 625. There were mechanical problems at first, which were solved. No problem with materials was indicated.

6. Reheater - Hot air from an oil-fired reheat system is blended with the flue gas in a tee-pipe mixer to achieve a temperature of 250 F. Materials of construction were not specified.

7. Pumps - All the slurry pumps are rubber-lined Denver pumps and have not been a problem.

8. Tanks - The tanks are carbon steel with a flakeglass/polyester lining.

9. Agitators - Not discussed.

10. Storage Silo - Not discussed.

11. Thickener - None used.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - Not discussed, except that the ducts are lined.

14. Piping and Valves - All piping is rubber-lined carbon steel and has performed satisfactorily. The spray headers are FRP and are unsatisfactory because of abrasion by the slurry.

Valves are avoided insofar as possible. There is one valve (diaphragm type) in the limestone feed line. The only valves in the slurry lines are fully-open or fully-closed types at inlets to pumps. These are to isolate the pumps for repairs, and are rubber lined.

15. Stack - Not discussed, except that the existing stack was used.

16. Ball Mill - None used on-site; ground limestone is delivered to the plant.

17. Ponds - The ponds are unlined.

(Tombigbee Units 2 and 3)

The Tombigbee scrubber system differs from the one at St. Clair in that particulate removal is accomplished in an electrostatic precipitator ahead of the SO_2 absorber. Therefore, the limestone slurry contains little or no fly ash.

1. Prescrubber - An inlet thimble of Incoloy 825 is used to presaturate the flue gas ahead of the absorber.

2. Absorber - The absorber is a spray tower, which is divided into zones. In the spray zone the vessel is rubber-lined steel because of the high abrasion. Above and below the spray zone, the vessel is lined with flakeglass/polyester (Corrosioneering Resista-Flake 1101). Each of the joints between sections is a full-body flange. In this way the edges of linings are outside the abrasive and corrosive conditions. Carpenter 20 bolts and nuts are used at flanges along with Carpenter 20 backup rings (large washer) to protect the rubber lining which laps around the flange.

3. Spray Nozzles - The limestone slurry is sprayed into the absorber through Refrax (silicon carbide) nozzles. Stellite nozzles are used for washing the mist eliminator tray bottom.

4. Mist Eliminator - There is a Type 316L stainless steel wash tray above the spray zone. This tray is essentially a perforated plate, which is easy to replace if necessary. There are also plastic chevrons (General Electric Noryl®). Slurry water is passed through a hydroclone to remove $CaCO_3$ solids and sprayed on the underside of the tray through Stellite nozzles to prevent clogging. The hydroclone is rubber-lined carbon steel with a silicon carbide vortex finder.

5. Fan - The fan is on the dry side, between the electrostatic precipitator and the scrubber. It is carbon steel.

6. Reheater - The unit is designed for bypass reheating. An Inconel 625 deflector baffle is used for mixing. This reheat area, and the entire duct from the scrubber outlet to the stack breeching is lined with fluoroelastomer (Colebrand CXL-2000, Pullman Power Division). The cost of this lining was thought to be about $25/ft^2. This lining was selected to meet full bypass conditions (300 F flue gas), and has been used several months under full bypass.

7. Pumps - All slurry line pumps, wash pumps and sump pumps are rubber lined (A-S-H).

8. Tanks - The tanks are carbon steel lined with flakeglass/polyester (Corrosioneering Resista-Flake 1101, 80 mils, in critical areas and 1151, 60 mils, in less critical areas).

9. Agitators - All agitators are rubber-coated carbon steel.

10. Storage Silo - The limestone silo is carbon steel.

11. Thickener - None used.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The inlet duct is carbon steel with a flanged connection to the Incoloy 825 inlet thimble. The entire outlet duct from the scrubber to the stack is lined with a fluoroelastomer (see reheater discussion).

All expansion joints are Viton®.

Guillotine (isolation) and louver (control) type dampers are used in the inlet side. These dampers are carbon steel. Dampers in the outlet side are Incoloy 825, guillotine type. The bypass damper is carbon steel, louver type. Damper problems have been mechanical rather than materials related.

14. Piping and Valves - The piping is rubber lined carbon steel. Slurry valves are avoided except for the limestone slurry feed line which has a diaphragm type valve. The isolation valves on the suction side of each pump are used for maintenance only and are DeZurik rubber-lined eccentric plug valves. Gravity overflow controls the scrubber bleed.

15. Stack - The stack is a concrete shell with twin flues of acid resistant brick with a pressurized annulus. The stack was constructed by Continental Heine of Chicago.

16. Ball Mill - The ball mill is rubber lined carbon steel (one serves both units).

17. Pond - The pond is not lined.

COMMONWEALTH EDISON COMPANY
WILL COUNTY UNIT 1

Trip Report Number: EPRI-CM24

Date of Trip: March 26, 1979

Persons Interviewed: John Reid, Engineer, Will County Station, Commonwealth Edison.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Babcock & Wilcox is the process designer, vendor, and contractor; Bechtel is the consulting engineer; retrofit installation.

2. Boiler Type - Babcock & Wilcox cyclone boiler rated at 167 MW but operated at 140 MW; heat rate is about 11,000 Btu/kWh.

   a. About 10 percent excess air.

   b. Intermediate loading unit with a capacity factor of about 65 percent; the unit is off from 9:00 p.m. to 6:00 a.m. and is also off on weekends; depends on system load conditions.

   c. The stack height is 350 ft above grade.

3. Flue Gas Flow Rate - 770,000 acfm at 350 F; the scrubbing system treats 100 percent of the flue gas, but the system can be bypassed; there are two identical scrubber modules.

   a. 7 to 10 percent oxygen in the flue gas to the scrubber.

4. SO_2 Concentration - Currently, 500 ppm SO_2 in inlet gas and 50 ppm SO_2 in outlet gas with low-sulfur coal; previously, with Illinois coal there was about 2400 ppm SO_2 in the inlet gas and about 300 ppm SO_2 in the outlet gas.

5. Fuel Currently, subbituminous coal from Wyoming and Montana with 0.5 percent sulfur, 4.9 percent ash, 27.6 percent moisture, and a heat content of 8,900 Btu/lb; previously, Illinois coal with 3 to 4 percent sulfur, 15 percent ash, and a heat content of 10,000 Btu/lb.

6. Scrubber Reactant - Limestone with 98.75 percent $CaCO_3$; ground to 95 percent minus 325 mesh in wet ball mill.

7. Removal Efficiency - The system is now operated mainly for particulate removal; the design particulate removal efficiency is 98 percent; the SO_2 removal efficiency is about 85 percent.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1; flow rates shown are design flow rates for high-sulfur coal.

2. Process Variables -

a. Gas inlet temperature is 300 to 355 F.

b. Gas outlet temperature is 125 F before the reheater.

c. The fly ash loading to the scrubber is 0.343 grains/scf.

d. The scrubbing liquor pH is about 5.4

3. Absorber Design -

a. Old electrostatic precipitator with an efficiency of 30 percent is on when the scrubber is operating. A wet approach venturi with a variable throat is used for particulate removal; the venturi also functions to cool and saturate the gas.

b. A two-stage perforated tray tower is used for SO_2 removal.

c. The superficial gas velocity is about 150 ft/sec in the venturi throat and 12 ft/sec in the absorber.

d. The absorbers have some dampers to control velocity for turndown, but they are pinned open and the velocity is not regulated. Both modules are operated even when the load is reduced to 90 MW in order to meet particulate emission regulations.

4. Liquid-to-Gas Ratio - 15 gal/1000 acf in the venturi and 27 gal/1000 acf in the absorber at full load.

5. Oxidation - Close to 100 percent oxidation of sulfite to sulfate with low-sulfur coal.

6. Pressure Drop - 9.0 inches of H_2O across the venturi, 6.0 inches of H_2O across the absorber mist eliminator, 5.5 inches of H_2O across the reheater, and 22.5 inches of H_2O total for the FGD system.

7. Solids Level - Less than 5 percent solids in the recirculating slurry for low-sulfur coal; 20 percent solids in limestone makeup slurry.

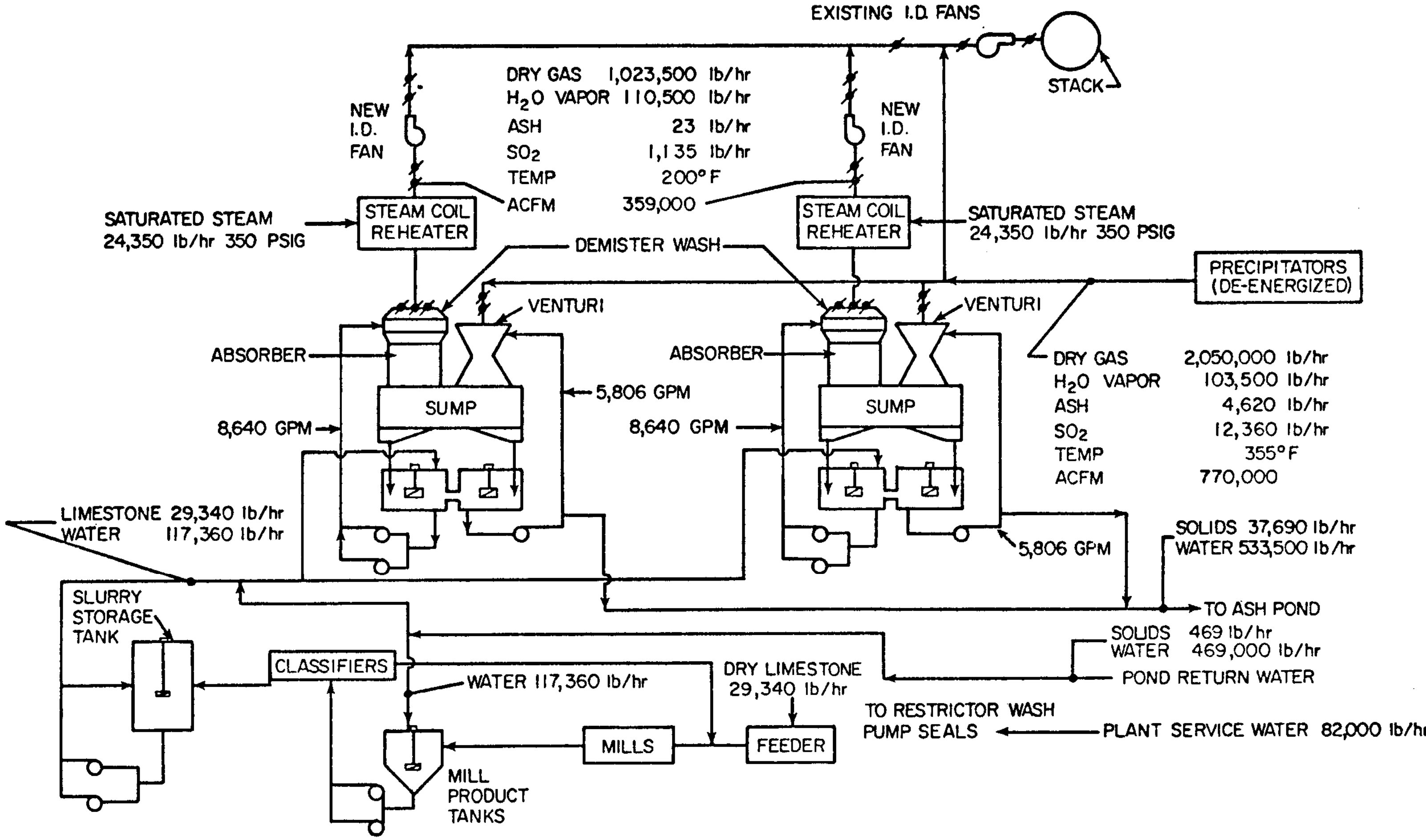


FIGURE 1. FLUE GAS DESULFURIZATION SYSTEM ON WILL COUNTY UNIT 1

8. <u>Reactant Addition</u> - Limestone slurry is added to the absorber recycle tank.

9. Reactant Feed Rate - About 200 lb of limestone per ton of coal (0.5 percent sulfur) burned, or 1.5 to 1.7 moles limestone/mole SO_2 removed.

10. Slurry Retention Time - About 5 minutes retention time if plug flow is assumed, but dye tests have indicated almost complete backmixing in the recycle tanks.

11. Mist Eliminator - Two-stage, horizontal chevron Z-shape, three-pass mist eliminator with a superficial gas velocity of 10 ft/sec. Washed from above first stage with a deluge of 1200 gpm of pond return water once per hour and washed from below first stage with 110 gpm of fresh water for 5 minutes twice per hour.

12. Reheat System - In-line reheat with steam at 350 psig and 450 F in carbon steel and stainless steel tubes. The flue gas is supposed to be reheated from 125 F to 200 F, but when tube fouling occurs, the gas is reheated to only 150 to 160 F. Originally there were 9 banks of tubes with three bundles per bank, but now only 20 bundles per module are in operation because leaking tube bundles are blanked out. The reheater protects the ID fan and adds buoyancy to the gas.

13. Waste Disposal - The waste disposal is closed-loop; scrubber effluent is sent to a thickener and thickener underflow is sent to a horizontal belt filter. The filter cake is mixed with 10 percent lime and 20 percent fly ash in a cement mixer truck and dumped in a clay-lined area one-half mile from the plant.

14. Fans - Original induced-draft fans located just ahead of the stack, and induced-draft booster fans located after the reheaters.

C. RELIABILITY

1. Start-up - February, 1972.

2. Availability - Refer to Table 1 (operability based on boiler operating hours and availability based on hours in each month).

3. Longest Run - About 400 hours for both modules in simultaneous operation.

4. Calendar of Operation - Module A has operated for more than 23,000 hours and Module B for more than 16,000 hours since start-up. As of the end of June, 1977, the unit has been burning only low-sulfur coal. Prior to this time, low-sulfur coal was sometimes burned alone or as a blend with Illinois coal. The average coal sulfur content was slightly higher than one percent in 1975, and about 1.5 percent in 1974. During

TABLE 1. OPERABILITY OR AVAILABILITY OF WILL COUNTY SCRUBBERS

Month		Operability, percent[a] Module A	Module B	Modules A and B Together
1972	February	0.0	39.2	0.0
	March	0.0	39.4	0.0
	April	34.0	13.7	0.0
	May	69.5	31.8	31.8
	June	8.5	31.0	8.3
	July	27.6	18.0	0.0
	August	69.0	21.1	20.9
	September	0.0	31.7	0.0
	October[c]	0.0	0.0	0.0
	November	0.8	16.9	0.8
	December	20.9	23.6	20.9
	Total for 1972	29.5	25.2	9.6
1973	January	9.2	11.3	0.0
	February	24.0	10.6	0.0
	March	63.0	10.6	10.5
	April[d]	0.0	13.7	0.0
	May	0.0	0.0	0.0
	June	86.5	0.0	0.0
	July	47.8	0.0	0.0
	August	17.1	0.0	0.0
	September	14.0	0.0	0.0
	October	48.0	0.0	0.0
	November	31.8	0.0	0.0
	December	0.0	0.0	0.0
	Total for 1973	<27.1	4.2	0.8
1974	January	0.0	0.0	0.0
	February	0.0	0.0	0.0
	March	25.8	0.0	0.0
	April	72.4	0.0	0.0
	May	93.1	0.0	0.0
	June	54.6	0.0	0.0
	July	95.8	0.0	0.0
	August	91.2	0.0	0.0
	September	84.9	0.0	0.0
	October	93.6	0.0	0.0
	November	97.0	0.0	0.0
	December	99.2	0.0	0.0
	Total for 1974	69.0	0.0	0.0

TABLE 1. (Continued)

Month		Availibility, percent[b]		
		Module A	Module B	Modules A and B Together
1975	January	99.5	0.0	0.0
	February	99.4	0.0	0.0
	March	94.0	0.0	0.0
	April	37.0	0.0	0.0
	May[e]	84.5	37.1	--
	June	64.2	85.5	--
	July[f]	0.0	79.2	0.0
	August[f]	0.0	93.5	0.0
	September[f]	0.0	62.7	0.0
	October[c, f]	0.0	32.3	0.0
	November[c, f]	0.0	0.0	0.0
	December[c, f]	0.0	0.0	0.0
	Total for 1975	39.9	32.5	--
1976	January[c, f]	0.0	0.0	0.0
	February[c, f]	0.0	0.0	0.0
	March	30.1	8.8	--
	April	23.0	51.2	19.2
	May	0.0	86.6	0.0
	June	52.0	72.0	31.5
	July	20.0	84.0	--
	August	78.3	65.4	11.5
	September	42.3	79.4	4.1
	October	27.9	76.4	0.0
	November	20.1	72.2	6.5
	December	44.9	53.4	0.0
	Total for 1976	28.2	54.1	∿7.3
1977	January	98.1	13.6	0.0
	February	38.8	72.9	11.8
	March	96.9	80.9	50.7
	April	27.2	61.1	20.4
	May	89.4	98.0	0.0
	June	31.8	93.2	10.4
	July	26.9	70.3	2.7
	August	99.8	10.0	9.7
	September	61.0	52.3	36.9
	October	--	--	--
	November	0.0	11.4	0.0
	December	47.7	95.0	31.2
	Total for 1977	∿56.1	∿59.9	∿15.8

Month		Availability, percent[b] Module A	Module B	Modules A and B Together
1978	January	66.3	22.0	22.0
	February	35.4	59.3	35.4
	March	94.0	88.5	26.3
	April[g]	99.9	100.0	99.9
	May	89.5	89.3	89.3
	June	87.1	85.6	85.6
	July	97.0	99.2	94.6
	August	97.9	99.6	97.5
	September	77.6	77.8	77.6
	October	93.6	93.6	93.6
	November	96.3	85.2	81.8
	December	65.3	64.5	64.5
	Total for 1978	83.3	80.4	72.3
1979	January	83.5	62.2	62.2
	February	93.0	93.0	93.0

(a) Operability is defined as hours the FGD system was operated divided by boiler operating hours in time period.
(b) Availability is defined as hours the FGD system is available for operation (whether operated or not) divided by hours in time period.
(c) Scheduled boiler shutdown.
(d) Decision was made to concentrate on Module A.
(e) Module B placed in service for the first time since April, 1973.
(f) Module A placed out of service to await installation of new reheater.
(g) Regulatory authorities ordered scrubber to operate.

1972 and 1973, the coal sulfur content ranged from 0.3 to 4 percent. Probably less than half the operating hours were accumulated while burning high sulfur Illinois coal alone.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - The venturi and the sump are constructed of 1/4 inch Cor-Ten steel. Over this is a coating of 12-15 mils Plasite 7122 and a 2-inch covering of Kaocrete HS. About 3 years ago some renewal of this covering in limited areas was required. The inlet duct above the venturi is unlined steel and some holes have developed in this area. At the time of the original installation there were restrictor blocks in the venturi throat which were constructed of Grade A silicon carbide. However, problems with clogging necessitated removal of these blocks and none are in use at present.

2. Absorber - The absorber section is constructed of 1/4 inch Cor-Ten steel with a lining of 3/16 inch natural gum rubber. This rubber lining is still in good condition and has given no problems. The trays are constructed of Type 316 stainless steel.

3. Spray Nozzles - All the nozzles on the scrubber system are Type 316 stainless steel. The nozzles serve three purposes, namely, wall wash (64 per module), venturi spray (48 per module), and absorber spray. There has been some erosive wear on the nozzles, but they have never been changed, and it is hoped that they will last until the scrubber is eventually replaced with a baghouse.

4. Mist Eliminator - The mist eliminator is a two-stage chevron type of Z design. It is made of fiberglass-reinforced plastic (Hetron® 197). The mist eliminator is washed once each hour with pond return water, and there is also an underspray of fresh water which is used twice per hour. The mist eliminator was subject to embrittlement and was replaced 3 or 4 years ago with a heavier type of similar material.

5. Fans - The ID fan is a 1250-hp Westinghouse Sturdivant with a capacity of 290,000 cfm, and is made of carbon steel. The ID booster fan, which is constructed of Cor-Ten steel, is also a Westinghouse fan and the original one is still in use. The FD fan is a 3000-hp Westinghouse Sturdivant with a 200,000 cfm capacity.

6. Reheater - The top portion of the reheater was originally Cor-Ten steel and the bottom part was Type 304 stainless steel. However, both of these components corroded rapidly, developing pin holes in about 6 months. The top portion was replaced with carbon steel and the bottom portion with Type 316L stainless steel. However, the corrosion is still occurring, with the carbon steel requiring replacement about once a year, and the stainless steel lasting about 1-1/2 years. The cause of failure in the stainless steel has been traced to stress corrosion cracking. The chloride content of the deposit on the reheater has been found to be 0.1 to 0.12 percent, which promotes this type of attack. The carbon steel tubes are subject to pinhole corrosion caused by sulfuric acid. The reheater duct itself is carbon steel. The reheaters are kept on even when the boiler is down to minimize corrosion of its components.

7. Pumps - The pumps for absorber recycle, venturi, and slurry transfer were all supplied by Allen-Sherman-Hoff. The absorber pump (88 ft head) has a 200-hp GE motor, and the venturi pump (86 ft head) uses a 350-hp GE motor. These pumps are all rubber lined and have not given any materials problems. The only difficulty has been when the linings were torn up by pieces of a broken isolation valve which got into the system. The limestone recycle and the pond return pumps are all of carbon steel, supplied by Allis-Chalmers.

8. Tanks - The absorber tank and the slurry storage tank are constructed of 1/4-inch carbon steel lined with 3/16-inch natural gum rubber. The mill product tank is made of concrete. There have been no problems with any of these tanks.

9. Agitators - The agitators in the four recycle tanks are all Philadelphia mixers, which are made of carbon steel with a rubber coating. The agitators in the slurry storage and mill product tanks have the same construction. There have been no problems with any of these items.

10. Storage Silo - The limestone storage silo is made of 1/4-inch carbon steel. No problems have been encountered with this component.

11. Thickener - The thickener was supplied by the American Admixture Company, and the walls and rake are constructed of uncoated steel. No corrosion has occurred as yet. The bottom is concrete.

12. Vacuum Filter - The horizontal belt vacuum filter also was supplied by the American Admixture Company. It is believed to be nylon cloth on a rubber belt.

13. Ducts, Expansion Joints, and Dampers - The inlet duct to the venturi is unlined 3/16-inch carbon steel and was repaired about 3 years ago with the same material. The outlet duct to the reheater is 1/4-inch Cor-Ten steel which had a 12-15 mil lining of Plasite 7122H. The lining deteriorated 10 ft ahead of the reheater where there is now much corrosion. Downstream of the reheater, all ducts (including the bypass duct) are lined 1/4-inch Cor-Ten steel which has some deposits but no corrosion.

Expansion joints are a standard nonmetallic type supplied by Babcock & Wilcox. They are believed to be of an asbestos-type construction.

The dampers for the venturi inlet and the induced draft booster fan are of the louvered type and are constructed of Cor-Ten steel. The outlet block damper is carbon steel. The only problem with the dampers has been clogging as a result of fly ash collecting at the damper.

14. Piping and Valves - All the piping for the venturi, the absorber, and the headers is carbon steel with a 3/16-inch natural gum rubber lining. The pond return line is unlined carbon steel. Any piping inside the absorber is made of Type 316L stainless steel. The header outside the venturi is rubber-lined carbon steel and has undergone erosion at 90-degree elbows. The reducers also were eroded and were replaced after 6 to 7 years. No other problems have been encountered in the piping.

The spent slurry valve was originally a rubber-lined pinch valve that lasted only 250 hours. This valve was replaced by a butterfly-type media valve which also was rubber lined. Some of the valves (16 and 18 inch) in the scrubber system were supplied by Mosser and these are made of Ni-Resist Type 2. Shaft failure occurred in three of these valves because they had not been supplied with the specified CD-4MCu alloy discs. Proper materials were installed in December, 1976. There have been no problems since then. There are also some 6- and 8-inch butterfly valves supplied by DeZurik, which are made of Type 316 stainless steel.

15. Stack - The scrubbed gases are exhausted through two welded steel stacks which are lined with brick, joined by acid-resistant mortar. The brick linings are directly against the steel shells of the stacks. These are the original power station stacks which have been up for 25 years and no problems have been encountered with them.

16. Ball Mill - The ball mill was supplied by Allis-Chalmers and there have been no difficulties with this installation. The mill is recharged with balls once a month.

17. Pond Lining - The thickener overflow is sent to an unlined pond which serves as a source of recycle water.

CENTRAL ILLINOIS LIGHT COMPANY (CILCO)
DUCK CREEK UNIT 1

Trip Report Number: EPRI-CM25

Date of Trip: March 27, 1979

Persons Interviewed: Larry Haynes, Environmental Manager, and Kim Swahlstedt, Air Pollution Control Engineer, CILCO

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Riley/Environeering is the process designer, vendor, and contractor of the new system and Commonwealth Associates Inc. are the consulting engineers.

2. Boiler Type - Riley Stoker pulverized coal-fired boiler, front-fired, dry bottom; construction completed June, 1976; nominally rated at 400 MW; design heat rate 9840 Btu/kWh net.

   a. 20 percent excess air.

   b. 55-60 percent annual capacity factor; about 1/2 load at night, but this varies because of computerized dispatch.

   c. 500-ft stack.

3. Flue Gas Flow Rate - 25 percent or 303,470 acfm (125 F) of the total 1,213,880 acfm (125 F) of flue gas is passed through each of four scrubber modules.

   a. Oxygen in the flue gas is less than 7 percent.

4. SO_2 Concentration - 2800 ppm SO_2 in the inlet gas and 300 ppm SO_2 in the outlet gas for the 3.3 percent sulfur coal burned. For the design coal with 4.0 percent sulfur, the SO_2 inlet and outlet concentrations are estimated to be 3,060 ppm and 440 ppm, respectively.

5. Fuel - The boiler is operating on high-sulfur Illinois coal (3.3-3.4 percent S). The design coal has 4 percent sulfur, 0.02 to 0.08 percent chloride, and a heating value of 9,800 Btu/lb.

6. Scrubber Reactant - Limestone with a calcium carbonate content equal to or greater than 90 percent; ground to 90 percent less than 200 mesh in a wet ball mill.

7. Removal Efficiency - The SO_2 removal efficiency is 85.3 percent, and the overall fly ash removal efficiency is 99.8 percent (includes electrostatic precipitators).

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1 and Table 1.

2. Process Variables -

   a. Flue gas inlet temperature to scrubber is 275 F.

   b. Flue gas outlet temperature from scrubber is 125 F (no reheat).

   c. Fly ash inlet loading to scrubber is 0.009 grains/acf (design value).

   d. Scrubbing liquor pH is 6 at the inlet and 5.5 at the outlet.

3. Absorber Design -

   a. A Pollution Control Walther electrostatic precipitator for fly ash removal.

   b. Four identical Ventri-Sorber® scrubbers for SO_2 removal, each consisting of 7 decks of 1-inch O.D. rods with a 1-inch gap between the rods of a single deck. Flue gas enters at the bottom and flows upward through the rod decks. The limestone slurry enters the scrubber on top, through open pipes, and travels downward. A turbulent layer at the top of each ventri-rod deck is the actual site of the scrubbing reaction. The spent slurry drains from the bottom of the scrubber into a single-stage recycle tank.

   c. Superficial gas velocity is 12 ft/sec through the scrubber.

   d. Turndown ratio is down to 25 percent of design flue gas flow rate. Turndown can be achieved by taking modules off-line or by reducing the gas velocity. However, not enough sustained operation has been achieved to determine turndown capabilities.

4. Liquid-to-Gas Ratio - L/G is 50 gal/1000 acf.

5. Oxidation - Oxidation of sulfite to sulfate is 10 percent based on pilot plant design data; the recycle slurry was analyzed at Battelle and the oxidation was found to be slightly less than 10 percent.

6. Pressure Drop - 8.0 in. H_2O through the Ventri-Sorber® and 13 in. H_2O through the entire system.

7. Solids Level - 35 percent solids in limestone feed slurry and 15 percent solids in recycle slurry.

8. Reactant Addition - Limestone slurry is added to the scrubber recycle tank.

9. Reactant Feed Rate - 75,200 lb/hr of limestone for a design mole ratio of 1.5 moles of limestone per mole of SO_2 removed at a design coal sulfur content of 4.2 percent.

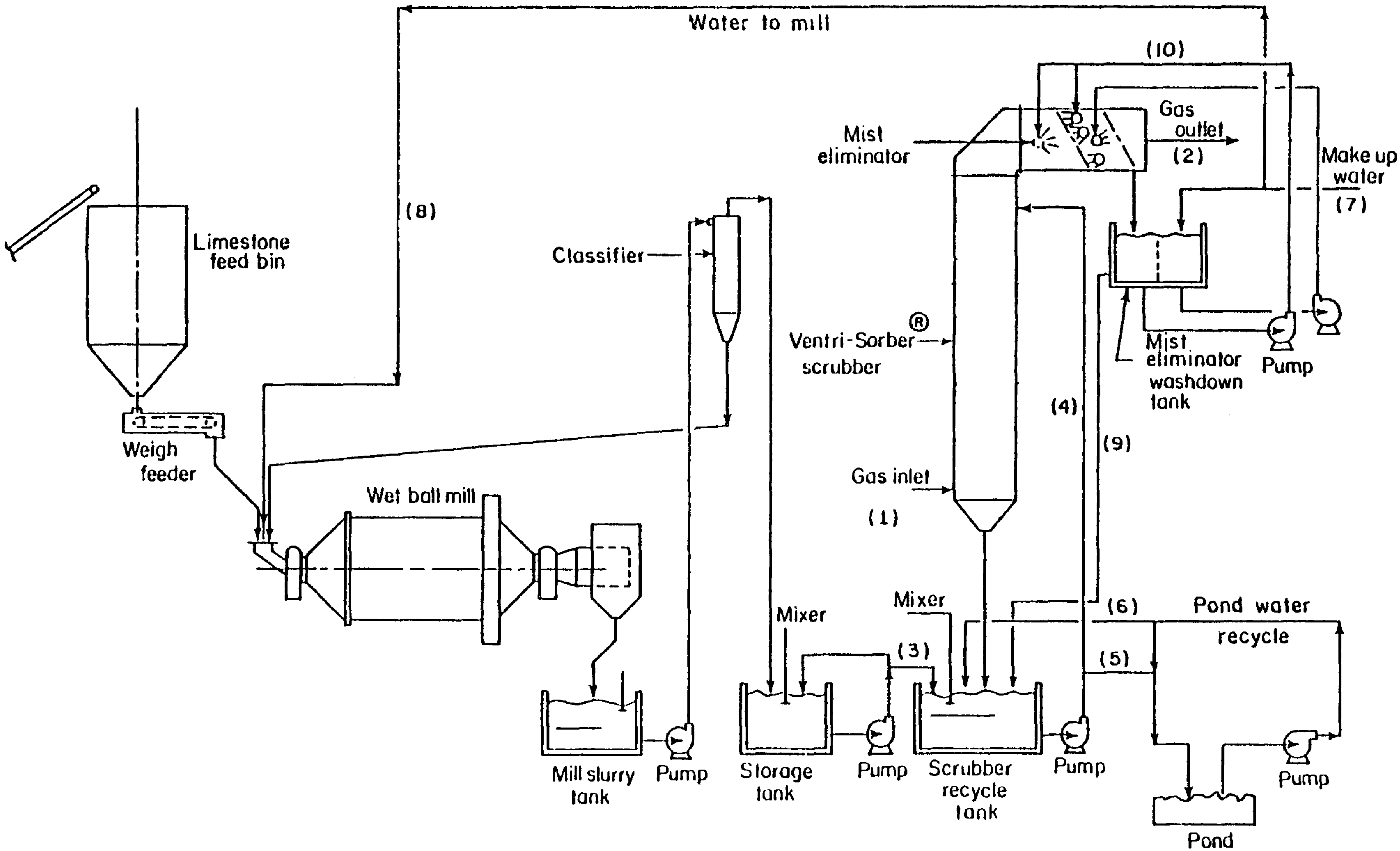


FIGURE 1. SCHEMATIC FLOW DIAGRAM OF DUCK CREEK FGD SYSTEM

TABLE 1. MATERIAL FLOW RATES FOR MAJOR PROCESS STREAMS

Flow No.	Flow Description	Flow Rate*
1	I.D. Fan Discharge	354,050 acfm at 275 F
2	Absorber Outlet	303,470 acfm at 125 F
3	Limestone Slurry to Recycle Tank	84 gpm (35 percent solids)
4	Slurry to Scrubber	15,171 gpm (15 percent solids)
5	Slurry to Pond	268 gpm (15 percent solids)
6	Pond Water Recycle	185 gpm
7	Makeup Water	150 gpm
8	Water to Mill	70 gpm
9	Water to Recycle Tank	105 gpm
10	Mist Eliminator Wash	885 gpm

* For one scrubber module.

10. Slurry Retention Time - 10 minutes in the recycle tank.

11. Mist Eliminator -

a. Design - Chevron type.

b. Configuration - Two banks of vanes slanted approximately 30 to 40 degrees with the vertical.

c. Superficial gas velocity - 13 ft/sec.

d. Type of washing - Continuous with 885 gpm of makeup water. The mist eliminator wash tank is partitioned into two separate chambers. The makeup water is introduced into the first chamber from where it is withdrawn and sprayed on the second-stage mist eliminator bank. The water drains from this bank into the second tank chamber from where it is withdrawn and is sprayed on the upstream and downstream sides of the first-stage mist eliminator bank. Approximately 660 gpm of wash water drains from the second tank chamber into the scrubber recycle tank.

12. Reheat System - There are no provisions for stack gas reheat.

13. Waste Disposal - The sludge disposal system is closed loop, with the spent scrubber slurry discharged along with the fly ash to a 65-acre, clay-lined pond; the only water that escapes the scrubber and disposal system is from the stack or from pond evaporation. The pond has an estimated storage life of 5 years at the full 400-MW scrubber load.

14. Fans - Buffalo Forge fans located between electrostatic precipitator and scrubbers; fans meet boiler induced draft and scrubber pressure drop requirements.

C. RELIABILITY

1. Start-up - Operation with all four modules began on July 24, 1978. One module was constructed earlier and began operation in July, 1976, and was operated intermittently until a one-month test program in March, 1977. The module was then shut down and the unit was on low-sulfur coal until the July, 1978 start-up of the four modules.

2. Availability - The availability (hours the FGD system is available for operation divided by hours in period) was 45 percent in August and September, 1978, 16 percent in October, 8 percent in November, 20 percent in December, and 0 percent in January, 1979. The FGD system was down from before Christmas until March, 1979 because of frozen pipes which were not drained properly at shutdown.

3. Longest Run - About 50 hours for all four modules and 343 hours for Module B.

4. Calendar of Operation - The FGD system has seen limited operation thus far.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - No prescrubber is used in this system.

2. Absorber - This station utilizes the Riley Stoker Corporation/ Environeering Ventri-Sorber® scrubber which consists of 7 banks of 1-inch OD rod beds with a 1-inch gap between the rods. Both the absorber walls and the rods are Type 316L stainless steel. The limestone slurry and ash cling to the absorber wall and could become a potential source of corrosion as the chloride level in the system has not yet reached a steady state. However, no problems have been encountered as yet. The Hastelloy G part of the system begins where the gas flow turns at a 90-degree angle to enter the mist eliminator.

3. Spray Nozzles - No spray nozzles are used in the absorber. Instead, open pipe reducing from 4 to 12 inches and made of Type 316L stainless steel is used to introduce the limestone slurry. However, the mist eliminator has nozzles which are constructed of aluminum oxide ceramic.

4. Mist Eliminator - The mist eliminator comprises two banks of vanes slanted at approximately 30 to 40 degrees with the vertical. Both the vanes of the mist eliminator and the walls of the absorber in this area are constructed completely of Hastelloy G.

5. Fans - Carbon steel fans manufactured by Buffalo Forge Company are located after the electrostatic precipitator and ahead of the scrubber. Because these are on the hot side, no corrosion problems have been encountered.

6. Reheater - No reheater is used in this system.

7. Pumps - Allen-Sherman-Hoff pumps are used on all the recycle lines except for Module D where Worthington pumps are used. These originally were lined with natural rubber but after a failure occurred, the linings were all changed to neoprene rubber. The lining on the slurry transfer pump has a life of approximately 3 months. The impeller is normally replaced at the same time. The pond water recycle pump is carbon steel and has given no problem. A Galigher pump is used between the mill slurry tank and the classifier.

8. Tanks - The mill slurry tank, the storage tank, and the recycle tank are made of carbon steel with a rubber lining. There has been no sign of any wear on these linings as yet. The only tank which is not carbon steel is the mist eliminator wash down tank, which is constructed of fiberglass-reinforced plastic and has presented no problems.

9. Agitators - All the agitators were manufactured by Chemineering and are rubber coated. There have been no difficulties with the agitators.

10. Storage Silos - A carbon steel silo is used for limestone storage, and it has not been the source of any difficulties.

11. Thickener - None used.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - Carbon steel is used for the gas inlet duct to the scrubber. However, the bypass duct and the outlet ducts are all Hastelloy G. No problems have been encountered with any of these components. All the expansion joints in the system are made of Hastelloy G. Internal cover plates were added to prevent ash buildup. All inlet dampers are carbon steel guillotine type including Module D which was changed from a louver type because of problems with ash clogging. Except for the inlet dampers, all the dampers in the system are constructed completely of Hastelloy G. The outlet dampers are guillotine type. The bypass and isolation dampers are louver type with seal air between them. The bypass dampers have presented some leakage problems.

14. Piping and Valves - At the present time practically all the piping in the system is fiberglass-reinforced plastic supplied by the Atlantic Bridge Company. Originally, the mist eliminator wash lines were constructed of polyvinyl chloride piping but these were subjected to too much heat and had to be replaced with the fiberglass-reinforced plastic. Part of the pond return pipe is constructed of concrete with the remainder being FRP. There has been some erosion loss on the FRP piping, particularly at elbows. This problem has been alleviated by replacing with larger diameter pipe and reinforcing the elbows. The number of valves was kept to a minimum in this system. Some rubber pinch valves were used where they were absolutely necessary. Plug valves were used on the recycle pump system. All recycle pump discharge valves have been replaced with pinch valves.

15. Stack - The stack is carbon steel with a Flakeline 151 lining. The lining has blistered and has required repair whenever the unit is down. The lining for the transition section and the ash hopper also was Flakeline 151, but this has been destroyed and has not yet been replaced. Inconel 625 is being considered as a replacement material.

16. Ball Mill - The ball mill is carbon steel with a rubber lining (Kennedy Van Saun) and has presented no problems, because the good grade of limestone being used makes for easy grindability.

17. Pond - The scrubber effluent is sent to a 57-acre pond which is lined with clay. At present there is only 62 ppm Cl^- in the pond water, as a steady state has not yet been reached.

SOUTHERN ILLINOIS POWER COOPERATIVE (SIPC) MARION UNIT 4

Trip Report Number: EPRI-CM26

Date of Trip: March 28, 1979

Persons Interviewed: Clyde Rice, Plant Superintendent, and Henry Neicamp Operations Supervisor, Marion Power Plant, SIPC; Ray Walters, Engineer, and Clark Collier, Design Section Chief, Air Quality Control Division, Burns & McDonnell.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Babcock and Wilcox (B&W) supplied process requirements, and furnished and erected the absorber modules, hold tanks, and recycle pumps. Process systems (limestone slurry, waste slurry, make-up water, reclaimed water, sludge disposal mist eliminator wash, etc.) designed by Burns & McDonnell, consulting engineer; process systems furnished and erected by Broyles & Broyles; new installation.

2. Boiler Type - B&W cyclone boiler rated at 184 MW; the design gross heat rate is 7,900 Btu/kWh.

   a. 17 percent excess air.

   b. Base load unit with 90 percent capacity factor.

   c. 400 ft stack.

3. Flue Gas Flow Rate - About 630,000 acfm of flue gas at 300 F; all the flue gas is treated in two scrubbing modules, but there are provisions for complete bypass.

   a. About 5.0 percent oxygen in flue gas.

4. SO_2 Concentration - About 2200 ppm SO_2 in inlet gas and 220 ppm SO_2 in outlet gas.

5. Fuel - Blend of 40 percent gob refuse from mine tailings and 60 percent Illinois coal. The refuse contains 2.75 percent sulfur, 15 percent ash, and high moisture, and has a heat content of 9,200 to 9,300 Btu/lb. The Illinois coal contains 3 to 5 percent sulfur and 18 percent ash, and has a heating value of 11,000 Btu/lb.

6. Scrubber Reactant - Limestone from a local quarry received as minus 3/4-inch and ground to 95 percent minus 325 mesh in a wet ball mill.

7. Removal Efficiency - Design SO_2 removal is 89.4 percent. Design fly ash removal is 99.6 percent in the electrostatic precipitator.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables -

a. Flue gas inlet temperature to scrubber is 300 F.

b. Flue gas outlet temperature is 130 F.

c. Fly ash loading to the scrubber should be less than 0.015 grains/scf.

d. Scrubbing liquor pH is 5.5.

3. Absorber Design-

a. A B&W electrostatic precipitator for particulate removal.

b. Two-stage sieve tray tower plus quencher for SO_2 removal.

c. Superficial gas velocity was not specified.

d. Turndown will be accomplished by taking one module off-line at 50 percent of the design gas flow rate.

4. Liquid-to-Gas Ratio - About 70 gal/1000 acf @ 300 F.

5. Oxidation - Not specified.

6. Pressure Drop - 12.3 in. of H_2O for the FGD system.

7. Solids Level - 8 percent solids in recirculating slurry; 30 percent solids in limestone feed and thickener underflow; 55 percent solids in centrifuge cake and greater than 70 percent solids from the pug mill.

8. Reactant Addition - Limestone slurry is added to the recirculation tanks.

9. Reactant Feed Rate - 1.3 moles $CaCO_3$ per mole of SO_2 entering the scrubber.

10. Slurry Retention Time - 10 minutes in the recirculation tank.

11. Mist Eliminator - Two-stage chevron mist eliminator with prewash tray; the underside of the first stage is continuously washed with a 50-50 blend of make-up water and reclaimed water; the top of the first stage is washed intermittently with make-up water for five minutes every two hours.

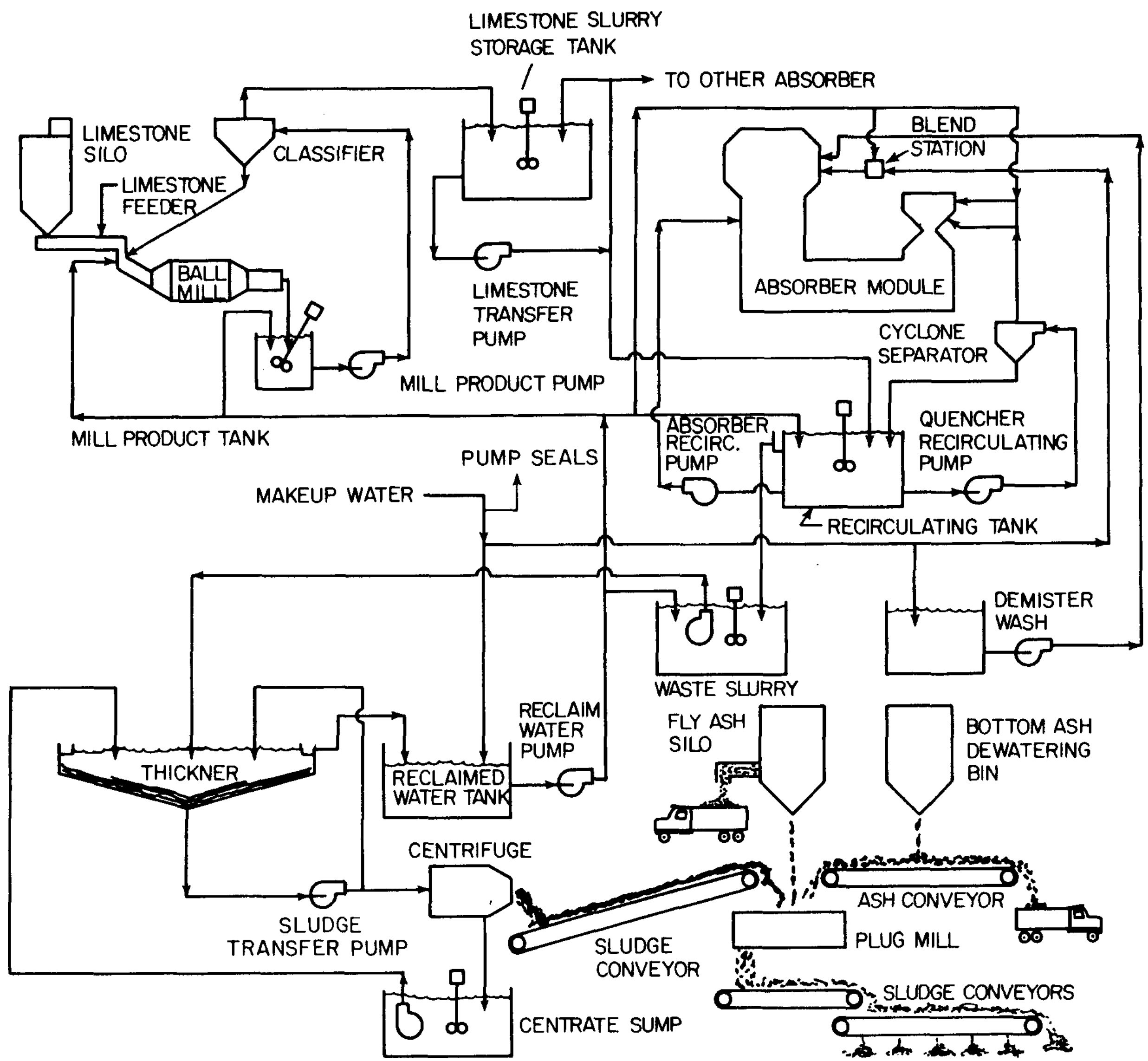


FIGURE 1. SCHEMATIC DIAGRAM OF MARION POWER PLANT FGD SCRUBBER SYSTEM

12. Reheat System - There is no stack gas reheat.

13. Waste Disposal - Closed-loop system; scrubber effluent is sent to a thickener, centrifuge, and pug mill where it is mixed with fly ash and dewatered bottom ash to get the right solids content for landfill. The centrate is returned to the thickener, and the thickener overflow is reclaimed for recycle to the system.

14. Fans - Two booster fans between the electrostatic precipitator and the absorbers. The fans are radial tipped centrifugal type.

C. RELIABILITY

1. Start-up - Sometime in April, 1979.

2. Availability - Not applicable before startup.

3. Longest Run - Not applicable before startup.

4. Calendar of Operation - Not applicable before startup.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - The prescrubber for this unit consists of a quench section in which the walls are steel covered with 30 to 40 mils of Resista-Flake 1251, and two inches of Kaocrete HS.

2. Absorber - The inlet to the absorber is constructed of Type 316L stainless steel. The wall of the absorber is constructed of carbon steel with a covering of 60 to 80 mils of Resista-Flake 1103. The absorber sump bottom has a similar thickness of Resista-Flake 1251. The spray header and the trays in the absorber are made of Type 316L stainless steel.

3. Spray Nozzles - The wall wash spray nozzles are made of Type 316L stainless steel with spray headers of fiberglass-reinforced plastic. The slurry spray nozzles also are Type 316L stainless steel.

4. Mist Eliminator - The mist eliminator housing is carbon steel with 60 to 80 mil thickness of Resista-Flake 1103 as a coating. There is a prewash tray which is Type 316L stainless steel. The chevrons are fiberglass-reinforced plastic. The hydroclone for the mist eliminator wash water is carbon steel lined with soft natural rubber plus some silicon carbide (Refrax) in the high abrasion areas.

5. Fans - The fans in this system are all carbon steel.

6. Reheater - None used.

7. Pumps - There are seven absorber recycle pumps all supplied by Ingersoll-Rand, all lined with soft natural rubber. The intermittent mist eliminator wash pumps, one operating and one spare, are standard and suction centrifugal, cast iron, supplied by Worthington. The limestone slurry transfer, mill product, and reclaimed water pumps are end suction rubber-lined centrifugal pumps supplied by A-S-H. The waste slurry and centrate pumps are vertical rubber-lined centrifugal sump pumps supplied by A-S-H. The sludge transfer pumps are diaphragm type pumps manufactured by Dorr-Oliver.

8. Tanks - The absorber hold tanks are constructed of carbon steel with a 30 to 40 mil coating of Resista-Flake 1103. The cover has a coating of 30 to 40 mils of Resista-Flake 1251. The mill product and limestone slurry storage tands are carbon steel with rubber lining. The mist eliminator wash tank is carbon steel with coal tar epoxy finish. The centrate and waste slurry sumps are concrete with a bitumastic coating. The reclaim water tank is carbon steel with a coating of Flakeline 103.

9. Agitators - The agitators in the absorber hold tanks were furnished by Lightnin'. The agitators in the mill product, limestone slurry storage, centrate and waste slurry tanks were furnished by Chemineer. All agitators are carbon steel with a rubber coating.

10. Storage Silo - The limestone storage sile is constructed of carbon steel.

11. Thickener - The thickener has a concrete base with steel sidewalls. All surfaces have a bitumastic coating.

12. Centrifuge - The centrifuge was supplied by Pennwalt-Sharples and is carbon steel.

13. Ducts, Expansion Joints, and Dampers - Both the inlet and outlet ducts are constructed of carbon steel. However, the inlet duct has no lining and the duct from the scrubber to the stack has a coating of Resista-Flake.

The expansion joints are Flow-Flex butyl rubber.

The booster fan inlet isolation dampers are dual-blade guillotine carbon steel dampers. The absorber outlet isolation dampers are dual guillotine dampers, made of Inconel 625. The bypass isolation damper is a double louver damper. The louvers closest to the stack are of Inconel 625, and the opposite side are carbon steel. All dampers are equipped with seal air systems, and were furnished by Mosser.

14. Piping and Valves - The piping on the absorber recycle system is carbon steel with a natural rubber lining. That on the limestone slurry system also is steel with a rubber lining. Fiberglass-reinforced plastic is used for the piping in the reclaim water, the waste, slurry, and the sludge piping. The piping on the pH control system is Type 316L stainless steel.

The large valves on the absorber recycle lines are Type 316L stainless steel knife gates. Other valves used on the systems include pinch valves, rubber coated plug valves, rubber coated butterfly valves, and fiberglass-epoxy type knifegates.

15. Stack - The stack has an acid-resistant brick liner. All metal components, including breeching between the liner and the concrete shell, are Inconel 625. A steel liner with Flakeline 151 coating was originally specified but was not used due to withdrawal of the coating product by the manufacturer.

16. Ball Mill - The ball mill (Koppers) is rubber-lined carbon steel.

MONTANA POWER COMPANY
COLSTRIP UNITS 1 AND 2

Trip Report Number: EPRI-CM27

Date of Trip: April 10, 1979

Persons Interviewed: Robert Olmstead, Plant Manager; Robert L. Hofacker, Senior Plant Engineer; and John Horst, Waste Water Engineer.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Combustion Equipment Associates (CEA) is the process designer, vendor, and contractor; Bechtel is the consulting engineer; new boilers.

2. Boiler Type - Combustion Engineering tangential-fired, pulverized coal, dry bottom boilers; Units 1 and 2 are each rated at 330 MW but can operate at 360 MW with 5 percent overpressure; heat rate is about 9400 Btu/kWh. (Currently operates between 300 and 320 MW.)

   a. Excess air is normally 21 percent.

   b. Capacity factor is not established yet; it may be greater than 70 percent since the plant is a base load unit.

   c. Each unit has a 503-ft stack; stack velocity is 95 ft/sec.

3. Flue Gas Flow Rate - 1,430,000 acfm at 291 F per boiler; all the flue gas passes through the scrubbers and there is no bypass.

   a. As high as 5 percent oxygen in the flue gas because of some leaks.

4. SO_2 Concentration - 600 ppm SO_2 in inlet gas and about 200 ppm SO_2 in outlet gas.

5. Fuel - Colstrip coal containing about 0.7 percent sulfur (range: 0.4% - 1%), 8.5 percent ash (range: 6.1% - 12.6%), and 21 to 25 percent free moisture; heat content is about 8,500 Btu/lb.

6. Scrubber Reactant - Pebble lime containing 90 percent CaO; the lime is trucked from Rapid City, South Dakota, at a cost of $58.05/ton delivered; the system is designed for continuous lime addition, but lime is only added at higher boiler loads; the fly ash contains about 16 to 21 percent CaO and 5 percent MgO.

7. Removal Efficiency - 75-80 percent SO_2 removal for 0.7 percent sulfur coal and greater than 99.5 percent fly ash removal; probably no NO_x removal in scrubber. SO_2 emissions of 0.6 lb/10^6 Btu are met 99 percent of the time.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables - Effluent to the sludge pond is 1300 gpm, effluent to the tray pond is 1875 gpm, and makeup water requirement is 500 gpm; the steam required for stack gas reheat is 1620 lb/min.

a. Inlet gas temperature to scrubber is 291 F.

b. Outlet gas temperature from scrubber is 110 to 120 F prior to reheat.

c. Fly ash inlet loading to scrubber ranges from 1.9 to 3.6 grains/acf; outlet loading is 0.03 to 0.13 grains/dry scf.

d. pH of recirculating scrubber slurry is 4.5 to 5.5; pH of recirculating wash tray water is 3.8 to 3.9.

3. Absorber Design -

a. Plumb bob venturi scrubbing vessel for particulate removal (see Figure 2).

b. The same scrubbing vessel is used for SO_2 removal, but after passing downward through the venturi throat the gas turns 180 degrees and passes through a lower absorber spray and then through a Koch tray which is concentric to the venturi portion of the scrubber.

c. The gas velocity is 170 to 220 ft/sec in the venturi throat and 5.8 to 11 ft/sec (superficial) in the concentric section with a design value of 8.7 ft/sec.

d. There are three scrubbing modules per boiler, each capable of handling 40 percent of the total flue gas flow rate; each module can be operated down to 50 percent of design capacity.

4. Liquid-to-Gas Ratio - The total L/G is 33 gal/10^3ft^3 at rated flow which includes the plumb bob spray, the tangential spray in the venturi dome, and the lower absorber spray; the L/G to the plumb bob and venturi dome is 15 gal/10^3ft^3. Slurry flow remains constant with variable gas flow.

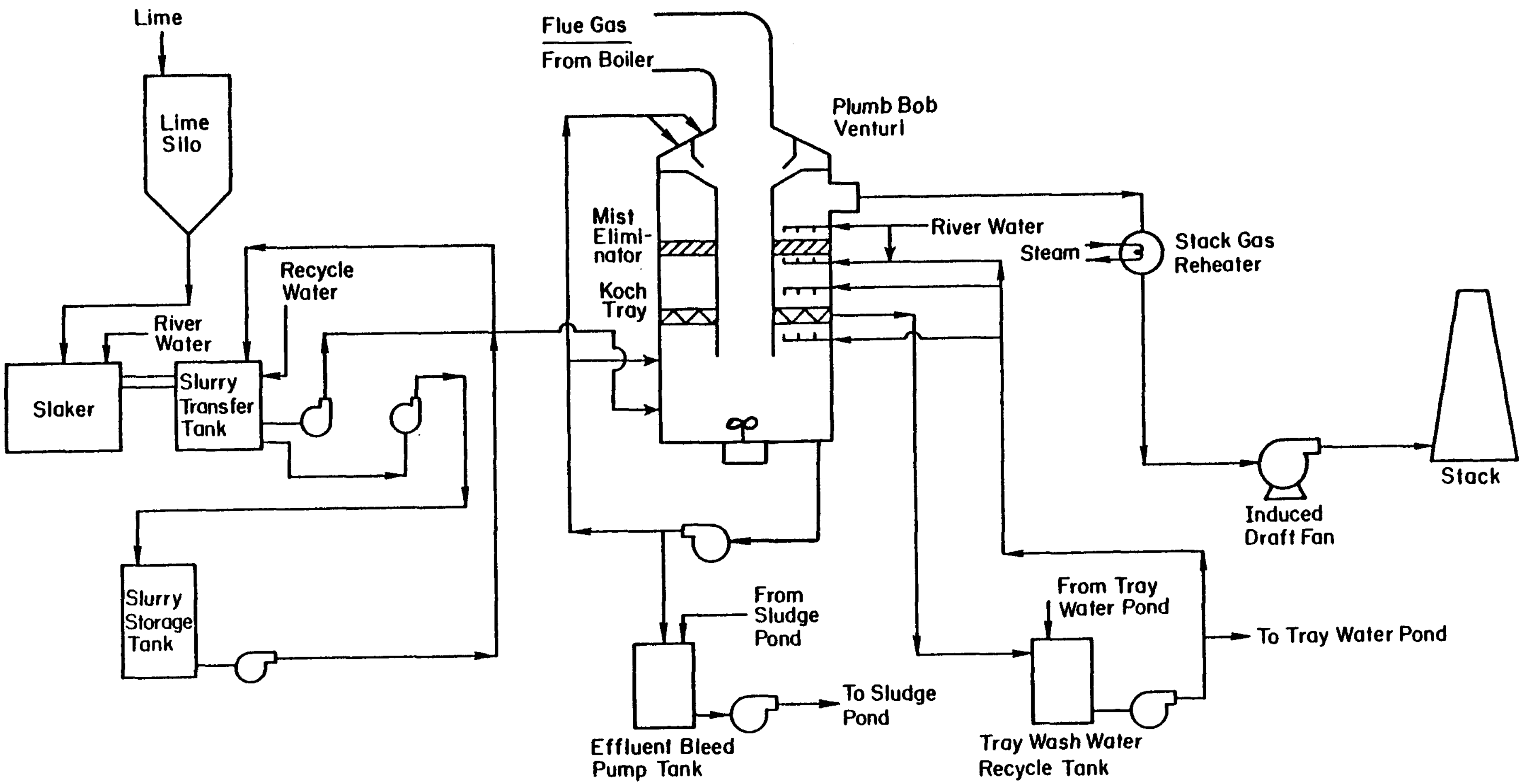


FIGURE 1. SCHEMATIC FLOW SHEET FOR FLUE GAS SCRUBBING AT COLSTRIP

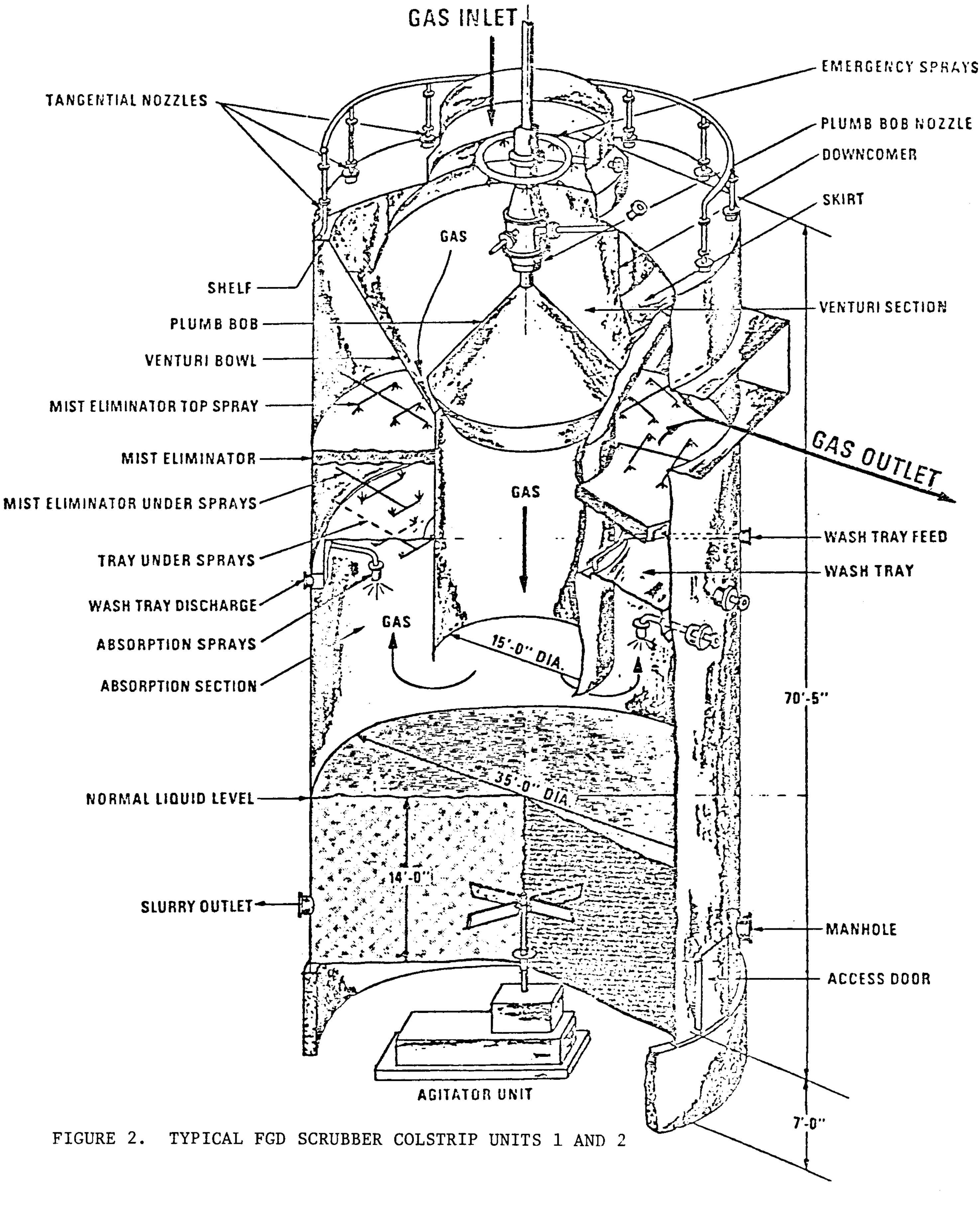


FIGURE 2. TYPICAL FGD SCRUBBER COLSTRIP UNITS 1 AND 2

5. Oxidation - The recirculating scrubber slurry was analyzed by Battelle about 2-1/2 years ago and found to contain less than 0.04 percent sulfite on a dry basis; this is not surprising for a system burning low-sulfur coal with fly ash and SO_2 removal in the same scrubber.

6. Pressure Drop - The total system pressure drop is 38 in. H_2O; the pressure drop is 17.5 in. H_2O in the venturi, 5 in. H_2O across the wash tray and mist eliminator, and 2.9 in. H_2O through the stack gas reheater.

7. Solids Level - The recirculating slurry contains 12 percent suspended solids and 3 percent dissolved solids; based on an analysis performed at Battelle, the suspended solids are about 60 percent fly ash, 39.8 percent $CaSO_4 \cdot 2H_2O$, and 0.2 percent $CaCO_3$.

8. Reactant Addition - Lime is added as a 10 percent slurry just above the water level in the bottom of the scrubber; the point of addition is below the absorber sprays.

9. Reactant Feed Rate - Lime usage is about 5 tons/day per unit. This is equivalent to about 0.16 moles calcium per mole of SO_2 removed. The balance of the calcium comes from the ash.

10. Slurry Retention Time - The bottom of the scrubber acts as a hold tank with a retention time of 8 minutes.

11. Mist Eliminator - Four-pass chevron mist eliminator made by Heil with hooks on the trailing edge to minimize reentrainment; the mist eliminator is located above the Koch tray and is also concentric to the venturi portion of the scrubber; the superficial gas velocity is 5.8 to 11.9 ft/sec; the mist eliminator is continuously sprayed from underneath with 300 gpm of wash tray recycle water and 60 gpm of fresh water; each section is sprayed from above with river water for 20 minutes every 24 hours at a rate of 450 gpm.

12. Reheat System - Platecoil® heat exchangers manufactured by Tranter, Inc., are located in the duct; the lower row of banks is constructed of Hastelloy G and the upper row of banks is constructed of Inconel 625 with steam soot blowers between the two rows; a typical bank has 11 Platecoil®, each 43 in. by 143 in., to provide 1060 ft^2/bank; there are 6 banks per row; 150 psig steam is used to provide 60 F of reheat; additional reheat is supplied by friction in turning vanes and duct. Reheater is overhauled once a year.

13. Waste Disposal - Closed-loop system; the solids level of the scrubber slurry is kept at 12 percent by means of a bleed stream to an effluent storage tank and then to the clay-lined sludge pond; the supernate from the sludge pond is recycled to the effluent storage tank; there is a separate clay-lined pond 355 ft by 210 ft by 14 ft for the tray water recycle system; the separate pond for tray water results in less total solids in the tray

return water; the return water from the tray pond has 2.7 percent total solids and 2 percent dissolved solids, while the return water from the sludge pond has 3 percent total solids and 2 percent dissolved solids; the tray pond is below saturation with respect to $CaSO_4$ while the sludge pond is above saturation.

14. Fans - One carbon steel, induced draft fan per scrubber located after the reheater.

C. RELIABILITY

1. Start-up - Unit 1 started up in September, 1975, and began commercial operation in November, 1975; Unit 2 started up in May, 1976, and began commercial operation in August, 1976.

2. Availability - Since there is no bypass, the scrubbers must operate whenever the boilers operate; two scrubbing modules are capable of handling 80 percent of the boiler load. The date of Battelle's visit, one boiler was down for overhaul; the other was down for a few hours due to an air preheater problem. There was no problem that day with the scrubbers. Montana Power estimates the scrubber availability now to be about 95 percent defined as hours the FGD system is available for operation (whether operated or not) divided by hours in period.

3. Longest Run - Now about 16 weeks with one module; need for cleaning of mist eliminators and repair of flake lining eventually shuts down the scrubber.

4. Calendar of Operation - The scrubbers operate whenever the boilers operate; Unit 1 has operated for about 30,000 hours and Unit 2 for about 25,000 hours.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - No prescrubber is used.

2. Absorber - The absorber walls are carbon steel and originally had two 40 mil coats of Rigiflake 4850 lining. However, the lining was not applied properly and adhered poorly to the base metal. The lining was replaced with Plasite 4030 from the top of the absorber to the downcomer and with a 6 to 12 ft band of Plasite 4020 below the downcomer. The lining below the Plasite 4020 is still Rigiflake 4850. All of these linings have performed satisfactorily thus far. The absorber floor still has its original Rigiflake lining which was described as an abrasion resistant, hard, black material about 1/2 to 1-inch thick. The absorber tray is Type 316L stainless steel and has presented no problems.

3. Spray Nozzles - The tangential nozzles in the venturi, those under the absorber tray, and those to wash the mist eliminator are all Type 316L stainless steel. The absorber spray nozzles are alumina ceramic.

4. Mist Eliminator - The mist eliminator is constructed of Noryl® plastic. Even without temperature excursions there have been problems with sagging and melting of the chevrons. As a result, about 30 percent of the chevrons are replaced each year.

5. Fans - Three Buffalo Forge ID fans are employed. They are located after the reheater and are constructed of mild steel with a Cor-Ten center plate and a rubber-lined housing. Weld defects have required some new center plates. There has been some "checking" of the rubber linings and patching has been required. These linings are being replaced with a chlorobutyl rubber.

6. Reheater - The lower banks of the reheater are Hastelloy G, and the upper banks are Inconel 625. Cracks have developed on the outlet line of plates, because of a lack of flexibility in the line. There also has been some cracking on the top of the plates, but it occurred during installation rather than as a result of corrosion. Copes-Vulcan sootblowers are used in the reheater. Feed tubes and lances for the sootblowers are Type 316L stainless steel. Some feed tubes have bent and some lances have become scored. The latter are being replaced by a Timken type when the scoring becomes serious.

7. Pumps - The pumps connected with the scrubber liquids are all rubber-lined A-S-H Models C65 and D65. The lime system pumps are unlined carbon steel (Worthington). The carbon steel pumps on the pond return line (Ingersoll-Rand) do not have large enough capacity. There have not been any materials problems with the pumps.

8. Tanks - All tanks in the system are carbon steel coated with Rigiflake 4850. No serious problems have been encountered with these surfaces. During the annual overhaul some patching is necessary because of damage during cleaning of the tanks.

9. Agitators - The agitator in the tray recycle tank is a Lightnin' Mixco with rubber-coated mild steel shaft and blade and a Type 316 stainless steel hub. All of the other agitators are by Chemineering and have a Type 316 stainless steel shaft and rubber-coated mild steel blade. The packing sleeves on the Chemineering mixers originally were chromium plated, but have now been replaced with tungsten carbide sleeves.

10. Storage Silo - The lime storage silo is carbon steel and has presented no problems.

11. Thickener - None used.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The inlet duct to the venturi is carbon steel. The outlet duct from the absorber to the stack has a coating of Rigiflake 4850 on carbon steel. The reheater duct is Type 316L stainless steel. There have been no problems with ducts.

A fiber-reinforced rubber is employed for the expansion joints on both the inlet and the outlet of the scrubber. There has been some erosive wear on the inlet joint and replacement is necessary. The same material will be used, however.

The inlet dampers are carbon steel butterfly type (Allis-Chalmers). The gaskets are gone after 2 years of use. The high pressure drop (> 40 inches of water) has caused some distortion and stiffeners are needed. The outlet dampers are guillotine type (Mosser) and have a Type 316 stainless steel blade and angle iron. Some minor seal problems have developed.

14. Piping and Valves - Most of the piping in the system is carbon steel with a 1/4-inch natural rubber lining, which has been no problem. However, the makeup lines and the feed to the tray pond return pumps are underground and are FRP. These lines have been damaged in cold weather as a result of shocks from mining operations and it is planned to replace them with rubber-lined steel piping. Erosive wear in the slurry recycle line has required replacement of elbows every 6 months. Those in the recycle discharge line are replaced annually.

DeZurik plug valves with natural rubber lining were installed initially, but the larger ones (12-18 inch) required replacement after a year of operation. The replacements have been R.K.L. pinch valves with fiber-reinforced rubber lining. These are particularly desirable where throttling is necessary. The tray recycle system has valves of Type 316 stainless steel which have given no problems.

15. Stack - The stack has a carbon steel liner with a Flakeline 151 coating. The lining appears to be in good condition, but has only been observed up to the 250 ft level. A full inspection is due soon.

16. Slaker - Not discussed.

17. Pond Lining - The two scrubber ponds are lined with bentonite clay.

E. COMMENTS

The lime feed system is being revised (controls, pumps, pipings, etc.) with plans for switching to automatic control as much as possible. Montana Power is planning to enclose the scrubbers for freezing protection during periods of repair or maintenance. During the winter, temperatures frequently drop to as low as -40 F. As far as on-line capability is concerned, however, freezing is a minimal problem. Montana Power would like to provide a means of cleaning under tray spray headers on-line (to reduce shut-down time) by redesigning the system to remove one spray header at a time. They are replacing, or will replace, fiberglass slurry lines with rubber-lined pipe because of damage to this brittle plastic material in cold weather as a result of vibrations and settling caused by nearby mining operations. Montana Power would also like to replace the bottom entering mixers at the base of the scrubbers with side- or top-entering units in order to simplify maintenance of this equipment.

MINNKOTA POWER COOPERATIVE (MPC)
MILTON R. YOUNG UNIT 2

Trip Report Number: EPRI-CM28

Date of Trip: April 11, 1979

Persons Interviewed: Philip Richmond, Plant Chemical Engineer, Milton R. Young Station, MPC.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Combustion Equipment Associates (CEA) is the designer and vendor; Sanderson and Porter, and A. D. Little are the consulting engineers; CEA is responsible for equipment construction and installation; new installation.

2. Boiler Type - Babcock and Wilcox cyclone type, rated at 438 MW. It is currently operating at about 460 MW. It contains 12 cyclones, each of which consumes up to 30 tons of lignite per hour. The heat rate is about 10,500 Btu/kWh.

   a. The boiler uses about 22 to 28 percent excess air.

   b. The unit is intended to be baseload, and has operated at an average load of 70 ro 75 percent during the week and 50 percent load on weekends.

   c. The stack is 550 feet high.

3. Flue Gas Flow Rate - The design value is 2,030,800 acfm at 350 F. This is 85 percent of the total flue gas. Each scrubber can take up to 56 percent of the total boiler flue gas.

   a. Oxygen content of the flue gas is about 5 to 6 percent.

4. SO_2 Concentration - From 400 to 1500 ppm SO_2 in inlet gas and 380-410 ppm in outlet gas (or 0.7 - 1.1 lb $SO_2/10^6$ Btu).

5. Fuel - The fuel contains about 0.7 percent sulfur (average) with a maximum of about 1.5 percent (range is 0.3% - 1.5% S). Its heating value is about 6500 - 6600 Btu/lb, and it contains about 9 percent ash. It is air dried down to about 28 percent moisture from an as-mined value of about 40 percent.

6. Scrubber Reactant - The reagent for scrubbing is slurried fly ash from Units 1 and 2. The ash composition is shown in Table 1. About 40 percent of the ash ends up as fly ash. About 16 tons/hr are available. Lime is 1/4-inch lump from Rapid City, South Dakota (same source as for Colstrip), and costs $60 per ton. The lime is required if the SO_2 content of the flue gas is above 1100 ppm.

TABLE 1. X-RAY FLUORESCENCE ANALYSIS OF FLY ASH FROM UNIT NO. 1

Date	11-5-76	9-13-76	Average for March thru August 1976 not including June and July 1976
Ignition loss	3.4	2.1	3.0
Silica	28.5	32.9	32.8
Aluminum oxide	12.8	14.6	13.9
Ferric oxide	8.8	9.5	9.3
Titanium oxide	0.5	0.6	0.6
Phosphorus oxide	0.4	0.3	0.4
Calcium oxide	20.1	24.6	22.3
Magnesium oxide	5.9	8.2	6.4
Sodium oxide	7.0	1.1	3.3
Potassium oxide	1.7	1.9	2.0
Sulfur trioxide	12.1	4.1	5.8
Total	100.1	99.9	99.7

7. Removal Efficiency - Design particulate removal in the precipitators is 99.8 percent, and 55 to 85 percent of the remaining fly ash is removed by the scrubber. At the highest SO_2 concentration, 75 percent of the SO_2 entering the spray towers is removed.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables -

a. Inlet temperature of flue gas to the scrubber is 350 F ($\pm$ 30 F).

b. Outlet gas temperature from the scrubber is 140 F (170 F after reheat).

c. Fly ash inlet loading to the scrubber is about 0.0162 grains/acf; outlet loading from the scrubber is 0.0002 to 0.0035 grains/scf; outlet loading to stack depends upon how well ESP works since 15 percent of the flue gas is bypassed for reheat.

d. pH of the scrubbing liquor is about 7.4 - 8.6 (pH is 4.0 - 5.5 at scrubber bottom).

3. Absorber Design -

a. Electrostatic precipitator for primary particulate removal followed by CEA spray tower.

b. Spray tower provided with six spray zones; countercurrent flow of slurry and flue gas; no packing is employed; the FGD system has two scrubber modules.

c. The superficial gas velocity in the spray tower is about 9.1 ft/sec.

d. A turndown ratio of 4:1 can be achieved by manipulating the absorber wash tray recycle flow; the gas flow rate needs to be high enough to prevent liquid from weeping through the perforated plate wash tray.

Sets of boiler draft fans	Boiler Load, MW	Tray recycle feed
2	280-440	In service
2	220-280	Out of service
1	140-220	In service
1	110-140	Out of service

For loads less than 220 MW with both sets of draft fans in service, or 110 MW with one set of draft fans, the scrubber is shut down.

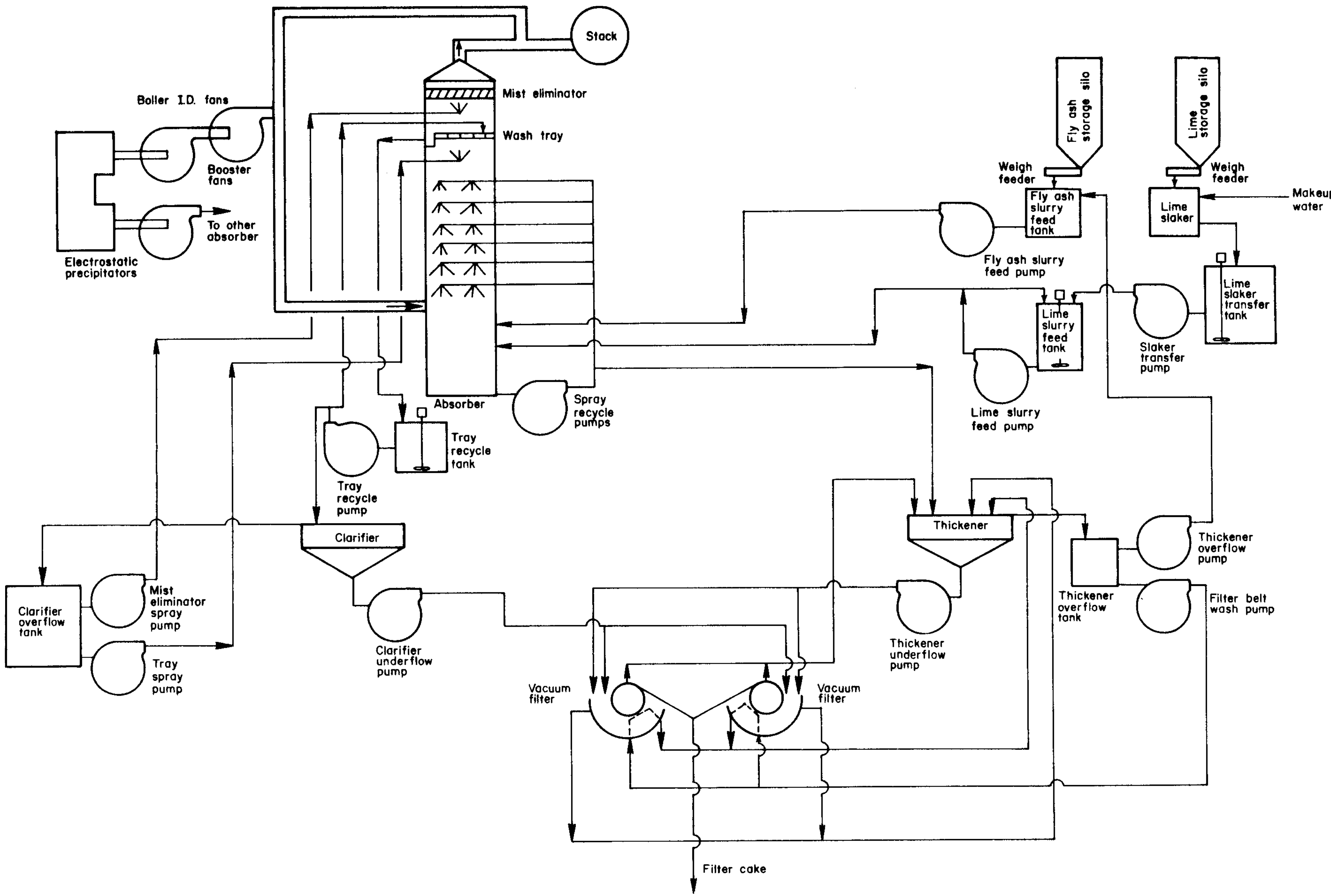


FIGURE 1. FLOW SHEET FOR SO_2 CONTROL AT THE MILTON R. YOUNG STATION

4. Liquid-to-Gas Ratio - The total L/G in the absorber is approximately 80 gal/1000 acfm.

5. Oxidation - MPC has an analysis of the sludge showing it to be sulfate (about 100 percent oxidation).

6. Pressure Drop - A total pressure drop of about 5.5 inches of water was reported, including 1.0 in the spray tower, 0.5 in the mist eliminator, 3.5 in the wash tray, and 0.5 in the ducts. The system is designed to deliver +0.9 inch W.G. at the stack breeching.

7. Solids Level - The system design involves a 12 percent solids level in the slurry with transfer velocities of about 7 ft/sec. (Ranges are 2 percent - 10 percent for dissolved solids and 6 percent - 12 percent for suspended solids.)

8. Reactant Addition - The fly ash slurry is added near the base of the spray tower.

9. Reactant Feed Rate - Fly ash with minor amounts of added lime; about 16 tons/hr fly ash is used at 960 ppm SO_2 inlet (design basis is 4 tons/hr of lime if coal has 1.5 percent sulfur). Overall stoichiometry is about 1.2 moles of total Ca/mole of SO_2 removed.

10. Slurry Retention Time - An eight-minute retention time is designed for the slurry at the base of the absorber.

11. Mist Eliminator - The mist eliminator is a one-stage, horizontal, chevron-type, Z-shaped, 120-degree smooth angle bend, 4-pass unit. The unit is located 8 ft above a knockout tray, which is located 5 ft above the top spray nozzles. 220 gpm of fresh water plus 160 gpm of wash-tray clarifier overflow is continuously sprayed upward toward the underside of the mist eliminator in each module at a pressure of 80 psig. The knockout tray is a perforated plate continuously washed with an underspray of 220 gpm of wash-tray clarifier overflow at a pressure of 80 psig.

12. Reheat System - Fifteen percent of the flue gas is bypassed and then mixed in carbon steel duct work lined with Flakeline 103, with the 85 percent of the flue gas that is wet scrubbed. No special mixing chamber is employed. 30 F of reheat is provided (140 F to 170 F).

13. Waste Disposal - A bleed stream is taken off the recycle to both scrubbers and sent to a common thickener. The thickener bottoms, together with the bottoms from the common clarifier on each of the wash-water tray loops, are sent to the rotary vacuum filters whenever the solids level reaches about 30 percent solids. Two rotary vacuum filters, operating in parallel, are housed in a separate building. The filter cake, which is produced at a rate of 35 tons/hr under design conditions, is transported by conveyor to three 35-ton off-the-road trucks for hauling back to the

mine without further treatment. Water recovered in the process is used for fly ash slurry preparation. During upset conditions (mechanical malfunctions, high flow rates), the sludge from the vacuum filter system can be piled outside the vacuum filter building for handling by front-end loaders and off-the-road trucks.

14. Fans - The booster fans are located between the ESPs and the scrubbers. Each scrubber has its own booster fan in series with the ID fan. The bypass damper is louvered and the reheat inlet and outlet dampers are guillotine. Fans are axial flow.

C. RELIABILITY

1. Start-up - Unit went commercial on May 1, 1977. Two modules were first placed in simultaneous service about a year later on June 4, 1978.

2. Availability - The average availability defined as total hours available/total hours in year 1978 was 46.1 percent. For details on availability, see Table 2.

3. Longest Run - Twenty-four days on one module.

4. Calendar of Operation - Not available.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - None used.

2. Absorber - The absorber walls are carbon steel with a 60-80 mil coating of Flakeline 103 (Ceilcote). The only area requiring repair of the coating has been on top of the tunnel, where spray impingement caused 4 holes to develop. The wash tray is Type 316L stainless steel.

3. Spray Nozzles - The absorber spray nozzles are made of an alumina ceramic. The mist eliminator wash nozzles are Type 316L stainless steel.

4. Mist Eliminator - Noryl polyphenylene oxide is used for the mist eliminator. There have been no problems with this material. An emergency water spray has been provided to prevent overheating if the absorber liquid flow is lost and hot gases pass through before bypass is achieved.

5. Fans - The ID and booster fans are all on the hot side and are constructed of carbon steel. They are K.K.K. fans supplied by B&W.

6. Reheater - Reheat is supplied by partial flue gas bypass. The gases are mixed in a flake-lined carbon steel duct with no special mixing chamber.

7. Pumps - There are 5 slurry recycle pumps (A-S-H) on each tower. These pumps are carbon steel with a rubber lining, which can be pulled out if a positive pressure is not maintained. The tray recycle pumps

TABLE 2. FGD UPDATE REPORT FOR 1978
MILTON R. YOUNG UNIT 2

Total hours in year = 8760
Hours boiler in operation = 6926
Hours FGD system available = 4040
Hours FGD system is called upon = 6776
Hours FGD system in operation = 3650

$$\text{Availability} = \frac{4040}{8760} = 46.1\%$$

$$\text{Operability} = \frac{3650}{6926} = 52.1\%$$

$$\text{Reliability} = \frac{3650}{6776} = 53.9\%$$

$$\text{Utilization} = \frac{3650}{8760} = 41.7\%$$

The above indices are calculated as defined in the report "EPA Utility FGD Survey", EPA-600/7-78-015d, (PEDCo, November, 1978).

Based on the total number of hours FGD system was down while the boiler was operating, the percentage of responsibility for downtime was distributed as following between the two scrubbers.

Reason for Downtime	Scrubber A	Scrubber B
	%	%
Booster and Fan	51	9
Thickener and Vacuum Filter	25	35
Guillotine Dampers	15	34
Spray Recycle Pump & Lining	2	2
Instrumentation	0	5.5
Flake Lining Failure	0	9
Lime & Fly Ash Feeder	2	0
Stand-by	0	5
Miscellaneous	5	0.5
Total	100.	100.

and the thickener underflow pumps (Worthington) also are rubber lined. The latter require lining replacement every 6-9 months as a result of erosion by the fly ash. The fly ash slurry pump is an erosion-resistant hard metal of unknown specifications (possibly Ni-Resist). The lime slurry pumps are rubber-lined carbon steel. The only unlined steel pump is that for the clarifier overflow.

8. Tanks - The recycle tanks are the tower bottoms and are carbon steel with a Flakeline 103 lining. All other tanks are carbon steel with a Dudick lining (no further identification provided).

9. Agitators - The agitators in the absorber and the spray recycle tanks are Type 316L stainless steel. Those for the fly ash slurry and lime slurry tanks are carbon steel.

10. Storage Silo - The silo is constructed of carbon steel.

11. Thickener - The thickener and clarifier have a Dudick (lining name not provided) fiberglass - reinforced resin liner. There have been problems with the lining breaking away from the wall on the thickener tank. The thickener rakes and paddles are rubber-coated carbon steel. The coating wears off the bottom of the paddles and a stainless steel bottom for them is being considered. The cone at the bottom of the thickener was torn off after 6 months of operation and was replaced with stainless steel.

12. Vacuum Filter - The filter is rubber lined (Envirotech) and has polypropylene cloth. The chief problem has been settling of the heavy components, which then plug the vat. If the pH in the absorber becomes either too high or too low, it is hard to remove the filter cake from the cloth.

13. Ducts, Expansion Joints, and Dampers - The inlet ducts are carbon steel. The outlet ducts are coated internally with Flakeline 103. The only problem has been with condensate forming in the outlet duct and leaking into the inlet duct, which then corrodes. The outlet ducts are located above the inlet ducts and the condensate leaks through the damper bonnets.

The expansion joints on the inlet side are a Viton®-asbestos type. Those on the outlet side are chlorobutyl rubber and asbestos. The frames are all carbon steel.

The guillotine dampers on the inlet are carbon steel, while those on the outlet are Type 316 stainless steel. It has been necessary to replace the chains which open and close the dampers with stainless steel because of corrosion.

14. Piping and Valves - The lime slurry piping is unlined carbon steel. All other piping larger than 3-inch-diameter is rubber lined. Fly ash erosion has required some lining replacement. Lines smaller than 3 inches are Type 316 stainless steel.

R.K.L. rubber-lined pinch valves are used on the slurry recycle lines. DeZurik plug valves with rubber lining are used elsewhere, and are showing wear of the linings.

15. Stack - The stack has a concrete shell and a Cor-Ten steel liner. There has been some condensation on the liner where external insulation was removed from small areas to install holes for stack monitoring, but no corrosion has occurred yet.

16. Slaker - The lime slaker is constructed of carbon steel.

17. Pond Lining - There is no pond at present. One is being considered for the thickener and spray tower drains, which at present have nowhere to go.

NORTHERN STATES POWER COMPANY (NSP)
SHERBURNE COUNTY UNITS 1 AND 2

Trip Report Number: EPRI-CM29

Date of Trip: April 12, 1979

Persons Interviewed: Rickey J. Kruger, Environmental and Chemical Systems Supervisor; and Steve Bluhm, Chemical Engineer

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Combustion Engineering is the process designer and vendor; Black and Veatch are the consulting engineers; new boilers.

2. Boiler Type - Tangential fired, pulverized coal, controlled circulation boiler; 720 MW gross and 680 MW net; heat rate is 9300 Btu/kWh.

   a. 20 percent excess air.

   b. Capacity factor is about 70 percent.

   c. Units 1 and 2 have a common 650-ft stack; stack velocity is about 90 ft/sec.

3. Flue Gas Flow Rate - 2,431,000 acfm at 266 F; all the flue gas passes through the scrubbers and there is no bypass.

   a. 3.5 to 4 percent oxygen before air preheater and 5.5 to 7 percent oxygen in stack; air preheater has 6 to 10 percent leakage and there is also some leakage in the scrubbers.

4. SO_2 Concentration - 600 to 700 ppm SO_2 in inlet gas and 300 to 350 ppm SO_2 in outlet gas.

5. Fuel - Colstrip coal from Rosebud and McKay seams in Montana; 0.8 percent sulfur, 9 percent ash, and 25 percent free moisture; heat content is 8300-8500 Btu/lb; coal is delivered by rail.

6. Scrubber Reactant - Limestone containing 95 percent $CaCO_3$; crushed to equivalent of 80 percent through 200 mesh in a wet ball mill and delivered as a 4 percent slurry to each module's reaction tank; fly ash contains about 17 percent CaO and 5 percent MgO.

7. Removal Efficiency - 65 percent SO_2 removal; 99 percent fly ash removal; no removal of NO_x has been detected on spot checks. Limits for the SherCo stack emissions are: 0.96 lbs $SO_2/10^6$ Btu and 0.087 lbs particulates/10^6 Btu.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables - The recirculating scrubbing liquor contains 500 to 600 ppm calcium, 3000 to 9000 ppm magnesium, 10,000 to 30,000 ppm sulfate, 300-500 ppm chloride, and no sulfite. Pond water return has 100-200 ppm chloride.

a. Inlet gas temperature to scrubber is about 300 F.

b. Outlet gas temperature from scrubber is 130 F before reheater; 171 F after reheater.

c. Fly ash inlet loading to scrubber is about 3 to 3.5 grains/dry scf; outlet loading is 0.04 grains/dry scf.

d. pH of recirculating scrubbing liquor is 5.5.

3. Absorber Design - Refer to Figure 2.

a. Venturi rod scrubber for particulate removal; scrubber has two offset rows of rods with one row being manually adjustable; the rods are Type 316L stainless steel, 2.5 in. in diameter and 2 ft 2 in. long.

b. One-stage marble bed for SO_2 removal; the limestone and ash in the slurry remove part of the SO_2 in the venturi rod scrubber; both scrubbing stages have a common recirculation tank. About 25 percent of the marble beds have now been replaced by spray units.

c. The superficial gas velocity in the marble bed scrubbers is 7 to 10 ft/sec.

d. One scrubbing module can operate from 105 percent to 85 percent of design gas flow rate; the system was designed with 12 scrubbing modules, but with one scrubber always off-line for maintenance; turndown can be achieved by taking additional scrubbers off-line; a computerized control system is now being used to put scrubbers in and out of service.

4. Liquid-to-Gas Ratio - Total L/G is 27 gal/10^3 ft^3; 15 gal/10^3 ft^3 goes to the venturi rod scrubber and 12 gal/10^3 ft goes to the marble bed. L/G ratios will be increased by about 20 percent in the future for increased SO_2 removal and as a safety factor.

5. Oxidation - Air sparging is done in the reaction tank to achieve complete oxidation to sulfate; 3 blowers are available but only two at a time are used; 350 percent of the stoichiometric amount of air is used for sparging.

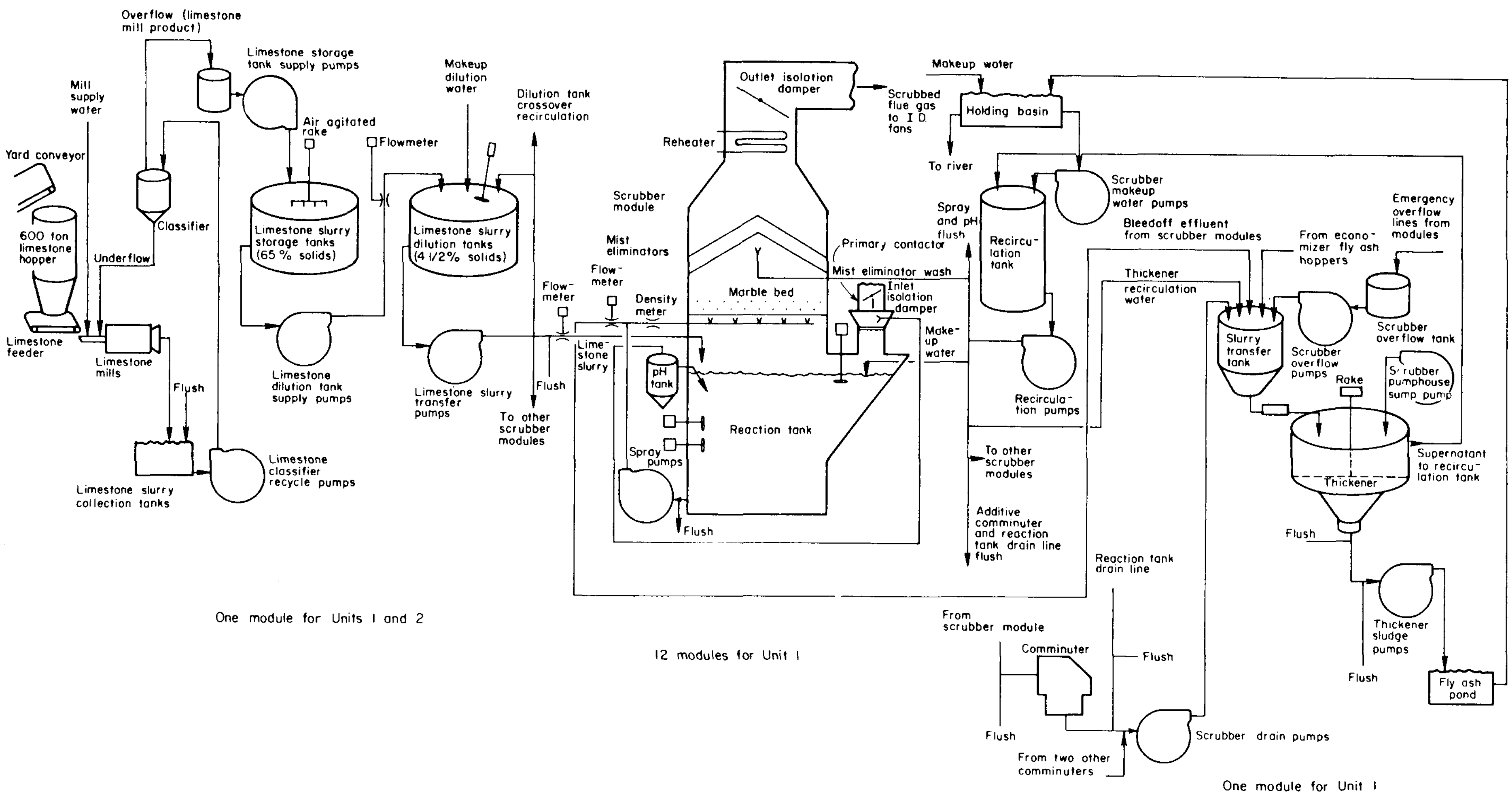


FIGURE 1. FLOW SHEET FOR WET SCRUBBING OF FLUE GAS AT SHERBURNE UNITS 1 AND 2

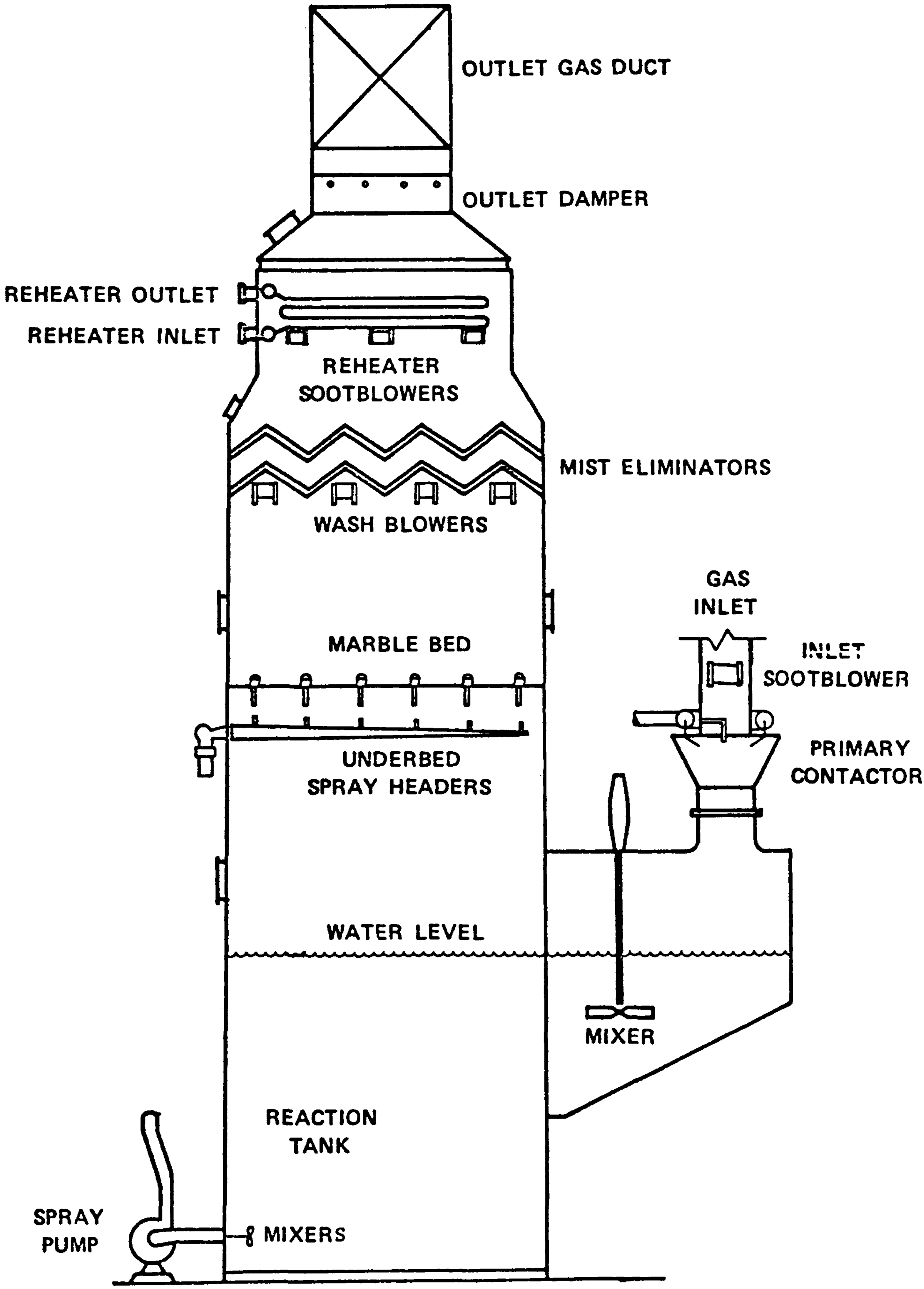


FIGURE 2. SHERBURNE COUNTY SCRUBBER MODULE

6. Pressure Drop - Total system pressure drop is about 21-23 in. H_2O including ducts and dampers; the pressure drop is about 14 in. H_2O in the venturi rods and about 6 in. H_2O in the marble bed.

7. Solids Level - 10 percent solids in recirculating slurry (2 percent $CaSO_4$ and 8 percent fly ash and unreacted limestone); it is desirable to control the $CaSO_4$ solids content.

8. Reactant Addition - Limestone slurry is diluted from 65 percnet solids to 4 percent solids with make-up water and is added to the reaction tank in the bottom of the scrubber.

9. Reactant Feed Rate - Three to 3-1/2 tons/hr of limestone are used for each unit at full load. On the assumption that all the sulfur in the coal is converted to SO_2 in the flue gas, the stoichiometric ratio is 0.55 to 0.65 moles calcium (from limestone)/mole of SO_2 removed; the remainder of the alkalinity is supplied by the coal which has a Ca/S mole ratio of about one.

10. Slurry Retention Time - About 12 minutes in reaction tank at the bottom of the scrubber but this is expected to decrease when L/G ratio is increased; 26 ft by 18 ft rectangular tank (ca. 66,000 gallons capacity) with one vertical and two horizontal mixers; the horizontal mixers are on the same side of the tank and mixing is unsatisfactory; the spargers are located below the horizontal mixers.

11. Mist Eliminator - Two-stage chevron mist eliminator of the standard Combustion Engineering design (inverted V configuration with Z-shaped sections of three passes each) located 10.5 ft above the marble bed; the blades are 1/4 inch thick FRP; the superficial gas velocity is the same as in the marble bed scrubber (7 to 10 ft/sec); the mist eliminator is washed with scrubber makeup water once every 24 hours when the module is down; there are four washers per module, all located below the first stage; the mist eliminator is washed for 3 to 4 minutes at a rate of 500 gpm per washer.

12. Reheat System - Four rows of finned carbon steel tubes located 10 ft above the mist eliminator section; the steel tubes contain hot water at 265 to 230 F; the stack gas is reheated from 130 to 170 F.

13. Waste Disposal - Fly ash pond and holding basin are lined with 18 in. of clay; fly ash pond is 62 acres by 50 ft deep and has a capacity of 900 x 10^6 gal; there is a continuous discharge from the holding basin to the river to keep down the level of dissolved solids. Estimated solids to disposal is 84,000 lb/hr.

14. Fans - Four ID fans for each unit; there is a header system with one fan capable of servicing any three scrubbing modules of both units; the fans are downstream from the reheaters.

C. RELIABILITY

1. Start-up - Unit 1 started up on March 16, 1976, and commercial operation began on May 1, 1976; Unit 2 started up on January 25, 1977, and went into commercial operation on April 1, 1977.

2. Availability - Operability is 100 percent when defined as scrubber operating hours divided by boiler operating hours because there is no bypass; however, there have been many outages, not all scrubber related; scrubber problems cause plant deratings; during 1978, average scrubber availability (hours FGD system is available for operation divided by hours in period) was 93.3 percent for Unit 1 and 93.9 percent for Unit 2.

3. Longest Run - Several months for the plant as a whole; 24 hours per scrubber module because of mist eliminator washing which is done off line; aside from the mist eliminator wash, a module has been operated for several weeks; a maintenance crew cleans 5 or 6 venturi-rod sections every night.

4. Calendar of Operation - The scrubbers operate whenever the boiler operates.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - This unit is actually the first stage section of the scrubber which serves to remove the particulates. Details of construction are shown in Figure 3. The skirt and the venturi sections are constructed of Type 316L stainless steel. There are two rows of Type 316L stainless steel "venturi rods" which are actually 2.5 in. OD schedule 40 pipe. The spacing between the two rows can be adjusted by manually jacking the bottom row up or down. The deflector plate below the venturi was constructed of carbon steel, and erosive wear required installation of Type 316L stainless steel wear plates after six months. Wear plates of this material have been added to the compartment in the areas where the slurry impinges in order to minimize erosion of the flakeglass lining. Stainless steel angle irons also have been welded to the bottom row of venturi rods as a temporary measure to combat erosive wear at that point. Rubber-coated stainless steel rods were evaluated at one time, but the rubber came off in a short time. It should be noted that the venturi is operating at a pressure drop of 14 inches of water to insure particulate removal, although the design was for 8.5 inches. The increased velocity through the venturi undoubtedly contributes to the erosion problem. Experiments are being conducted to test the performance of venturi rods of larger diameter and with different configurations of rods in the unit.

2. Absorber - The shell is constructed of 1/4 inch carbon steel with a flake-glass lining. Unit 1 has Flakeline 151, which has required some patching. Unit 2 had Flakeline 151AR, which debonded between layers, resulting in bubbles and blisters. The lining was replaced with Flakeline E in 1978. The marble bed of the absorber comprises a Type 316L stainless steel

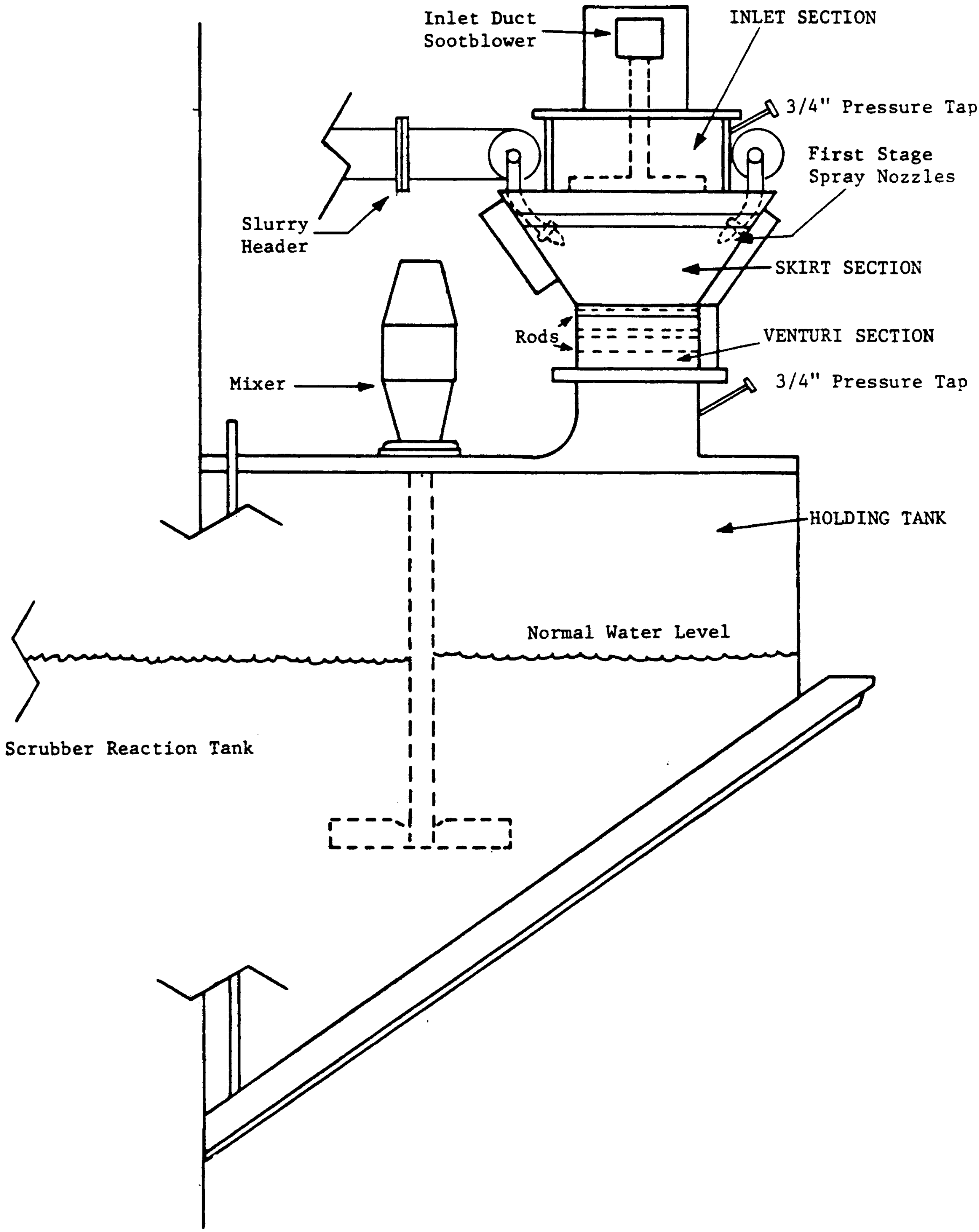


FIGURE 3. SCRUBBER FIRST STAGE

perforated plate (3/8 inch holes on 3/4 inch centers) with about 40 percent open area, and glass spheres (13/16 inch diameter) on the plate to a depth of 4 inches. There is a slurry drainage system consisting of 48 drain pots evenly spaced throughout the bed. The pots are FRP and have a domed, expanded metal Type 316L stainless steel cover. Failures of several of the covers during the early Unit 1 operation allowed marbles to get into the reaction tank and plug the spray water pump strainer. After annealing the covers, few failures have occurred, although wear has been observed.

3. Spray Nozzles - There are 28 alumina spray nozzles in the venturi section. Positioning of these nozzles has been the biggest problem. Two replacements were necessary to get nozzles which would keep slurry on the rods without collecting deposits themselves.

The 54 underbed spray nozzles (Nordel rubber) present problems both with erosion and with pluggage of the swirl vane holes. They are being replaced with alumina nozzles.

4. Mist Eliminators - The mist eliminators are constructed of FRP and consist of two levels of vane assemblies located 10.5 ft above the marble bed. 144 vane assemblies are used in each scrubber module. Pluggage constitutes a minor problem and requires periodic manual washing. Some breakage occurs during the cleaning process.

5. Fans - There are a total of 8 ID fans in the two systems. All are carbon steel and have presented no problems. They have only required washing 2 or 3 times in the operating history of the station.

6. Reheaters - Finned carbon steel tubes are located about 10 feet above the mist eliminator section. They are in staggered horizontal rows and each tube circuit has three 180 degree bends, allowing four tube passes through the flue gas stream. Four failures occurred in the area of the return bends early in the operation (1976). These were weld failures from excessive stress at the point of attachment of a straightening bar. Only infrequent leaks have occurred since the bar was removed.

7. Pumps - The spray water pumps (Worthington 10M234) carry the slurry from the reaction tank to the venturi spray nozzles, the underbed spray nozzles and the thickener. The Ni-Hard #1 impellers require replacement every 6000-8000 hours and the suction side wear plates last about 6 months. After trying 28 percent chrome-iron and rubber-lined pump internals on selected units, the latter have been chosen as the preferred replacement material.

Other pumps in the system have not been a problem. They are categorized below:

Type of Service	Manufacturer	Material
Limestone classifier recycle	Allis-Chalmers	Carbon steel
Limestone dilution tank supply	Robbins & Myers	Carbon steel
Limestone slurry transfer	Worthington	Ni-Hard
Recirculation	Worthington	Cast iron
Scrubber makeup water	Peerless	Cast iron
Thickener sludge	Warman	Ni-Hard

8. Tanks - All of the tanks in the system are unlined carbon steel. The problem with erosion of the sidewalls above the water level actually occurred in the first stage hopper area and was described in the prescrubber section. No difficulties have been encountered with any of the other tanks.

9. Agitators - The agitators used in the scrubber are uncoated carbon steel except for those in the reaction tank, which are rubber-coated (Lightnin').

10. Silos - The limestone hopper and classifier silos are carbon steel. Weld failures occurred in the classifier after 3 years of operation.

11. Thickener - The thickener components are all uncoated carbon steel.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - Both the inlet and outlet ducts are unlined carbon steel and have presented no problems.

The inlet expansion joints were chlorobutyl rubber, but they failed during the first year of operation and were replaced with Viton®. The chlorobutyl rubber has performed satisfactorily on the outlet expansion joints.

Carbon steel butterfly dampers are used on both inlet and outlet. Soot blowers help to keep the inlet dampers clean. No problems have been encountered.

14. Piping and Valves - The main spray water and effluent bleed piping are rubber-lined (La Favorite). Break-off of pieces of the lining has plugged nozzles and headers. When the lining was removed, the carbon steel eroded badly at reducers and elbows. FRP piping is being used for replacement. The internal headers in the absorber unit are FRP and have performed satisfactorily. The original FRP piping for the thickener underflow was damaged as a result of a water hammer and has been replaced by carbon steel and some Type 316L stainless steel directly below the thickener.

The Hilton knife-gate valves on the spray pump inlet have given problems with poor sealing. The additive feed line valves (Invalco) and the DeZurik plug valves for flow control have been satsifactory. A Grinnell pinch valve was tried in the pilot run and its lining did not last, so these were not used.

15. Stack - A single stack serves both units. It has a Cor-Ten steel liner, and no problems have been observed.

16. Ball Mill - An Allis-Chalmers unlined carbon steel mill is used.

17. Pond Linings - The fly ash pond and the holding basin are lined with 18 inches of a local Minnesota clay.

E. COMMENTS

The original strainers ahead of the spray water pumps have been pulled out and replaced with submerged performated-plate type filters like those at Lawrence. The original steel pumps have been replaced with rubber-lined equipment. Fiberglass reinforced polyester (FRP) pipes have replaced rubber-lined equipment in regions of high velocity or change in direction flow. Soot blowers are still a high maintenance problem area, as are the Hilton knife-gate valves. The only problem with the mist eliminators is occasional breakage. NSP now encounters a reheater tube leak perhaps only once every six weeks or so. Although some ceramic nozzle breakage and pluggage still occurs, these perform much better than the original Nordel swirl vane nozzles, which eroded quite badly.

NSP's current objectives are to improve the scrubber system availability to 97 percent while maintaining or improving particulate and sulfur dioxide removal, and to reduce the system's operating and maintenance costs. Future development activities will include: applying an improved control (scrubber management) system; continuing to follow sludge utilization developments; and improving (or replacing) unsatisfactory mechanical or control components.

BLACK & VEATCH
OVERLAND PARK, KANSAS

Trip Report Number: EPRI-CM30

Date of Trip: April 23, 1979

Persons Interviewed: Donald Swenson, Engineer, Black & Veatch.

A. BACKGROUND

Black & Veatch is a firm of consulting engineers. As such, they do not design or build scrubbers. They do provide consultation in numerous ways such as interfacing of scrubber with power plant, waste-water management, materials selection, etc. They have provided consulting services for the following:

Kansas City Power and Light - Hawthorn 3 and 4
Kansas Power and Light - Lawrence 4 and 5, and Jeffrey 1
Northern States Power - Sherburne 1 and 2
Columbus & Southern Ohio Electric - Conesville 5 and 6
United Power Association - Coal Creek 1.

In addition, Black & Veatch have been called in to improve the scrubber operation at the La Cygne Station of Kansas City Power and Light, and the Milton R. Young Station of Minnkota Power Cooperative. They are also the consulting engineers for the following scrubbers under design or construction:

Eastern Kentucky Power Cooperative - Spurlock
Columbus & Southern Ohio Electric - Poston 5 and 6
United Power Association - Coal Creek 2
Kansas Power and Light - Jeffrey 2
Northern States Power - Sherburne 3
Colorado Platte River Power Authority - Rawhide 1
United Power Association - Stanton 2.

All of the above installations use lime or limestone as the scrubbing reagent.

Some general comments about scrubbers and materials were provided. The flakeglass-filled linings are all right if everything is done correctly. However, if there are any flaws in application, and the lining has to be patched, the patched area tends to fail again. The rubber linings are a flammability problem.

The La Cygne scrubbers are Type 316L stainless steel and look like new inside. Mr. Swenson now prefers use of stainless steel except in high chloride service (10,000 to 40,000 ppm in liquor). If nothing is known about the coal, the first guess would be to use an electrostatic precipitator and a spray tower. Lime or limestone would be suggested, based on economics. A pH of 5 to 5.5 was formerly suggested, but 3 to 3.5 would be suggested now in order to get better reagent utilization. In special cases with low sulfur coal, the use of a spray dryer might be recommended. All tanks would be lined with flakeglass/polyester. Originally plain carbon steel piping was used but rubber lined pipe is now suggested because of erosion.

One of the biggest problems in scrubbers at present is instrumentation. The following rough materials cost comparisons were given:

Flakeglass/polyester-lined carbon steel is lowest,
Rubber-lined carbon steel is about 15 percent higher than flake-lined carbon steel,
Type 316L stainless steel is about 50 percent higher than flake-lined carbon steel.

B. MATERIALS OF CONSTRUCTION

The following choices would probably be made for components in a scrubber system.

1. Prescrubbers (for particulate matter) - Electrostatic precipitators would normally be recommended unless there was a reason to change, with quencher left up to manufacturer. The proposed new regulations of 0.03 pounds particulate per 10^6 Btu dictate the use of an electrostatic precipitator. Sherburne has a two-stage scrubber because of alkalinity of the fly ash. This provides significant savings on additive but gives high erosion problems.

2. Absorbers - Assuming that there are no qualifications on the coal to be burned, the choice would be a spray tower, constructed of Type 316L stainless steel.

3. Spray Nozzles - Ceramic nozzles would be sought, but with a two-year guarantee asked.

4 Mist Eliminators - A specified mist eliminator efficiency would be requested. Generally the material would be fiberglass reinforced plastic, but the vendor would be allowed to select the material.

5. Fans - Dry fans would always be recommended, either by using sufficient reheat, or by placing fans ahead of scrubbers. In a new installation fans would be on the dry (upstream side) of scrubber and would be carbon steel. If the fan follows a reheater in a retrofit (downstream from scrubber) it might be a little higher quality steel than carbon steel.

6. Reheaters - Some amount of reheating would be recommended to protect downstream equipment and help prevent acid mist. Having used almost all types, a reevaluation of reheaters is now in progress. A firm choice of reheaters is still to be made. However, indirect hot air reheat is not preferred because of the cost of additional fan power.

7. Pumps - Performance experience has been gained with both hard metals and rubber linings in pumps. The rubber-lined pumps are now preferred. The pump problems in service are caused by abrasion. No good solution to pump selection has been found when static head pressure is above 100 to 150 feet.

8. Tanks - Would use flakeglass/polyester lined carbon steel for tanks with a low pH service.

9. Agitators - According to recommendations of manufacturer, but would probably be rubber-lined Lightnin.

10. Storage Silos - Carbon steel silos would be used for limestone storage, and concrete for lime storage.

11. Thickeners - The thickener would have a concrete bottom and steel sides. The choice of concrete might be an acid-resistant type. The steel walls would be lined but the bottom would be unlined.

12. Vacuum Filters and Centrifuges - The preference is for pond disposal of thickened sludge. Only the Conesville plant among the B&V associated scrubbers has a filter, and it is part of an IUCS system for sludge stabilization.

13. Ducts, Expansion Joints, and Dampers - The ducts would be Cor-Ten steel if kept dry, with enough reheat to prevent condensation. Wet ducts would be Type 316L stainless steel.

The expansion joints have always given problems. The best success has been obtained from non-metallic types (asbestos reinforced elastomers) if they are properly installed.

Control dampers would be louver type. Guillotine dampers would be considered first for isolation. Hastelloy would be the materials choice for the blades, especially downstream. If control and isolation are required at the same point, B&V would use two louver dampers with pressure between them.

14. Piping and Valves - Rubber-lined piping is good to resist erosion and corrosion, but would use American Bridge, fiberglass reinforced plastic. The best piping system is one with fewest valves. Control valves should not be closed too tight in order to avoid excessive wear. For this service, rubber-lined pinch valves would be selected, because of no known better valve. For isolation, hard steel gate valves or ball valves would be used. Problems with gate valves are related to deposits within slides.

15. Stack - The stack choice would be a concrete shell with an acid resistant brick lining bonded with acid resistant mortar.

16. Grinding Mill or Slaker - A paste slaker would be chosen. Present ball mills do not give much problem.

17. Pond - The preferred lining for the pond is clay, but the lining would be selected from whatever will do the job.

KANSAS CITY POWER & LIGHT COMPANY
HAWTHORN UNITS 3 AND 4

Trip Report Number: EPRI-CM31

Date of Trip: April 24, 1979

Persons Interviewed: Ralph Boehm, Operating Supervisor, Hawthorn Station.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Combustion Engineering was designer and vendor of retrofit system to existing boilers; Black & Veatch was consultant for scrubbers. System for Unit 3 installed November, 1972 and for Unit 4 in August, 1972. Tail end lime slurry addition with lime fed directly into the reaction tank. In early operation, limestone was injected into the boilers.

2. Boiler Type - Units 3 and 4 are each nominal 100 MW CE tangential pulverized coal-fired boilers with dry bottom furnaces. Unit 3 was installed in 1953 and uprated to 125 MW in 1967. Unit 4 was installed in 1955 and was uprated to 142 MW in 1968. Units burn natural gas when available. Presently, with scrubbers operating, each unit produces 90 MW gross; the heat rate is 11,000 Btu/kWh.

a. 25 percent excess air.

b. Capacity factor is about 25 percent; each unit operates at 60 MW for 16 hours per day.

c. Single 200-ft stack serves both units.

3. Flue Gas Flow Rate - 400,000 acfm at 300 F per unit. All flue gas passes through scrubbers when operating. Scrubber may be completely bypassed.

a. In early operation, oxygen was about 6 percent; now about 4.5 percent.

4. SO_2 Concentration - In early operation there was 500 to 3000 ppm in inlet; less than 100 to 2000 ppm in outlet from scrubber. Presently, 1000 ppm inlet and about 500 ppm outlet. System mainly for fly ash removal. Consideration is now being given to replacement of the scrubber with an electrostatic precipitator since this would enable the Hawthorn Station to meet local air emission regulations.

5. Fuel - Natural gas when available, but mostly coal. In early operation, the coal was a blend of 3 percent sulfur coal from Oklahoma and low sulfur coal from Wyoming. Presently using mostly Peabody Oklahoma coal with 4 percent sulfur, 12 percent ash, and a heat content of 10,500 Btu/lb.

6. Scrubber Reactant - Lime containing 93 percent CaO and delivered as 3/8 in. pebbles.

7. Removal Efficiency - Normally 50 percent SO_2, 99.5 percent fly ash, and NO_x unknown.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables -

   a. Flue gas inlet temperature to scrubber is 270 to 300 F.

   b. Flue gas outlet temperature is 120 F from scrubber and 180 F after reheating.

   c. Fly ash loading to scrubber is 2.8 to 3.3 grains/scf.

   d. pH of the recirculating slurry is 6.0 to 6.5.

3. Absorber Design -

   a. One stage marble bed for particulate removal.

   b. The same scrubber is also used for SO_2 removal; there are two modules per unit.

   c. The superficial gas velocity is about 6 ft/sec.

   d. Turndown is achieved by operating the scrubbers at lower velocity; the system can operate down to 30 MW per boiler.

4. Liquid-to-Gas Ratio - Probably about 26 gal/1000 acf.

5. Oxidation - Probably about 30 to 40 percent oxidation.

6. Pressure Drop - 15 in. H_2O across entire FGD system.

7. Solids Level - The blowdown rate is very high in order to maintain a very low solids level in the scrubbing liquor; the thickener underflow contains 12 percent solids.

8. Reactant Addition - Slaked lime is added to the reaction tank at the bottom of the scrubber.

9. Reactant Feed Rate - 450 gal/hr of lime slurry at 60 to 70 MW; lime is not added when Wyoming coal is burned.

10. Slurry Retention Time - About 15 minutes at L/G of 26; retention (reaction) tank is bottom 16 ft of scrubber module and has capacity of about 56,000 gal.

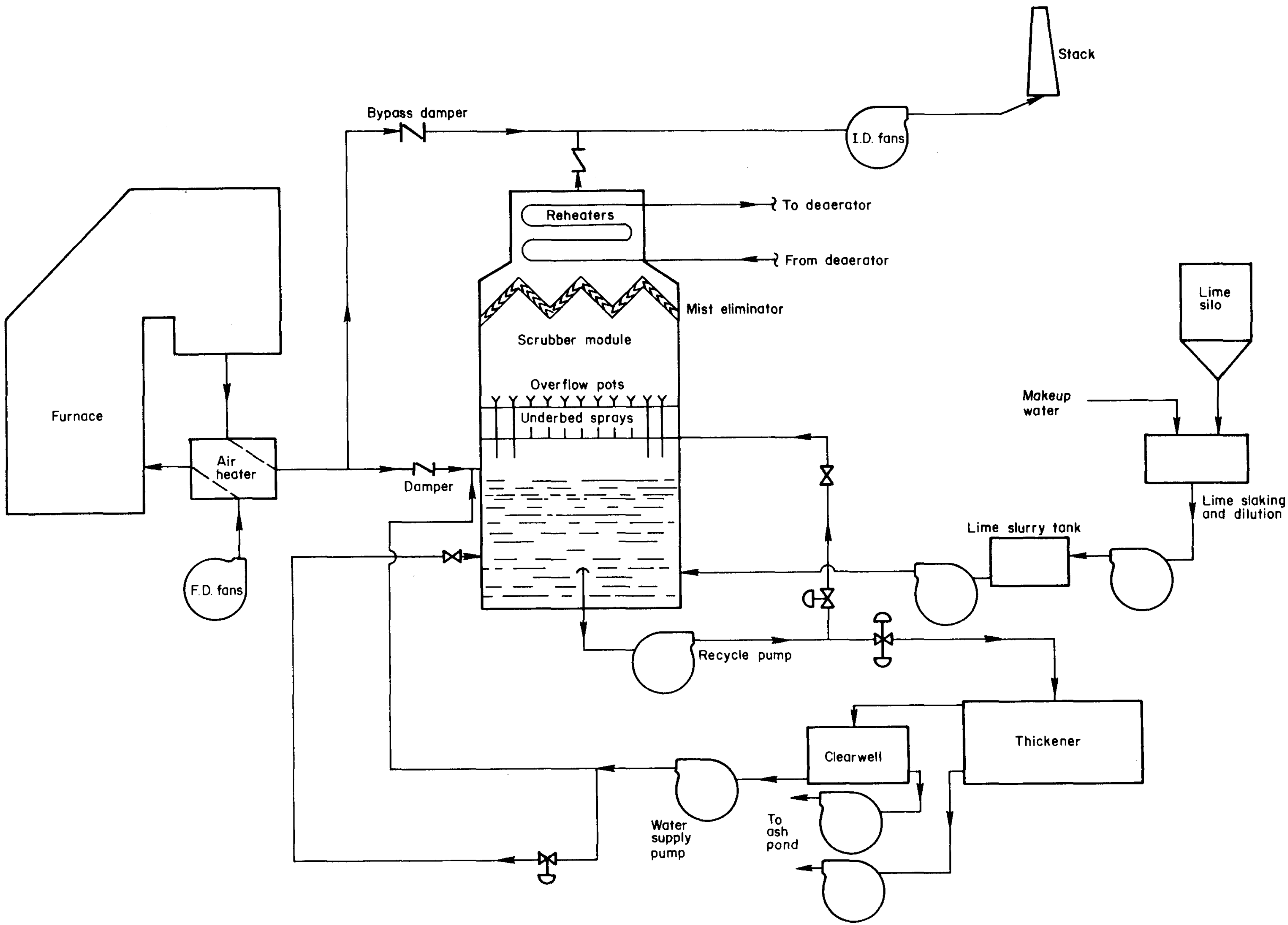


FIGURE 1. SCHEMATIC DIAGRAM OF SO_2 CONTROL SYSTEM

11. Mist Eliminator - Two stage chevron mist eliminator in A-shape configuration; manual washing with firehoses at least once every other day when module is down; on-line wash lances have been out of service for about two years.

12. Reheat System - Carbon steel, finned tube heat exchanger using hot water from deaerator reheats flue gas to 180 F; the fins plug constantly and cause a high pressure drop.

13. Waste Disposal - Open-loop operation; blowdown from reaction tank goes to thickener, and thickener bottoms are pumped to ash pond; overflow from ash pond goes to the Missouri River; the overflow is better quality than the river water which has a pH of 9.5.

14. Fans - Squirrel cage induced draft fans located after the reheater; one fan per module.

C. RELIABILITY

1. Start-up - August, 1972, for Unit 4; November, 1972, for Unit 3.

2. Availability - About 15 to 20 percent at most (hours the FGD system is available for operation divided by hours in period).

3. Longest Run - About one month for a specific module (Module 4A); probably about 10 days for two modules in simultaneous operation.

4. Calendar of Operation - Kansas City Power & Light tries to operate the scrubbers whenever the units are coal fired; natural gas is fired when it is available. The units were converted to tail end lime scrubbing in 1976. Since 1977, the units have not operated on coal without the scrubbers; when the scrubbers and natural gas are not available, the units are turned off. The units themselves (boiler and turbine) have a high availability.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - None used.

2. Absorbers - The module was originally constructed of carbon steel with a Ceilcote lining (no further identification). The lining failed because of temperature excursions, pH excursions, and damage by welding. During the early period of operation, numerous changes were being made which required a great deal of welding. The module was completely relined with Type 316L stainless steel from bottom to four feet above the marble bed. Bolts, washers, headers, etc., are all Type 316L stainless steel. The original support tray for the marbles (marble bed) is Type 316L stainless steel, as well as the support bars and the compartment dividers, which extend 18 inches from the floor of bed. Without these dividers, the marbles would migrate if one of the 7 headers became plugged. The pots for drainage from the marble bed were originally fiberglass reinforced plastic (FRP), but have been replaced with Type 316L stainless

steel welded to the perforated plate. The upper portion of the module still has the original Ceilcote lining which is in need of repair.

3. Spray Nozzles - Spray nozzles were originally FRP which did not last. Galvanized steel nozzles made in house were used next and also did not last. Ceramic nozzles (Coors Al_2O_3) were tried next but failed because of pounding when plugged, or being dropped while cleaning. They were best wearing type but their brittleness was a problem. Presently, Type 316L stainless steel nozzles are used. They last about 6 months to one year. Marbles still get into the nozzles and contribute to their plugging.

4. Mist Eliminators - Mist eliminators are FRP construction.

5. Fans - The fans are Cor-Ten steel. Some fan problems have been scrubber related. No fan problems have occurred from January, 1977, through September, 1978. All four fans were replaced in 1979.

6. Reheaters - The finned carbon steel heat exchanger tubes did not give corrosion problems but they tended to plug up. Consequently, smooth Type 304 stainless steel tubes in one large section were tried on one module and they lasted about 6 months. A change will be made to Type 316L stainless steel tubes in smaller sections for all four modules.

7. Pumps - All pumps are same as originally installed. The recycle pumps are 350 MIR Ingersoll-Rand, which are hard cast iron. The clear water supply pumps are Fairbanks-Morse, horizontal split case, centrifugal type (6,400 gpm, 156 ft head, 70 psig). They have bronze sleeves, steel shaft and steel impellers. The sludge pumps are by Goulds with special impellers having high chromium content. Blowdown pumps are basically the same design as the sludge pumps, but with twice the capacity. The mist eliminator wash pumps are Goulds but they are not used now. The reheater pumps are Goulds and are made of carbon steel. They operate with 300 F water at 100 psig, and have mechanical seals instead of packing. The lime slurry pumps are positive displacement BIF (General Signal).

8. Tanks - The reaction tank in the bottom of the scrubber was carbon steel with a Ceilcote lining (type not specified). The lining was removed by blasting and replaced with a Type 316L stainless steel lining fastened to the shell with stainless steel bolts, which were sealed by welding around bolt heads. The lime slurry and clearwell tanks are carbon steel.

9. Agitators - Lightnin mixers with rubber-coated blades and carbon steel shafts are used in the reaction tanks (3 per tank). The lime slurry tank and slaker hold tank have carbon steel agitators.

10. Storage Silo - The storage silo is carbon steel. It is part of a new, self-contained unit with slaker and holding tank by Coffman Industries.

11. Thickener - The thickener (Eimco) has carbon steel sides and a concrete floor. The steel is painted but the type of paint was not identified.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The ducts are Cor-Ten steel with a 2 inch gunite lining (Plibrico) in the sections to the stack, at the fan inlet and outlet sections, and in the sections to the scrubber.

Expansion joints are Cor-Ten, saw tooth, bellows type. They are being replaced with Viton®-asbestos joints because of corrosion of the Cor-Ten.

The dampers are multi-louver type, made of Cor-Ten steel. They were described as being essentially useless. Self-designed and installed guillotine dampers (Cor-Ten plate steel) are used for the bypass. They replaced the water seals which gave continual problems.

14. Piping and Valves - The piping from suction of reaction tank to the underbed spray headers is rubber-lined carbon steel. This piping was originally Bondstrand FRP, which presented problems because of plugging. The pipe could not be maintained properly because it would not stand pounding and the required piping changes. The blowdown piping and clear well return are Schedule 80 carbon steel, all flanged for easy fitting. Original welded piping for these services lasted 6 years. The lime slurry line is also carbon steel.

The valves are mostly knife gate type of Type 316L stainless steel. Some stainless steel ball valves with Teflon® seals are also used. A few DeZurik plug valves are left but most have been replaced because they gave problems in blockage, breakage, and were too big and bulky.

15. Stack - The stack is gunite lined carbon steel. It is about 20 years old and has never run wet. Gas temperature is about 175-185 F after reheat. There has not been any problem with the stack.

16. Slaker - The slaker is carbon steel.

17. Pond - The pond is not lined.

KANSAS POWER & LIGHT COMPANY (KP&L)
LAWRENCE UNITS 4 AND 5

Trip Report Number: EPRI-CM32

Date of Trip: April 24, 1979

Persons Interviewed: Ron Teeter, Plant Superintendent, Lawrence Energy Center.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Combustion Engineering is the designer and vendor; Black & Veatch are the consulting engineers; Unit 4 is a retrofit and Unit 5 was originally a new installation. Units 4 and 5 began scrubber operations in October, 1968, and September, 1971, respectively. The original FGD systems were replaced with new systems, with startup in January, 1977 for Unit 4 and April, 1978 for Unit 5. The old systems utilized boiler injection of limestone with marble bed scrubbers, while the new systems utilize tail end limestone scrubbing with rod venturis for fly ash removal and spray towers for SO_2 removal. The materials section of this report compares the materials used in the various components of the old and new scrubber systems.

2. Boiler Type - Unit 4 is rated at 125 MW and Unit 5 at 400 MW. Both units are CE tangential fired boilers, and can fire coal, oil and/or gas in any combination. The heat rate is about 10,300 Btu/kWh.

a. Excess air for both units is now about 15 percent when firing mainly with coal.

b. Both units are on automatic dispatch but are not base loaded; the boilers operate continuously.

c. The stack height is 180 ft above grade for Unit 4 and 350 ft above grade for Unit 5.

3. Flue Gas Flow Rate - The actual flow rate entering the rod scrubbers is 403,000 acfm at 280 F for Unit 4 and 1,271,000 acfm at 300 F for Unit 5.

a. The oxygen content of the flue gas entering the scrubbers is about 8 to 9 percent (10-13 percent leakage in air heaters).

4. SO_2 Concentration - The design inlet concentrations for both units is 748 ppm; the design exit concentration for Unit 4 is 200 ppm and for Unit 5 it is 359 ppm.

5. Fuel - The coal burned at Lawrence is now Medicine Bow coal from the Hanna mine in Wyoming. It contains up to 16 percent ash and 0.9 percent sulfur, but typical compositional information is as follows:

Ultimate Analysis		Ash Analysis	
Moisture, percent	11.8	SiO_2, percent	38
Carbon, percent	60.7	Fe_2O_3, percent	9.5
Chlorine, percent	0.03	Al_2O_3, percent	23.9
Sulfur, percent	0.55	CaO, percent	13.2
Ash, percent	9.8	MgO, percent	3.5
Heat Value (as rec'd)	10,000 Btu/lb		

Coal from Colorado and Oklahoma is also used sometimes. In former times, 3.3 to 4.0 percent sulfur coal from Kansas was burned. A substantial amount of oil is still used, as well as a little gas.

6. Scrubber Reactant - Limestone is trucked about 9 miles from a quarry located about 2 miles north of the plant. It is 93 percent $CaCO_3$ and about 7 percent $MgCO_3$. It is wet ball mill ground to an 80 percent through 200 mesh grind as a 60 percent slurry.

7. Removal Efficiency - The design SO_2 removal efficiency of the scrubbers on Unit 4 is 73 percent and for Unit 5 it is 52 percent. The actual SO_2 removal efficiency has varied between 70 and greater than 90 percent, depending upon the liquid-to-gas ratios and the additive flow rates. A 70 percent removal efficiency is generally sought. Greater than 99 percent particulate removal can be achieved at 10 inch pressure drop across the rods, yielding an emission rate of 0.08 lb/10^6 Btu under favorable operating conditions. No significant NO_x removal is expected or claimed.

B. PROCESS DESIGN

1. Process Flow Sheet - A flow sheet for the new FGD system on Unit 4 is shown in Figure 1; the flow sheet for Unit 5 is the same except that there is only one recycle tank for the entire system, there is no thickener, and the limestone preparation system is common for both units. A flow sheet for the old FGD system is shown in Figure 2.

2. Process Variables -

a. Flue gas inlet temperature is 280 to 300 F.

b. Flue gas outlet temperature is 125 F before reheat

c. Fly ash loading to the scrubber is about 2.5 grains/scf.

d. The pH of the recirculating slurry is 6.5 with the current system; with the old system, the pH was 8.5 to 9.5 at the scrubber inlet and 5.0 to 5.5 at the marble bed drain pots

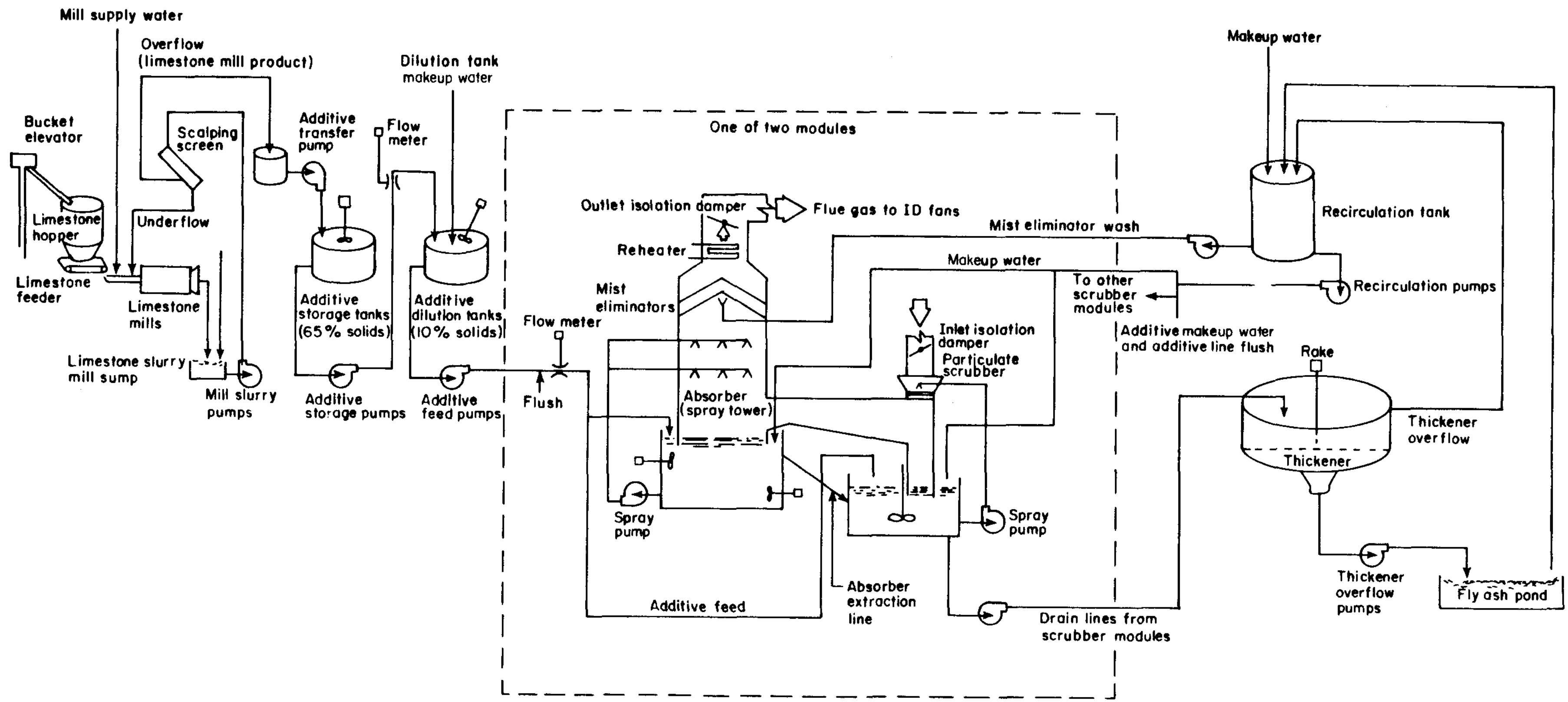
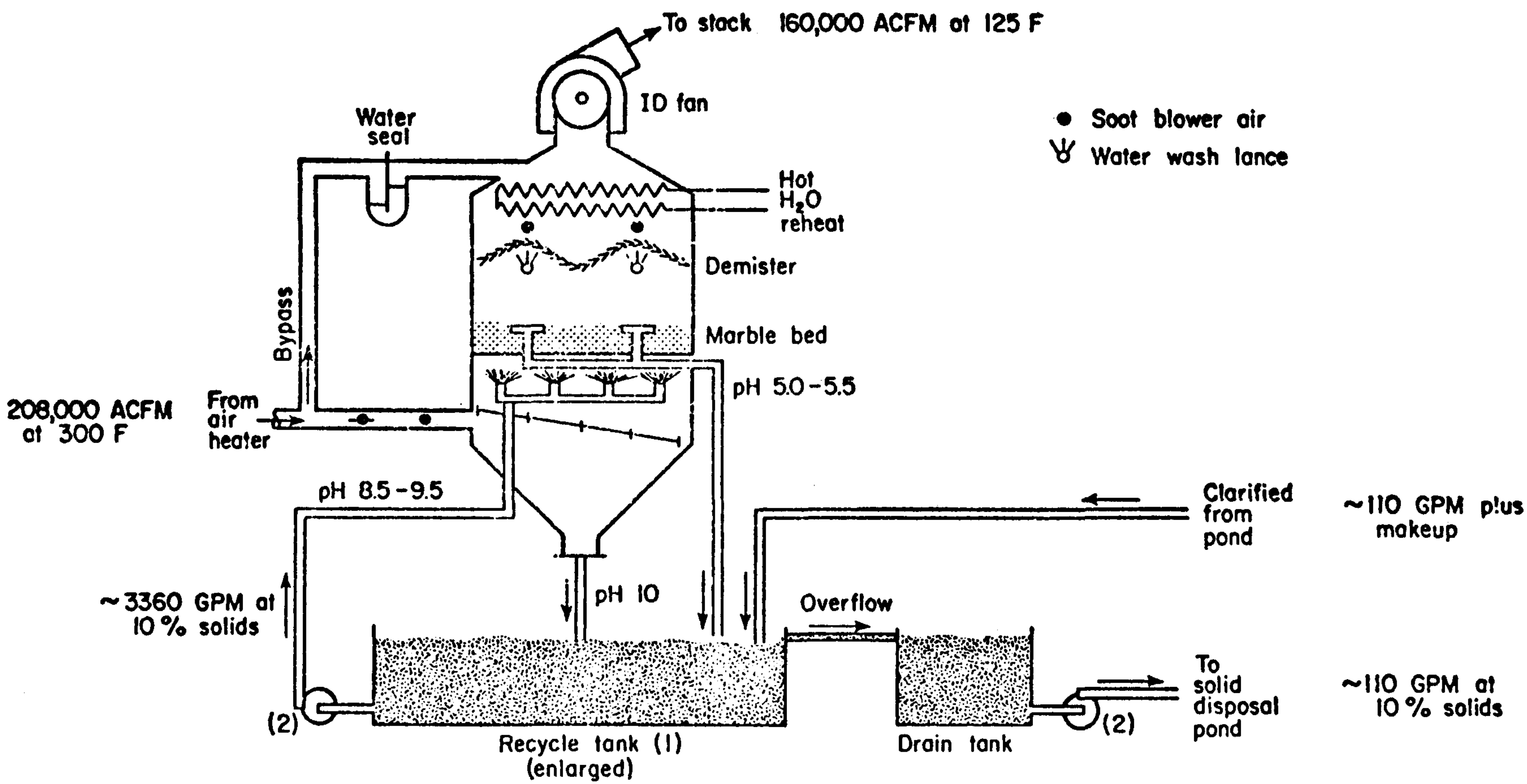


FIGURE 1. FLOW SHEET FOR NEW FGD SYSTEM ON LAWRENCE UNIT 4



Note: Flow rates shown are for one of two modules

FIGURE 2. FLOW SHEET FOR OLD FGD SYSTEM ON UNIT 4

3. Absorber Design - Both the old and new systems have two modules per unit.

a. The new system has rod venturis for particulate removal while the old system had single stage marble beds. The vertical spacing between the two rows of rods in each venturi is varied automatically in proportion to the gas flow rate.

b. The new system has spray towers for SO_2 removal, while the old system used the same marble bed that was used for particulate removal. The spray towers on Unit 4 each have two spray zones, one located 10 ft above the inlet, and the other 20 ft above the inlet. The spray towers on Unit 5 each have one spray zone located 10 ft above the inlet.

c. The superficial gas velocity is about 50 ft/sec in the rod venturis and about 6 ft/sec in the spray towers.

d. Turndown can go from full load to zero load; one module can be taken off line, but the system is always operated with two modules except at night when a module is taken off line to wash the mist eliminator.

4. Liquid-to-Gas Ratio - The design L/G's are 20 gal/10^3 ft^3 in the rod scrubbers for both units, 30 in the spray towers for Unit 4, and 20 in the spray towers for Unit 5. The L/G in the marble beds was 20 to 22 gal/10^3 ft^3.

5. Oxidation - Unit 4 has been operated with and without forced oxidation. Oxidation to sulfate was 77 percent in the rod scrubber collection tank at 400 percent air stoichiometry. The lack of complete oxidation is primarily due to the high pH (7.3) in the tank caused by the calcium oxide in the fly ash. The oxidation in the spray tower reaction tank is 95 to 99 percent, with or without oxidizing air.

6. Pressure Drop - Draft classes in the two systems are as follows: (inches water gauge)

	Unit 4	Unit 5
Boiler, Preheater, Ducts	11.2	17.0
Rod Scrubbers	9.0	9.0
Spray Tower	2.5	0.8
Reheating and Mixing	0.5	0.5
Duct and Stack	0.8	1.5
Total	24.0	28.8

7. Solids Level - Solids concentration in the recirculating slurry is maintained between 5 and 10 percent.

8. Reactant Addition - The 60 percent slurry from the mill is pumped to an additive storage tank which feeds both modules on each unit. This concentrated slurry is then transferred to an additive dilution tank by means of a variable speed pump. The limestone is diluted with makeup water to maintain 10 percent solids in the additive dilution tank. The limestone is fed to the spray tower reaction tanks at a rate proportional to the unit firing rate and the sulfur content of the fuel.

9. Reactant Feed Rate - About 3000 lb/hr of limestone for Unit 4 and about 8000 lb/hr for Unit 5.

10. Slurry Retention Time - About 10 minutes in the reaction tank.

11. Mist Eliminator - Moisture entrained in the clean fuel gas is removed in the mist eliminator section which consists of a bulk entrainment separator (BES) followed by a two-stage chevron mist eliminator. The chevrons are horizontal, slanted, and have an inverted V-shape, with sharp angle 90 degree bends. Two passes are used with 3-4 inches between vanes. The angle between vanes and gas flow is variable because of the slanted configuration. The distance between stages is about one foot. The BES is basically a one-pass chevron system. The material of construction is FRP and about one inch of water pressure loss is encountered over the ME. The BES is located about eight feet above the top spray nozzles, and the first stage of the ME is located 4-5 inches above the BES. The passage geometry is a straight, nonexpanded flow path. Pond recycle water is used for washing Unit 4 and fresh water is used for washing Unit 5. The first stage of the ME is washed both vertically upwards and downwards. The second stage is washed only from below. Wash duration is 45 minutes/day with the module off-line and with 200 gpm per module at 60-70 psig water pressure. No plugging or scaling problems are now encountered.

12. Reheat System - In-line reheat with hot water in finned carbon steel tubes to provide 20 to 30 F of temperature rise to the flue gas; the same type of reheat system was used in the original installation.

13. Waste Disposal - Closed-loop operation; for Unit 4, slurry from the reaction tank at 5 percent solids is bled to the collection tanks. Collection tank solids are maintained at 8 to 10 percent by varying the effluent bleed pump flow. The pump delivers the effluent bleed to the system thickener where the solids are concentrated to 30-35 percent before being pumped to the disposal pond. Unit 5 does not employ a thickener. The 30-40 percent slurry waste from Unit 4 is pumped some 3400 feet to Pond 3 with Warman centrifugal pumps and the pumps must be replaced every three or four weeks. The ten percent slurry waste from Unit 5 is pumped only 1200-1500 feet to Pond 1. Abrasion is much less of a problem

with this dilute short-distance transfer. Water is separated from the slurry in Pond 2, flows through Pond 2 to Pond 3, where it mixes with separated water in Pond 3, and finally the combined flow goes to Pond 4 where it is pumped back to the scrubbers. Pond 1 is now overflowing and is being dredged.

14. Fans - The fans at Lawrence are Buffalo Barron units, basically the same as originally installed. They are located after the reheaters. New rotors must occasionally be installed, but no major problems in seven years of operation. There is one fan for each module on each unit.

C. RELIABILITY

1. Start-up - The original FGD systems started up in October, 1968 on Unit 4 and September, 1971 on Unit 5. The new systems started up in January, 1977 and April, 1978 for Units 4 and 5, respectively.

2. Availability - Beginning in July, 1973, the old system on Unit 4 had a high availability (hours the FGD system is available for operation divided by hours in period), but when the unit was operating at half load during the night, one module was taken off line and cleaned out. Unit 5 had to burn oil for a few days during 1973 because of problems with the FGD system.

The new systems have essentially 100 percent availability, but bypass has caused some half-load operation. No recollection of any down time for Unit 4 because of the new scrubber since it was rebuilt. One-half of Unit 5 was down for five hours because of a pipe failure. No hand cleaning of any reheaters or mist eliminators on either unit since start up. Modules are shut down each night for 45 minutes for washing mist eliminators with Vulcan water lance. KP&L has never yet had to clean the new scrubbers.

3. Longest Run - About six months if allowance is made for brief down time (half load) each night to wash mist eliminators.

4. Calendar of Operation - With the old scrubbers, Units 4 and 5 were always able to carry load when they were required to burn coal except for a few days during the year. The new scrubbers have been in operation essentially all the time since start up.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber -

a. Old system: None used.

b. New system: The rod venturi for fly ash removal is constructed of Type 316L stainless steel. The stainless steel starts immediately above the quench section of the venturi and extends through the absorber past the reheat section. The rods in Unit 5 are Type 316L stainless steel, 6-5/8 inch O.D. Schedule 80 pipe sections. The rods in Unit 4 are Noryl (G.E.) plastic over fiberglass reinforced plastic and are 7 inches in diameter. The rods can be rotated a full 360 degrees to get four times the life as from a fixed position rod.

2. Absorbers -

   a. Old system: The old absorber was constructed of carbon steel protected with organic linings. A number of different linings were used including Ceilcote, Flexane, and Odell 4 (latter two by Devcon, which was believed to be a subsidiary of Mobil). No lining was found to provide both the abrasion and corrosion resistance needed. The marble bed caused serious erosion problems. The marble bed trays in the old scrubbers were made of Type 316L stainless steel, and the pots were Type 316L stainless steel with a fiberglass base.

   b. New system: The new absorber modules are constructed of Type 316L stainless steel.

3. Spray Nozzles

   a. Old system: The old nozzles were plastic with swirl vanes which required considerable maintenance.

   b. New system: The new nozzles are ceramic (probably silicon carbide on Unit 5 and aluminum oxide on Unit 4). The quench section in the rod venturis uses nonatomizing fan type nozzles located around the perimeter of the scrubber.

4. Mist Eliminators -

   a. Old system: FRP

   b. New system: FRP for mist eliminator and bulk entrainment separator.

5. Fans -

   a. Old system: The original fans were carbon steel.

   b. New system: Original carbon steel fan still on Unit 5, but with different rotors (SSS-100 by U.S. Steel). The new fan on Unit 4 is Cor-Ten steel.

6. Reheaters -

   a. Old system: Carbon steel finned tubes; fins were 60 mils thick and one section had two fins per inch while another section had three fins per inch. KP&L has not had a reheat tube failure due to corrosion for the past 8 years.

   b. New system: Same as old.

7. Pumps -

   a. Old system: Spray pumps were hard metal. Unit 4 had Goulds pumps constructed of HC 250 alloy and Unit 5 had Ingersoll-Rand MIR 500 pumps constructed of Ni-Hard. The latter pumps ran for 5 years without replacement.

   b. New system: The spray pumps on Unit 4 are rubber lined, and 60 percent of those on Unit 5 are rubber lined. Two of the original Ingersoll-Rand MIR 500 pumps are still used on the absorber side of Unit 5. Several of the spray pumps required repacking every two or three days. The major change involved the incorporation of high flow gland seal water (14 to 15 gpm as opposed to the 7 to 8 gpm originally used). Limestone slurry pumps are rubber lined. Additive pumps are Robbins & Myers with rubber-lined stators and chrome-molybdenum rotors. The pump liners and rotor wear out in 10 to 15 weeks of service. This life expectancy is short, but since there are only two of these pumps in the system and the wear can be predicted, it has been decided to operate with the existing additive pumps. The extraction pumps on Unit 4 are hard metal and on Unit 5 are rubber lined. Thickener underflow pumps are Ni-hard (Warman).

8. Tanks -

   a. Old system: The old system had carbon steel tanks.

   b. New system: The new recycle tank on Unit 4 is Cor-Ten steel. Unit 5 uses the original carbon steel tank. The additive tanks are carbon steel.

9. Agitators -

   a. Old system: The old carbon steel agitators (3/16-inch thick blades) lasted only three months on Unit 4. Unit 5 had horizontal mixers with unprotected blades which did not last. After coating with Devcon plastic/carbide, they never wore out.

b. New system: The new mixers have rubber-coated carbon steel blades. The shafts on Unit 4 are also rubber coated, but not on Unit 5. Several of the rubber coated blades on the top entry mixers in the collection tank experienced stabilizer fin failure last year. They were replaced by the manufacturer of the mixers and no additional failures have occurred. There were also several bearing failures of the side entry mixers in the reaction tanks due to improper lubrication.

10. Storage Silo - Carbon steel.

11. Thickener - Thickener has Cor-Ten steel walls and concrete bottom, both without a lining.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers -

a. Old system: Inlet ducts were carbon steel which gave no problems. Outlet ducts were also carbon steel and gave all kinds of corrosion problems. The bypass ducts were carbon steel.

Expansion joints were originally metal which failed. They were changed to butyl rubber which also failed. Finally, Raybestos-Manhattan joints were used (described as being intermediate grade, below Viton®).

Inlet and outlet dampers were carbon steel, louver types which corroded. Bypass dampers were water seals.

b. New system: The inlet and outlet ducts in the new system are Cor-Ten steel. The full bypass duct is also Cor-Ten steel on each unit.

Expansion joints are Garlok with asbestos/butyl rubber or asbestos/Viton®.

Dampers are Cor-Ten steel. Only one damper on the Unit 4 bypass is a guillotine type; the others are louver type. During some preliminary tests in April, 1978, it became obvious that the bypass dampers did not seal completely, thereby allowing some particulate matter to bypass the AQCS. New seals have been installed to minimize this leakage. Further, it appears that the damper drives drift. Thus. every 5 to 10 minutes the dampers move off their limit switches. The controls are activated and the damper is driven back. This allows flue gas to bypass the scrubber and causes nuisance alarms in the control room. A redesign of the damper drive mechanism is being supplied by the damper manufacturer.

14. Piping and Valves -

a. Old system: The old system had rubber-lined piping. The lining eroded and ripped, causing plugging. A change was made to Fibercast piping, and some PVC, along with a change to lower velocity by switching from 8-inch to 10-inch diameter. The PVC piping for discharge off recycle tanks looked good after 2-1/2 years. The pump isolation valves were stainless steel knife gates. Plug valves were also used in the old system but failed rapidly because they could not provide complete shut off. Butterfly valves were also used in the old system.

b. New system: The new spray piping and spray headers are American Bridge Company's Fibercast material with an abrasion-resistant liner. Carbon steel piping is used where FRP piping is not needed, including line from tank to pond on Unit 5. Polyethylene tubing is used from thickener underflow to pond (2-inch diameter).

A failure in the FRP was discovered in May, 1978. The failure was directly downstream of a butterfly valve that was throttling flow to the spray tower sprays. The valve is now completely opened, thereby eliminating the turbulence and resultant wear. The spray pressure has increased from 18 to 23 psi, which seems to have solved the problem.

It is best not to have valves in the piping. Where valves are needed for pump isolation they are stainless steel, knife gate type. Eccentric plug valves on new scrubber failed because of incomplete shut off so they were replaced with gate valves. Some butterfly valves are also used.

15. Stack - Unit 4 originally had a carbon steel stack with a Haydite/Lumnite gunite lining which held up after the scrubber was put in. A new Cor-Ten steel stack with a Sauereisen No. 33 lining was put in with the new scrubber. The new stack is the same height as the old one.

Unit 5 has a carbon steel stack with a 2-inch gunite lining. This stack is due to be relined, probably with the same gunite, because some spalling has occurred.

16. Ball Mill - In the old system, the coal mills were used to grind the limestone. The new system has a separate ball mill.

17. Pond - The pond is not lined.

KANSAS CITY POWER & LIGHT COMPANY
LA CYGNE UNIT 1

Trip Report Number: EPRI-CM33

Date of Trip: April 25, 1979

Persons Interviewed: Terry Eaton, Supervisor of Air Quality Control, and Dale Feuerborn, Engineer, La Cygne Station.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Babcock & Wilcox is the process designer and vendor; Daniels Construction Company was the contractor; new unit, not a retrofit.

2. Boiler Type - Babcock & Wilcox crushed coal fired, wet bottom boiler with cyclone-type burners with a steam turbine of 870 MW.

   a. 15-20 percent excess air for combustion plus about 5-10 percent leakage through air preheater.

   b. The unit is normally at full load for 16 hours per day and at half load for 8 hours per day; the capacity factor has been about 40 percent for the past several years.

   c. Stack is 700 feet high.

3. Flue Gas Flow Rate - 8,000,000 lb/hr (about 2,760,000 acfm at 285 F); 100 percent through scrubbing system without provisions for bypass; 345,000 acfm per module (8 scrubber modules).

   a. 2.4 percent O_2 in the flue gas entering scrubber; 5.3 percent O_2 in flue gas leaving scrubber and entering the stack.

4. SO_2 Concentration - Approximately 5000 ppm SO_2 in inlet gas (depends on sulfur content of coal, excess air, and air leakage); approximately 1100 ppm SO_2 in outlet gas.

5. Fuel - Medium and high volatile subbituminous coal supplied by Pittsburg and Midway Coal Company from a nearby surface mine; sulfur content ranges from 5 to 6 percent with 5.4 being typical; the ash content ranges from 25 to 35 percent with 25 percent being a typical average; the average chlorine content is 0.027 percent; the high heating value is typically 9400 Btu per lb on a dry basis; the fuel is delivered by truck.

6. Scrubber Reactant - Limestone obtained from a nearby quarry is delivered by truck; contains about 91 percent calcium carbonate and one percent magnesium carbonate.

7. Removal Efficiency - 78 percent SO_2 removal; no measurements on NO_x reduction, but probably low; system design calls for 99 percent removal of particulate matter; particulate removal is achieved in venturis placed ahead of perforated plate scrubbers. Actual particulate removal is 95 percent.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figures 1 and 2; Figure 2 is a more detailed schematic of an individual scrubbing module.

2. Process Variables - See Figure 1; recirculating slurry contains 15 to 20 percent suspended solids and about 5000 ppm dissolved solids which is mainly $CaSO_4$; monitoring of chloride ion concentration is important in corrosion control; the recirculating slurry composition is about 20 percent $CaCO_3$, 50 percent $CaSO_3$, 15 percent $CaSO_4$, and 15 percent fly ash at 120 F and a pH of 5.8 to 6.0.

a. 285 inlet gas to venturi.

b. 120 F outlet scrubber temperature reheated to 150 F.

c. An estimated 5 lb fly ash per 650 lb flue gas to the venturi (about 3.7 grains/scf).

d. Recirculating scrubbing liquor pH is maintained at 5.5; fresh feed liquor is at 8.5 pH.

3. Absorber Design - Eight parallel flow trains or modules. Each module consists of a venturi, absorber, and reaction tank. The venturi and absorber have a common sump.

a. Wet venturi with variable throat width (but operated wide open mostly) for fly ash removal; slurry nozzles are currently located below throat.

b. Each SO_2 absorber consists of two perforated plate liquid/gas reaction trays or sieve trays made of stainless steel.

c. Gas velocities are 8.5 ft/sec in absorber and 160 ft/sec in venturi throat.

d. Turndown is achieved by taking modules off line; each module has individual inlet and outlet dampers; usually remove one module per 100 MW decrease in load. Turndown ratio has been varied continuously by operating the module outlet dampers. The liquid flow rates are not changed, however.

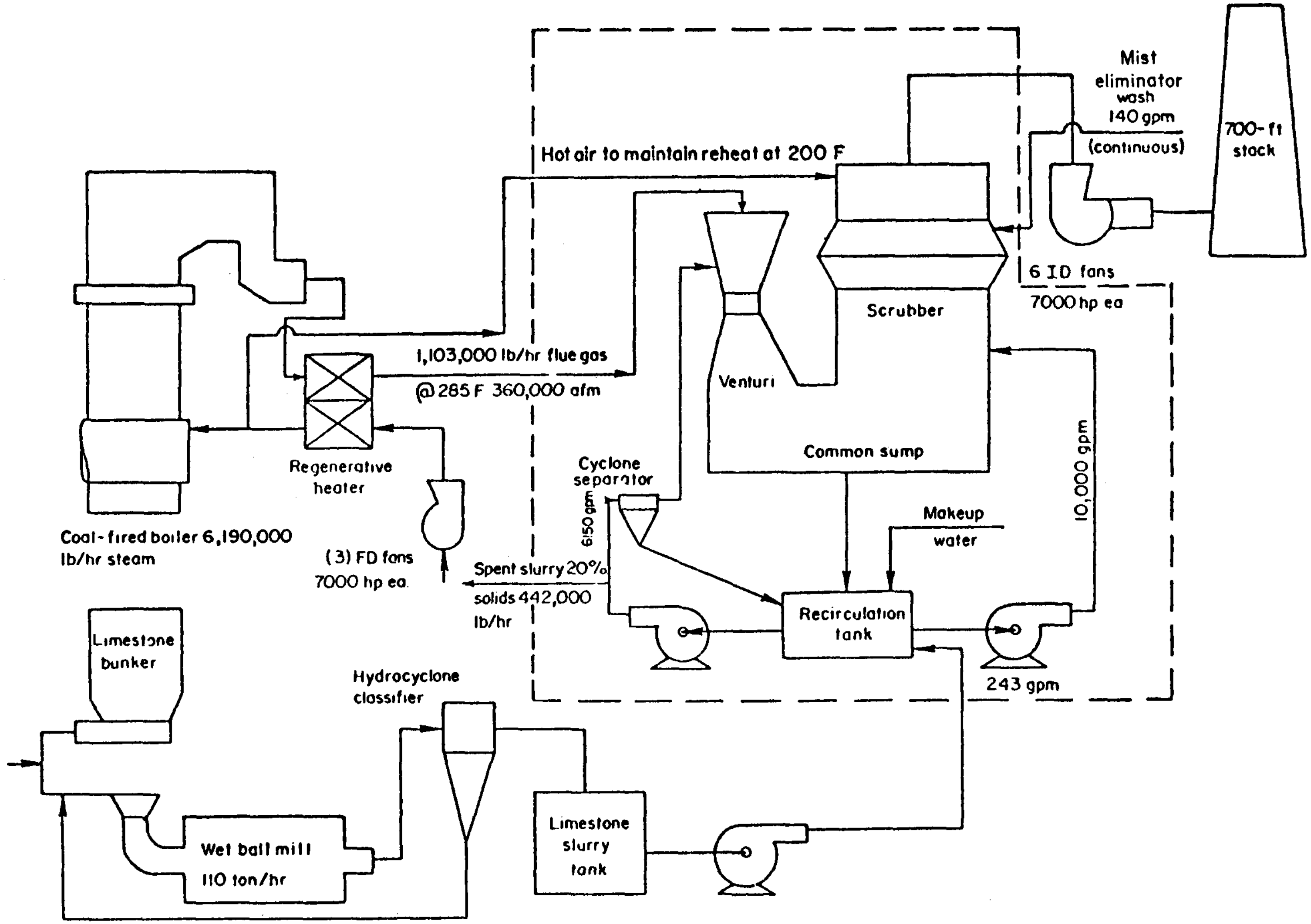
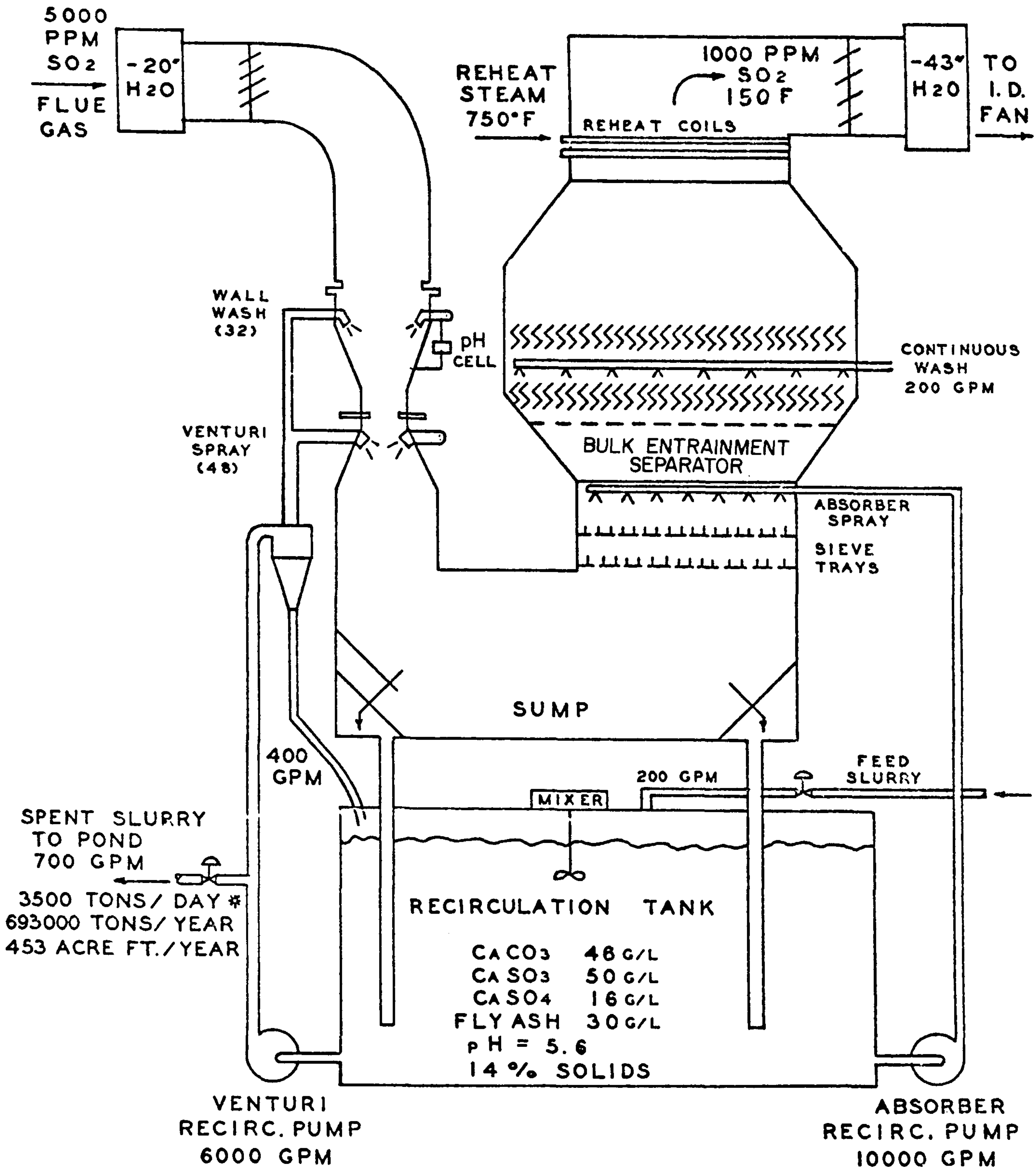


FIGURE 1. SIMPLIFIED FLOWSHEET OF SCRUBBING SYSTEM AT LA CYGNE

(Equipment within dashed-line box is one of eight modules)



* TOTAL FOR ALL MODULES

FIGURE 2. LA CYGNE FGD MODULE

4. Liquid to Gas Ratio - L/G is 17 gal/10^3 ft^3 for each venturi at full load; L/G is 33 gal/10^3 ft^3 for absorbers at full load.

5. Oxidation - It is estimated that about 16 percent of the calcium sulfite oxidizes to calcium sulfate. However, scale formation on equipment surfaces is not a problem any more. The oxidation is not critical to process operation, but useful in waste disposal.

6. Pressure Drop - Total pressure drop is about 23 inches H_2O at full load from plenum to plenum; 10 in. H_2O in venturi; 3 in. H_2O in absorber including mist eliminator; 3 in. H_2O in reheater, and the remaining in the ductwork and other equipment.

7. Solids Level - 18 percent solids including fly ash in recirculating slurry (diluted slightly by mist eliminator wash water); incoming limestone slurry to system is 10 percent solids; spent slurry is about 18 percent solids.

8. Reactant Addition - Limestone slurry is added to recirculation tanks.

9. Reactant Feed Rate - One ton of limestone per 5 tons of coal under best process control conditions.

10. Slurry Retention Time - 7.3 minutes retention time in recirculation tank based on a combined absorber and venturi flow of about 15,000 gpm. Slurry is in absorber for 0.6 seconds contact time.

a. Recirculation tanks are 116,000 gal each with a 200-hp mixer and baffles; mixers just keep solids off the bottom of the tank and turbulence keeps tanks well mixed.

11. Mist Eliminator - Double-stage chevron Z-shape mist eliminator; washed constantly with recycle water at about 230 gpm per module with a 50 percent blend of pond and service water; intermittent top wash with pond water is not used; the gas velocity is about 8.5 ft/sec in the absorber at full load; problems with carryover of particulates at higher velocities. The continuous washing has eliminated mist eliminator plugging.

12. Reheat System - Type 316L stainless steel tube reheat bundles are used. Steam at 690 F and 170 psig is used to reheat the flue gas to 150 F. Reheat bundles need washing once every third day.

13. Waste Disposal - Spent slurry, at 18 weight percent solids, from the recirculation tank is sent to a 160-acre pond; pond overflow is recycled to the system as makeup water. Plans to build a 30-year pond are underway. A clear supernatant liquor is recycled to the scrubber for washing mist eliminators and to prepare limestone slurry. The wash water

for the mist eliminators consists of 50 percent fresh water from the lake. The scrubber is operated closed-loop as much as possible, but there is a blowdown of 80 gpm per module which represents less than 0.5 percent of the water requirement for the FGD system.

14. Fans - Three 7000-hp forced draft fans ahead of the scrubber system and six 7000-hp induced draft (ID) fans ahead of the stack; particulate carryover from absorber causes deposit to form on ID fan blades; 12 mil vibration is the maximum tolerated before fan shutdown.

C. RELIABILITY

1. Start-up - Commercial operation began on June 1, 1973; first firing took place on December 26, 1972.

2. Availability - The total scrubber system of eight modules must be in service for maximum load. Each module is cleaned once every 7 to 10 days on the night shift and all modules are available during the day unless maintenance problems occur. The overall availability (hours the FGD system is available for operation divided by hours in period) has been as follows:

1973	31.0 percent
1974	76.3 percent
1975	84.3 percent
1976	92.0 percent
1977	92.5 percent
1978	93.5 percent
January, 1979	95.2 percent
February, 1979	94.0 percent
March, 1979	95.8 percent.

With the addition of an eighth module in April, 1977, continuous daytime load capability has exceeded 800 MW without appreciably affecting average module capability.

3. Longest Run - 7 to 10 days for a specific module.

4. Calendar of Operation - The FGD system has accumulated about 27,800 hours of operation through the end of 1978.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - The variable throat venturi scrubber is constructed of Type 316L stainless steel protected by a Kaocrete (ceramic) lining. The venturi has a sump which is common with the absorber (see description under absorber).

2. Absorber - The entire absorber is constructed of Type 316L stainless steel. The floor of the sump (common with venturi) is covered with Kaocrete (ceramic). Some patch work was required in the Kaocrete in one sump, under the venturi section. The two sieve trays in each absorber are also Type 316L stainless steel.

3. Nozzles - The venturi and absorber nozzles were described as pink ceramic (alumina). The original stainless steel nozzles wore so they were replaced with the ceramic nozzles. The wash nozzles for the mist eliminator are Type 316 stainless steel.

4. Mist Eliminator - The two-stage mist eliminators are chevron type, and they are constructed of FRP (fiberglass reinforced plastic).

5. Fans - The fans are downstream from the absorber. Some are carbon steel with a glass-reinforced, polymeric coating (type not specified), and some have Inconel rotors. Some blades have Inconel clips. There have been corrosion and erosion problems with the fans since startup. They also require washing on a 4-day cycle.

6. Reheaters - The reheaters comprise smooth, Type 316L stainless steel tubes in bundles. These tubes have to be replaced about every two or three years. The reheaters raise temperature of flue gas to about 150 F.

7. Pumps - The recycle pumps are rubber-lined A-S-H (Allen-Sherman-Hoff). They have given good service except for frequent loosening of throat liners, (can be replaced in 5 or 6 hours) because of cavitation when tank level is not maintained. The lime transfer pumps are rubber-lined, Denver. Classifier pumps are rubber-lined, A-S-H. Specific information was unavailable on pond return pumps, but they probably are not rubber-lined.

8. Tanks - The slurry recirculation and limestone slurry makeup tanks are rubber-lined carbon steel and they have given no problems.

9. Agitators - All agitators are rubber-coated carbon steel.

10. Storage Silo - The limestone storage silo is carbon steel.

11. Thickener - None used.

12 Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The ducts are carbon steel without lining. In 1977, Plasite 4005 was installed in duct from the fan outlet to stack. If this lining is good when examined, other ducts will be replaced and lined with the Plasite 4005. In high wear areas, a layer of glass fiber was used to reinforce lining.

The expansion joints were originally 14 to 18 gauge carbon steel. They did not last long and have been replaced with glass fiber-reinforced Viton®. These have given good service.

The louver-type inlet dampers are carbon steel and have given good service. The carbon steel, louver-type dampers on module outlets corroded badly. They will be replaced with Type 316L stainless steel.

14. Piping and Valves - Slurry piping is rubber lined. The original natural gum rubber (Gates and La Favorite) was too soft and is being changed to synthetic rubber (Telex 200). The slurry line to pond and the return water line are also rubber lined. The hoses to the nozzles are natural gum rubber with wire reinforced neoprene lining. The spray headers are carbon steel with rubber covering.

No good answer has been found to the valve problem. Experimentally, two types of valves have been examined: (1) a high density polyethylene lined butterfly valve which looks pretty good, and (2) a Tuffline valve which has a Type 316L stainless steel body with a high density polyethylene plug and seat. For the past 4 or 5 years, Fabri valves have been used. They are knife gate valves constructed of Type 316 stainless steel. They last about one year, but with really good service for only 2 or 3 months. Butterfly valves and gate valves wear out quickly. Double seat valves provide better seating but cost about 3 times as much as single seat valves.

15. Stack - The steel stack (in concrete shell) was originally lined with Rigiflake lining, which failed in 6 months. A change was made to hot air injection (about 250 F stack gas), but because of plant derating, the hot air reheat was shut off for 6 months. There was acid corrosion so new reheat bundles were installed. Experiments with new metals for reheat tubes were tried and then in 1975, the stack (and duct from fan to stack) was lined with Plasite 4005. It was relined in 1976 and failed for a second time. Finally, in 1977, the Plasite 4005 was installed properly (3 spray applied coats to give 40 mils total).

16. Ball Mill - The steel ball mill is Koppers Hardinge with Ni-hard liner. It is a noisy high-maintenance item. The liner in the mill is in 300 sections, each bolted to the shell. These sections require replacement because of wear and about 2/3 of them have been replaced thus far. There are also problems from leaks around seals. Each mill weighs 400 tons and has a 2000 hp motor. Capacity of each is 110 tons per hour but highest throughput has been 55 tons, and current throughput is 35 tons per hour of dry limestone feed. The slurry produced contains 20 percent limestone by weight.

There is a hydrocyclone classifier in the slurry feed line to the venturi. Its purpose is to separate large particles from the slurry. The upper portion of the carbon steel shell is lined with rubber and the lower portion with ceramic (aluminum oxide) blocks.

17. Pond - The pond is not lined; the Corps of Engineers found a fairly impermeable layer of shale and limestone at the pond site.

CITY UTILITIES OF SPRINGFIELD, MISSOURI
SOUTHWEST UNIT 1

Trip Report Number: EPRI-CM34

Date of Trip: April 26, 1979

Persons Interviewed: Bryan Brooker, Scrubber Specialist, City Utilities.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - UOP is the process designer and vendor; Enerco is the contractor; Burns and McDonnell is the consulting engineer; new installation.

2. Boiler Type - Riley Stoker pulverized coal-fired boiler nominally rated at 194 MW with a heat rate of 9300 Btu/kWh.

   a. 22 percent excess air.

   b. Capacity factor is about 60 percent; full load during peak hours in morning and evening; about 100 MW during the day and about 65 MW at night.

   c. Stack height is 389 ft.

3. Flue Gas Flow Rate - 795,000 acfm at 330 F at full load; all the flue gas is scrubbed.

   a. About 4.0 to 4.5 percent oxygen in the flue gas to the scrubber.

4. SO_2 Concentration - 2500 ppm SO_2 in inlet gas and 600 ppm or less SO_2 in outlet gas.

5. Fuel - Bituminous coal from Kansas or Oklahoma; 3.5 to 4 percent sulfur, 12 percent ash, and 0.3 percent chloride; heat content is about 11,000 Btu/lb; ash contains substantial quantities of lime.

6. Scrubber Reactant - Limestone with a maximum of 2 percent inerts, mostly flint; there is no classifier on the outlet of the wet ball mill so that the inerts enter the system and affect the thickeners and vacuum filter; however, this is much less of a problem since the inerts have been reduced and the limestone is ground more.

7. Removal Efficiency - Average of 85 percent SO_2 removal but 91 percent is possible; 99.75 percent of the fly ash is removed by electrostatic precipitator; there is no intent to remove NO_x in the scrubber as this is taken care of by the boiler design.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1. This schematic is essentially correct except there is only one presaturator tank and one mist eliminator wash tank to serve both modules.

2 Process Variables -

a. Flue gas enters the scrubber at 320 to 340 F.

b. Outlet gas temperature from scrubber is 135 F.

c. Fly ash inlet loading to scrubber is very low, probably about 0.03 grains/scf.

d. Scrubbing liquor pH is 5.5 at the inlet and not measured at the outlet.

3. Absorber Design -

a. Electrostatic precipitator for fly ash removal

b. Three-stage Turbulent Contact Absorber (TCA) for SO_2 removal; the static bed heights are 9 in., 9 in., and 6 in. with sponge rubber balls; there are two scrubbing modules.

c. The superficial gas velocity is 10 ft/sec.

d. Each module can be operated from 50 percent to 100 percent of rating so that the turndown ratio for the unit is 4 to 1; three sets of dampers per module (inlet, outlet, and bypass) are used to take one module off-line when the load gets to 110 MW; an attempt is made to keep the unit above 55 MW which is minimal for one module.

4. Liquid-to-Gas Ratio - The recycle pumps are constant flow so that the L/G varies from 65 at full load to 130 gal/10^3 ft^3.

5. Oxidation - The average oxidation of sulfite to sulfate is 20 percent, but the oxidation can get higher at the thickener outlet.

6. Pressure Drop - Total pressure drop is 16.5 in. H_2O from fan to stack; pressure drop is 13.5 in. H_2O across scrubber and mist eliminator and 0.6 in. H_2O across mist eliminator not including the trap out tray.

7. Solids Level - Up to 15 percent solids in recirculating slurry; 40 to 55 percent solids in thickener bottoms; 70 percent solids in filter cake.

8. Reactant Addition - Fresh limestone slurry is added to scrubber hold tank.

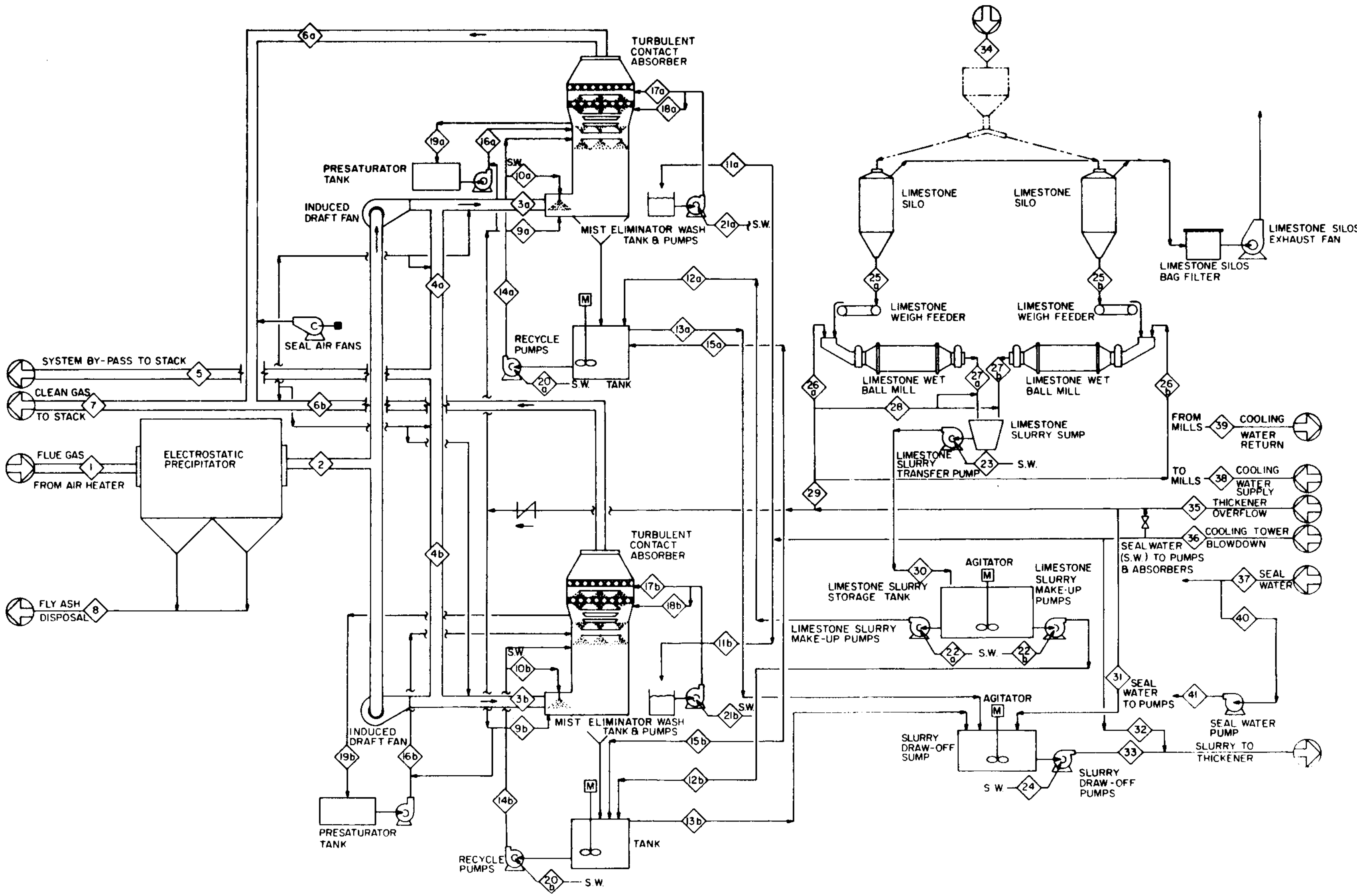


FIGURE 1. FLOW SHEET FOR THE LIMESTONE SCRUBBING PROCESS AT THE SOUTHWEST POWER PLANT

9. Reactant Feed Rate - 1.12 moles $CaCO_3$ per mole of SO_2 removed.

10. Slurry Retention Time - About 14 minutes.

11. Mist Eliminator - Two-stage chevron mist eliminator with 3 passes per stage; a trap-out tray is located below the mist eliminators; the lower stage is washed continuously from below with 130 gpm and above with 90 gpm of 20 percent cooling tower blowdown and 80 percent thickener overflow (sometimes 100 percent thickener overflow); all makeup water except for seal water is used for washing the mist eliminators; the superficial gas velocity is a maximum of 10 ft/sec.

12. Reheat System - None.

13. Waste Disposal - Closed-loop operation except for emergency situations; thickener overflow and filtrate are returned to the scrubber system; thickener bottoms are filtered and mixed with dry fly ash in a pug mill; the mixture is landfilled in a clay-lined disposal site along with the remainder of the fly ash.

14. Fans - Two induced draft fans between electrostatic precipitator and scrubbers.

C. RELIABILITY

1. Start-up - April, 1977.

2. Availability - The system operated about 60 percent of the time for a few months between shakedown and October, 1977, and then was shut down until July, 1978; from restartup, the monthly availabilities (hours the FGD system is available for operation divided by hours in period) are as follows:

July, 1978	8.3 percent
August	29.5 percent
September	11.1 percent
October	0 percent
November	51.8 percent
December	63.5 percent
January, 1979	21.3 percent
February	26.4 percent
March	58.5 percent

3. Longest Run - About 15 days.

4. Calendar of Operation - Module A has operated for a total of 1695 hours and Module B for a total of 1152 hours through March, 1979.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - There is a presaturator ahead of the absorber. Originally, it was constructed of carbon steel with a Pre-Krete G-8 lining. The lining failed so it was replaced with stainless steel (Uddeholm 904L), which was installed as a liner inside the carbon steel shell.

2. Absorber - The absorber is constructed of carbon steel with rubber lining throughout. This has provided good service. The three stages of nitrile sponge rubber balls are supported and retained on grids which are constructed of carbon steel with a rubber coating. The internal stage dividers for the balls are fiberglass-reinforced plastic grates.

3. Spray Nozzles - The main slurry recycle nozzles in the absorber are constructed of silicon carbide to resist the abrasion. Other nozzles (for mist eliminator, trap out trays, and presaturator) are constructed of Carpenter 20 stainless steel. The only nozzle wear problems are in the presaturator.

4. Mist Eliminators - The mist eliminators are FRP (fiberglass-reinforced plastic). They are satisfactory but not massive enough to support a man's weight. They will be replaced with thicker chevrons capable of supporting a man. The trap out trays are also FRP, but presently thick enough to support a man.

5. Fans - The hot side fans are ordinary carbon steel.

6. Reheater - There are no reheaters. This does cause some stack rain-out problems and contributes to the failure of outlet duct linings.

7. Pumps - The recycle pumps are Denver SLR (rubber lined). The rest of the pumps are rubber lined A-S-H (Allen-Sherman-Hoff). They have caused very little problem. All are still with the original rubber linings. The only significant problem occurred from a failure in packing in the recycle pumps, which allowed the slurry to get into the bearings.

8. Tanks - The recycle tanks are concrete with a glass flake-reinforced plastic lining (source unknown). The limestone slurry storage tank is unlined carbon steel, as is the ball mill sump. The mist eliminator wash tank and the supply tank for the presaturator are carbon steel with glass flake-reinforced plastic lining (source unknown). Tank materials have not been a problem source.

9. Agitators - The agitators are rubber-covered carbon steel Lightnin' mixers. There was a shaft breakage in the recycle tank agitator caused by ultrasonic vibration. The agitator was replaced with the same material but there is concern that the problem might reoccur.

10. Storage Silo - The limestone storage silo is carbon steel with a double skin bottom.

11. Thickener - The thickener has carbon steel walls and a concrete bottom. There is a bitumastic lining on the carbon steel but information was unavailable regarding presence or absence of lining on the conctete bottom.

12. Vacuum Filter - The rotary filter is from Envirotech and is constructed of carbon steel.

13. Ducts, Expansion Joints, and Dampers - The inlet ducts are carbon steel. The outlet ducts are lined carbon steel. The original lining was a glassflake-filled material (Rigiflake 4850) which failed within one month and was repaired about three times during the first year of operation. This lining was replaced in October, 1978, with Plasite 4005 and Plasite 4030; the latter in the high abrasion areas immediately following the outlets from the absorber modules. About 100 square feet of the lining on internal parts which vibrate has required replacement since then (in April, 1979). The reason for failure of the original lining is unknown but may have been faulty application. The bypass ducts are carbon steel and go directly into the stack.

The expansion joints at the I.D. fan outlet are Viton®. They have given many problems and may be replaced with Inconel 625. The expansion joints in the bypass ducts are Cor-Ten steel. The expansion joints at the scrubber outlet appear to be asbestos-filled.

The double louver-type inlet and bypass dampers are carbon steel with Inconel seals. The outlet dampers are Uddeholm 904L with Inconel 625 seal strips. They are also double-louver type. Original outlet dampers were Type 316L stainless steel but they failed in about 3 months because of high chloride in the flue gas.

14. Piping and Valves - Recycle piping is rubber-lined carbon steel. All other piping is FRP. The FRP piping gives problems because it will not take shock, and joints fall apart. The spray headers are FRP, except for main recycle headers which are carbon steel with rubber lining inside and out.

DeZurik rubber-lined eccentric plug valves are used for practically all the valves in the system. The plugs wear so valves are rebuilt periodically.

15. Stack - The stack has a concrete shell with an acid resistant brick lining held together with acid resistant mortar (Corlok B). There is a Stackfas coating on the upper part and there have been some problems in the top 5 or 10 feet. The annulus is not pressurized.

16. Ball Mill - The Kennedy Van Saun steel ball mill is rubber lined, with lining by A-S-H.

ENVIRONEERING, INC.
SUBSIDIARY OF THE RILEY COMPANY
SCHILLER PARK, ILLINOIS

Trip Report Number: EPRI-CM35

Date of Trip: May 23, 1979

Persons Interviewed: Hal Taylor, Chief Engineer, Daniel Beal, Assistant Sales Manager, and Ronald Klimek, Marketing Manager, Utility FGD Systems.

A. BACKGROUND

Environeering currently has three operating utility FGD systems using lime or limestone. These units (Duck Creek Unit 1 and Morrow Units 1 and 2 in Table 1) are Ventri-Sorber™ scrubbers which contain up to 9 decks of rods (actually tubes), each of which maintains a several inch head of scrubber slurry through which the flue gas must pass. The lower deck of rods may be adjustable to control turn down, but the other 8 decks are fixed, although the tubes are free to rotate to minimize build up. A schematic of this system is shown in Figure 1.

B. MATERIALS OF CONSTRUCTION
(Duck Creek Unit 1)

1. Prescrubber - No prescrubber is used in this system as ESP's are used to get 0.08-0.1 lb/10^6 Btu loadings; can use higher loadings but maintenance goes up. A&E usually set limits based on codes.

2. Absorber - This station utilizes the Riley/Environeering Ventri-Sorber™ scrubber which consists of 7 decks of 1 inch O.D. Type 316L stainless steel rod (tube) beds with a 1 inch gap between the rods. There are supports every 5 feet along the rods and provisions for a 9th deck with variable spacing in all units. The rods maintain a liquid head of $\sim$ 6 inches above each stage of rods through which the gas bubbles. The rods are freely supported to enable them to vibrate or rotate, thus preventing scaling or build-up. The absorber walls are also Type 316L stainless steel. The limestone slurry and ash cling to the absorber wall and could become a potential source of corrosion as the chloride level in the system has not yet reached a steady state. However, no problems have been encountered as yet. Where the gas flow turns at a 90 degree angle to enter the mist eliminator, the walls are constructed of Hastelloy G.

3. Spray Nozzles - Alumina spray nozzles (with internal vanes) were originally used to introduce the limestone slurry, but they plugged and were replaced with Type 316L stainless steel open pipe reducing from 4 to 2 inches. The mist eliminator has nozzles which are constructed of aluminum oxide ceramic (inner vane type). Originally PVC nozzles were used, but they wore out in about a week.

TABLE 1. RILEY STOKER/ENVIRONEERING FGD INSTALLATIONS

	Philadelphia Electric Co.	Central Illinois Light Co.	S. Miss. Electric Co-op	S. Miss. Electric Co-op
Plant	Eddystone 1	Duck Creek 1	R. D. Morrow 1	R. D. Morrow 2
Location	Eddystone, Pa.	Canton, Ill.	Purvis, Miss.	Purvis, Miss.
Unit size, MW	360	400	180	180
Scrubber size, ACFM	300,000	300,000	404,000	404,000
Fuel sulfur content, percent	2.5	4.0	1.5	1.5
Outlet gas temperature, F	132	130	130	130
Guaranteed efficiency, percent	90	85	85	85
Scrubber additive	MgO	Limestone	Limestone	Limestone
Initial operation	11/75	6/77 6/78	6/78	12/78
Scope of supply	Scrubber only	Boiler to stack inlet	ESP to stack inlet	ESP to stack inlet
Number of units	3	4	1	1

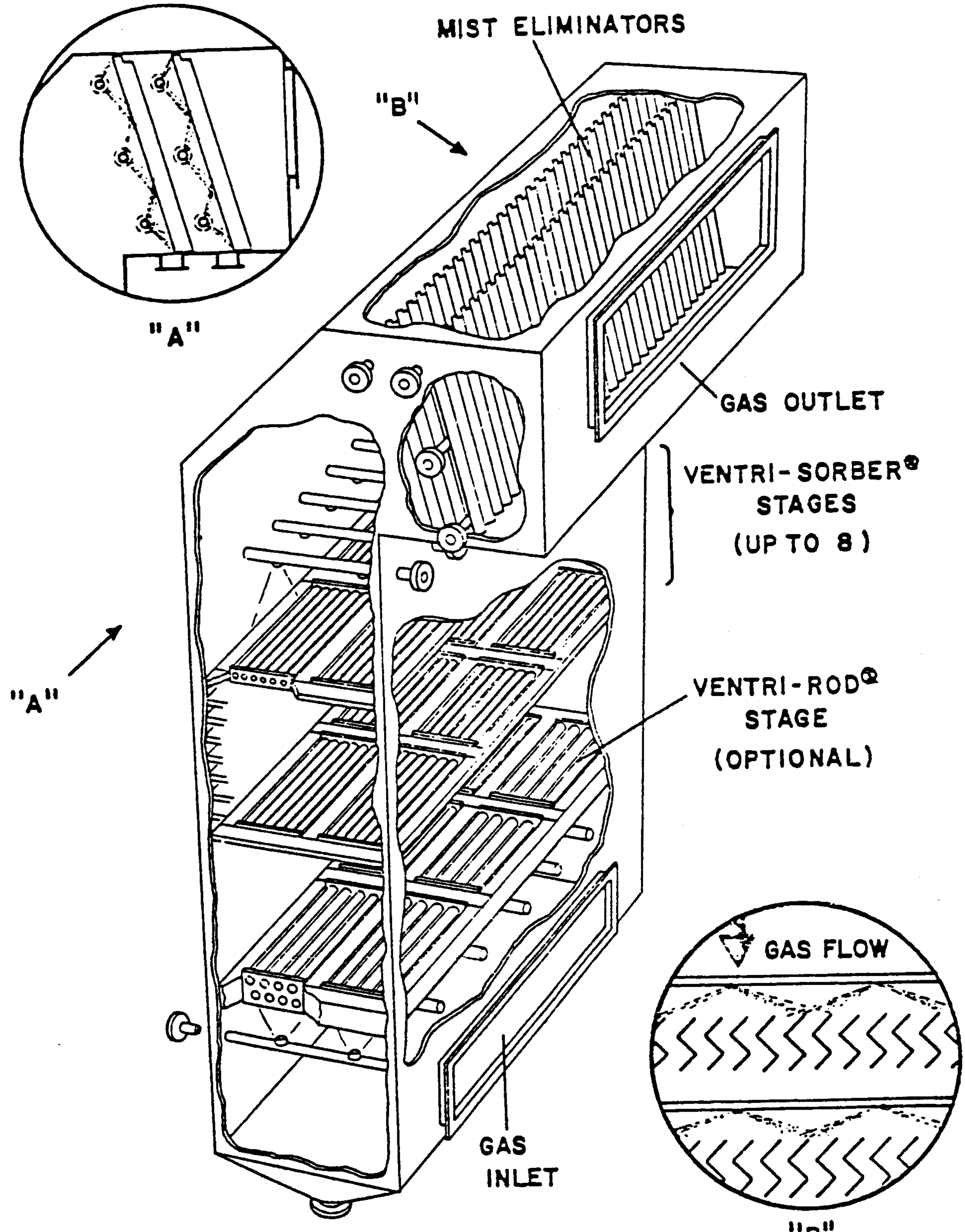


FIGURE 1. VENTRI-SORBER® SCRUBBER

4. Mist Eliminator - The mist eliminator comprises two banks of vanes slanted at approximately 30 to 40 degrees with the vertical. Both the vanes of the mist eliminator and the walls of the absorber in this area are constructed completely of Hastelloy G. Where the unit is washed and the Hastelloy G is visible there is no evidence of corrosion.

5. Fans - Carbon steel fans manufactured by Buffalo Forge Company are located after the electrostatic precipitator and ahead of the scrubber. Because these are on the hot side, no corrosion problems have been encountered.

6. Reheater - None used as stack designed for wet operation. However, system has operated without scrubbers, resulting in hot stack conditions.

7. Pumps - Worthington pumps are used on the recycle lines in module D. These originally were lined with natural rubber, but after a failure occurred, the linings were all changed to neoprene rubber which also eroded rapidly (about 3 months). The impeller and lining in the module D pump is normally replaced at the same time. Allen-Sherman-Hoff (A-S-H) recycle pumps used on modules A, B, and C have been less trouble. The pond water recycle pump is carbon steel and has given no problem. Rubber-lined Galigher pumps are used between the mill slurry tank and the classifier, and in the slurry transfer line (Galigher does not build big enough pumps to use in recycle lines). Mist eliminator wash pumps are A-S-H or Worthington (some mechanical failures, but no materials failures).

8. Tanks - The mill slurry tank is unlined carbon steel. The storage and recycle tanks are made of carbon steel with a bonded neoprene rubber lining. There has been no sign of any wear on these linings as yet. The only tank which is not carbon steel is the mist eliminator wash tank which is constructed of fiberglass-reinforced plastic ("Atlac" polyester from Ashland) and has presented no problems.

9. Agitators - All the agitators in modules A, B, and C were manufactured by Chemineering and are rubber coated. There have been no difficulties with the agitators. The agitator in module D is a Philadelphia mixer, also rubber coated.

10. Storage Silo - A carbon steel silo is used for limestone storage and it has not been the source of any difficulties.

11. Thickener - None used.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - Carbon steel is used for the gas inlet duct to the scrubber, and for the bypass duct. However, the outlet duct (to stack) is Hastelloy G. No problems have been encountered with any of these components.

The expansion joints in the outlet duct are made of Hastelloy G (bellows design) and have not been the source of any difficulty. Carpenter 20 bellows are used in the inlet duct (might use Viton® in future).

All the dampers in the system are constructed completely of Hastelloy G. Louver dampers are used on the inlet side and have presented problems with ash clogging in module D (design problem). The outlet dampers (Hastelloy G clad mild steel on wet side, uncoated steel on other) are of the guillotine type and have presented no problems (except for design problems with bonnets). Bypass damper is of the louver type and has given some actuator problems (clutch failure).

14. Piping and Valves - At the present time practically all the piping in the system is fiberglass-reinforced plastic supplied by the Atlantic Bridge Company (ABCO #150). Originally, the mist eliminator wash lines were constructed of polyvinyl chloride piping but these were subjected to too much heat and had to be replaced with the fiberglass-reinforced plastic. There has been some erosion of the storage tank/recycle tank FRP piping, particularly at elbows. This problem has been alleviated by replacing with larger diameter pipe and reinforcing the elbows. Part of the pond return pipe is constructed of concrete with the remainder being FRP. The ball mill slurry pipe (up to storage tank) is rubber lined and no failures have been noted. The spray headers in the absorber are Type 316L stainless steel.

The number of valves was kept to a minimum in this system. Originally rubber lined DeZurik eccentric plug valves were used on the recycle pump lines, but deposits built up and caused plugging, so valves have since been replaced with R.K.L. pinch valves. Grigsby pinch valves are also favored for this application.

15. Stack - The stack consists of a concrete shell with a carbon steel liner and a Flakeline 151 spray-up coating about 20-30 mils thick. The coating has blistered and has required repair whenever the unit is down. The lining for the transition section and the ash hopper also was Flakeline 151, but this has been destroyed and has not yet been replaced. The utility is considering purchasing an Inconel 625 liner to replace the lower damaged portion of the steel liner. This was designed to be a wet stack (no reheat system) but the system has been operated without the scrubber using low sulfur coal, exposing the coating to excessive temperatures.

16. Ball Mill - The ball mill is carbon steel with a rubber lining and has presented no problems.

17. Pond - The scrubber effluent is sent to a 65 acre pond which is lined with clay.

(R. D. Morrow Units 1 and 2)

1. Prescrubber - There is no prescrubber. ESP provides for initial particulate removal.

2. Absorber - The design of the absorber is similar to Duck Creek. However, these vessels are carbon steel with a 60-80 mil (2 coat) Dudick flakeglass coating. The lining was applied by troweling and rolling. The tubes are Type 316L stainless steel. Originally the lower walls and floor section had an acid resistant brick lining applied over the flakeglass membrane, but the bricks on the wall section fell out twice and have not been replaced. The mortar (type unknown) was apparently sound and the failure was believed due to a mechanical problem (insufficient expansion allowance). The inlet section temperatures have not been as severe as expected and the coating is apparently holding up even without the bricks on the walls (the floor is brick lined).

3. Spray Nozzles - The slurry spray headers are Hastelloy G, and Type 316L nipples are used as nozzles. The nozzles on the mist eliminator wash lines are alumina.

4. Mist Eliminator - The walls are carbon steel with the same Dudick flakeglass lining used in the absorber. No problems were mentioned with the coating, but some difficulties have been experienced with the vanes. Original vanes were made from a GE Noryl resin which failed by pluggage and heat distortion. They have since been replaced with compression molded FRP (Diamond Shamrock #6694 resin) vanes of Environeering's own design. In addition, the original flakeglass-lined vane supports were replaced with Hastelloy G supports. Piping was originally PVC and has been replaced with ABCO piping. The wash nozzles are alumina (with internal vanes).

5. Fans - Same as Duck Creek (see above).

6. Reheater - Reheat is obtained by bypassing about 35 percent of the flue gas.

7. Pumps - Rubber lined Ingersoll-Rand pumps are used throughout these systems. There have been a few mechanical problems (one reline and some seals) but no major failures.

8. Tanks - Slurry recycle tank is carbon steel and originally had a flakeglass polyester coating (Glassflake International) which debonded catastrophically and has since been replaced with the same Dudick troweled and rolled flakeglass coating used in the absorber. The base of the recycle tank is also carbon steel which has buckled in spots. To prevent flexing, holes were drilled through the base and a grouting pumped below the base to provide additional support. The storage and mill slurry tanks are both carbon steel, and the mist eliminator wash tank is FRP, none of which have given any problems.

9. Agitators - Agitators are rubber-coated carbon steel (manufacturer uncertain).

10. Storage Silo - Limestone storage silo is carbon steel and no problem was mentioned.

11. Thickener - Not supplied by Environeering.

12. Vacuum Filter - Not supplied by Environeering.

13. Ducts, Expansion Joints, and Dampers - Inlet and bypass ducts are uncoated carbon steel. Outlet duct and mixing duct (for reheat) were coated with Glassflake International flakeglass polyester which debonded and blistered badly. Dudick flakeglass has been used to replace all the duct linings on the outlet and mixing sides.

Some expansion joints are metallic (Cor-Ten) and some are laminated fabric and rubber (EPDM).

Inlet dampers are carbon steel; outlet dampers are steel with a flakeglass coating. Sealing strips are Type 316L stainles steel. All are of a louver design; some leakage has been encountered at the seal but these have been mechanical or jamming problems.

14. Piping and Valves - Slurry recycle piping is rubber-lined carbon steel; mist eliminator piping is now ABCO FRP (see mist eliminator discussion), and mill slurry piping is now all rubber-lined carbon steel (some FRP had been used as a temporary measure).

DeZurik eccentric plug valves used at these units have flush ports added to minimize plugging. There have been minor sticking problems but they are serviceable. Pinch valves would be preferred in future designs.

15. Stack - The stack is a concrete shell with two independent brick liners. It was not supplied by Environeering so no other details were available.

16. Ball Mill - Same as Duck Creek (see above).

17. Pond - A thickener/filter system (not supplied by Environeering) is used in lieu of pond disposal, but a small (30 day capacity) pond is available for temporary storage.

(Other Systems)

Environeering has built some particulate-only scrubbers based on the Ventri-Sorber design and has tested 80 percent alumina ceramic tubes (Electrical Refractories, East Palestine, Ohio) in these systems. However, for large utility scrubbers they are not used because of concern for damage from falling tools/men.

CUSTODIS CONSTRUCTION COMPANY
CHICAGO, ILLINOIS

Trip Report Number: EPRI-CM36

Date of Trip: May 23, 1979

Persons Interviewed: Dick Wilber, Sales

A. BACKGROUND

Custodis Construction designs and/or builds power plant chimneys of all types, most of which have an outer reinforced concrete shell to carry the wind load and provide support for inner linings. Although they will do a complete design/construction job, they will often only design and install a portion of the chimney (shell and/or lining) according to overall capacity/size/material specifications established by the utility or A&E firm. Consequently, linings may be brick, steel, or FRP, which may or may not have additional protective coatings. Although Custodis indicates there is not a universally superior lining material, they generally prefer the following:

Acid resistant bricks (with potassium silicate mortars) are superior for high temperature, low pH environments

FRP (fiberglass reinforced plastic) for low temperature, high pH environments

Organic or inorganic coated mild steel where initial cost is of concern; chemically (silicate) bonded inorganics would be preferred to those bonded with hydraulic setting cements; adhesion can be a problem with inorganics, and temperature excursions the main concern for organics.

They apparently have not installed any of the high nickel/molybdenum alloy linings being considered by some utilities, and indicated that these materials are extremely costly and require long lead times (2-3 years) just to obtain the material.

B. CONSTRUCTION EXPERIENCE

Chimney systems for utility FGD installations with which Custodis has been involved are listed in Table 1. Materials used in these chimneys are generally type H acid resistant brick bonded with a potassium silicate mortar (Pennwalt's Corlok B or Sauereisen No. 65), or uncoated steel liners (coatings applied by others).

TABLE 1. CUSTODIS CHIMNEY INSTALLATIONS FOR UTILITY LIME/LIMESTONE FGD SYSTEMS

Utility	Station	Chimney[a] Liner[b]	Chimney[a] Coating	Chimney[a] Comments	Breeching
Colorado Ute Electric Assn.	Craig 1 & 2	HARB with Corlok B	None	Pressurized annulus	Cor-Ten
Indianapolis Power & Light	Petersburg 3	Carbon steel	--	Custodis built shell only	--
Kansas City Power & Light	Hawthorn 3 & 4	HARB with Corlok B	None	Built in 1967; un-pressurized	Unlined carbon steel
Kansas Power & Light	Jeffrey 1	HARB with Corlok B	None	Pressurized annulus	Carbon steel lined with Sauereisen No. 72
Southern Illinois Power Coop	Marion 4	HARB with Corlok B	None	Changed from carbon steel liner	Inconel 625
Tennessee Valley Authority	Widows Creek 8	Carbon steel	--	Custodis built only shell and liner	--
Texas Utilities	Monticello 4	HARB with Sauereisen No. 65	None	Unpressurized annulus	--
Utah Power & Light	Hunter 1	HARB with Corlok B	None	Provisions for pressurization	--
Utah Power & Light	Huntington 1	HARB with Corlok B	None	Provisions for pressurization	--
Utah Power & Light	Huntington 2	LARB	None	Provisions for pressurization	--

(a) All chimneys on the list have a concrete shell.
(b) HARB = Type H acid resistant brick; LARB = Type L acid resistant brick.

UNITED ENGINEERS & CONSTRUCTORS
PHILADELPHIA, PENNSYLVANIA

Trip Report Number: EPRI-CM37

Date of Trip: May 31, 1979

Persons Interviewed: Warren R. Thompson, and Robert E. Moore, Supervisory Engineers, Corrosion Engineering, United Engineers & Constructors (UE&C).

A. BACKGROUND

United Engineers & Constructors is one of the five largest engineering firms in the country designing power generation facilities, both nuclear and, more recently, fossil fuel. They are acting as consulting engineers for the Pleasants Station of Allegheny Power which has B&W lime FGD systems on two 625 MW units, one of which has started up. In addition, UE&C has been selected by Arizona Public Service to install retrofit FGD systems on Four Corners Units 4 and 5. Each of these 755 MW units will probably be equipped with a horizontal spray scrubber using a lime slurry. UE&C also designed and constructed the 120 MW MgO scrubbing system at the Eddystone Station of Philadelphia Electric.

B. MATERIALS OF CONSTRUCTION

Although general features of UE&C's activities were freely discussed, specific design aspects (such as materials) were considered proprietary to each client, from which approval would have to be obtained before the information could be released to Battelle.

Approximate price information (installed) on several types of stack lining systems were provided as follows:

- Steel: $\$25/ft^2$ plus $\$10/ft^2$ for organic coating
- Fiberglass reinforced plastic: $\$35/ft^2$
- Acid-resistant bricks: $\$25\text{-}30/ft^2$
- Inconel 625: $\$100\text{-}125/ft^2$

(Pleasants Units 1 and 2)

Information on materials used at this utility station is of interest since Unit 1 is operational and a problem with debonding of a Plasite 4005 lining in the top of the steel-lined stack has been identified by Allegheny Power. United Engineers & Constructors would not discuss this or other material aspects of the Pleasants Station during the visit but promised to provide materials information subject to Allegheny Power Service Corporation approval.

PULLMAN KELLOGG
RESEARCH AND DEVELOPMENT CENTER
HOUSTON, TEXAS

Trip Report Number: EPRI-CM38

Date of Trip: June 19, 1979

Persons Interviewed: A. Glenn Sliger, Manager of Chemical Engineering Development, and Robert H. Roberts, Manager, of Mechanical Engineering Development, Pullman Kellogg.

A. BACKGROUND

Pullman Kellogg engineers the Kellogg/Weir scrubbing system. The key element of the system is a simple, open, horizontal spray chamber. A list of the Kellogg/Weir systems scheduled for start-up follows:

1. Associated Electric Coop, Thomas Hill 3 (North Central Missouri)- This is a 670 MW plant. The scrubber is designed for 4.8 percent sulfur coal. The scrubber will use magnesium-promoted limestone. It is scheduled for start-up in January, 1982.

2. Pennsylvania Power, Bruce Mansfield 3 - This is a 825 MW unit. The scrubber is designed for 4.7 percent sulfur coal and will use thiosorbic lime. Start-up is scheduled for April, 1980.

3. Salt River Project, Coronado 1 and 2 (Arizona) - This is a 350 MW unit. Plans are to use 1 percent sulfur coal, and use plain limestone for SO_2 removal. Start-up for Unit 1 was February, 1979, and Unit 2 is scheduled for January, 1980.

The system for the Salt River Project is an exact duplicate of the demonstration unit that operated at the Mohave Power Station.

B. MATERIALS OF CONSTRUCTION
(Preferences for Kellogg/Weir Systems)

1. Prescrubber - No prescrubber is used.

2. Absorber - The materials choice at the entrance (hot end) of the absorber chamber is Type 316L stainless steel, or carbon steel with a fluoroelastomer lining (Pullman Kellogg's CXL-2000). The material for the rest of the absorber is carbon steel with a flakeglass/polyester lining troweled on 40-mils thick per coat for a total thickness of about 80 mils. The flat bottom is protected by Pre-Krete. The downcomers are rubber lined.

3. Spray Nozzles - The materials choice for slurry spray nozzles is stellite, ceramic, or Refrax (there is no one single choice for all absorber modules). For mist eliminator spray nozzles (clear water), the choice is either Type 316 stainless steel or polyvinyl chloride.

4. Mist Eliminators - The mist eliminator preference is for a chevron-type constructed of polyvinyl chloride, Noryl®, or other plastic.

5. Fans - The fan is on the dry side and materials choice is carbon steel.

6. Reheater - The reheater is generally specified by the customer and there is no single choice. Types which have been used are: (a) Mansfield, oil-fired burners outside the duct (refractory-lined carbon steel chamber and duct), and (b) Coronado, bypass reheat. There is no reheat at Thomas Hill.

7. Pumps - Rubber-lined pumps (manufacturer not specified) are the choice for any slurry handling. These pumps will handle a maximum head of about 110 feet of water. Carbon steel is the probable choice for clear water pumps.

8. Tanks - The reaction tanks are carbon steel with natural or Buna rubber lining (not neoprene). If limestone is used, the slurry mixing and feed tanks are rubber-lined carbon steel, but if lime is used, they are unlined carbon steel.

9. Agitators - The agitator choice is rubber-covered carbon steel.

10. Storage Silo - The storage silo choice is either carbon steel or concrete. Concrete is less expensive for the very large silos so would probably be the choice. However, the type of silo is often specified by the customer.

11. Thickener - The thickener tank choice is carbon steel with flakeglass/polyester or rubber lining, but the bottom might be carbon steel or concrete.

12. Vacuum Filters - The choice for vacuum filters would be stainless steel or rubber-clad carbon steel.

13. Ducts, Expansion Joints, and Dampers - Inlet ducts will be carbon steel unless customer specifies Cor-Ten steel. Outlet ducts will normally be carbon steel with flakeglass/polyester lining. However, where ducts are hot, such as areas near reheater, and if high-temperature excursions are a possibility, Colebrand CXL-2000 will be used.

A variety of expansion joints may be used. Some expansion joints may be carbon steel omega or accordian joints. Others may be rubber, or asbestos-filled plastic.

Where there is a choice of dampers, guillotine-type will be used. They will be double gate with a space between. Louver dampers will be avoided if possible. The preferred material is carbon steel, and dampers are to be completely open or completely closed.

14. Piping and Valves - The piping used for slurry, including the spray headers, will be rubber lined. Connectors between spray headers and nozzles are rubber boots. Clean water piping is ordinary carbon steel.

The valves for slurry service will be Type 316 stainless steel, knife gate type. Valves will be used only for full-on or full-off. Control valves will not be used.

15. Stack - Pullman-Kellogg has a separate division that builds stacks. They will choose the stack materials. A new innovation is the use of a fiberglass-reinforced liner which is installed in sections (rings of the proper diameter) which are hung from the concrete shell. Since these rings are so large they they may be impossible to ship to the site, they are manufactured on site, or nearby. One such liner is 1200 feet in height by 25 feet in diameter. It is at a copper smelter in Magna, Utah.

16. Grinding Mill or Slaker - Ball mills will be rubber lined. Lime slakers will be carbon steel.

17. Pond - Decisions regarding ponds are not normally made by Pullman Kellogg.

UTAH POWER & LIGHT COMPANY
HUNTINGTON UNIT 1

Trip Report Number: EPRI-CM39

Date of Trip: June 20, 1979

Persons Interviewed: Fred Busch, Process Engineer, Huntington Power Plant, Utah Power & Light, and Charles Kirby, Construction Superintendent, Chemico.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Chemico is the process designer and vendor; Jelco, Inc. is the contractor and Stearns-Roger is the consulting engineer; new installation.

2. Boiler Type - Combustion Engineering pulverized coal-fired tangential boiler rated at 432 MW gross and 400 MW net; heat rate was not specified.

   a. 26 percent excess air.

   b. Base loaded unit with a capacity factor of about 90 percent; the unit is operated at full load 24 hours per day.

   c. The stack height is 600 ft.

3. Flue Gas Flow Rate - 1,742,000 acfm of flue gas at 260 F; 90 percent of the flue gas is scrubbed and 10 percent is bypassed.

   a. 4.0 percent oxygen in the flue gas.

4. SO_2 Concentration - 450 to 632 ppm SO_2 in inlet gas and 90 to 125 ppm SO_2 in outlet gas.

5. Fuel - Utah bituminous coal from the Blind Canyon seam; 0.59 percent sulfur, 9.43 percent ash, and a heating value of 12,200 Btu/lb.

6. Scrubber Reactant - Pebble quickline with about 92 percent CaO and 6 percent MgO.

7. Removal Efficiency - About 80 percent SO_2 removal and about 99.5 percent fly ash removal in an electrostatic precipitator.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables -

   a. Gas inlet temperature is 260 F.

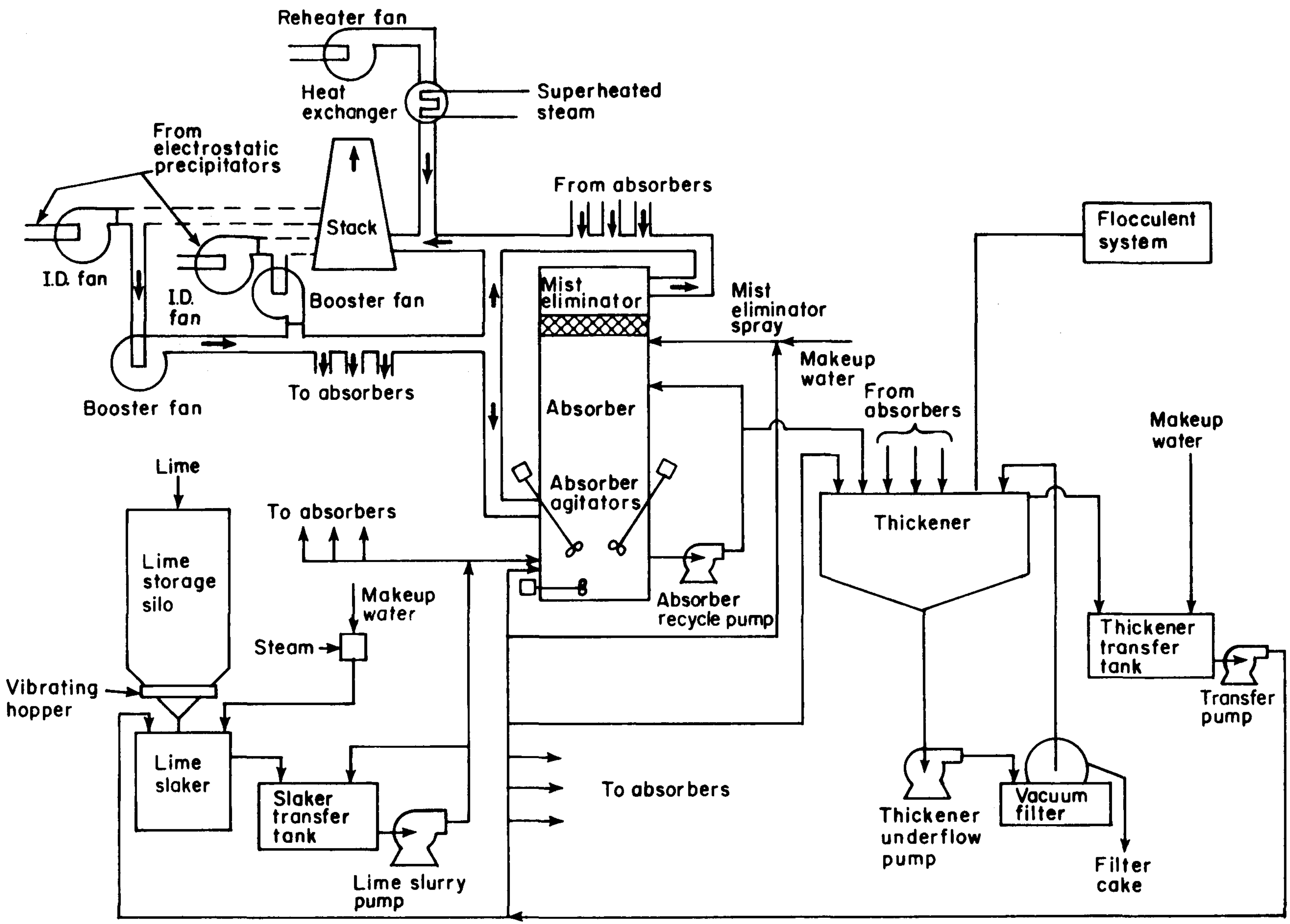


FIGURE 1. FLUE GAS DESULFURIZATION SYSTEM ON HUNTINGTON UNIT 1

b. Gas outlet temperature is 115 F prior to reheat.

c. Fly ash inlet loading to the scrubber is 0.0138 grains/dry acf.

d. Scrubbing liquor pH is 10.0 at the inlet and 5.5 at the outlet.

3. Absorber Design -

a. Buell electrostatic precipitator for particulate removal.

b. Four countercurrent spray towers for SO_2 removal.

c. The superficial gas velocity is 10 ft/sec.

d. The turndown ratio is 4:1; individual spray towers are taken off line at a specified minimum velocity point; the spray towers can be completely bypassed.

4. Liquid-to-Gas Ratio - 70 gal/1000 acf (saturated).

5. Oxidation - About 40 percent oxidation at a scrubber outlet pH of 5.5 and about 90 percent oxidation at a scrubber outlet pH of 4.5.

6. Pressure Drop - Total pressure drop for the FGD system is 5 inches of H_2O.

7. Solids Level - About 5 percent solids in recirculating slurry, 30 percent solids in thickener underflow, and 50 percent solids in filter cake.

8. Reactant Addition - Slaked lime is added to the reservoirs at the bottom of the absorbers.

9. Reactant Feed Rate - The maximum lime feed rate is 6,000 lb/hr.

10. Slurry Retention Time - About 4 minutes in the bottom of the absorbers.

11. Mist Eliminator - Four pass horizontal chevron mist eliminator washed continuously from below on a sequential basis and intermittently from above with makeup water; the superficial gas velocity is 10 ft/sec.

12. Reheat System - 20 F of reheat is provided by mixing scrubbed flue gas with the 10 percent of the flue gas that has bypassed the absorbers and by adding hot air which has been heated by steam coils.

13. Waste Disposal - The waste disposal system is closed loop; scrubber effluent is sent to a thickener and vacuum filter, and the filter cake is truck hauled to a landfill site; thickener overflow and filtrate are recycled to the scrubber system.

14. Fans - The ID fans and the booster fans are located between the electrostatic precipitator and the spray towers.

C. RELIABILITY

1. Start-up - May, 1978.

2. Availability - The availability (hours FGD system is available for operation divided by hours in period) has been about 94 percent since start-up; between May, 1978, and February, 1979, the FGD system was unavailable for 293 hours.

3. Longest Run - 67 days from August 20 to October 25, 1978.

4. Calendar of Operation - The FGD system has operated for about 8,000 hours since startup.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - None used.

2. Absorber - The absorber is carbon steel with Ceilcrete 2500AR in high abrasion areas and Flakeline 103 in other areas (refer to Figure 2). There is an acid resistant brick covering over the Flakeline 103 in the bottom (retention tank) and about 2 or 3 feet up the sides. Supports for the spray piping are rubber coated carbon steel I beams. The piping is protected by Ceilcrete 2500AR. Flanges and bolts are protected by the Ceilcrete 2500AR but without the woven mat. The flanges and tops of spray nozzles are covered by polyvinyl chloride boots, which are giving good protection.

3. Spray Nozzles - The slurry spray nozzles are Refrax and the mist eliminator wash nozzles are Type 316L stainless steel.

4. Mist Eliminators - The mist eliminators are polypropylene chevrons. Basically, they are satisfactory, but they have been broken by men walking on them. When the unit operates satisfactorily, there is no plugging of the mist eliminators.

5. Fans - The fans (hot side) are ordinary carbon steel.

6. Reheater - The reheat is supplied mostly by blending scrubber outlet gas with the bypass flue gas. However, some of the reheat is supplied by hot air which is heated by steam coils located near ground level, just above the reheat fan. This reheater (Happy) is constructed of carbon steel. The bypass reheat is added to both ends of the outlet manifold, and this area is carbon steel protected by 1 or 2 inches of Pre-Krete G-8. The Pre-Krete is also in the duct following the reheat zone.

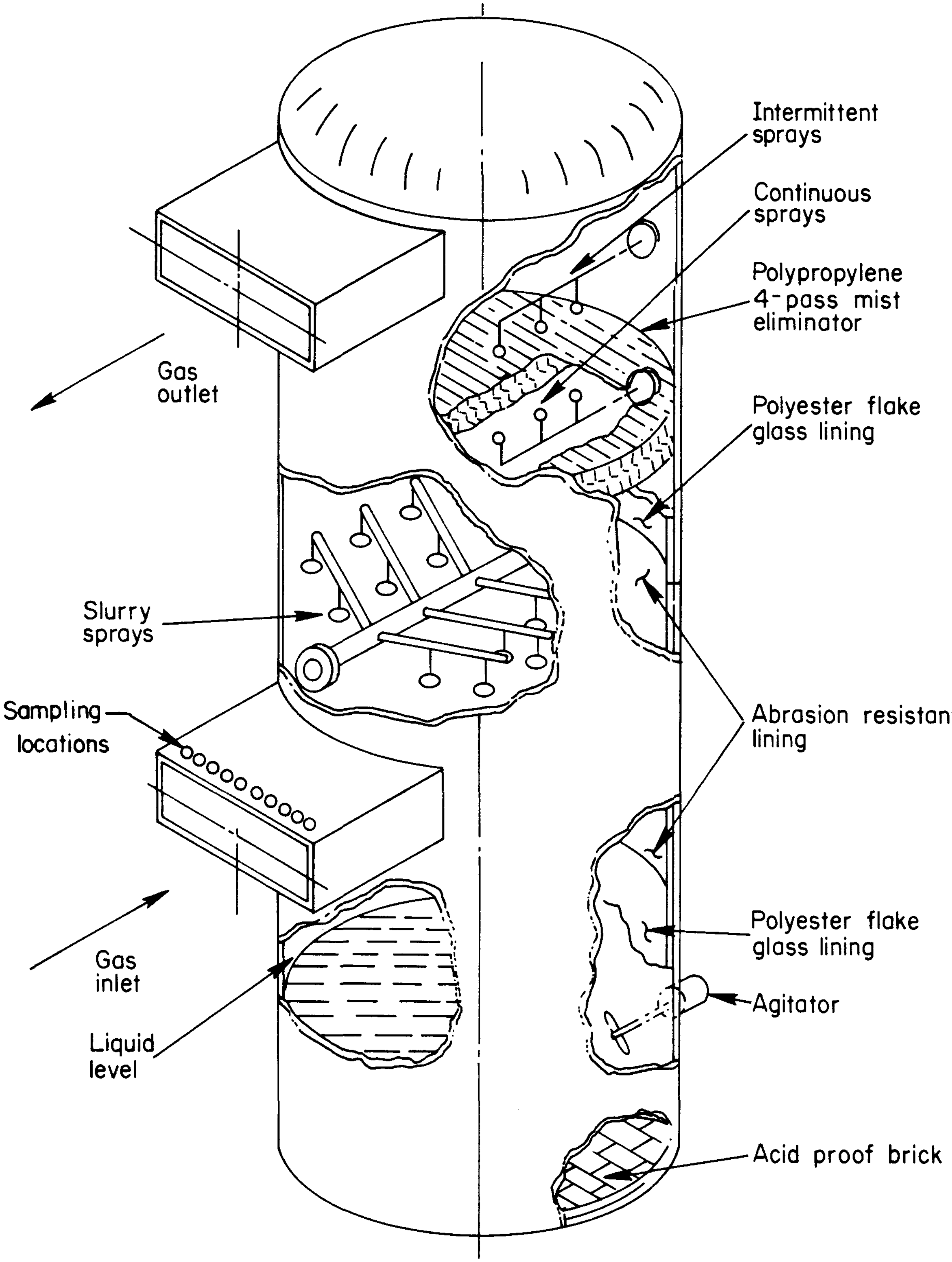


FIGURE 2. SPRAY TOWER ISOMETRIC SKETCH

7. Pumps - The slurry recycle pumps are rubber-lined (Galigher). There have been no problems with wear of the linings but foreign objects in the slurry have torn up some of the linings. The thickener underflow and slurry transfer pumps are also rubber-lined by Galigher. The thickener overflow pump is Durco and is made of Alloy 20 and Type 316L stainless steel. The filtrate pump is a Dorr-Oliver, made of carbon steel. The mist eliminator wash pumps are Durco. The wash is transfer water from the thickener overflow, ash water overflow, and make up water, which is all filtered through a cartridge. The thickener sump pumps are vertical rubber-lined Galigher (2-1/2-inch). The process sump pump is a vertical 3-1/2-inch Galigher with rubber lining.

8. Tanks - The retention tank is the bottom of the absorber (see Figure 2). The lime slurry tank is A-36 carbon steel. The transfer water tank is A-36 carbon steel with a Ceilcote Flakeline 103 lining. The flocculation system is Type 316L stainless steel.

9. Agitators - The agitator for the lime slurry tank is A-36 carbon steel. Type 316L stainless steel agitators are used in the following tanks: thickener sump, process sump, and flocculation system. The agitators for the retention tanks are side mounted, and are rubber-covered carbon steel.

10. Storage Silo - The lime storage silo is plain carbon steel (A-36).

11. Thickener - The thickener is constructed of A-36 carbon steel and is lined with Flakeline 103. The rake is rubber-covered carbon steel.

12. Vacuum Filter - The vacuum filter is Dorr-Oliver, and is constructed of carbon steel. It has a polypropylene waffle and cloth. Rusting has been a problem because the pH of the filtrate has dropped to 1.3 under upset conditions.

13. Ducts, Expansion Joints, and Dampers - The inlet ducts are unlined carbon steel. The outlet ducts are carbon steel lined with Pre-Krete G-8. They look good.

The expansion joints are fabric impregnated with rubber (Garlok).

The dampers for booster fan inlet and outlet are carbon steel. The inlet isolation damper is a dual-blade, guillotine constructed of carbon steel. The outlet damper is a single-blade, inverted guillotine constructed of Type 316L stainless steel, followed by a louver (Type 316L stainless steel) for throttle. The blade is raised to close the damper and dropped to open it. The bypass and reheat dampers are Type 316L stainless steel of the butterfly type. The seals for all dampers are constructed of Hastelloy. The reheat fan dampers have carbon steel vanes.

14. Piping and Valves - The recycle slurry piping is rubber-lined carbon steel. The lime slurry piping is plain carbon steel, as is the piping for raw water, ash water, and steam. The mist eliminator wash piping is fiberglass-reinforced plastic (from the main header up). Transfer water piping is fiberglass-reinforced plastic (Chemtron 1222). The seal water piping above 3/4 inches in diameter is carbon steel and 3/4 inches and under is Type 316 stainless steel. The flocculation system piping is carbon steel.

Pure gum rubber-lined pinch valves (R.K.L.) are used wherever throttle is needed in water lines, lime system, etc. Rubber-lined plug valves (Grinnell) are used on all flush connections. Brass gate valves are used in some discharge piping systems and they do not last long. Both rubber-lined and unlined Keystone and rubber-lined Media butterfly valves are used in some places. Some carbon steel gate valves are used on water lines, and some stainless steel valves are used in the seal water system. Some PVC valves are used to bleed off air, but they break easily. Some carbon steel and stainless steel knife gate valves (Carbon Industries) are also used.

15. Stack - The stack was constructed by Custodis and has a concrete shell with an ASTM Type H acid-resistant brick and Corlok B mortar lining. The brick lining looks good.

16. Slaker - The lime slaker is plain carbon steel (made by BIF). The weigh feeder is by Fair Electronics.

ARIZONA ELECTRIC POWER COOPERATIVE (AEPCO)
APACHE UNITS 2 AND 3

Trip Report Number: EPRI-CM40

Date of Trip: June 21, 1979

Persons Interviewed: Robert Maurice, Environmental Engineer, and Lyle Davis, Retired Engineer, Apache Generating Station, AEPCO; Robert Cmiel, Field Engineer, Research-Cottrell.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Research-Cottrell is the process designer and vendor; Burns & McDonnell is the consulting engineer; new installation.

2. Boiler Type - Two identical Riley pulverized coal-fired boilers with front and rear burners; each unit is rated at 195 MW gross and has a heat rate of about 9,900 Btu/kWh.

   a. 20 percent excess air.

   b. The units are designed to be base loaded but the capacity factor has not been determined yet; the load follows demand and ranges from 70 to 195 MW per unit.

   c. There is a 400-ft common stack with two flues (one for each unit).

3. Flue Gas Flow Rate - 735,000 acfm of flue gas at 270 F per unit; the FGD system is designed to scrub all the flue gas, but only half the gas is scrubbed as this is sufficient to meet the State emission regulation of 0.8 lb $SO_2/10^6$ Btu.

   a. 3.5 percent oxygen in flue gas at full load and 6 percent at low load.

4. SO_2 Concentration - 430 ppm SO_2 in inlet gas (1.0 lb/10^6 Btu) and 250 to 300 ppm SO_2 in outlet gas (0.6 lb/10^6 Btu).

5. Fuel - Coal from the Mentmore Mine near Gallup, New Mexico; contains 0.51 percent sulfur, 16 percent ash, and 13 percent moisture and has a heating value of 9,900 Btu/lb.

6. Scrubber Reactant - Limestone from Douglas, Arizona, containing more than 93 percent $CaCO_3$; the limestone is kiln rejects from a lime plant.

7. Removal Efficiency - The FGD system is designed for 85 percent SO_2 removal when all the flue gas is treated, but only half the gas is scrubbed for an overall removal efficiency of 40 percent; the electrostatic precipitators are designed for 99.56 percent fly ash removal.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables -

a. Gas inlet temperature is 270 F

b. Gas outlet temperature is 115 F.

c. Fly ash inlet loading to the scrubber is about 0.04 grains/scf.

d. The pH of the scrubbing liquor is 6.0 in the packed tower slurry and 5.0 in the quencher slurry.

3. Absorber Design -

a. Hot electrostatic precipitators by UOP are used for particulate removal.

b. Each unit has two absorption towers for SO_2 removal; the towers consist of a quencher, a gas/liquid bowl separator, a packed zone with "egg crate" packing, and mist eliminators (refer to Figure 2).

c. The superficial gas velocity in the towers is 9 to 11 ft/sec.

d. One tower per unit is used at full load with 50 percent of the gas being bypassed; therefore, in effect, each unit has a spare module; at a unit load of 70 MW, the FGD system is totally bypassed.

4. Liquid-to-Gas Ratio - About 25 gal/1000 acf (saturated) to the quencher and about 40 gal/1000 acf to the absorber.

5. Oxidation - Not specified, but probably high because of low sulfur coal and double loop scrubbing.

6. Pressure Drop - About 5 in. of H_2O through the FGD system.

7. Solids Level - About 10 percent solids in recirculating slurry in the packed tower and 15 percent solids in the quencher.

8. Reactant Addition - Fresh limestone slurry is added to the absorber feed tank; double loop system--fresh slurry is fed to the absorber section and spent slurry is fed to the quencher section.

9. Reactant Feed Rate - The limestone feed rate is 5,360 lb/hr of 34 percent solids slurry for one tower.

10. Slurry Retention Time - About 6.5 minutes in absorber feed tank with two towers and about 13 minutes with one tower; about 5.3 minutes in quencher sumps.

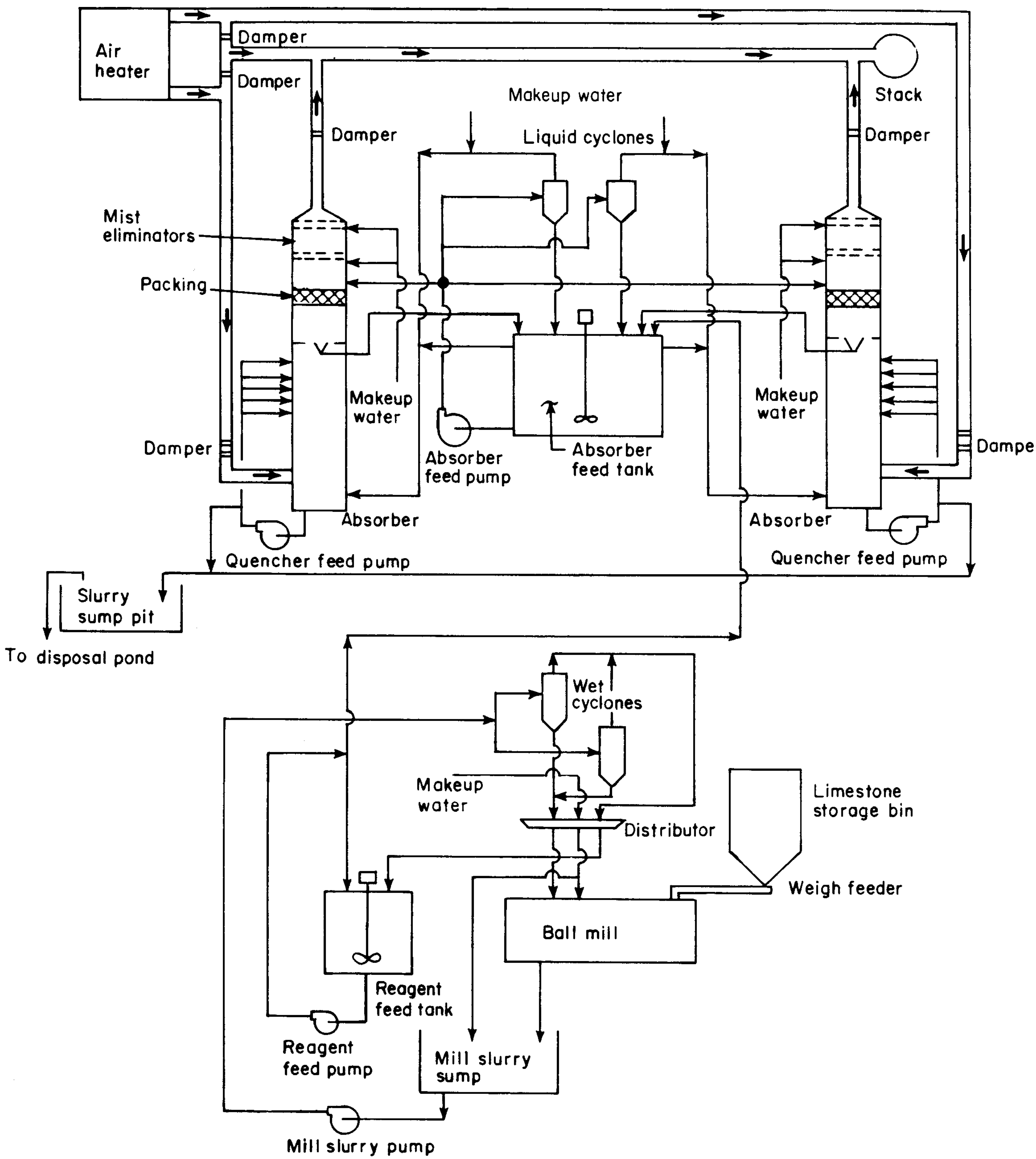


FIGURE 1. FLUE GAS DESULFURIZATION SYSTEM ON APACHE UNITS 2 AND 3

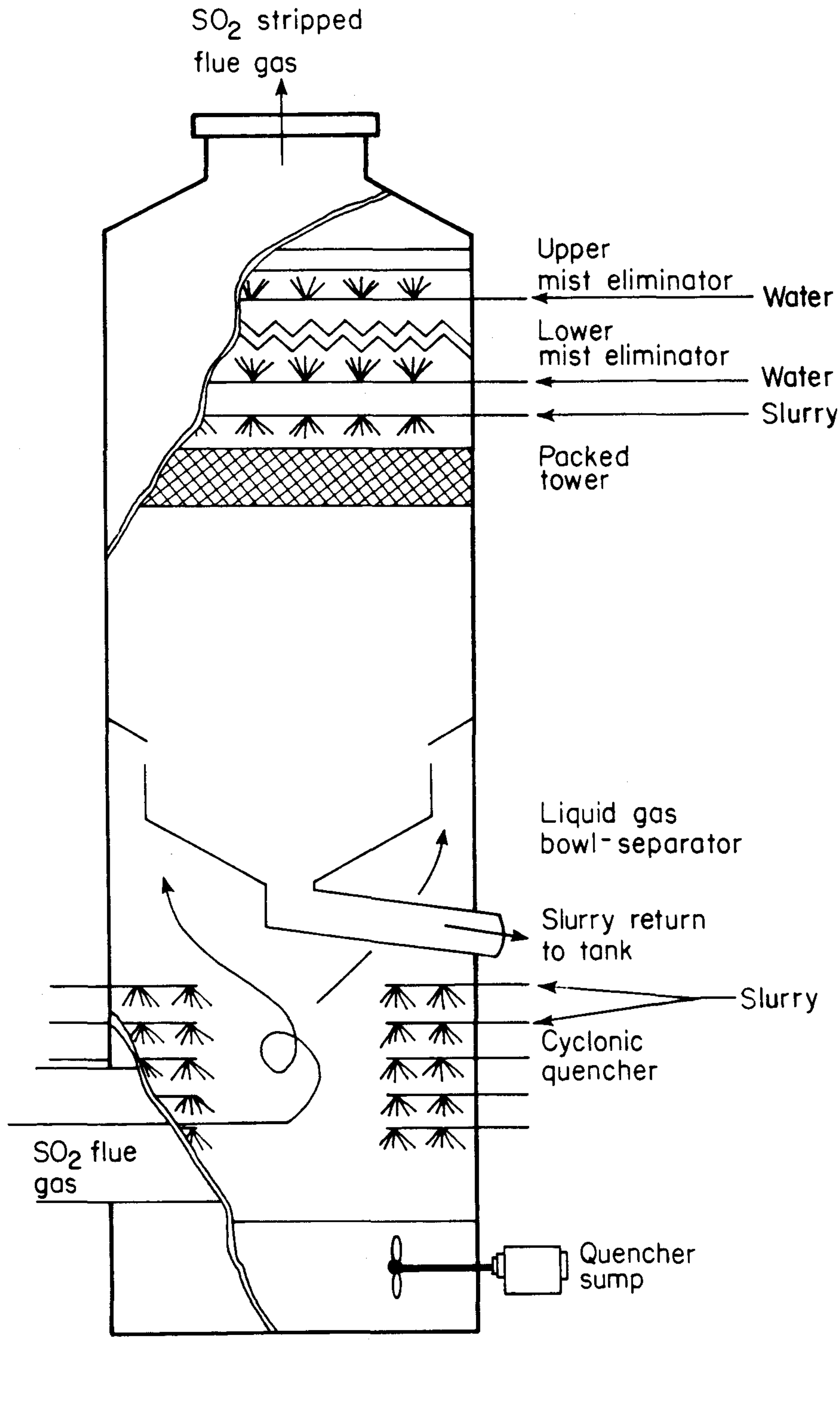


FIGURE 2. SCHEMATIC OF ABSORPTION TOWER

11. Mist Eliminator - Two-stage Munters mist eliminator; the lower stage is an A-frame chevron type and the upper stage is a horizontal "egg crate" type; the superficial gas velocity is 9 to 11 ft/sec; the lower stage is washed intermittently from below with makeup water and the upper stage is washed once every 8 hours from below at the rate of 200 gpm.

12. Reheat System - There is no reheat when both towers on a unit are in use, but one tower is usually bypassed so that the scrubbed gas is reheated by the bypassed gas to give an outlet temperature of about 193 F (refer to Figure 3).

13. Waste Disposal - A continuous bleed stream from the quenchers is sent to a waste slurry sump and then to a diked pond; there are three ponds of 25 to 30 acres each, one for bottom ash, one for fly ash, and one for scrubber sludge; there is a combined water return system from the ponds, but currently water is not being returned; therefore, the system is being operated in an open-loop mode although the blowdown is lost by evaporation from the pond.

14. Fans - Each unit has two ID fans located upstream from the scrubbers.

C. RELIABILITY

1. Start-up - Unit 2 started up in February, 1979, and Unit 3 in June, 1979.

2. Availability - Thus far, the FGD system has operated about 75 percent of the time it is needed (75 percent operability--hours the FGD system was operated divided by boiler operating hours in period).

3. Longest Run - About 2 months.

4. Calendar of Operation - The units are supposed to run continuously, and Unit 2 has been in continuous operation since the middle of March, but the scrubbers have been down part of the time.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - None used.

2. Absorber - Each absorber is carbon steel lined (upper part) with Ceilcote Flakeline 103 (with No. 370 primer). The primer was spray applied, 2- to 3-mils thick. Flakeline 103 was trowel-applied in two coats, each 40-mils thick (80-mils). Coroline 505AR was used in the bottom of each tower, and it extends up to the separating bowl, which is lined with Flakeline 103. The plastic packing in the towers was originally supported by fiber-glass-reinforced plastic beams. These beams were changed to Type 316L stainless steel for added strength.

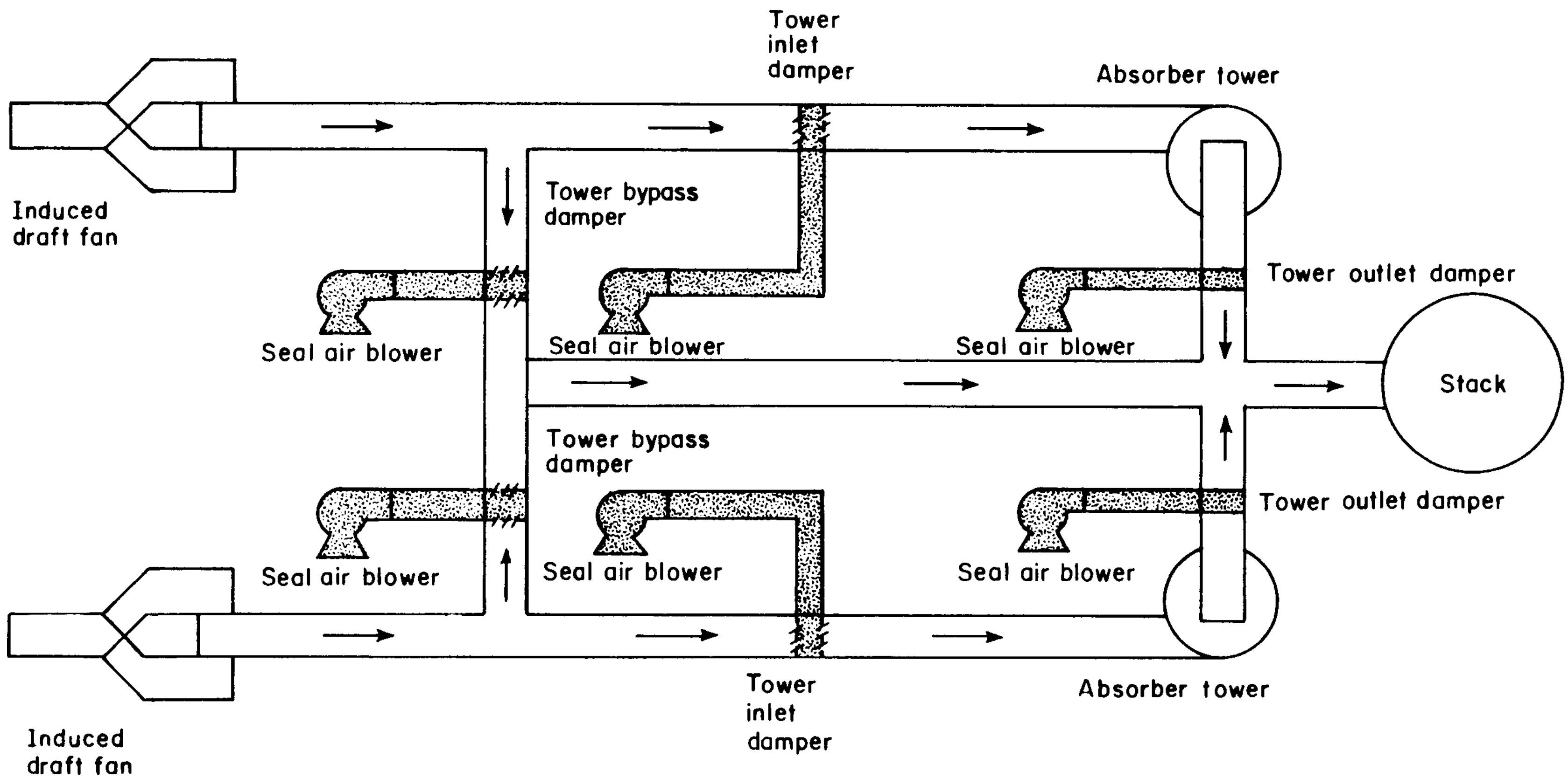


FIGURE 3. SCHEMATIC OF DUCTWORK FOR APACHE UNIT 2 OR 3

3. Spray Nozzles - The nozzles for the slurry spray and for the mist eliminator wash are Type 316 stainless steel.

4. Mist Eliminators - The mist eliminators are constructed of polypropylene.

5. Fans - The fans are on the inlet side and are constructed of carbon steel.

6. Reheater - There is no reheater. Instead, bypass gas is blended with desulfurized gas in the outlet duct. However, if both scrubbing towers on a unit are used, there is no reheat.

7. Pumps - The slurry recycle pumps are rubber-lined (Denver). The mill slurry transfer pumps (ball mill to retention tank) are rubber-lined (Galigher). The slurry transfer pumps are rubber-lined (Ingersoll-Rand). Durco pumps are used for the mist eliminator wash. The rubber-lined sump pump impellers were replaced with a Type 316 stainless steel impeller in one case, and with Type 317 stainless steel in another. A Moyno pump transfers the slurry to the pond.

8. Tanks - The reagent feed tank (next to ball mill) is unlined carbon steel. The absorber feed tank is carbon steel with a Ceilcote Flakeline 103 lining.

9. Agitators - The agitators are rubber-coated carbon steel.

10. Silo - The limestone storage silo is carbon steel.

11. Thickener - None used.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The inlet ducts and bypass ducts are unlined carbon steel. The outlet ducts for Unit 2 are lined with Colebrand CXL-2000 (Pullman Power Products) fluoroelastomer. The outlet ducts for Unit 3 are lined with a Ceilcote experimental lining (Flakeline 282-X).

Expansion joints are Viton®/asbestos by Raybestos-Manhattan.

Inlet dampers are louver-type and have carbon steel blades and frames. Outlet dampers are guillotine-type and are constructed of carbon steel, protected on the wet side by Incoloy 825 cladding. They have Inconel seals. The bypass dampers (louver) are carbon steel with an Incoloy 825 cladding on the wet side (downstream side) only.

14. Piping and Valves - From absorber to pump and pump to absorber, the piping is rubber-lined carbon steel. Piping inside the tower is Type 316L stainless steel. The piping after the bowl and out of the tower is fiberglass-reinforced plastic. The line to the pond is rubber-lined carbon steel.

The valves on the suction side of the pumps are butterfly-type (Keystone) with Bakelite plastic discs and rubber-lined seats. The discharge valves are rubber-lined DeZurik plug valves. Drain valves are Type 316L stainless steel with Teflon® seats.

15. Stacks - The stack has a concrete shell with steel liners. The steel liner for Unit 2 is protected by Colebrand CXL-2000. The cost of this lining was about $\$26/ft^2$ at time of installation but present cost is believed to be about double this figure.

The steel liner for Unit 3 is protected by a Ceilcote experimental material, Flakeline 282-X. An emergency spray system is available to prevent heat damage to this lining in the outlet duct and the stack. The same type of spray system will also be put in on Unit 2.

16. Ball Mill - The ball mill is rubber-lined carbon steel (Kennedy Van Saun).

17. Ponds - The ponds are not lined.

ARIZONA PUBLIC SERVICE COMPANY (APS)
CHOLLA UNIT 1

Trip Report Number: EPRI-CM41

Date of Trip: June 22, 1979

Persons Interviewed: Cleo Walker, Plant Superintendent, Cholla Station, APS, and Mike Machusak, Operations Advisor, SO_2 Operations, Research-Cottrell.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Research-Cottrell is the process designer and vendor, and did the subcontracting for this turnkey job; retrofit installation.

2. Boiler Type - Combustion Engineering pulverized coal-fired boiler rated at 115 MW but can operate at 126 MW gross; heat rate is 10,320 Btu/kWh.

   a. 15 percent excess air.

   b. Base load unit is on all the time; capacity factor for past 12 months is 93 percent.

   c. 250 ft stack.

3. Flue Gas Flow Rate - 480,000 acfm at 276 F; 100 percent of the gas passes through two scrubber modules; one module is operated for particulate removal only; the scrubbing system can be completely bypassed.

   a. 3 percent oxygen in flue gas.

4. SO_2 Concentration - About 400 ppm SO_2 in inlet gas to scrubbers and about 180 ppm SO_2 in combined outlet gas from both modules.

5. Fuel - Gallup, New Mexico coal from the McKinley mine containing 0.4 to 0.6 percent sulfur and 12 percent ash; heat content is 10,400 Btu/lb.

6. Scrubber Reactant - Limestone at 75 percent minus 200 mesh is delivered by truck from the Superior Company in St. Johns, Arizona; a ball mill which has been installed for the other units at Cholla can handle the limestone requirements for Unit 1, but has not been used for this purpose.

7. Removal Efficiency - About 90 percent SO_2 removal in the module in which SO_2 is scrubbed, and about 50 to 60 percent overall SO_2 removal; 99.7 percent overall removal of fly ash; mechanical collectors are about 75 to 80 percent efficient and Flooded Disc scrubber is about 99 percent efficient.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1; this flow diagram represents the A module; the B module has no limestone feed and no packing in the absorption tower; water is sprayed into the Flooded Disc scrubber for fly ash removal; in Module A, there are individual recycle tanks for the fly ash circuit and the limestone circuit so that no fly ash circulates in the SO_2 absorber circuit; bleed from the SO_2 absorption tower recycle tank is sent to the scrubber recycle tank to prevent corrosion in the fly ash removal system, to minimize makeup water requirements, and to take advantage of any unreacted limestone for additional SO_2 removal; bleed from the scrubber recycle tank is sent to the sludge storage tank and then to the ash pond.

2. Process Variables -

a. Inlet gas temperature to scrubber is 276 F.

b. Outlet gas temperature from absorber is 121 F.

c. Fly ash inlet loading to scrubber is 1.2 to 2 grains/scf.

d. pH in absorber holding tank is 6.5 and pH in scrubber holding tank is 5.2.

3. Absorber Design -

a. Multitube Research-Cottrell mechanical dust collectors followed by Research-Cottrell's Flooded Disc scrubber for particulate collection; scrubber is of the venturi type where the orifice is the annular space between the circumference of a horizontal disc and the wall of a tapered duct section; the disc can be moved up or down within the tapered duct to increase or decrease the area of the orifice; the scrubber is followed by a cyclonic mist eliminator to separate the slurry from the gas.

b. The SO_2 absorber in Module A is a tower packed with a rigid, wetted-film packing made of polypropylene and manufactured by the Munters Corporation; Research-Cottrell has an exclusive license from Munters for the packing; the packing has a high specific surface area and low pressure drop; the packed tower section is separated from the cyclonic mist eliminator by a plate containing a conical hat; this arrangement allows the flue gas to leave the cyclonic mist eliminator while preventing the slurry leaving the packed tower from combining with the slurry leaving the Flooded Disc scrubber, thus preventing fly ash from entering the tower.

c. The superficial gas velocity in the absorber is 9 to 11 ft/sec.

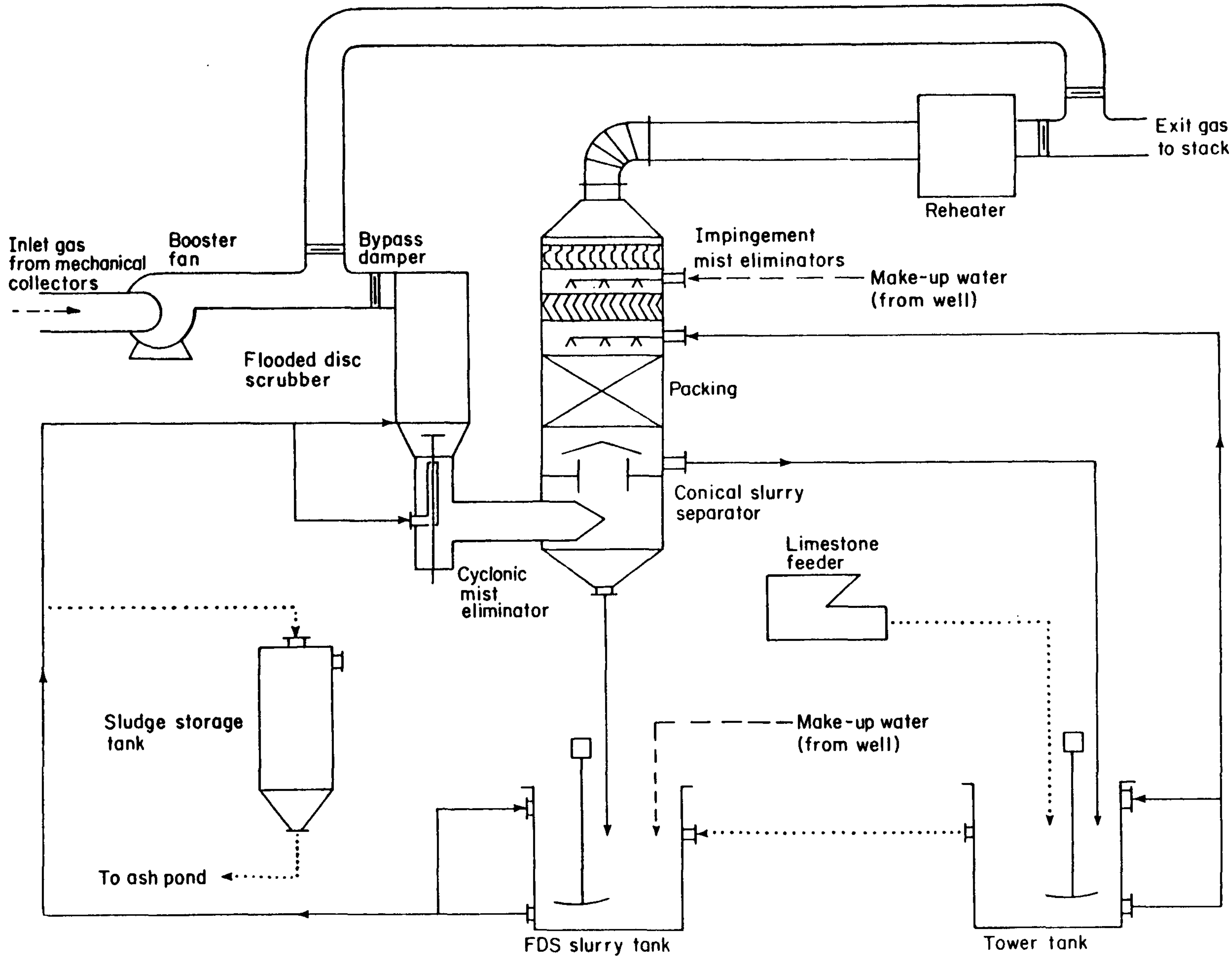


FIGURE 1. FLUE GAS DESULFURIZATION SYSTEM ON CHOLLA UNIT 1

d. Turndown is no problem down to 50 MW by maintaining constant liquid flow; modulating flows causes problems with solids deposition in the lines; area of orifice in Flooded Disc scrubber can be varied; automatic feed forward control of limestone feed rate based on SO_2 concentration in inlet gas.

4. Liquid-to-Gas Ratio - L/G is 20 gal/10^3ft^3 in Flooded Disc scrubber based on outlet gas temperature and 45 gal/10^3ft^3 in packed tower.

5. Oxidation - Most of the scrubbed SO_2 is oxidized to sulfate because of the double loop operation and the low sulfur coal.

6. Pressure Drop - 15 in. H_2O for Flooded Disc scrubber; 0.5 in. H_2O for packed tower; possibly 5 in. H_2O for reheater; negligible pressure drop across mist eliminators.

7. Solids Level - Solids concentration in circulating slurries is kept below 15 percent by withdrawing a bleed stream to the sludge storage tanks; the sludge tanks containing about 12 to 14 percent solids are emptied to the ash pond about once per shift; there is no sludge dewatering step prior to the ash pond.

8. Reactant Addition - Limestone is added to absorption tower recycle tank.

9. Reactant Feed Rate - About one mole of $CaCO_3$ per mole of SO_2 removed.

10. Slurry Retention Time - 5 minutes residence time with agitation in absorption tower recycle tank; residence time in stirred scrubber recycle tank is 7 minutes.

11. Mist Eliminator - Two-stage polypropylene slat impingement type mist eliminator; first stage is chevron design with two reverses in direction; second stage is different design with four reverses in direction; first stage and second stage are washed from below on a timed cycle with makeup water; one quadrant is washed at a time.

12. Reheat System - Steam reheat in tubes which directly contact the gas; smooth tubes constructed of Type 316L stainless steel; 60 F of reheat is supplied; there is a vibration problem with the reheater shell.

13. Waste Disposal - Open-loop system; effluent from sludge storage tanks is sent to existing fly ash pond; water inflow is lost by evaporation.

14. Fans - Booster fans are located between the mechanical dust collectors and the Flooded Disc scrubbers.

C. RELIABILITY

1. Start-up - December 15, 1973.

2. Availability - The monthly reliabilities (hours the FGD system was operated divided by the hours the FGD system was called upon to operate) for each module have generally been higher than 95 percent with the following exceptions:

Module A		Module B	
Month	Reliability, percent	Month	Reliability, percent
April, 1974	66	March, 1974	66
October, 1974	83	April, 1974	57
April, 1975	88	October, 1974	68
May, 1975	48	April, 1975	65
October, 1975	84	May, 1975	40
May, 1976	76	October, 1975	55
June, 1976	64	November, 1975	80
October, 1976	56	June, 1976	39
January, 1977	72	October, 1976	56
March, 1977	72	January, 1977	93
May, 1977	87	March, 1977	93
March, 1978	74	May, 1977	87
May, 1978	87	January, 1978	91
		February, 1978	88
		March, 1978	74

During the past 12 months, Module A had an availability (hours the FGD system is available for operation divided by hours in period) of 98.7 percent.

3. Longest Run - About 3 months.

4. Calendar of Operation - The operation of the scrubbing system has been as follows:

Year	Operating Hours Module A	Operating Hours Module B
1974	8,053	7,554
1975	7,692	6,964
1976	7,773	6,886
1977	6,093	6,728
1978	7,563	7,425
1979 (through May 31)	3,576	3,208
Total	40,750	38,765

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - The Cholla 1 prescrubber is carbon steel above the tapered section of the venturi and Type 316L stainless steel everywhere below the venturi. It was originally uncoated, but severe chloride corrosion caused pitting. Erosion was also encountered on the Type 316L tapered wall of the venturi throat, on the slurry deflector cone above the flooded disc, and on the cone supports. Although coatings were tried initially on the deflector cone and supports, Research-Cottrell recommended that they be replaced with Hastelloy C or Incoloy 825. The current material used in these critical areas was not identified, but the disc and throat were replaced with Type 316L stainless steel in January, 1977 (coating not mentioned). The wall of the vessel was lined with Coroline 505AR which eroded away in the wet sump and floor. It was replaced and overlayed with a conventional brick/portland cement mortar by Arizona Public Service. These bricks washed out. Research-Cottrell then installed acid-resistant bricks using Corobond mortar (furan base resin mortar from Ceilcote) above the Coroline coating. This brick lining extends up the side walls about a foot and into the cross-over duct about two feet, and has held up well. Except for the floor/sump area, there are no other bricks in the Cholla 1 scrubber or absorber vessels. The Coroline 505AR coating has required some patching, but has also held up well and apparently eliminated the severe chloride corrosion problems originally encountered in the sump area where the Cl^- concentration is high (2000 ppm) and the pH is low.

2. Absorber - The A side of the system is a tower containing rigid, wetted-film, polypropylene packing which is replaced about once a year. The B side contains no packing in the tower. The slurry is removed from the gas stream entering the absorber tower by means of a centrifugal plate separator containing a conical hat. This unit is located in the bottom of each absorber tower. The absorber vessels are constructed of Type 316L stainless steel. Areas wetted by the scrubber slurry (lower part of absorber) have undergone pitting and crevice corrosion which is approximately equal in severity to that observed in the scrubber. Areas in the bottom of the towers were repaired with an epoxy (Coroline 505AR) and have exhibited debonding and erosion. In contrast, areas wetted by the absorber slurry (upper part of absorber) have undergone much less severe attack although significant buildup of solids is observed. The better performance of the Type 316L stainless steel in the latter application is thought to be the results of the lower Cl^- concentration and higher pH (about 6.5) found in the absorber slurry.

3. Spray Nozzles - The headers and nozzles are constructed of Type 316L stainless steel. Some erosion damage has been observed but, in general, these components have performed satisfactorily.

4. Mist Eliminators - Two mist eliminators are found in each module; a cyclonic mist eliminator located between the scrubber and the absorber, and an impingement mist eliminator located at the top of the absorber tower. The cyclonic mist eliminator is constructed of Type 316L stainless steel and is exposed to the scrubber slurry. Materials problems encountered were the same as those encountered with the wet well of the scrubber.

An impingement mist eliminator is located above the absorber packing. It consists of two stages, each of which contain polypropylene slats. The unit is contained in the Type 316L stainless steel absorber vessel. Few materials problems have been encountered. One case of weld attack of the stainless steel was observed when the slag located over a weld was not removed. It was speculated that HF was generated as a result of the reaction of fluoride in the slag with moist vapors. The slag may also have acted as a crevice and caused some concentration of chloride ions there.

5. Fans - Booster fans are located between the mechanical dust collectors and the scrubbers. They are constructed of Cor-Ten steel. Fly ash abrasion caused wear of the paddle wheel so Cor-Ten wear plates were placed on the ends of the paddles.

6. Reheater - A direct contact steam reheater is used. The vertical heat exchanger tubes and the vessel are constructed of Type 316L stainless steel. Some flanges on the vessel door on Module B were inadvertently fabricated of Type 304L stainless steel. These flanges suffered severe pitting and general attack and were replaced with ones constructed of Type 316L stainless steel. Pitting of the vessel and the deposit covered tubes has also been observed. Repair of the vessel is easily accomplished by welding, but most of the tubes are inaccessible and require replacement. Tubes fabricated of Incoloy 825 have been recommended as replacements, but Type 316L stainless steel is still in use. The reheater is designed to use 3 coils per side, but only two are needed. Therefore, one can be used as a spare to replace others when removed for cleaning and repair. Each coil has been repaired about 3 times during the life of the unit. Gutters (or baffles) were installed to divert the low pH condensate away from the area where tubes are welded to headers. This had been an area of high corrosion (acid attack) in the past but the problem was solved by diverting the condensate away from the area.

7. Pumps - All slurry recycle pumps are Type 317 stainless steel (Goulds). These pumps lasted about 3000 hours because of erosion and had to be replaced. The impellers and housings are now built up with additional metal on a regular maintenance schedule so they do not need to be replaced as frequently. The mist eliminator wash pumps are also Type 317 stainless steel.

8. Tanks - The tanks are fabricated of mild steel coated with an organic lining (Flakeline 103 in absorber tank and probably the same lining in the tank for the Flooded Disc scrubber). The linings have required occasional patching. Sometimes the damage was caused by welding outside the tanks.

9. Agitators - The large agitators in the absorber and FDS tanks are rubber coated. The small agitators in the limestone slurry tank are Type 316L stainless steel.

10. Storage Silo - The limestone storage silo is constructed of carbon steel. No materials problems have been encountered.

11. Thickener - None used.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The ductwork ahead of the scrubber is fabricated of unlined carbon steel. No problems were reported. The ductwork between the absorber tower and the reheater is mild steel coated with organic linings. The A side is coated with its original Flakeline 252 which has given good service. The B side is not treated with limestone slurry and is used for particulate removal only. The original lining failed under the high acid (condensate) conditions on the B side. This Flakeline 252 lining was replaced with other Ceilcote lining materials including Flakeline 103, and these linings were patched several times. Finally, Plasite 4030 was applied and is still performing satisfactorily after 1-1/2 years. There is a by-pass duct of unlined carbon steel for each scrubber module which joins the outlet duct ahead of the booster ID fan such that either or both of the modules can be by-passed.

The original expansion joints were Type 316L stainless steel. Condensate puddled in bottoms of joints causing failures. The expansion joint replacements are fabricated of Viton® reinforced with canvas, which performs satisfactorily.

The dampers are a guillotine design and are constructed of Type 316L stainless steel. No problems with the dampers were reported. The seal strips are also Type 316L stainless steel and have given no problems.

14. Piping and Valves - Type 316L stainless steel, fiberglass-reinforced plastic (FRP) and some rubber-lined carbon steel are used for the slurry piping. Pump discharge piping was FRP. It has been changed to rubber-lined steel piping in areas that are closer to the scrubber. Blisters have been observed in some of the rubber lined pipe. In areas of high Cl^- concentrations, a high molybdenum grade of Type 316L stainless steel is used. Stainless steel piping is also used inside the FDS and the absorber. No problems have been encountered with the stainless steel piping. Elbows on the FRP piping have undergone erosion.

Rubber-lined, steel butterfly valves are used for most applications in the slurry lines. They perform satisfactorily. In one case, a flow restriction valve constructed of cast CD-4MCu was used in a slurry recirculation line. This unit had a carbon steel orifice plate with a Stellite insert. Severe erosion of the casting was observed. The Stellite insert also cracked and exposed the carbon steel to the slurry feed to scrubber line resulting in rapid general corrosion of the orifice plate. An alumina orifice plate has satisfactorily solved this problem.

15. Stack - The stack is a concrete shell with an acid-resistant brick and mortar lining supported on corbels. The stack was built in 1962 and is on a three-year maintenance schedule; there have been no problems.

16. Ball Mill - There is no ball mill because limestone is purchased in powdered form for Unit 1.

17. Pond - The pond is not lined.

E. COMMENTS

The FGD system on Unit 1 at the Cholla Power Plant consists of two modules. The modules are identical except that the absorption tower in Module B contains no packing and has no limestone slurry flow to reduce acidity of the gas. Materials applications and associated problems for this system have been detailed above. Most of the problems have occurred in the B module of the scrubber system.

ARIZONA PUBLIC SERVICE COMPANY (APS)
CHOLLA UNIT 2

Trip Report Number: EPRI-CM42

Date of Trip: June 22, 1979

Persons Interviewed: Cleo Walker, Plant Superintendent, Cholla Station, APS, and Mike Machusak, Operations Advisor, SO_2 Operations, Research-Cottrell.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Research-Cottrell is the process designer and vendor, Bechtel is the contractor, and Ebasco is the consulting engineer; new installation.

2. Boiler Type - Combustion Engineering pulverized coal, tangential fired boiler rated at 285 MW gross and 250 MW net; the heat rate is about 11,200 Btu/kWh.

   a. 20 percent excess air.

   b. Capacity factor is 89 percent for the first year of operation.

   c. 550 ft stack.

3. Flue Gas Flow Rate - 1,100,000 acfm at 288 F; 100 percent of the flue gas is scrubbed.

   a. 3.5 percent oxygen in the flue gas.

4. SO_2 Concentration - The inlet SO_2 concentration ranges from 250 ppm to 950 ppm, but is normally about 350 ppm; the outlet SO_2 concentration is less than 10 ppm at the normal inlet concentration.

5. Fuel - Same coal as Cholla Unit 1; 0.4 to 0.6 percent sulfur, 12 percent ash, and 10,400 Btu/lb.

6. Scrubber Reactant - Limestone from Peach Springs, Arizona, delivered as 3/4-in. or less and ground in on-site ball mill.

7. Removal Efficiency - Greater than 98 percent SO_2 removal at the normal inlet concentration; multiclone mechanical collector removes 65 to 70 percent of the fly ash, and the overall particulate removal efficiency is greater than 99 percent including the Flooded Disc scrubber and the absorber.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables -

a. Gas inlet temperature is 280 F.

b. Gas outlet temperature is 121 F.

c. Fly ash inlet loading to scrubber ranges from 1 to 5 grains/scf, but is normally 1.8.

d. The pH in the scrubber loop is 4.8 to 5.2 and the pH in the absorber loop is 5.9 to 6.2.

3. Absorber Design -

a. Multiclones plus Flooded Disc scrubbers for fly ash removal; there are four scrubbers with one being redundant.

b. Four absorber towers (one redundant) for SO_2 removal; each tower has two 1-ft layers of "egg crate" packing.

c. The superficial gas velocity in the absorber towers is 9 to 11 ft/sec.

d. Towers are taken off-line for turndown; the minimum desirable gas flow rate is 150,000 acfm per tower; the FGD system can handle from zero load to 10 percent above the rated load with a maximum of three towers.

4. Liquid-to-Gas Ratio - 25 gal/10^3 ft^3 in the Flooded Disc scrubber and 40 gal/10^3 ft^3 in the absorber.

5. Oxidation - Probably greater than 90 percent sulfate in waste slurry because of double-loop operation and low-sulfur coal.

6. Pressure Drop - 23 inches of H_2O across the Flooded Disc scrubber and 26 to 27 inches of H_2O total for the FGD system.

7. Solids Level - 15 percent solids (mostly fly ash) in scrubber loop and 10 percent solids (mostly $CaCO_3$) in absorber loop; the bleed stream from the absorber loop is controlled on the basis of 15 percent solids.

8. Reactant Addition - Limestone slurry is added to the absorber feed tank; one absorber feed tank is used for two absorber towers.

9. Reactant Feed Rate - 1.0 moles of Ca per mole of SO_2 removed; 22.5 gpm of 25 percent $CaCO_3$ slurry at full load and 350 ppm SO_2.

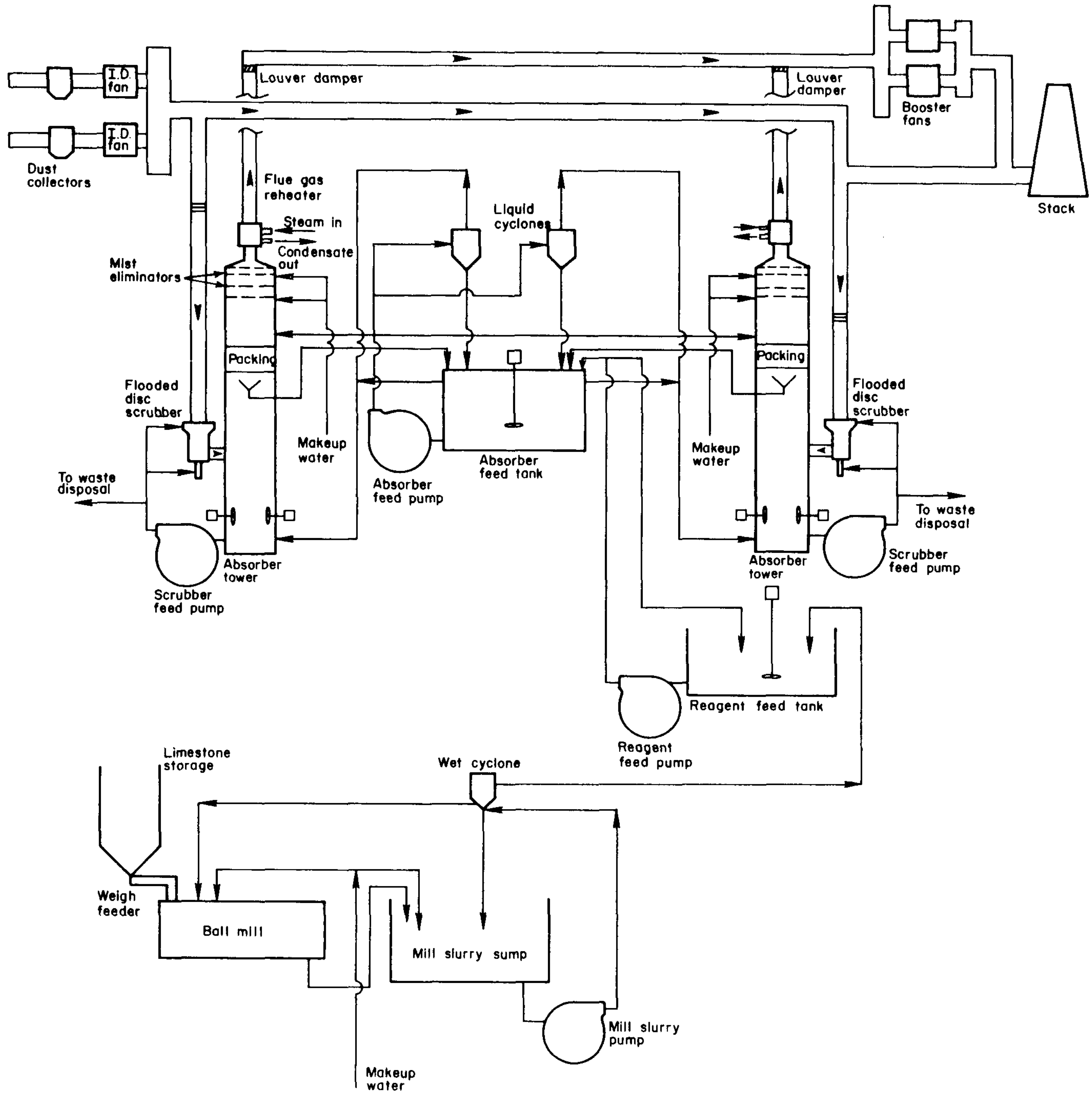


FIGURE 1. FLUE GAS DESULFURIZATION SYSTEM ON CHOLLA UNIT 2

10. Slurry Retention Time - 7 minutes in absorber feed tank for two towers and 14 minutes for one tower; about 7 minutes in scrubber feed tank which is the bottom of the absorber tower.

11. Mist Eliminator - Cyclonic spinning action mist eliminator is located between the scrubber and absorber; two-stage mist eliminator at the top of the absorber towers; the first stage is a two-pass chevron A-frame and the second stage is a four-pass horizontal chevron; the superficial gas velocity is 9 to 11 ft/sec; both stages are washed from below intermittently with fresh water; the lower stage is washed one or three times per hour for 2 minutes (based on density in absorber feed tank) at about 250 gpm; the upper stage is washed once every 8 hours for 2 minutes at about 250 gpm.

12. Reheat System - Flue gas is reheated to 160 F with in-line steam coils using smooth Inconel 625 heat exchanger tubes.

13. Waste Disposal - A bleed stream from the scrubber loop based on density is mixed with dry fly ash to obtain 65 percent solids and pumped 3 miles to a diked pond; there is no recycle of water from the pond as the water inflow is lost by evaporation.

14. Fans - Two ID fans are located between the mechanical collectors and the scrubbers, and two booster fans are located after the reheaters.

C. RELIABILITY

1. Start-up - May, 1978.

2. Availability - 98.6 percent total scrubber system availability (hours the FGD system is available for operation divided by hours in period) for the first year of operation (including spare tower).

3. Longest Run - Over 1 year for the whole system and greater than 4 months for an individual tower.

4. Calendar of Operation - Greater than 9,000 hours of operation for the whole system.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - The shell of the scrubber vessel is carbon steel with a Coroline 505AR coating. In the tapered section of the venturi, there is a Ceilcote 8300 membrane (plasticized gilsonite), then a SiC brick/Sauereisen No. 33 mortar overlay above the coating. This SiC brick overlay system (but with Corobond mortar) is also on the part of the vertical walls below the venturi (extending down to just below the top of the cross-over duct), in the sump, and extends about two feet into the cross-over duct. At the end of the cross-over duct where the gas hits the absorber wall, there is a "target" area of acid-resistant bricks bonded with the Corobond mortar. The disc and slurry deflector plate (now flat

rather than conical as used in Cholla 1) in the Cholla 2 prescrubber are Hastelloy C. A rubber-coated Uddeholm 904L deflector shield hangs around the disc support housing (material unidentified) to prevent erosion from the slurry, and re-direct it back to the outside wall of the vessel (SiC brick zone).

2. Absorber - The absorber vessel is carbon steel. From the bottom of the absorber to 3 feet above the gas/liquid separator bowl, the lining is Coroline 505AR. From this point to the centerline of the packing support beams, the lining is Flakeline 103. From the centerline of the packing support beams to the centerline of the spray nozzles (8 ft of high abrasion area), the lining is Coroline 505AR. The latter lining represents a modification from previous designs. Above this area, the lining is Flakeline 103. The separator bowl is carbon steel lined with Coroline 505AR. The packing is polypropylene supported by Type 317L stainless steel beams.

3. Spray Nozzles - The slurry spray nozzles are cast Type 317L stainless steel and the mist eliminator wash nozzles are machined Type 317L stainless steel. The spray headers are also Type 317L stainless steel.

4. Mist Eliminators - The mist eliminators are constructed of polypropylene.

5. Fans - The booster fans have rubber-lined carbon steel housings and stainless steel blades (type unknown).

6. Reheater - The reheaters have Inconel 625 tubes and shells with Uddeholm 904L stainless steel baffles. They are excellent from a materials standpoint. The baffles were installed because of a vibration problem.

7. Pumps - The recycle pumps for the scrubbers and the absorbers are rubber-lined cast steel (Denver) with closed-face impellers. The mill slurry sump pumps (ball mill to reagent feed tank) are rubber lined (Galigher) with open-faced impellers. The mist eliminator wash pumps are stainless steel by Goulds. The reagent feed pumps (reagent feed tank to absorber feed tanks) are rubber lined (Goulds).

8. Tanks - All tanks (absorber feed, reagent feed, mill slurry sump, and sludge) are carbon steel lined with Coroline 505AR. The Flooded Disc scrubber feed tank is the bottom of the absorber tower.

9. Agitators - All are rubber-lined carbon steel except the small ones (such as in mill slurry sump), which are Type 316L stainless steel.

10. Storage Silo - Carbon steel.

11. Thickener - None used.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The inlet ducts are unlined carbon steel. The outlet ducts are carbon steel lined with Flakeline 103 from the absorber to the I.D. booster fans, and with Plasite 4030 from the fans to the stack. The stiffeners are protected by Flakeline 252. After one year of operation, these linings are still intact. The bypass duct is unlined carbon steel and has an emergency quencher spray to protect the stack lining.

The expansion joints are Viton®/asbestos by Raybestos-Manhattan.

The dampers on the inlet side are guillotine type (double bladed) and are constructed of carbon steel with Type 317L stainless steel cladding. The outlet dampers are louver type constructed of Type 317L stainless steel. All the dampers have Inconel 625 seals and are from Mosser Industries.

14. Piping and Valves - All piping more than 4 inches in diameter is rubber-lined carbon steel. All smaller piping is fiberglass-reinforced plastic, except where rubber hose is used in some places.

All valves are rubber lined. Keystone butterfly valves are used on the suction side of the pumps and DeZurik plug valves on the discharge side. There is also one rubber-lined pinch valve per module.

15. Stack - The stack has a carbon steel liner inside a concrete shell. The liner is protected with Plasite 4030. The lining has not been inspected so performance is unknown. Units 2 and 3 have a common stack with separate flues. There is no scrubber on Unit 3 so that the flue is unlined. There are emergency quench sprays in the bypass ducts on Unit 2 to protect the stack and breeching linings, but the sprays have never been used as three out of four modules required for scrubbing have never been bypassed.

16. Ball Mill - The ball mill is rubber lined (Kennedy Van Saun).

17. Pond - The pond is unlined.

SOUTH CAROLINA PUBLIC SERVICE AUTHORITY (SCPSA)
WINYAH UNIT 2

Trip Report Number: EPRI-CM43

Date of Trip: June 26, 1979

Persons Interviewed: Al Saunders, Results Engineer, Winyah Generating Station, SCPSA.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Babcock & Wilcox is the process designer, vendor, and contractor; Burns & Roe is the consulting engineer; new installation.

2. Boiler Type - 280 MW Riley turbo-fired pulverized coal unit with a design heat rate of 9300 Btu/kWh and an actual heat rate of 10,200 Btu/kWh.

a. 20 percent excess air.

b. 70 percent capacity factor; full load during daytime and 50 to 60 percent load at night, except in the summer when the load does not drop.

c. 400-foot stack.

3. Flue Gas Flow Rate - 814,000 acfm at 270 F is the total flue gas flow rate; 50 percent of the flue gas is scrubbed; the scrubber can be bypassed using double guillotine dampers.

a. 3.6 percent oxygen at economizer outlet and 5 percent oxygen in flue gas into scrubber.

4. SO_2 Concentration - 840 ppm SO_2 in inlet gas and 260 ppm SO_2 in outlet gas from the scrubber.

5. Fuel - Eastern Kentucky coal containing 1 percent sulfur and 14 percent ash and having a heat content of 11,500 Btu/lb; the coal is delivered by rail.

6. Scrubber Reactant - Limestone containing 90 percent $CaCO_3$, 2.5 percent $MgCO_3$, 0.9 percent moisture, and 4.6 percent acid insolubles is delivered by truck from a quarry 25 miles away as 100 percent minus 1/2 inch; the limestone is ground to 90 percent minus 325 mesh in a wet ball mill.

7. Removal Efficiency - 99 to 99.6 percent fly ash removal in the electrostatic precipitator and 69 percent SO_2 removal in the scrubber; SCPSA can obtain between 75 and 80 percent SO_2 removal and they will try to get up to 90 percent removal with MgO addition because of burning higher sulfur coal.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables -

   a. Inlet gas temperature to quencher is 276 F.

   b. Outlet gas temperature from scrubber is 126 F.

   c. Fly ash inlet loading to scrubber is less than 0.05 grains/scf.

   d. pH of scrubbing liquor is 5.7 at quencher inlet.

3. Absorber Design -

   a. Electrostatic precipitator for particulate removal.

   b. One module consisting of a venturi quencher plus a one-stage perforated plate tower for SO_2 removal.

   c. The superficial gas velocity is 90 ft/sec in the venturi throat and 10.5 ft/sec in the absorber tower.

   d. SCPSA tries to maintain 50 percent of the flue gas flow to the scrubber at all times by controlling the booster fan with a signal from the air flow to the boiler; the boiler can be turned down to 20 or 25 percent of full load.

4. Liquid-to-Gas Ratio - L/G is 14.4 gal/10^3 ft^3 in the quencher and 47.5 gal/10^3 ft^3 in the absorber tower.

5. Oxidation - The amount of sulfite oxidation to sulfate is estimated to be 30 percent.

6. Pressure Drop - The total pressure drop is 9.5 in. H_2O including 3 in. in the quencher and 5 in. in the absorber.

7. Solids Level - Up to 16 percent solids in recirculating slurry; 35 percent solids in limestone feed slurry.

8. Reactant Addition - Limestone slurry is added to the quencher and absorber recirculation tanks.

9. Reactant Feed Rate - 44 to 48 tons/day of limestone at full load; 1.1 to 1.2 moles $CaCO_3$ per mole of SO_2 removed.

10. Slurry Retention Time - About 6 minutes in the combined quencher and absorber recirculation tanks.

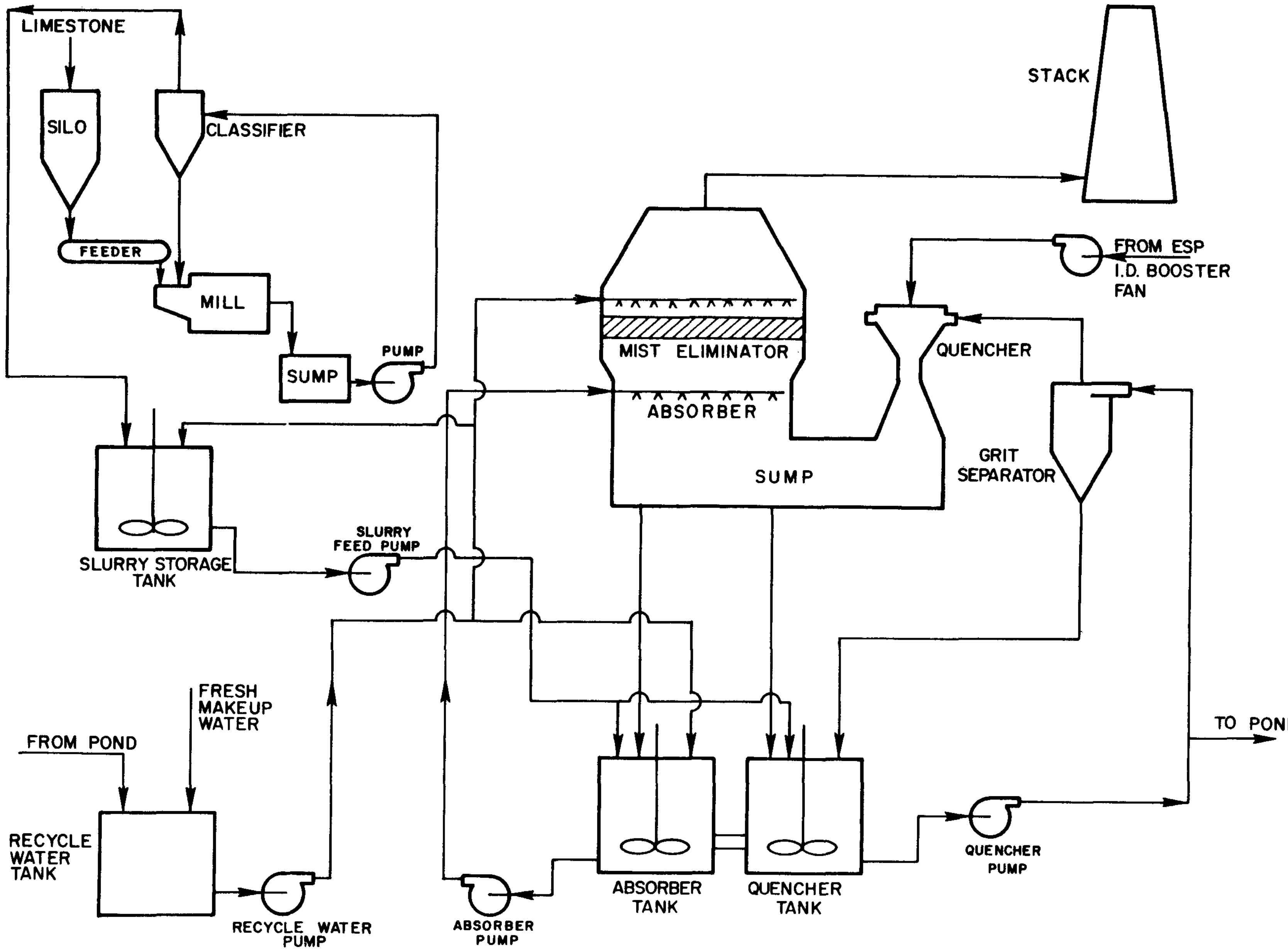


FIGURE 1. FLOW SHEET FOR FGD SYSTEM ON WINYAH UNIT 2

11. Mist Eliminator - Two-stage horizontal chevron mist eliminator with perforated plate knockout tray; each stage consists of a three pass Z-shape chevron; the superficial gas velocity is less than in the absorption section of the tower; the first stage is washed continuously from above with fresh water at 150 gpm; when pond water is returned, the mist eliminator will be washed with a 50/50 blend of fresh water and recycle water.

12. Reheat System - Bypass reheat with 50 percent of the flue gas to a reheat temperature of about 196 F.

13. Waste Disposal - The thickener has been out of service since November, 1978, and it is not needed because the scrubber effluent is sent to a 35-acre pond which is 12 to 15 ft deep; water has been recycled in the past but is not being recycled now because the return piping was torn up; the liquid level in the pond is increasing.

14. Fan - Centrifugal booster fan ahead of quencher inlet.

C. RELIABILITY

1. Start-up - Commercial operation began July 1, 1977 and the system went on-line in mid-August, 1977.

2. Availability - The system availability has been high until June, 1979, when there were quite a few outages due to plugged nozzles; the monthly availabilities (hours the FGD system is available for operation divided by hours in period) have been as follows:

January and February, 1978	81 percent
March and April, 1978	93 percent
May and June, 1978	98 percent
July and August, 1978	99.9 percent
September and October, 1978	93.4 percent
November and December, 1978	84 percent
January, 1979	92 percent
February and March, 1979	96 percent
April, 1979	99 percent
May, 1979	98 percent.

3. Longest Run - Not specified.

4. Calendar of Operation - Not specified.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - The flue gas passes down through a quench section before entering the absorber. Most of the quencher is constructed of carbon steel with a 2-inch Kaocrete lining. However, the nozzle region has a band of Type 316L stainless steel (minimum of 2.75 percent Mo) to provide greater corrosion resistance. The quencher sump also has the Kaocrete lining on the entire bottom and halfway across the walls where the lining changes to 3/16-inch natural rubber. There has been a buildup of scale on the quencher walls, but no evidence of deterioration.

2. Absorber - The absorber walls are carbon steel with a 3/16-inch natural rubber lining (Goodyear). The tray is Type 316L stainless steel, and its supports are rubber-coated mild steel. No problems with materials have occurred in the absorber.

3. Spray Nozzles - The quencher, absorber, and mist eliminator spray nozzles are all Type 316L stainless steel. Plugging rather than wear has been the chief problem with the nozzles. Plugging started to occur when the grating was removed from the sump for cleaning and was forgotten to be replaced.

4. Mist Eliminator - The mist eliminator is a fiberglass-reinforced plastic of the Derakane type.

5. Fan - The fan is on the hot side of the scrubber and is made of carbon steel.

6. Reheater - The reheat is provided by bypass of 50 percent of the flue gas. The scrubbed gas and the bypassed gas enter the stack through separate breechings. The bypass breeching is about 100 ft below the scrubbed gas breeching.

7. Pumps - The quencher and absorber recycle pumps are all A-S-H rubber lined. The slurry feed and mill product pumps also are rubber lined but are Galigher pumps. The recycle water pump is an Ingersoll-Rand unlined type. Lining failures in the pumps to date have been the result of coal chunks falling into the system. All tanks have now been covered to eliminate this problem.

8. Tanks - The quencher, absorber, slurry storage, and recycle water tanks all are 1/4-inch carbon steel with a rubber lining. The mill product sump is unlined. The grit separator (Krebs cyclone) has a silicon carbide (Refrax) lining in the cone and apex sections, and the inlet head is rubber lined. The Refrax at the bottom of the separator is showing erosive wear.

9. Agitators - The agitators all are rubber-coated carbon steel and have been no problem.

10. Storage Silo - The storage silo is unlined carbon steel.

11. Thickener - The thickener is rubber-lined carbon steel, but is no longer in use. On Unit 3, the thickener will be lined with flakeglass polyester.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The inlet duct is Cor-Ten steel with carbon steel stiffeners. The outlet duct from the mist eliminator to the outlet damper is Cor-Ten steel covered with 60-80 mils of Flakeline 103 and 2 inches of Kaocrete. From the outlet damper to the stack the coating is 12-15 mils of Plasite and 2 inches of Kaocrete. A small section of Kaocrete fell out in the section beyond the damper, and this has been repaired. No other problems have been encountered. The bypass duct materials were not discussed.

The expansion joints are some type of nonmetallic material whose specifications were not available.

The inlet damper is guillotine type and is made of Cor-Ten steel. The outlet damper is a double louver type and has a protective coating which probably is Flakeline 103. There is also a louver type damper ahead of the booster fan, which is made of Cor-Ten steel.

14. Piping and Valves - All piping carrying slurry is rubber-lined carbon steel if it is larger than 2-inch diameter. Small piping is Type 316L stainless steel. Fiberglass-reinforced polyester is used for the mist eliminator spray piping and for the spent slurry to the pond and return from the pond. The absorber spray headers are Type 316L stainless steel. There has been wear of the rubber linings in high velocity sections and replacement spool pieces are on order.

The valves in the system are Type 316L stainless steel knifegate type (Fabri-Valve). There have been problems with leakage, which is alleviated by frequent lubrication.

15. Stack - The stack for Unit 2 is concrete made with a fly ash additive. The liner is Cor-Ten steel with a coating of Rigiflake 480-4800. The average gas temperature in the stack is 210 F; the bypassed gas at 320 F enters the stack about 100 ft below the scrubbed gas at 125 F. There have been some lining failures below the area where the scrubbed gas enters. These spots will be repaired during the next scheduled outage. The stacks for Units 3 and 4 will have FRP liners.

16. Ball Mill - The ball mill is rubber-lined steel (Koppers).

17. Pond - The pond is unlined.

ALABAMA ELECTRIC COOPERATIVE
TOMBIGBEE UNITS 2 AND 3

Trip Report Number: EPRI-CM44

Date of Trip: June 27, 1979

Persons Interviewed: Royce Hutcheson, Environmental Results Supervisor, Tombigbee Station, Alabama Electric Cooperative.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Peabody Process Systems is the process designer and vendor; Burns & McDonnell are the consulting engineers; new installation.

2. Boiler Type - Riley pulverized coal turbo-fired boiler rated at 255 MW; Units 2 and 3 are identical; heat rate is about 9400 Btu/kWh.

a. About 30 percent excess air.

b. The units are meant to be base loaded, but power lines are still being installed to connect the load.

c. 400 ft common stack with twin flues for Units 2 and 3.

3. Flue Gas Flow Rate - 640,000 acfm per unit at 291 F is passed through the scrubbers; the design gas flow rate is 333,550 acfm at 291 F per absorber; 273,000 acfm per unit, or 30 percent of the flue gas, is bypassed.

a. 8 percent oxygen in the flue gas.

4. SO_2 Concentration - 1000 to 1200 ppm SO_2 in inlet gas and 100 to 150 ppm SO_2 in outlet gas from the absorbers.

5. Fuel - Alabama, Tennessee, and Kentucky coal blended by stockpiling; 1.5 to 1.75 percent sulfur, 15 to 18 percent ash, and 10,000 to 11,000 Btu/lb.

6. Scrubber Reactant - Limestone containing 95 percent $CaCO_3$ is ground to 80 percent through 200 mesh in a wet ball mill.

7. Removal Efficiency - 85 percent SO_2 removal in the absorbers and 99.5 percent fly ash removal in electrostatic precipitators; the emission regulation that must be met is 1.2 lb $SO_2/10^6$ Btu.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

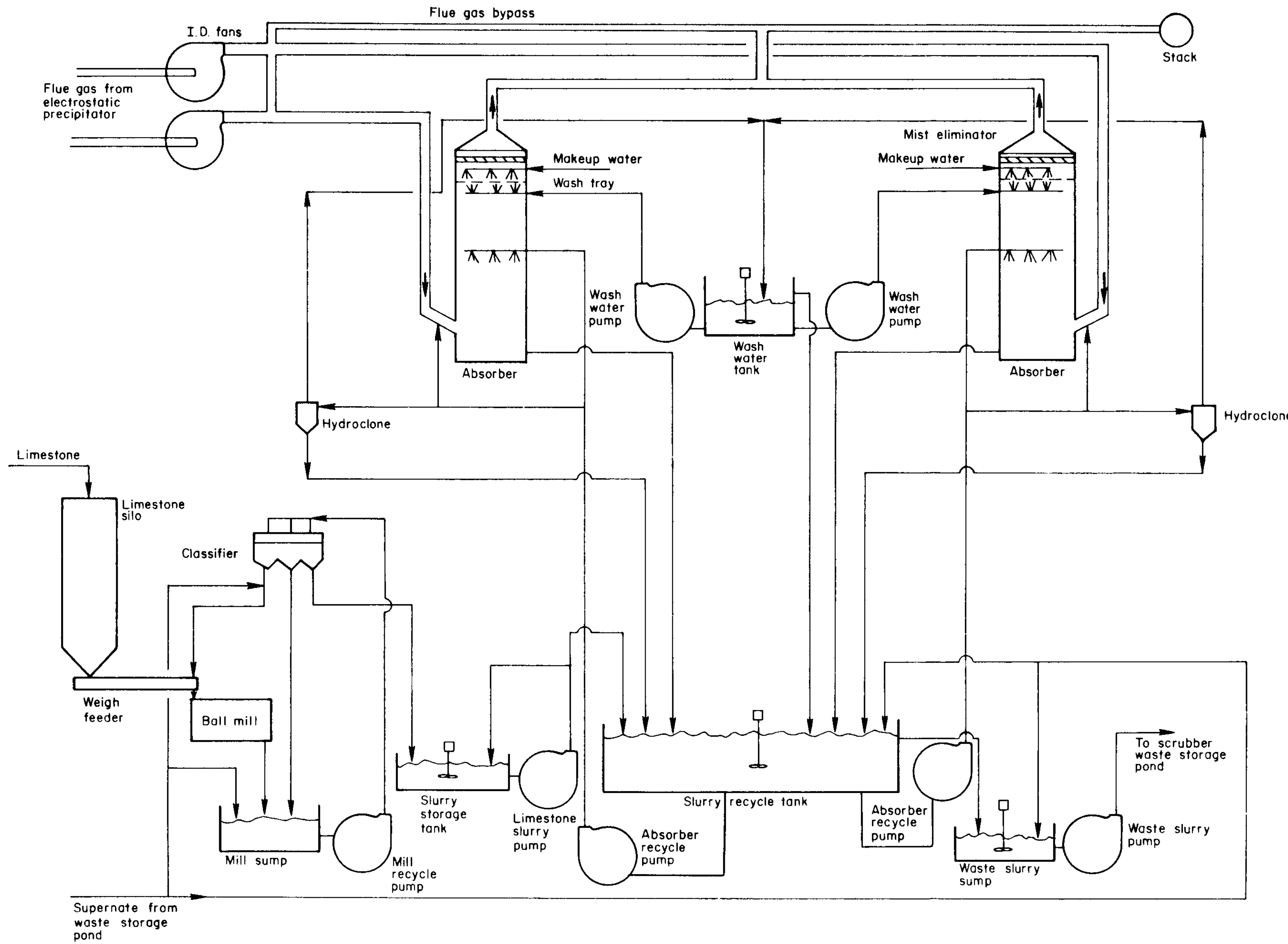


FIGURE 1. FLUE GAS DESULFURIZATION SYSTEM ON TOMBIGBEE UNIT 2 OR 3

2. Process Variables -

   a. Gas inlet temperature is 291 F.

   b. Gas outlet temperature is 130 F.

   c. Fly ash inlet loading to the absorber is 0.046 grains/acf.

   d. pH of scrubbing liquor is 5.8 to 6.0.

3. Absorber Design -

   a. Electrostatic precipitators from Research-Cottrell for fly ash removal.

   b. Two spray towers per unit with three pumps per tower for SO_2 removal; the system is operated to meet standards which means typically two towers and one pump per tower in operation per unit.

   c. The superficial gas velocity in the tower is 10 ft/sec.

   d. The bypass ratio remains about the same as the load goes down; pumps are taken off line to vary the L/G to get the removal efficiency required.

4. Liquid-to-Gas Ratio - The design L/G at full load is 74 gal/1000 acf.

5. Oxidation - Not specified.

6. Pressure Drop - Maximum pressure drop is 4.5 inches of H_2O for the total FGD system.

7. Solids Level - 15 percent solids in recirculating slurry.

8. Reactant Addition - Limestone slurry is added to the recycle tank.

9. Reactant Feed Rate - The design feed rate is 14,068 lb/hr of $CaCO_3$ for both units; this is equivalent to about 1.1 moles Ca per mole of SO_2 removed.

10. Slurry Retention Time - About 10 minutes in recycle tank.

11. Mist Eliminator - One stage, four pass chevron mist eliminator with perforated plate tray with 1/4-inch holes located below the mist eliminator; the superficial gas velocity is 10 ft/sec; the tray is continuously washed from below over the entire surface at the rate of 250 gpm with slurry which has passed through hydroclones; the mist eliminator is washed from below intermittently with makeup water.

12. Reheat System - Bypass reheat with mixing in the outlet duct to the stack; the reheat temperature is 178 F.

13. Waste Disposal - Overflow from the recycle tank goes to a sump where it is mixed with supernate from the sludge pond to control the velocity in the pipe; the waste slurry from the sump is pumped out to the pond and the supernate is returned; the overflow from the sludge pond goes to the process waste pond; the flow and pH (pH is in the range of 6 to 9) from the latter pond is monitored and discharged to the river.

14. Fans - Induced draft fans located between electrostatic precipitators and absorbers.

C. RELIABILITY

1. Start-up - Unit 2 started up in September, 1978, and Unit 3 in June, 1979.

2. Availability - The monthly availabilities (hours the FGD system is available for operation divided by hours in period) and operabilities (hours the FGD system was operated divided by boiler operating hours in period) for Unit 2 are as follows:

Month	Availability, percent	Operability, percent
September, 1978	81.4	81.4
October, 1978	66.3	57.9
November, 1978	88.9	88.4
December, 1978	97.8	97.6
January, 1979	89.2	89.2
February, 1979	98.4	96.2
March, 1979	94.9	94.8
April, 1979	100.0	100.0

3. Longest Run - Probably about 1 month.

4. Calendar of Operation - On Unit 2, Module A has operated for 3915 hours, Module B has operated for 4012 hours, and either Module A or Module B for 4768 hours as of June 27, 1979.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - The flue gas is quenched in the inlet duct of the absorber using slurry sprayed through 12 nozzles. The quench zone is constructed of a corrosion resistant alloy, Incoloy 825. There are no visible signs of deterioration.

2. Absorber - The absorber has a carbon steel shell with natural rubber lining in the spray zone. Above and below this region, a Resista-Flake 1151 lining is used on the steel. The perforated plate is Type 316L stainless steel with carbon steel supports lined with Resista-Flake 1151. No problems have been encountered with any of these components.

3. Spray Nozzles - The quencher nozzles are a gray ceramic material (Carborundum Refrax) and have a deflector but no internal parts. The nozzles in the absorber are the same material. The wash tray nozzles are by Bete Fog Nozzle, Inc., and have a Stellite tip. The mist eliminator wash nozzles have the same construction. Pluggage has been the only problem with nozzles, and this was overcome by putting a strainer between the suction valve and the pump. The strainer is cleaned by flushing the pump.

4. Mist Eliminator - The mist eliminators are Noryl plastic. High fly ash loading in the flue gas caused some plugging; also, there was heat backup. This problem required replacement of the mist eliminator in both modules of Unit 2. No further problems have occurred.

5. Fans - All fans in the scrubber system are carbon steel (supplied by Peabody).

6. Reheater - Reheat is supplied by mixing the scrubbed gas with bypass gas in the outlet duct. A mixing vane constructed of Inconel 625 is located at the junction of the scrubber outlet and bypass ducts.

7. Pumps - All pumps are A-S-H, rubber lined, except two on the ball mill sump which are Galigher, also rubber lined. One liner suffered mechanical damage, but there have been no lining failures.

8. Tanks - Most of the tanks are carbon steel with a Resista-Flake 1151 lining. The hydroclone on the wash water line has a natural rubber lining over carbon steel, and a ceramic nozzle. The hydroclone underflow tank is FRP. No problems have been encountered.

9. Agitators - The agitators are all rubber-coated steel and have three blades with stabilizers.

10. Storage Silo - The limestone silo is carbon steel.

11. Thickener - None used.

12. Vacuum Filter - None used.

13. Ducts, Expansion Joints, and Dampers - The inlet duct up to the quench zone is carbon steel. The outlet duct is lined with CXL 2000 (Pullman Kellogg) from the bypass damper and the absorber outlet damper to the stack, including the area where reheat mixing occurs. Blisters developed in an area about 10 ft x 20 ft. These are believed to result from poor application of the lining. The duct is still being protected in spite of the blisters. The cost of the CXL 2000 lining was $\$25/ft^2$ in early 1978.

The expansion joints are a rubberized asbestos type and have not presented any problems, except one expansion joint in the bypass duct has failed and was patched unsuccessfully.

The inlet and outlet dampers are a guillotine type (Mosser) and are made of carbon steel with an Incoloy 825 cladding. The seals are Type 316 stainless steel on the inlet and Inconel 625 on the outlet. The bypass damper is a louver type, with two sections. It probably is carbon steel because it is always hot and dry. There have been design and operating problems with the dampers. Opening and closing has been difficult. Threads failed on five damper lift bolts and the seal air blowers have had corrosion problems.

14. Piping and Valves - All the slurry piping is rubber-lined carbon steel. Inside the spray zones the headers have both a rubber lining and a rubber coating. FRP piping is used for limestone slurry, makeup water, wash water, waste water discharge, mist eliminator wash headers, wash tray headers, hydroclone lines, and pond line and return. The only problem has been damage to the mill piping because of coarse output from the mill.

The isolation valves are DeZurik rubber partial plug type. The control valves are carbon steel butterfly type. All valves are air operated and have presented no problems.

15. Stack - The stack has a concrete shell and two flues constructed of acid resistant brick and mortar. The temperature in the stack is maintained at a minimum of 170 F, so there is no condensation and the stack is in good condition.

16. Ball Mill - The mill is rubber-lined steel (Kennedy Van Saun).

17. Pond - All the ponds are lined with natural clay.

SOUTH MISSISSIPPI ELECTRIC POWER ASSOCIATION (SMEPA)
R. D. MORROW UNITS 1 AND 2

Trip Report Number: EPRI-CM45

Date of Trip: June 28, 1979

Persons Interviewed: Wayne Downs, Plant Superintendent, R. D. Morrow Station, SMEPA.

A. PROCESS DESCRIPTION

1. Designer, Vendor, and Contractor - Environeering is the process designer and vendor; Burns & McDonnell are the consulting engineers; new installation.

2. Boiler Type - Two identical Riley pulverized coal turbo-fired boilers each rated at 200 MW gross and 180 MW net; the heat rate is 9,508 Btu/kWh gross and 10,765 Btu/kWh net.

   a. 30 percent excess air.

   b. About 55 percent capacity factor; minimum load after 8:00 to 9:00 p.m. and peak load at 9:00 to 10:00 a.m.

   c. Stack height is 400 ft; common stack with twin flues for Units 1 and 2.

3. Flue Gas Flow Rate - 404,000 scfm at 126 F per unit is the maximum flow rate through the scrubbers; at full load, 62 percent of the flue gas is scrubbed and below 62 percent load, 100 percent of the flue gas is scrubbed.

   a. 5 percent oxygen in the flue gas.

4. SO_2 Concentration - About 1,500 ppm SO_2 in inlet gas and about 200 ppm SO_2 in outlet gas when all the gas is scrubbed; about 700 ppm SO_2 in outlet gas at full load.

5. Fuel - Kentucky coal from SMEPA's own mine containing 1.64 percent sulfur and 18.3 percent ash and having a heat content of 11,200 Btu/lb.

6. Scrubber Reactant - Limestone from Birmingham, Alabama, containing a minimum of 85 percent $CaCO_3$ and ground to minus 325 mesh in a wet ball mill.

7. Removal Efficiency - 85 percent SO_2 removal from the scrubbed gas to meet an emission regulation of 1.2 lb/10^6 Btu; the electrostatic precipitator is designed for 99.6 percent fly ash removal but SMEPA is not sure if this removal level is being achieved.

B. PROCESS DESIGN

1. Process Flow Sheet - Refer to Figure 1.

2. Process Variables -

a. Gas inlet temperature is 290 F.

b. Gas outlet temperature from scrubber is 126 F.

c. Fly ash loading to the scrubber was not specified.

d. pH of the scrubbing liquor is 5.6 to 5.7 at the scrubber outlet.

3. Absorber Design -

a. Buell hot electrostatic precipitators for fly ash removal.

b. One Ventri-Sorber® scrubber per unit for SO_2 removal.

c. The superficial gas velocity was not specified but presumed to be about 12 ft/sec at maximum gas flow.

d. At loads up to 125 MW, all the flue gas passes through the scrubber; above 125 MW, the bypass damper is opened; all of the flue gas can be bypassed if necessary.

4. Liquid-to-Gas Ratio - Not specified but presumed to be about 72 gal/1000 acf.

5. Oxidation - Not specified.

6. Pressure Drop - 8 inches of H_2O total through FGD system.

7. Solids Level - 15 percent solids in recirculating slurry.

8. Reactant Addition - Limestone slurry is added to the recycle tank.

9. Reactant Feed Rate - Maximum of 2.1 tons/hr of limestone per unit.

10. Slurry Retention Time - Not specified but presumed to be about 10 minutes in the recycle tank.

11. Mist Eliminator - Two stage chevron mist eliminator with vanes slanted about 30 to 40 degrees with vertical; the superficial gas velocity was not specified; the first stage is washed with supernate and the second stage is washed with auxiliary water.

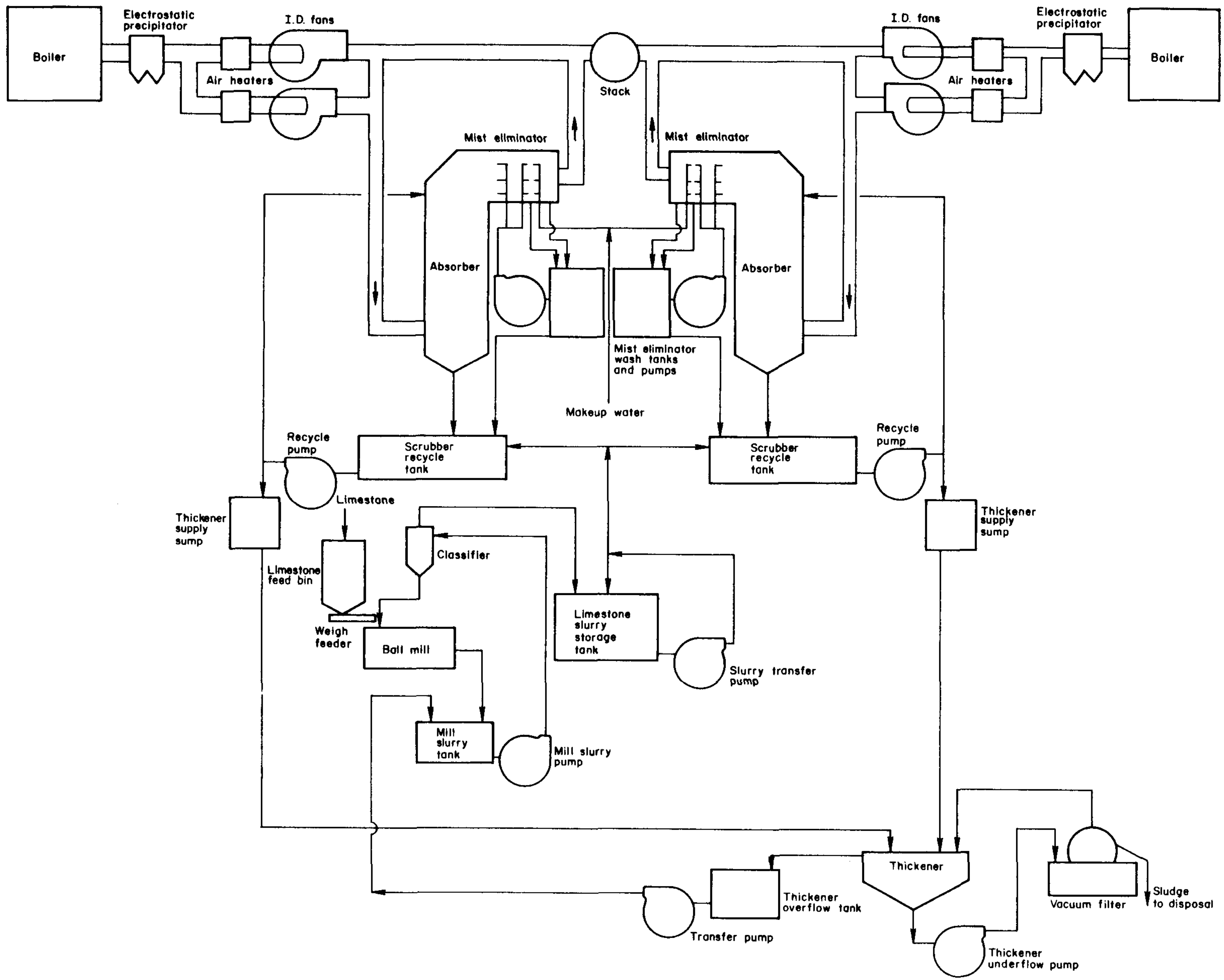


FIGURE 1. FLUE GAS DESULFURIZATION SYSTEM ON R. D. MORROW UNITS 1 AND 2

12. Reheat System - Bypass reheat with mixing zone on the discharge side of the scrubber; the temperature of the reheated gas depends upon the amount bypassed and can range from 126 F (zero bypass) to 290 F (full bypass); under design conditions at full load, the reheat temperature is about 188 F (38 percent bypass).

13. Waste Disposal - Closed-loop system; scrubber effluent is sent to a thickener and vacuum filter for dewatering, and the supernate and filtrate are returned to the system; the filter cake is conveyed to a landfill area as is if it can be transported; if not, it can be mixed with lime or fly ash in a pug mill prior to conveying to the landfill; currently, the filter cake is being mixed with fly ash in the pug mill.

14. Fans - Green double suction induced draft fans located between the air heaters and the scrubber; the hot electrostatic precipitators are located upstream from the air heaters.

C. RELIABILITY

1. Start-up - The scrubber on Unit 1 started up in September, 1978, and the scrubber on Unit 2 started up in June, 1979.

2. Availability - About 95 percent scrubber availability (hours the FGD system is available for operation divided by hours in period) for Unit 1 during the past 2 months; prior to that, problems with linings in the FGD system made the availability low.

3. Longest Run - About 1 month.

4. Calendar of Operation - The FGD system on Unit 1 has operated a total of about 2500 hours.

D. MATERIALS OF CONSTRUCTION

1. Prescrubber - None used.

2. Absorber - The shell of the absorber is carbon steel with a Dudick flakeglass/polyester lining (Protecto-Flake 550). The surface was prepared by sandblasting to a 3-mil profile. Two coats, each 30 to 40 mils, were troweled on and a 3-mil gel topcoat was sprayed over them. The coating was cured for 24 hours at a humidity less than 90 percent. The floor and sloping side wall were protected by acid resistant brick installed over the Dudick lining, but the unsupported wall bricks fell off, so only the floor brick remains. There have been some spot failures of the scrubber lining, and several pinhole leaks have developed in the absorber wall.

The absorber action is achieved by Ventri-rods of Type 316L stainless steel tubes (Riley/Environeering). During July, 1979, problems developed in Unit 1. Partial plugging of the spray nozzles and the rods led to high velocity flow that plugged the mist eliminators. Stains not yet identified appeared on the Ventri-rods and walls of the absorber shell. A number of the rods below the spray nozzles have been completely worn through due to slurry erosion.

3. Spray Nozzles - All of the slurry spray nozzles in the system are Hastelloy G. The only problem has been partial plugging, which has been alleviated by better control of the slurry pH. The mist eliminator wash nozzles are a white ceramic (Al_2O_3).

4. Mist Eliminators - The original material of the mist eliminators was Noryl plastic, but this material was deformed by heat. It has been replaced with fiberglass-reinforced plastic, which has not given any problems.

5. Fans - The fans are all on the hot side of the scrubber system, and they are constructed of mild steel.

6. Reheater - Bypass reheat is used and the mixing zone is in the ductwork.

7. Pumps - All of the pumps are rubber lined. The mill slurry pumps are Galigher and all the other pumps are Ingersoll-Rand. Three of the mill slurry pumps have had to be relined because of damage by gravel which spilled into the slurry sump. Another screen was installed to stop this problem.

8. Tanks - The tanks in the system utilize various materials:

Recycle - Carbon steel with flakeglass/polyester lining

Limestone slurry - Carbon steel with flakeglass/polyester lining

Mill sump - Unlined carbon steel

Thickener supply sump - Unlined concrete

Thickener overflow - Carbon steel with bitumastic liner

Mist Eliminator Wash - FRP which replaced carbon steel tanks lined with flakeglass/polyester; the reason for the replacement was not known.

The original flakeglass linings in the recycle tanks were applied poorly and actually fell off before the tanks were placed in service. They were relined with the same material from Glassflake International of Jacksonville, Florida.

9. Agitators - All of the agitators are rubber-coated mild steel.

10. Storage Silo - The limestone storage silo is constructed of carbon steel.

11. Thickener - The thickener is constructed of carbon steel with an epoxy coating.

12. Vacuum Filter - The metal components of the vacuum filter are epoxy-coated carbon steel. Nylon cloth is used to collect the filter cake.

13. Ducts, Expansion Joints, and Dampers - The inlet duct is unlined carbon steel and has not presented any problems. The outlet duct, including the mixing chamber for reheat and the bypass duct 7 ft back from the mixing chamber, originally had a spray-applied, two-coat flakeglass lining (Glassflake International) which failed in about one month, possibly because of poor application. The lining in both units was replaced in October, 1978, with a Dudick flakeglass lining (primer plus two trowel coats). At this time, a quench spray was added to Unit 1. The Dudick lining beyond the mixing chamber for reheat in Unit 1 failed by thermal shock in July, 1979, after 3 months of operation. The Dudick lining in Unit 2 has not yet been inspected. Unit 2 has a 7 ft section of Hastelloy G installed in the bypass duct just ahead of the reheat section. Consideration is being given to installing Hastelloy G, or similar alloy, from the scrubber to the stack on both units.

All expansion joints on the hot side are carbon steel. On the wet side, the expansion joints have Type 316L stainless steel shields, but the shields are badly corroded and will be replaced with Hastelloy G.

All the dampers are louver type. On the inlet side, the dampers are carbon steel. The outlet dampers have a flakeglass coating on a high alloy. Part of the coating is a Dudick material which was used to replace the original installation by Glassflake International. The seal strips are Hastelloy G.

14. Piping and Valves - Rubber-lined carbon steel pipe is used on the discharge side of the recycle pumps and for the mill slurry piping. Fiberglass reinforced polyester is used for the mist eliminator piping and for lines to and from the thickener. The absorber spray headers also are FRP. Spray headers (for protection against high temperature) in the outlet duct located after the bypass damper were Type 316L stainless steel, but they corroded badly in 3 weeks of operation and were removed. None are used now. The spray header supports in the absorber were originally carbon steel covered with flakeglass coating (Dudick), but have been replaced with Hastelloy G.

All valves (96) are DeZurik rubber-lined plug valves. Incorrect installation of the valves caused plugging problems. After relocation of the valves and provision for better flushing, the problems appear to have been corrected.

15. Stack - The stack has a concrete shell with two flues which are constructed of acid resistant brick and Sauereisen No. 65 mortar.

16. Ball Mill - The ball mill is rubber-lined carbon steel.

17. Pond - None used.

BURNS & McDONNELL
KANSAS CITY, MISSOURI

Trip Report Number: EPRI-CM46

Date of Trip: July 12, 1979

Persons Interviewed: Clark Collier, Design Section Chief, Air Quality Control Division, Burns & McDonnell.

A. BACKGROUND

Burns & McDonnell has engineered 14 SO_2 scrubber systems and one particulate scrubber system since 1972. The utilities that the company has worked for are listed in Table 1 along with the vendor of each flue gas scrubber system. All but one of the FGD systems that Burns & McDonnell has engineered are based on the use of limestone. They have not found lime systems to be particularly cost effective. Burns & McDonnell has on several projects, prepared specifications to buy only the absorbers and recirculation equipment from the FGD system vendor and specifies the remaining components from other sources in order to keep better control of materials of construction and to minimize system costs.

B. MATERIALS OF CONSTRUCTION (Current Materials Preferences)

The following discussion centers around Burns & McDonnell's current materials preferences and includes some comments on failures and problems that have occurred at specific sites.

1. Prescrubber - Burns & McDonnell does not recommend prescrubbers for particulate removal as they prefer electrostatic precipitators or baghouses. Although they do not normally use a wet scrubber for particulate removal, all of their scrubbers have quench sections of one design or another. A preferred material of construction for the quencher area is high alloy although various materials have been used with generally good success. Only two major problems have occurred with quench sections. At Southwest 1, City Utilities of Springfield, Missouri the refractory lining failed and at R. D. Morrow Station, South Mississippi Electric Power Association, the flakeglass polyester coating failed. The quencher at Southwest Power Station was subsequently clad with a high alloy and to date has performed very well. Cladding will be installed in the inlet section at the R. D. Morrow Station in the near future.

2. Absorber - Rubber-lined steel is a preferred material of construction for the absorber vessel as it does not fail because of thermal expansion or oil canning. Natural rubber is normally used with high alloy being a viable alternative. The unit with the longest service life thus far is Southwest 1 at Springfield, Missouri which started up in late 1975.

TABLE 1. LIMESTONE FLUE GAS DESULFURIZATION SYSTEMS ENGINEERED BY BURNS & McDONNELL

Client	Power Station	Size, MW	Sulfur in Coal, wt. Percent	Startup Date	FGD Vendor
Western Illinois Power Cooperative[(a)]	Pearl	22	--	1975	Riley/Environeering
City Utilities Springfield, Missouri	Southwest 1	194	3.5-4.0	1977	Universal Oil Products
Alabama Electric Cooperative	Tombigbee 2	233	1.5-1.8	1978	Peabody Corporation
	Tombigbee 3	233	1.5-1.8	1979	Peabody Corporation
South Mississippi Electric Power Association	R. D. Morrow 1	210	1.6	1978	Riley/Environeering
	R. D. Morrow 2	210	1.6	1979	Riley/Environeering
Arizona Electric Power Cooperative	Apache 2	194	0.4-0.5	1979	Research-Cottrell
	Apache 3	194	0.4-0.5	1979	Research-Cottrell
Southern Illinois Power Cooperative	Marion 4	173	∿3.5	1979	Babcock & Wilcox
City Water, Light & Power Springfield, Illinois	V. Y. Dallman 3	192	3.7	1980	Research-Cottrell
Missouri Basin Power Project	Laramie River 1	570	0.8	1980	Research-Cottrell
	Laramie River 2	570	0.8	1980	Research-Cottrell
Associated Electric Cooperative[(b)]	Thomas Hill 3	700	4.8	1981	Pullman Kellogg
Board of Municipal Util. Sikeston, Missouri	Sikeston	235	2.8	1981	Babcock & Wilcox
Missouri Basin Power Project[(c)]	Laramie River 3	570	0.8	1982	Babcock & Wilcox

(a) Particulate removal only.
(b) Magnesium promoted system.
(c) Dry scrubber utilizing lime.

Stainless steel for the absorber vessel is not a preferred material particularly if the system is a closed-loop where chloride build-up can occur and cause corrosion. They have no preference on the type of absorber and write specifications such that most acceptable vendors can bid competitively.

3. Spray Nozzles - Burns & McDonnell has no preference as to the type of slurry spray nozzles which are used. They have had a cracking problem with ceramic nozzles during installation which was remedied by using a rubber washer insert. They have also had some corrosion and erosion with stainless steel nozzles but no major problems with this component have been encountered.

4. Mist Eliminators - All of the mist eliminators on Burns & McDonnell engineered systems are fiberglass plastic supplied by the absorber vendor. They have no preference on the type of mist eliminator (horizontal or vertical) and leave that up to the scrubber vendor. Both types have advantages and disadvantages. They do check the gas velocities through the mist eliminator but otherwise leave the design aspects up to the vendor. The only mist eliminator failure that was mentioned was at Tombigbee Unit 2 where the mist eliminators sagged and warped apparently due to an excessive temperature.

5. Fans - Burns & McDonnell is a firm believer in the use of dry fans between the electrostatic precipitator and the scrubber. All of their installations are designed that way using A36 carbon steel as the material of construction for the fans.

6. Reheater - Reheaters are not recommended by Burns & McDonnell as the operating cost is considered to be excessive and the benefits marginal. Bypass ducts are used for keeping the boiler operating in the event of scrubber failures, and are not normally designed for reheat of the outlet gas from the scrubber.

7. Pumps - Rubber-lined centrifugal pumps are used for handling slurries and supernate. Both rubber-lined centrifugal and positive displacement pumps have been used for sludge. Pump problems have been encountered at Morrow, Southwest, and Apache where large limestone particles damaged the centrifugal rubber-lined mill product pump. In terms of pump quality, Burns & McDonnell has no manufacturer preference.

8. Tanks - Burns & McDonnell has used steel and concrete tanks both with and without protective linings depending on the application. Except for application problems with glass flake polyester coatings the only tank problem they have encountered was with the recirculation tank at Southwest where the concrete cracked and the lining cracked with it. These cracks although they leaked, eventually plugged with solids and have nearly healed themselves. As a result of this experience, Burns & McDonnell does not recommend the use of above ground concrete tanks but will use concrete sump tanks coated with a suitable material. Normally, plastic tanks are used only for polymer storage.

9. Agitators - Rubber-coated mild steel is normally used for all agitators.

10. Storage Silo - Carbon steel is normally used for all limestone storage silos.

11. Thickener - Thickeners are normally constructed with a concrete conical base and either steel or concrete sidewalls. Bitumastic coatings have been applied to the concrete but they have worn off at Marion and Southwest. The Bitumastic coating does, however, stay on sidewalls.

12. Vacuum Filters and Centrifuges - Vacuum filters have been installed at Southwest and Morrow. The materials of construction were a combination of mild steel, rubber-lined steel, stainless steel, and FRP. The centrifuges at Marion have a stainless steel bowl. Abrasion of centrifuges is not a major concern when there is essentially no fly ash in the slurry.

13. Ducts, Expansion Joints, and Dampers - Unlined carbon steel is used for the ducts upstream of the quench section. Normally, the bypass ducts are also unlined carbon steel and are insulated to keep the gas above the acid dewpoint and to protect personnel from the hot surface temperature. The design criteria is to keep the flue gas temperature drop between 10 to 20 F from the air heater to the outlet of the chimney. In the outlet duct carbon steel with polyester, epoxy, and fluoroelastomer coatings has been used. Coating failures have occurred at Southwest and R. D. Morrow Stations with a different coating being applied at Southwest and alloy cladding being installed at R. D. Morrow. Recent projects are using high alloy materials for all ductwork subjected to wet gas conditions. Burns & McDonnell's experience with inorganic gunite mixes has been with some linings installed at Western Illinois Power Coop and at Southwest; both failed in the service. As a result of this poor experience and the high weight problems with inorganic linings, the company has not used them since in ductwork.

Expansion joints are of the rubberized type with butyl rubber being used at low temperatures (wet side) and Viton® at high temperatures. The The biggest problem with wet side expansion joints has been procurement of appropriate alloys for attachment purposes rather than with the fabric itself.

Dampers for hot gas service are constructed of carbon steel with high alloy seals. Dampers in the downstream portion of the system are constructed of all high alloy parts. Guillotine dampers are preferred with seal air to prevent leakage. There has been a failure of an Inconel 625 leaf seal on the stack side of the absorber outlet damper at Marion. International Nickel has suggested replacement with Inconel 625 again.

14. Piping and Valves - Rubber-lined carbon steel piping is used almost exclusively for slurry lines. Fiberglass-reinforced plastic is used for light slurries and reclaimed water and unlined carbon steel is used for air and water. External recirculation piping has been rubberlined. Internal spray headers have normally been FRP, stainless steel, or rubber-lined carbon steel.

Rubber-lined eccentric plug valves and pinch valves have been used for slurry lines. Rubber-lined carbon steel butterfly valves are used for clear process water. Pinch valves have been used in sludge lines but have problems due to the space requirement for the actuator and problems in switching between manual and automatic operation. In many cases, knife gate valves with FRP or stainless steel gates (depending upon pressure) have been used for isolation.

15. Stack - Burns & McDonnell designs the stacks for wet conditions with effective velocities less than 50 feet per second. Brick liners with a pressurized annulus are preferred. The metal parts on brick-lined stacks are made of high alloy. If the area is prone to earthquakes, a steel-lined stack is sometimes used, but in the case of Marion 4, a brick liner was used. The concrete shell is capable of containing the brick liner in the event of earthquake damage to the brick work. The Marion 4 chimney was originally designed with a steel liner with a polyester coating because of earthquake considerations, but the design was changed to an acid-resistant brick liner when numerous problems with coatings on this application surfaced. Apache 2 and 3 is in an earthquake zone and, as a result, the stack has a steel liner with a fluoroelastomer coating. The Sikeston stack is somewhat unique in that it has two separate flues in a 400 ft concrete shell. One flue is unlined carbon steel for bypass gas and the other flue has a flake glass/polyester lining for scrubbed gas. The bypass flue is insulated to keep the temperature drop to 5 F, and the scrubbed gas flue is uninsulated.

16. Ball Mill - Ball mills are constructed of carbon steel with a thick rubber lining to reduce noise and abrasion. The feed chutes and discharge drums are normally plain carbon steel with Ni-hard or rubber liners for abrasion resistance. For systems in closed loop operation, concern has been expressed that the chloride build-up in the reclaimed water used for the mill may result in corrosion of the steel but this has not been a problem to date.

17. Pond - Ponds where used are unlined if possible; however, some areas such as Springfield, Missouri have high water tables and a sludge stabilization process is required. Burns & McDonnell tries to design for open-loop operation of FGD systems if possible, but this depends upon the type of water treatment required for blowdown.